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Harmonization of Knowledge Representation: Integrating Systems Thinking Ideas with Appropriate Domain Representation Strategies

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Abstract. The cognitive era is marked by the prevalence of Artificial Intelligence and information technologies, which implies digital transformation. However, the swift changes and oversimplified synthesis applied to complex domains have resulted in inadequate transformations, particularly in addressing intricate contexts. This paper examines the need for a methodological framework to guide the conceptualization and development of smart solutions. Moreover, the paper underscores the need to establish a comprehensive framework combining Knowledge Management and Systems Thinking to tackle complex situations effectively. It accentuates the significance of comprehending diverse perspectives, exploring solutions alternatives, and managing tacit knowledge within rapidly evolving domains. The integration of Knowledge Management and Systems Thinking through the KMoS-SSA framework allows the difficulty of complex domains to be effectively addressed, facilitating the conceptualization and development of intelligent solutions that are feasible, effective and desirable.

Keywords. KMoS-SSA, systems thinking, soft system methodology, complex domains, cognitive era, tacit knowledge, knowledge management.

1 Introduction

In a world where technology plays a fundamental role, we are immersed in a significant digital transformation. In this evolution, digital technologies leverage data to drive intelligent workflows, achieving more agile decision-making and real-time responses to environmental disturbances [1]. Those who have already carried out this transformation are entering the beginning of the Cognitive Era, where Artificial Intelligence (AI) and Information Technologies allow them to obtain, assimilate and adapt data, information, and knowledge, which also facilitates decision making and the generation of desired behaviors [2].

The Cognitive Era, considered the current phase of humanity's technological evolution, has created an anxiety to take advantage of all its tools generating hasty changes, which have also caused inadequate digital or cognitive transformations [3].

This is mainly due to an exaggerated synthesis that oversimplifies inherent complex domains, with the intention of keeping them affordable and ensuring the success of AI tools. Complex domains refer to fuzzy-defined areas that present a high number of variables, interactions, or elements, where the relationships between these elements are usually non-linear and may involve many interdependent factors.

They are characterized by their dynamism and the presence of emerging behaviors, which makes it difficult to treat them correctly. The excessive simplification in this kind of domains, not only limits support for strategic decision-making, but also hinder the necessary changes required in the operations of all actors within the domain.

Given this complexity, there is a significant expectation for innovative actions. Nevertheless, it

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is crucial to confront these challenges while preserving the unique features of complex domains.

This entails developing alternatives that consider these features and facilitate feasible, effective, and desirable solutions. A feasible solution is one that can be implemented within the constraints of the situation, considering factors such as resources, time, and practicality. An effective solution not only addresses the problem at hand but also produces the desired outcomes.

Finally, a desirable solution goes a step further, being not only effective but also preferred or considered beneficial in terms of satisfaction, convenience, or value. Otherwise, an inadequate understanding of such domains could result in the creation of negligent and insufficient solutions–quasi-solutions–that fail to support effective decision-making.

Specially, this paper describes the methodological framework KMoS-SSA [4], which is designed to guide the conceptualization, specification, and development of intelligent solutions in complex domains using Knowledge Management (KM) and Systemic Thinking (ST). This systemic approach should not only consider the diverse perspectives and alternative solutions of actors but also how they use and share information and knowledge.

Also, these solutions must be effective and align with client needs, particularly in contexts where multiple interconnected elements, ambiguity, and uncertainty are prevalent, leading to emergent properties. In such domains, the knowledge of the highly specialized professionals involved evolves rapidly, resulting in different and sometimes contradictory worldviews among these Domain Specialists (DS).

Tacit Knowledge (TK) becomes paramount, necessitating a systemic vision and effective TK management. Our approach diverges from traditional AI development, which often oversimplifies domains and struggles when addressing the complexities of identifying and conceptualizing solutions in complex environments. ST and related methodologies, such as Soft Systems Methodology (SSM), Strategic Options Development and Analysis (SODA) and Cognitive Mapping Technique, have demonstrated efficacy in proposing solutions for various complex domains.

For instance, within the educational sphere, numerous intricate issues arise, such as enhancing university promotion strategies [5]. Similarly, challenges manifest in diverse areas like the management of hazardous medical waste [6], the design of interactive artifacts in a blockchain-based precision healthcare ecosystem [7], and decision support within the coffee agro-industry [8].

Employing a systemic approach, specifically SSM, has facilitated the decomposition of these complex scenarios into fundamental components. This process reveals areas of conflict and discrepancy among different actors and stakeholders in each context.

However, as the demand for artificial intelligence in addressing organizational needs increases, we propose that integrating knowledge and systemic management into a methodological framework could facilitate the continuous adaptation of knowledge in response to evolving circumstances.

This approach is envisioned to help tackle the challenges posed by complex situations. The proposed methodological framework draws from Knowledge Management (KM), specifically KMoS-RE, and systems thinking, particularly Soft Systems Methodology (SSM), as detailed in subsequent sections. Additionally, we aim to expound upon the underlying theoretical and methodological foundations that serve as the framework's underpinning.

The structure of the paper is as follow: Section 2 will provide background information on Complex Domains, Systemic Thinking and Knowledge Management. Section 3 will describe the methodological framework KMoS-RE-SSA tailored to address the unique characteristics of this kind of domains. In section 4, an analysis of the integration of Systemic Thinking and Knowledge Management will be analyzed.

We will explore how these two perspectives can be effectively combined to enhance understanding and decision-making in complex domains. Finally, we will conclude with a summary of our proposals and suggestions for future research in this area.

2 Background

2.1 Complex Domains

In the present Cognitive Era, models that communicate perspectives of the real world are integrated into cognitive ecosystems [2].

These ecosystems define domains where decisions are made, and actions are taken to address problematic situations [3]. To address solutions to such problems, human actors perform high-level mental functions to make decisions based on heuristics, unconscious rules of thumb, emotions, clumsiness, insights, and shortcuts; that is, tacit knowledge. Unfortunately, with the rise of computer technology in the last century, there has been a tendency to oversimplify models and analyses of various domains.

This oversimplification often excludes the incorporation of human thinking, intelligence, intuition, and experiential knowledge into the conceptualization and specification of solutions. These aspects, rooted in individual and collective human situations, are shaped by cultural, idiosyncratic, and societal factors, including customs and practices [9].

The progression of AI and the unfulfilled quest for a general AI have prompted continued reflection on how to interact with the real world, that means cognitive ecosystems, and the domains within them. Consequently, depending on the problems we intend to address or solve, especially those that involve a significant human component, the way to address them must be appropriately selected, which implies understanding what the inherent characteristics of complex domains are.

A notable example illustrating these domains is work-related stress. Stress is the reaction to one or more psychosocial risks that can impact a person's mental or physical health and well-being. Therefore, when those risks are found in work organization, work design, and labor relations, it is called work-related stress.

It occurs when the demands of the job do not match or exceed the capabilities, resources, or needs of the worker or when the knowledge or abilities of an individual worker or group to cope are not matched with the expectations of the organizational culture of an enterprise or organization [10].

New modalities of work have imposed new challenges to study these risks and the knowledge representation necessary to prevent and diminish them in these contexts. This complex problem is further exacerbated within the Cognitive Era and holds substantial significance due to its adverse implications for public health, economy, organizations, and society at large.

Work-related stress is inherently complex due to several factors:

– The diversity of the workforce, encompassing different hierarchical levels and responsibilities, introduces a myriad of perspectives and reactions to stressors within the organizational dynamics.
– A multitude of actors, including employees, supervisors, and specialists such as doctors and psychologists, contribute to the intricacy of the situation.
– The existence of various theoretical models attempting to explain the phenomenon from diverse angles adds to its complexity. Examples include the Demand-Control Model [11], Effort-Reward Imbalance Model [12], Social Support Theory [13], Stress Burnout Theory [14], Transactional Stress Model Theory [15], Analysis of Mental Fatigue [16] among others.
– Organizational dynamics, unique to each context, necessitate tailor-made solutions.
– Government regulations introduce an additional layer of complexity.

2.1.1 Complex Informal Structured Domains

Currently, conceptualizing and developing AI solutions requires a transdisciplinary work group with highly specialized knowledge, due to its complexity. This team is generally foreign, and therefore neophyte, to the domain in which the solution will be implemented. When this situation occurs, a Complex Informal Structured Domain (CISD) is generated.

CISD are an evolution of Informal Structured Domains (ISD). In [3], a model addressing ISD with pertinent characteristics, encompassing even

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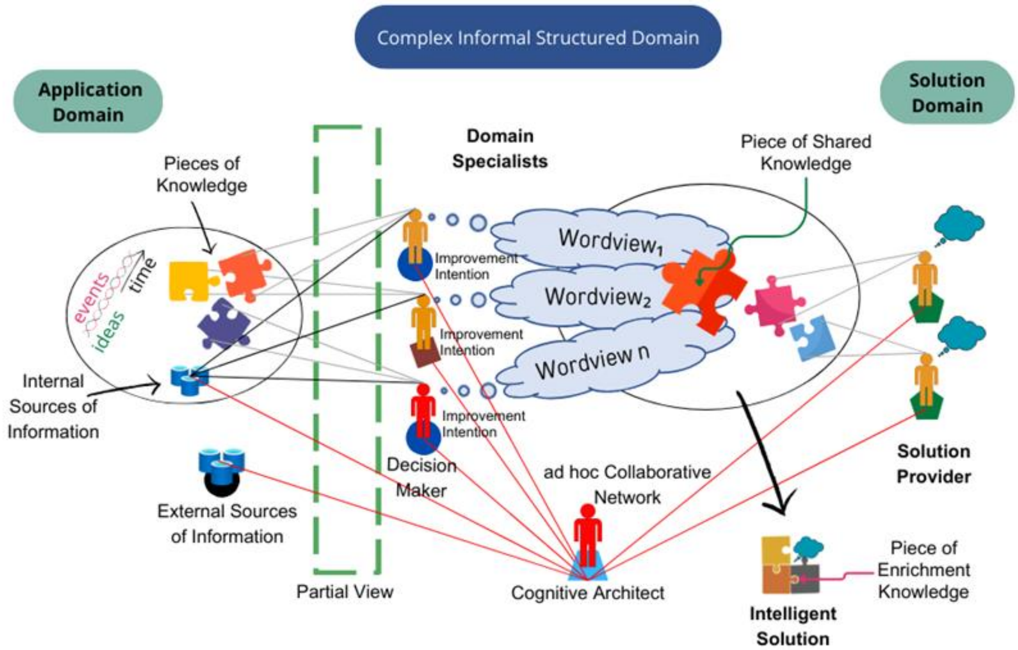

Fig. 1. Complex informally structured domain (own creation)

Complex Informal Structured Domains (CISD), is delineated. The description of this complex domain can be formulated as follows:

- Addressing the challenges inherent in ISD demands the expertise of a specialized team of professionals.
- The data, information, and knowledge within ISD exhibit heterogeneity.
- Most of the knowledge in ISD is tacit, lacking structure, and impractical to communicate effectively.
- Furthermore, highly specialized knowledge, whether partially explicit or even explicit, tends to be informal and characterized by a deficient information structure.
- Overall, ISD is marked by high levels of ambiguity and uncertainty.

CISD is distinguished by the presence of its actors, encompassing their cognitive processes, behaviors, and interactions with entities. The components within this domain demonstrate intricate interconnections addressing diverse levels of knowledge and experience, where boundaries are inherently fuzzy. Consequently, collaborative work unfolds in a social, cultural, intuitive, and consensual manner. The actors share interconnections containing both well-structured explicit information and unstructured or loosely structured knowledge.

These elements collectively contribute to comprehending the nature of the problem or need. Consequently, multiple perspectives of the phenomenon defining the complex domain emerge, yielding one or more alternatives for addressing it, with or without an algorithmic solution. The visual representation of the CISD is depicted in Fig. 1. The Application Domain (problematic situation area) portrays the domain in which Domain Specialists (DS) actively participate.

These specialists can come from different disciplines, can have partial knowledge depending on their role in the domain, and may assume one or more roles.

The knowledge possessed by these DS can be explicit (represented by the puzzle´s pieces), but is predominantly tacit, non-homogeneous, informal, and unstructured. Concepts and relationships within this domain are characterized by its ambiguity and are derived from the context and experience of the DS.

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Domain behavior exhibits dynamism and emergence, with a complex and interactive flow of events and ideas that evolve over time, influenced by both internal and external sources of information. Additionally, DS hold a partial view of the application domain and diverse worldviews regarding problem situations (represented by clouds), despite sharing knowledge.

It is expected that each DS is committed to enhancing the problem situation by having an improvement intention. The Solution Domain comprises a group of Solution Providers (SP), with the Cognitive Architect leading the providers and overseeing negotiation processes with DS through the ad hoc collaborative network.

Solution Providers also have tacit and explicit knowledge, contributing to the development of effective, feasible and desirable satisfaction resources through a set of artefacts that together form the domain's cognitive architecture. The satisfaction resource may manifest as a tangible or intangible intelligent solution containing enriched knowledge.

2.1.2 Exploring the Implications of CISD

Work stress illness is a physical and mental health problem that affects 75% of workers in Mexico. The causes of work stress in this country are diverse and can include work overload, workplace harassment, lack of support from superiors, lack of autonomy at work, among others.

To address this health problem, national authorities through the Ministry of Labor and Social Welfare (STPS) have developed regulations and programs such as NOM-035-STPS-2018 [17,18]. Consequently, organizations need to implement strategic solutions to solve current regulations and improve the productivity and performance of workers.

Conceptualizing, designing, and implementing intelligent solutions to address this phenomenon in organizations is presented as a CISD, due to:

- The phenomenon of work stress is a complex domain (section 2.1).
- The presence of multiple domain specialists, such as managers, occupational physicians, workers, decision makers, etc.
- The presence of a group of solution providers specialized in AI techniques, information technologies, development methodologies, etc.
- Diversity of scientific theories of work stress.
- Internal information in organizations related to work stress (Internal source of information).
- Regulations that influence the way the phenomenon is approached in an organization (External sources of information).
- Different worldview of domain specialists, which can converge in certain aspects, and which must be considered to conceptualize solution alternatives.

Recognizing that the challenge of assimilation in CISD is intricate and necessitates consideration of numerous factors is imperative. Typically, individuals experiencing a situation, problem, or need look for immediate solutions without being fully aware of the situation. This lack of awareness stems from the dynamic and ever-changing nature of activities related to the application domain, rendering prevention unfeasible. While the organization and processes may function acceptably under standard conditions, survival in the Cognitive Era mandates conscious innovation.

Facilitating this innovation necessitates alterations, interactions, and interrelationships among processes, their actors, and the communication channels between them. Domain knowledge remains uncertain and ambiguous, predominantly residing with a select few decision-makers, notably beneficiaries and domain specialists. Furthermore, this knowledge is both incomplete and exhibits varying degrees of specificity. As a knowledge base should ideally comprise formal and explicit knowledge, substantial gaps exist between reality and the ideal state.

Furthermore, a CISD involves a collaborative effort among a set of actors to understand the problem, need, or business, identify weaknesses, convert them into opportunities, and elicit knowledge requirements from this intricate domain to propose suitable satisfaction alternatives. These characteristics make it particularly challenging to facilitate effective communication between actors in the CISD.

This communication surpasses the traditional understanding of interpersonal interaction, involving spoken or written words, gestures, emotional expressions, or any other form modeling social behavior. It should be noted that a CISD, along with the high ambiguity and uncertainty that distinguish them, comprises different domains of knowledge. CISD knowledge, also known as metaknowledge, is independent of the domain and must be consciously managed by solution providers.

2.2 Systemic Thinking

Although its roots extend back decades, systems thinking remains foundational for comprehending and addressing complex situations through the analysis of interactions and relationships among the various elements of a system [19]. Before introducing the concept of systems thinking, it is noteworthy that systems thinking is an approach centered on comprehending the structure and behavior of systems, while systemic thinking is a perspective that acknowledges the interconnected and interdependent nature of elements within a system.

Both concepts underscore the significance of adopting a holistic viewpoint and grasping how different parts of a system mutually influence one another. The terms are occasionally used interchangeably, and the distinction might fluctuate according to the context and the preferences of different authors or practitioners. In this paper, we opt to use systemic thinking, represented by the acronym ST.

Thus, ST, fundamentally, conceives a system as an interconnected set of elements collaborating to achieve a common purpose. It surpasses the isolated analysis of individual components by prioritizing an overarching comprehension of the system, encompassing how its parts interrelate and mutually influence one another.

This perspective endeavors to elucidate the complexity of the world by considering it in terms of wholes and relationships rather than disassembling it into individual parts. Instead of concentrating solely on the components, attention is directed towards the interconnections and dynamics between them. Instead of solely focusing on the components, ST focus on the interconnection and dynamics between them.

According to Mardianto [20], the key principles of ST are the following:

a. Holism - the concept that a system must be viewed as a whole.
b. Inputs and outputs in a system - in a closed system, the input is determined once and is constant, while in an open system there are additional inputs that come from the environment.
c. Entropy - a unit for measuring abnormalities that exist in a system.
d. Hierarchy - something complex is made up of several smaller subsystems.
e. Goal seeking - a systemic interaction must have the same goal or end condition.
f. Regulation - feedback is much needed so that the system works as expected.
g. Equifinality - alternative ways to achieve the same goal.
h. Multifinality - achieve alternative goals from the same input.
i. Differentiation - specialized units have specialized functions as well.
j. Dualism - dual character system contradictory but very important for a system.
k. Modularity - separate or combine elements of the system according to the relationship.
l. Abstraction - the process of removing a characteristic of the system to define the basic characteristics.
m. Relation - the relationship between elements in a system.
n. Encapsulation - hide elements of the system.

ST has a rich tradition, and its effectiveness has been demonstrated since its introduction into the scientific field in diverse situations. Credited by Nakamori [21] as instrumental in the moon landing, ST has showcased transformative power across various fields such as management, engineering, ecology, health, and social sciences. Its contributions have fostered a more holistic understanding of dynamic systemics, solidifying its presence in the Cognitive Era.

Due to its holistic and interdisciplinary nature, numerous proposals have emerged, prompting a classification for improved comprehension [22, 23]. The most widely discussed classification, marked by opposing ideas and the necessity for varied

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approaches, categorizes ST into hard and soft [22, 23, 24].

In its early application, ST primarily found its place in science and technology, particularly in structured domains. Here, problems were perceived as systemics with specific objectives, leading to the application of engineering methods to optimize and achieve established goals.

However, Checkland [22] argued that this approach lacked effectiveness in complex situations in the real world. In response, a paradigm shift in conceptualizing ST was proposed, giving rise to the soft proposal.

This perspective emphasizes the dimensions of human relations in the social sciences, with these ideas materializing in the Soft System Methodology (SSM).

2.2.1 Soft System Methodology

SSM is an approach designed to tackle complex problems in environments where a singular, clear-cut solution is elusive. It prioritizes understanding the perceptions and needs of involved individuals, employing flexible conceptual models to explore diverse perspectives and formulate solutions that are socially or politically acceptable and feasible.

In essence, SSM comprises several steps. Initially, it identifies the complex problem and analyzes the perspectives of those involved. Subsequently, a flexible conceptual model is crafted, providing a holistic representation of the situation. Various perspectives are then explored, leading to the generation of potential solutions. Ultimately, an agreement is reached on a solution deemed acceptable and feasible within the given context.

Three fundamental ideas underpin the SSM proposal [25]. Firstly, it discards the notion of addressing a real-world system in need of repair or improvement. Instead, it embraces the complexity and dynamism of the real world, proposing a systemic inquiry process that facilitates continuous learning cycles and suggests models of systemic activities within the problematic situation.

Secondly, acknowledging diverse viewpoints within the domain leads to the recognition that multiple models of activity systemics can be constructed, each offering its own perspective or Weltanshauung[1]. This necessitates exploring the systemic approach, proven effective in solving complex problems and supporting strategic decision-making [2].

Thirdly, the shift from addressing an "obvious problem" to understanding that a situation is considered problematic by individuals prompts the construction of various models for improvement. These models are recognized as conceptual ideas, not descriptions of real-world components, fostering a learning system that generates new knowledge about problematic situations. Ultimately, the selection of a feasible and desirable proposal requires consideration not only of the actor's viewpoint but also their unique history, culture, and aspirations.

In essence, when applied in complex domains, the soft system approach distinguishes itself by its capacity to confront challenges, discern patterns, and propose enduring satisfaction alternatives through a profound comprehension of underlying dynamics. This attribute positions it as a valuable tool for surmounting persistent challenges in complex domains.

The soft system approach embodies a perspective that endeavors to integrate the complexity of a domain, portraying it as a real-world entity interconnected in terms of wholeness and relationships, as opposed to oversimplifying, and fragmenting it into smaller parts. Leveraging this approach as a method facilitates the development of effective actions leading to satisfactory alternatives in complex domains.

Moreover, both approaches furnish an array of tools and methods for addressing intricate problems across various contexts, spanning from modeling dynamic behavior to engaging in critical reflection and strategic decision-making. Each approach exhibits distinctive characteristics and applications, and collectively, they constitute a

[1] "Weltanschauung" is a German term that translates to "worldview" in English. It refers to a comprehensive and fundamental perspective or outlook on the world, encompassing one's beliefs, values, attitudes, and understanding of reality.It also includes an individual's or a collective's philosophical, cultural, religious, and moral framework that shapes their interpretation of the world and guides their behavior. It provides a lens through which individuals or cultures perceive and make sense of the complexities of existence, morality, knowledge, and the overall human experience.

comprehensive toolkit for navigating complexity in decision-making and change management [23].

2.3 Knowledge Management

Knowledge Management (KM) is a set of processes, techniques and methods that involves the capture, storage, distribution, and effective application of knowledge within an organization or in any domain. It entails identifying critical knowledge for organizational success, facilitating its efficient sharing among team members, and leveraging it to continuously enhance processes and decision-making.

Establishing an organizational culture conducive to learning and collaboration is integral to KM [26]. This culture encourages viewing mistakes as learning opportunities, valuing knowledge sharing, and providing recognition for such contributions.

One of the most challenging aspects in KM pertains to the handling of tacit knowledge. Coined by Michael Polanyi in 1958 [27], tacit knowledge refers to "aspects of our knowledge that we cannot tell or much less describe precisely by writing down symbols." In essence, tacit knowledge encompasses intuitive or experiential knowledge that may not be easily articulated in words.

This form of knowledge is foundational across various domains, such as science, technology, and general learning, influencing actions and decisions in ways not always explicit. In the realm of KM, tacit knowledge assumes a pivotal role, representing the personal, subjective, and challenging-to-formalize knowledge held by individuals. Unlike explicit knowledge, which can be readily documented, tacit knowledge is rooted in people's experiences, values, and perceptions.

Although Polanyi laid the groundwork for tacit knowledge, it was only years later that Nonaka built upon his work, proposing a model of organizational knowledge creation [28]. The model's objective is to cultivate knowledge creation through processes of socialization, externalization, combination, and internalization. This systematic conversion of individual knowledge into organizational knowledge aims to generate sustainable competitive advantages.

The repercussions of tacit knowledge are not foreign to systemic thinking. According to Nakamori [21], the central tenet in ST, revolves around emergence, regardless of whether one adopts a soft or hard approach.

Emergent properties represent qualitative distinctions from the properties of any individual part within the system. Grasping emergent properties necessitates insight and intuition – an ability to synthesize systemic knowledge.

The integration of tacit knowledge underscores the capacity to amalgamate diverse fragments of knowledge, inductively infer a coherent whole, and extract new meanings.

Thus, harnessing tacit knowledge becomes imperative for enhancing decision-making, fostering innovation, and promoting organizational learning, especially in intricate and complex domains. Effectively managing tacit knowledge entails establishing mechanisms for sharing and transferring it among organizational members, fostering a culture that values and encourages the creation and dissemination of this form of knowledge.

2.3.1 Knowledge Management on a Strategy for Requirements Engineering

In 2015, Olmos and Rodas [29] proposed leveraging the foundational concepts of Polanyi and Nonaka within a Knowledge Management on a Strategy for Requirements Engineering known as KMoS-RE. This approach aims to conceptualize and specify solutions in Informal Structured Domains (ISD) are domains where most of the knowledge is tacit and derived from expertise. Consequently, the definition of concepts and relationships between them is semi-informal and typically established through consensus.

The KMoS-RE process incorporates the five types of knowledge processes for complex problem-solving: Knowledge Elicitation, Knowledge Integration, Knowledge Application, Knowledge Validation, and Knowledge Exchange. These processes are amalgamated within a continuous and iterative cycle of model generation, verification, and validation until a solution that aligns with the decision-makers' preferences is specified, that is, make as many of the solution requirements explicit as possible.

KMoS-RE has demonstrated successful applications in various real-world scenarios [3, 29, 30, 31].

2.4 Fusing KMoS-RE and SSM

After exploring and experimenting with tools rooted in the philosophy of systemic thinking, the incorporation of SSM features into KMoS-RE was deemed advantageous. This involved establishing a foundational structure encompassing tools, methods, and processes to effectively tackle the intricacies of complex domains, as elaborated in section 3.

The idea of integrating ST into KM is not novel; Nakamori [21] advocates for collaborative efforts between the two disciplines. He contends that, while KM has predominantly focused on systemic approaches to knowledge, achieving innovation solely through KM is challenging.

On the contrary, ST, specialized in addressing complex problems, encounters formidable challenges when dealing with complex domains and endeavoring to manage knowledge pieces akin to KM practices.

Why is it advocated to fuse SSM and KMoS-RE? Like every tangible and intangible technological artifact devised by humans, both proposals have their advantages and disadvantages and are subject to improvement. KMoS-RE was specifically designed for eliciting knowledge requirements, so the artifacts it proposes and the cycle on which it is based are primarily conceptualized to convert as much tacit knowledge into explicit knowledge.

However, it does not have sufficient mechanisms to deal with complex domains, such as the management of uncertainty, the identification of alternatives, and the management of interdisciplinary work groups. Regarding the soft systems methodology, it does not have the mechanisms to deal with knowledge management, particularly with the challenges presented by tacit knowledge.

As a result, a strategic framework named Knowledge Management on a Strategy options through Soft Systemic Analysis (KMoS-SSA) has been devised [4]. This framework not only acquires pieces of knowledge but operates within a continuous cycle of knowledge enrichment. It involves all the actors involved in the project, from domain specialists, decision makers and solution providers. By representing the complex domain through models that incorporate diverse perspectives, KMoS-SSA supports the continuous reflection of all actors involved. It is about obtaining, validating, discussing, and sharing knowledge to achieve solutions that are not only efficient but also desirable and satisfactory.

3 Methodological Framework KMoS-SSA

KMoS-SSA is a methodological Framework that provides a systematic and knowledge-based approach to solving problems in Complex Informal Structured Domains (CISD). KMoS-SSA uses qualitative, rational, interpretive, and cognitive techniques and methods to generate a cognitive architecture, which can be defined as a set of artifacts composed of symbolic representations of knowledge that provide the semantic basis of the domain and allow interpreting, defining, and exploring the various alternatives of a domain to its problems and needs under scrutiny [2].

KmoS-SSA promotes the elicitation and enrichment of knowledge through debate, learning and understanding to evolve complex domains. It consists of the Knowledge enrichment cycle and the KMoS-SSA process model.

3.1 Knowledge Enrichment Cycle

Knowledge enrichment refers to the process of improving or expanding the depth, breadth, or quality of existing knowledge. This may involve adding, modifying, or even discarding information, context, or relationships to existing knowledge to make it more valuable, insightful, or useful.

The knowledge enrichment cycle is depicted as a cyclic process of symmetric loops converging at the center, forming an infinite horizontal structure, as illustrated in Fig. 2. This cycle involves two sets of fuzzy boundary stages: those aligned with System Thinking and those associated with real-world situations.

While the cognitive architect typically coordinates the actions in this cycle, active participation is encouraged from domain specialists, solution providers, and decision-makers. These actions revolve around acquiring, expanding, and consistently refining domain knowledge to underpin the conceptualization and construction of problem-solving alternatives.

The continuous engagement in the cycle contributes to the expansion and deepening of domain understanding. Although the set of stages that make up the cycle can vary based on the characteristics of the CISD under analysis, a fundamental set of stages would typically include:

– Knowledge Elicitation (KE): Knowledge elicitation is a stage where a systemic process, a series of interconnected and interdependent activities or steps that work together to achieve a particular goal or outcome within a system, is carried out involving the identification, acquisition, organization, and application of pertinent information to comprehend a specific domain. The relevant information, constituting pieces of knowledge, emanates from diverse sources, including domain specialists, knowledge users, customers, beneficiaries, and other actors within the domain. This process is imperative for a comprehensive understanding of beneficiaries' needs and expectations, ensuring that any proposed solution aligns with their knowledge and functional requirements. Typically, the process initiates with a clear identification of the domain to establish the limits and scope of the knowledge area to be acquired.

  Key actors, encompassing relevant individuals, groups, or entities in the domain, are identified, along with their roles and perspectives. The process involves the meticulous identification, analysis, and evaluation of internal and external information sources, considering factors such as reliability, relevance, and timeliness. Strategies for information gathering and knowledge piece development are formulated, followed by data collection and analysis.

  Tacit Knowledge is elicited through interviews or interactions with Domain Specialists. In subsequent stages of the cycle, knowledge modeling is undertaken, employing conceptual models or visual representations of the obtained knowledge. Validation and feedback mechanisms are employed to verify the integrity and coherence of the acquired knowledge, with Domain Specialists and key actors providing feedback to rectify potential errors. Documentation ensues, organizing the identified knowledge in an accessible and structured manner.

  The application and transfer of knowledge involves implementing acquired knowledge in practical domains and facilitating knowledge transfer through training and effective communication. Continuous evaluation is integral, involving the monitoring of knowledge-based applications' performance and the adaptive evolution of knowledge in response to changes in the domain.

  This process is iterative and dynamic, recognizing that knowledge evolves over time and through experience. Active collaboration with Domain Specialists and continuous feedback are indispensable components of an effective knowledge elicitation process. Finally, it is noteworthy that the knowledge enrichment cycle commences with this stage.

– Knowledge Enrichment (KEnr): This stage involves a thorough reflection and validation of the collected pieces of knowledge, evaluating their connection to the problem situation from each domain specialist's perspective. A critical assessment is conducted, addressing both the quality and relevance of the gathered information. Moreover, an organizational framework is established, offering a foundational structure for understanding relationships and patterns, with the goal of constructing alternatives based on validated knowledge fragments. This stage necessitates continuous exploration and the ongoing acquisition of knowledge, ensuring that all actors remain focused on the problem situation and its related issues, thereby maintaining clear and unambiguous definitions. It also involves a continuous search for and acquisition of pertinent information from various sources. These actions are carried out, both to enrich the knowledge of the application domain of the DS, as well as that of the solution domain, with the solution providers and decision makers.

- Model Generation (MGen): This stage encompasses the execution of artefacts or models to authenticate and strengthen knowledge. Employing suitable modeling tools is essential for producing artifacts that effectively represent a domain and potential solutions. Among these models are linguistic models, conceptual models, strategic objective models, knowledge matrices, pertinent systems models, etc. It also includes systems thinking techniques such as a discussion, and reflection guide (PQR), a tool facilitating the comprehension of various dimensions and considerations in the analysis (CATWOE), and root definitions.
- Model Discussion (MDisc): The model discussion stage is in the central part of the cycle, considering it is the union of the real world with ST. It is one of the most important stages in which the models are explained to the Domain Specialists, this knowledge made explicit, not only serves to validate that the content of the models represents in the most correct way possible the reality of the domain, but also it is essential to provoke reflection in the Domain Specialist about their vision of the world, which would allow them to modify their mental scheme. Likewise, the Domain Specialist could observe the knowledge of other Domain Specialist and together make decisions regarding the structure of the domain and possible alternative solutions.
- Model Validation (MVal): In this stage, Domain Specialists meticulously evaluates the model's alignment with reality, providing critical reflections and offering feedback. The validation process centers on ensuring that the artifact fulfills the requirements and expectations of the beneficiary concerning their problem situation, comprehending how it effectively addresses that situation. At this juncture, the cognitive architect coordinates a discussion involving all domain actors, including essential Domain Specialists and decision-makers. During this phase, results and experiences are analyzed, feedback from specialists is gathered, and the necessity to incorporate additional Domain Specialists or adjust the participation of some is assessed. Identified shortcomings pinpoint areas requiring deeper understanding. Artefacts are refined and enhanced, modifying concepts or approaches based on the reflection and feedback received. Finally, a comprehensive check ensures that the generated artifacts meet the requirements identified in the Knowledge Enrichment stage.

It is important to highlight that each stage involves actions geared towards facilitating knowledge gathering, communication, and sharing. These actions encompass activities aimed at comprehending the CISD, such as conducting interviews, transcribing interviews, and identifying/selecting internal and external information sources.

These activities contribute to a thorough description of the domain, encompassing elements such as actors, roles, values, norms, symbols, requirements, concepts, and relationships inherent to the domain. Ensuring clear and precise communication of concepts and findings is crucial, sharing all validated pieces of knowledge with every participant in the domain. This practice fortifies collective knowledge through presentations, publications, or interactions among all participants. Knowledge acquisition is achieved by pinpointing the problem situation and associated issues, ensuring a clear and unambiguous definition. It also involves actively seeking and obtaining pertinent information from diverse sources.

It is essential to bear in mind that the cycles typically maintain this structure because they consistently revert to the beginning of the cycle but start from the updated collective knowledge. Hence, it is an iterative knowledge enrichment cycle, wherein continuous learning implies ongoing enhancements and adaptations. The ability to identify unknowns, apply new knowledge, and share discoveries is fundamental for an effective knowledge enrichment cycle.

Various techniques and tools can be employed for the diverse actions at each stage, and the selection depends on the specific characteristics of

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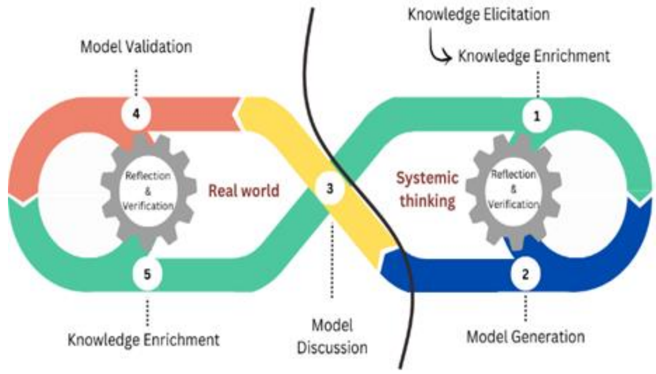

Fig. 2 Knowledge Enrichment Cycle: The illustration depicts a cyclical process of symmetrical loops converging at the center, forming an infinite horizontal structure

the problem and its domain. For instance, a detailed analysis of the relationships between system components is useful in identifying interconnections.

Visual tools like concept maps or influence diagrams can aid in visualizing these interconnections. Modeling feedback loops through visual representations helps explore how changes in one area affect other areas. Diagrams illustrating feedback loops are valuable for understanding how actions impact the system over time, differentiating between positive (change) and negative (no change) feedback to grasp amplification or stabilization effects.

This cycle comprises two sets of stages with fuzzy boundaries: those aligned with Systemic Thinking and those connected to real-world. The active stage within the cycle is identified by numbered circles and associated colors. It is crucial to emphasize that the knowledge enrichment stage is incorporated into both cycles, and the model discussion stage intricately interconnects them. Furthermore, reflection and validation activities are systematically conducted in both cycles. Source: Own creation.

Recognition of emergencies involves collecting and categorizing emergent behaviors, continually monitoring unexpected outcomes, and adapting to changes not directly attributed to individual elements. For domain considerations, analyzing contextual factors influencing the system, exploring complex and non-linear causal relationships, and using contextual maps to visualize the domain's breadth are desirable.

To support the holistic approach and distinguish patterns, data analysis and observation can aid in identifying recurring patterns. Implementing feedback systems for result evaluation and establishing continuous organizational learning processes is useful for feedback and continuous learning. Pursuing systemic change involves conducting root cause analyses to address problems at their source, proposing significant changes in domain structures and processes, and designing and implementing strategic interventions to achieve sustainable improvements. These actions are typically executed in an iterative and collaborative manner, engaging various actors, and employing specific tools based on the requirements of the systemic analysis.

3.2 KMoS-SSA Process Model

This subsection provides a schematic overview of the steps and actions required to integrate Systemic Thinking and KM. This involves developing a structured process model that takes as a basis the Knowledge Enrichment Cycle and that incorporates the principles and tools of both methodologies: SSM and KMoS-RE.

It is noteworthy that the realization of these models involves the application of KMoS-RE techniques, specifically employing KM to represent information through models and imparting structure to the acquired knowledge. KMoS-RE is augmented with a systemic approach to comprehend the domain from a broader perspective, encompassing the interconnections within the CISD. Strategic objectives are modeled and synchronized with desirable goals, thereby ensuring the feasibility and desirability of solutions. Consistent alignment is maintained across various KMoS-RE modeling stages, including knowledge modeling and the modeling of functional aspects of the proposed solution, with systemic principles.

The components of the KMoS-SSA process model are outlined below, following the sequence depicted in Fig. 3, guiding from the "start" point to the "end" point:

1. Initial Evaluation, along with subsequent actions, discerns the complex domain or problem situation necessitating intervention through knowledge elicitation tasks. Examine the characteristics of the domain to ascertain the existence of tacit knowledge, ambiguity, and uncertainty.

   Identify actors, encompassing Domain Specialists, beneficiaries, stakeholders, users, clients, and other pivotal participants. Grasp their viewpoints, roles, and contributions within the context. Additionally, pinpoint pertinent information sources and initiate initial exercises for constructing a domain structure. The initial steps of the scheme are depicted in the central section of Fig. 3, featuring the "start" indicator followed by the Initial Evaluation and Information Source Identification tasks. These tasks are taken from KMoS-RE.

2. Domain Framing and Conceptualization: The problematic situation is framed and conceptualized, considering social, cultural, and political aspects, along with a profile of domain specialists. Once the models or artifacts are generated, the cognitive architect must decide if it is appropriate to initiate the validation process with domain specialists.

   This decision should be based on the architect's judgment of having gathered enough material for validation. These tasks are adapted from analyzes 1, 2 and 3 of the SSM.

3. The cognitive architect will consider validating the artifacts or models to determine their approach to the real world, a task that must be carried out with domain specialists.

4. Models are deliberated upon during the Model Discussion (MDisc) stage, illustrating the problem, knowledge pertaining to it, and relationships within the CISD, culminating in their validation at the Model Validation (MVal) stage.

5. In the context of operating within CISD, the recurring tasks of reflection and verification (Sections of the fig. 3 are depicted at both the far-right center and far-left center), integral components of this framework, assume paramount significance. These tasks play a pivotal role in ensuring the precision and accuracy of both the information and models devised. Furthermore, they scrutinize the comprehension of the intricate domain and the alignment of the proposed alternatives with the authentic situational context. Ambiguity is systematically mitigated through these processes, offering actors the opportunity to reassess assumptions, interpretations, and models.

   Verification establishes the reliability and validity of information utilized in decision-making processes. This approach fosters a culture of continual learning, encouraging actors to review experiences, discern valuable insights, and adapt their methodologies accordingly. By learning from errors or misunderstandings, verification contributes to the progressive refinement of the overall problem-solving methodology. Confidence among actors, including specialists and beneficiaries, is reinforced as they seek assurance in the sound foundation of the generated alternatives.

   Verification functions as a testament to the credibility of the acquired information and models, thereby instilling confidence in the decision-making process. Moreover, these processes substantiate decision-making by allowing actors to critically assess proposed alternatives, consider alternative perspectives, and evaluate potential impacts. Verification ensures that decisions are anchored in validated and reliable information, thus facilitating more enlightened and effective decision-making outcomes. The iterative refinement of models, strategies, and actions is facilitated through the assimilation of lessons derived from reflection and the insights gleaned through verification.

Compliance with quality standards is streamlined, particularly in domains where reflection and verification assume a pivotal role in meeting prescribed standards. Furthermore, these processes contribute to consensus-building by transparently reviewing information and models.

This transparency enables actors to align their perspectives, thereby mitigating conflicts and fostering improved collaboration. At the edges of Fig. 3, it is illustrated the actors involved in this process. On the left side, representing the real world, domain specialists are responsible for carrying it out.

On the right side, representing systemic thinking, solution providers take on this role. In KMoS-RE this task is only considered for solution providers. The systemic approach is committed to an analysis of alternatives, which implies more in-depth involvement of domain specialists.

6. The knowledge enrichment stage holds paramount significance when operating within CISD, where decision-making concerning alternative solutions is of utmost importance. Through this stage, the quantity and quality of knowledge pieces related to potential solution alternatives are increased, erroneous knowledge is eliminated, contributing to enhanced comprehension, reduced uncertainties, alternative identification, and support for continuous improvement.

   Consequently, more robust, and effective decisions are facilitated. Thus, the undertaking of knowledge enrichment before and after deciding upon a solution alternative is deemed essential to guarantee that decisions are well-informed, effective, and adaptive to the intricacies presented in a CISD.

   This task can be predominantly performed by domain specialists (6a) or by solution providers (6b). This state is taken from KMoS-RE.

7. In CISD, a wealth of data and information, constituting valuable knowledge, is present. This data and information may originate from explicit sources within or external to the domain. Therefore, the analysis of data, information, knowledge, experience, and scientific literature (top center of Fig. 3) is deemed indispensable.

   This analytical process establishes a robust foundation for decision-making, diminishes uncertainties, optimizes resource utilization, cultivates innovation, and facilitates continuous improvement within complex contexts.

   The analysis, particularly conducive to informed decision-making, pattern identification, uncertainty reduction, resource optimization, enhanced learning, support for information and knowledge validation, and potential innovation stimulation, plays a pivotal role in these domains. This state is not explicitly considered, neither in KMoS-RE, nor in SSM. The model proposed by Nakamori [20] was considered for its inclusion.

8. The model generation stage creates a representation, albeit partial, of a potential structure within a CISD. This involves capturing the key components, relationships, and dynamics of the domain (MGen stage located in the center of Fig. 3). This process facilitates a more comprehensive understanding of the intricate nature of the domain, enabling actors to gain improved insight into the problem or situation at hand.

   A model serves as a visual or conceptual framework, aiding in the communication of complex ideas and the identification of interconnections among various elements within the domain. This fosters collaboration and shared understanding among actors, including specialists, beneficiaries, and decision-makers.

   Furthermore, a well-constructed model contributes to the information analysis task by helping to identify patterns, trends, and potential interdependencies within the CISD. Participation in the generation of a model not only contributes to the analysis of information but also encourages actors to articulate their tacit knowledge, assumptions, and mental models.

This, in turn, fosters a shared learning experience. The model generation process provides a platform for actors to collectively reflect on their perspectives and views, promoting a deeper and more nuanced understanding of the domain. It is proposed that models used in both KMoS-RE and SSM be considered.

From KMoS-RE the linguistic model, the conceptual model, the process model, among others, would be taken. From SSM the Big Picture, the strategic goals model, among others, would be taken.

9. In this context, the determination of whether a solution is satisfactory (upper central diamond in Fig. 3) involves a comprehensive assessment that encompasses various factors within the CISD.

   Several factors are related to understanding actors' perspectives, ensuring continuous knowledge enrichment, validating, and thoroughly testing models and alternatives through debates and reflection, aligning with beneficiaries' strategic objectives, making well-informed decisions, facilitating consensus building, and more.

   By considering these aspects, it can be collectively determined by actors whether a proposed solution adequately addresses the complexities and challenges presented by the CISD.

The integration of SSM into KMoS-RE within the methodological framework KMoS-SSA underscores a holistic approach to knowledge management in CISD.

This approach comprehensively considers both structured and unstructured elements, considering the social and cultural dimensions of the problem situation. This process is demanding, requiring the mapping, understanding, and structuring of different perspectives related to the phenomenon, particularly those related to the decision-making processes influencing the consideration of alternatives to address the situation and achieve a certain level of satisfaction.

The process involves all actors, stakeholders, or beneficiaries in the CISD, sources of information and relevant entities or objects providing assessments for decision-making. It is essential to recognize that the application of this process may require a significant investment of time and resources, with the primary objective being the production of sound and rational processes that can be effectively implemented.

4 Analysis of the Integration of Knowledge Management and Systems Thinking

The KM conducted by the KMoS-RE process to elicit pieces of knowledge, ISD models, or knowledge requirements involves systemic actions that consider the interconnected and dynamic nature inherent to CISD. Essentially, the KM within CISD through the methodological strategic framework KMoS-SSA, which comprehensively integrates the entire KMoS-RE, can be defined as follows:

1. Definition of the CISD and scope: Delineate and identify the CISD under analysis. Establish the system's boundaries and context, considering the interconnections and relationships between domains.
2. Identification of CISD actors: Identify and categorize the key actors involved in the CISD, considering their perspectives and roles within the system.
3. Problems and needs analysis: Conduct a thorough analysis of problems and needs within the domain. Utilize techniques such as interviews, surveys, and document analysis to gather information and knowledge on existing challenges.
4. Recognition of interconnections: Analyze the interconnections between different elements of the system. Identify how changes in one part of the system may impact other areas.

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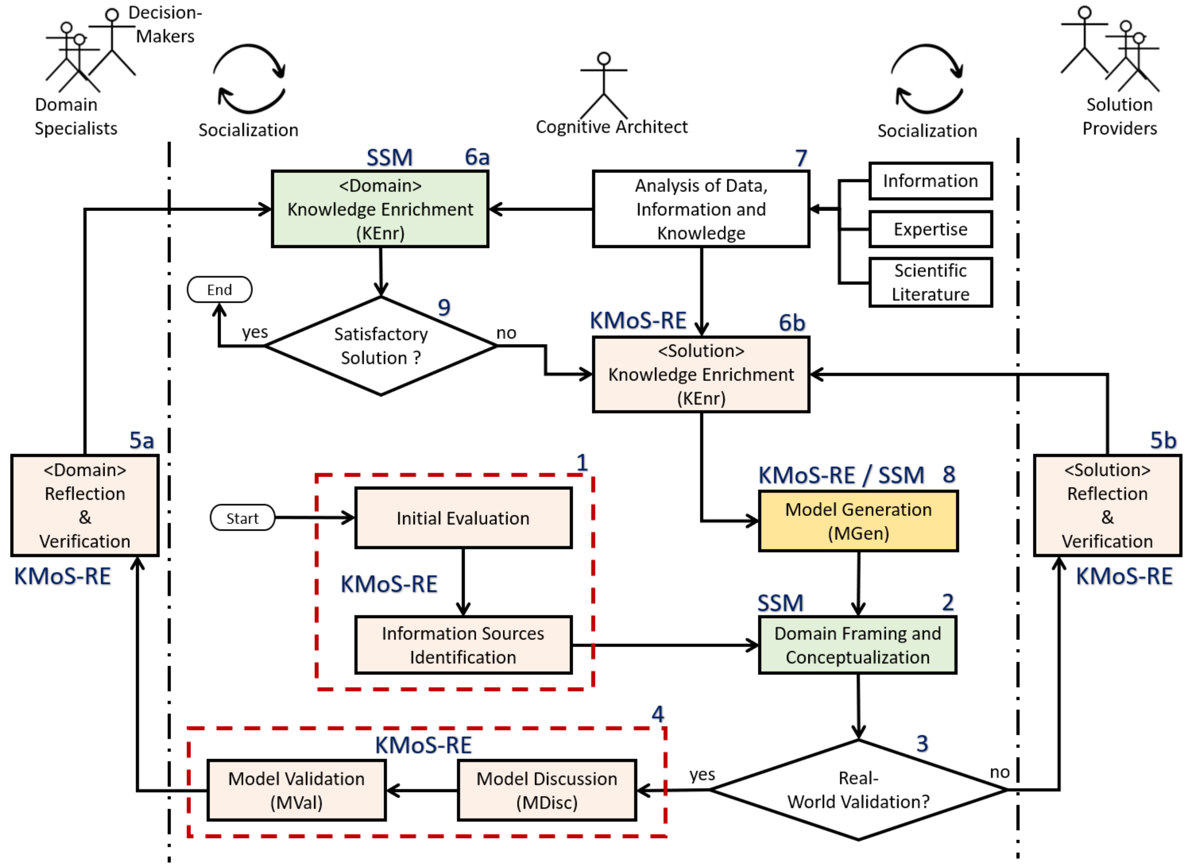

Fig. 3 Depicts the KMoS-SSA framework, illustrating the stages and tasks essential for achieving KM. Rectangular boxes symbolize the stages and their associated tasks, while diamonds represent decisions. “Start” and “End” points are denoted by ellipses. At the top, human figures symbolize the principal actors within a CISD and their interrelationships. Source: Adapted from [4]

5. Requirements elicitation: Employ methods such as interviews, workshops, and questionnaires to elicit requirements from decision-makers and relevant actors in the CISD. Encourage the participation of decision-makers to understand their expectations and needs.
6. Contingency and scenario analysis: Explore various scenarios and situations to understand contingencies and possible variations in domain behavior. Identify requirements that address all potential scenarios within the CISD.
7. Modeling the CISD through Domain Knowledge: Employ modeling tools to visually represent pieces of knowledge, requirements, etc. through images, documented descriptions, use case diagrams, flowcharts, and conceptual models. The objective is to enhance communication and ensure comprehension among all actors within the domain.
8. Documentation of the elicitation of pieces of knowledge and their impact on the CISD: Produce comprehensive documentation that includes all identified pieces of knowledge, their priorities, and associated constraints for actors within the CISD.
9. Change management: Establish a process for managing changes to requirements over time. Consider the ongoing evolution of the CISD and its impact on requirements.

The elucidates that the process of eliciting pieces of knowledge, requirements, and domain modeling navigates the intrinsic complexity of CISD by acknowledging the multiple dimensions, interconnections, and dynamics inherent in these environments. In conclusion, active collaboration with decision-makers and a commitment to adaptability amid continuous change are fundamental aspects of this approach.

5 Conclusions and Future Work

The incorporation of systems approaches, specifically SSM interventions, has garnered significant attention in addressing real-world situations characterized by intricate interrelationships, diverse perspectives, and the management of power relations in the context of the Cognitive Era. This integration aims to facilitate and embrace systemic KM. Conventional solutions may prove inadequate in addressing such complexity, prompting the need for innovative and adaptive approaches, including the integration of cognitive technologies such as AI.

One of the foremost challenges lies in effectively managing the extensive TK derived from experience to address the multifaceted aspects of work-related stress or any other CISD. Consequently, KM emerges as a pivotal strategy for proposing alternative solutions, particularly within the context of a CISD.

Historically, both systemic approach tactics and KM tactics have encountered notable challenges when individually applied to domains such as environmental and business management [21], social and mental health issues [29,30,31,32], sustainability, and others [33]. Consequently, these challenges endure, owing to the inherent complexity of such issues. The convergence and harmonization of perspectives, worldviews, and knowledge management, among other factors, present complexities that demand the formulation of integrated philosophies or approaches to effectively address CISD.

It is important to acknowledge that CISDs constitute an inherent aspect of everyday life. These domains extend beyond specific instances such as work-related stress, ergonomics management in supply chains, gender studies in industry, or education. Instead, CISDs permeate all contexts in which individuals utilize pieces of knowledge for decision-making and problem-solving. Consequently, frameworks like the proposed KMoS-SSA hold promise in effectively addressing these domains, whether they manifest on an industrial or institutional scale, at a local or global level, or involve processes of cognitive transformation.

In conclusion, the current study employs the KMoS-SSA framework to offer practical solutions for institutions, organizations, or companies aiming to alleviate the impacts of issues within a CISD. Specifically, in the domain of work-related stress, where initial positive outcomes of KMoS-SSA are emerging, the framework significantly contributes to the ongoing dialogue regarding effective stress management strategies. Currently, we are working on a detailed analysis of the artifacts or models that will be carried out in each stage of the process model.

As future work, we intend to support the maquiladora industry in intelligent solutions to support them in making decisions to mitigate the effects of work stress and enable them to comply with the corresponding regulations.

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