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Soft Systems Methodology (SSM) as a Viable Methodology for Knowledge Engineering: A Literature Review

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ABSTRACT

This paper presents a baseline perspective of knowledge engineering (KE) methodologies by taking a critical look at the methodological approaches currently used in knowledge engineering domain. A literature review bordering on; the knowledge role concept, knowledge elicitation techniques, and ontological approaches employed in knowledge engineering for the construction of knowledge-based systems (KBS's) was carried out. Journal and conference articles were sourced from multiple journals and research databases and a multi-step manual cross-checking based on carefully selected extraction and quality criteria were employed. The findings of the study show that the existing methodological approaches employed for constructing KBS's in KE is highly deficient and inefficient for solving KE problems under dynamic and uncertain environments. The paper concludes by presenting a strong argument as to why soft systems methodology is best suited for constructing knowledge base systems (KBS) in a spatially distributed, unstructured and shared domain specific context.

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1. INTRODUCTION

Knowledge engineering originated in the 1970s out of expert systems, following the need for a systematic method to build knowledge-based systems (as it was referred to in the early days). [1] First defined knowledge engineering as the process of reducing knowledge from a large body into a set of precise rules and facts. This definition was extended by [2] to include the necessity for gaining more understanding of the characteristics of expertise in itself as well as understand how this knowledge can be applied in eliciting expert knowledge in domain-specific contexts. As noted by [3], the early application of expert systems in knowledge engineering had a lot of setbacks due to its unstructured nature. Several attempts have been made in the past as to how to overcome this bottleneck especially in the area of knowledge elicitation. The initial purpose of knowledge elicitation was aimed at transferring expertise knowledge to the knowledge engineer in the field of software development [4]. Though some of the results of previous researches looked promising, the challenge of transferring technology from AI to developing KBS's proved abortive. [5] Attributed these failures largely to small natures of KBSs developed thereby making it difficult to explore the feasibility of different methodological approaches. The complexity of the problem is directly connected to the challenge faced in the late 1960s during the "software crisis", when the methods used for constructing traditional software system prototypes could not scale up to designing and maintaining large and sustainable commercial software for solving real life problems, which later led to establishing Software Engineering as a discipline. In the same vein, KE discipline was established for the primary purpose of transforming the processes involved in KBS's construction from an art to an engineering discipline in order to create a better analysis and understanding of the processes involved in building and maintaining KBS's, and to develop suitable methods, specialized tools and languages for the construction of KBSs. The rest of the paper is therefore structured as follows: Section 2 takes a critical look at the concept of knowledge role in KE. Section 3 briefly discusses the selection criteria methods employed for the study. Section 4 discusses findings of the literature review and Section 5 concludes the study, stating its limitations and areas of further studies.

2. STUDY BACKGROUND

In the early days, expert systems were used to separate domain knowledge from general reason to form sets of knowledge base rules. In the early 1980s, several studies identified setbacks to this approach and proposed the use of a systematic approach to KE. [6] noted that there are different levels at which knowledge is attained and that it should be considered when solving knowledge-based tasks. He posits that the knowledge level, which is higher than the symbolic level, addresses issues regarding knowledge representation such as why a system or agent performs an action independent from logic, symbolic frames or rules (symbolic level of knowledge). Currently, these description used by [6] at the knowledge level has since been the basic principles on which knowledge engineering is founded, and has provoked several other studies such as [7] in this regard. [8], [9] and [10] distinguished between the different types of knowledge in a knowledge-based system and in a related study, [11] provided a heuristic classification of the standard patterns used in solving knowledge-level problems [12]. Their findings later became very useful in solving knowledge engineering problems related to task knowledge. The 1990s saw a shift in focus from task knowledge to domain knowledge. Knowledge representation took center stage with ontology approaches becoming widely used for representing knowledge [13-14]. The increased use of ontologies for concept sharing in a distributed knowledge domain like the World Wide Web (WWW) led to the development of several modelling languages including Ontology Web Language (OWL) presently used in semantic web. Also, these modelling domain languages make use of patterns like in task knowledge.

Knowledge role can be simply defined as the role a particular knowledge domain plays in solving a particular problem [9]. This helps in structuring the problem by imposing constraints on the way a particular knowledge domain may be used in the course of reasoning, thereby increasing the feasibility of the problem solving process, unlike the uniform reasoning method used in the traditional expert systems where one large knowledge base applies to all [15]. Some examples of knowledge role commonly used in assessment method include decision, norm, and case data. [16], in his review of KE techniques, recommended [17] Personal Construct Psychology (PCP), automated by [18] and modified by [19]. PCP presents a model that addresses the unstructured nature of human psychology in representing, acquiring, and processing of knowledge. He argues that PEGASUS, a computer program developed by [20-21] were more suitable for encoding aspect of human reasoning based on the vocabulary of experts into formal concepts and structured knowledge. [22] also asserted to this by suggesting it could also be used in teaching by allowing other teachers make use of one expert's vocabulary in same way as the expert (teacher in this case). The major setback with this technique though is that it bridges the principles of psychology used in PCP with its logics and systemic principles when producing a framework for KE. Also, [23] noted that verbal reports had no correlation with mental behavior in his study on psychologist's attitude towards verbal data from patients. Furthermore, the hierarchy employed by PCP assumes a strongly formal and idiosynchratic postulation based on uniformity. This is wrong in the notion of soft systems, which assumes that there is no valid "right answer" for all situations, in other words, there is no one-size-fits-all approach.

3. METHODOLOGY

The literature review was based on the structure provided by [24]. The study adopted the guidelines stated by [25]. The review was framed by the questions which this research tried to answer and influenced the search criteria employed for the study. The research questions covered five different subdomains of KE based on the scope of and objective of this study which bordered on the knowledge role concept, knowledge elicitation techniques, and ontological approaches employed in knowledge engineering for the construction of knowledge-based systems (KBSs). The research questions are: a) What are the current knowledge elicitation techniques employed in KE? b) What are the current methodological approaches used in KE? c) What role does Ontology play in KE? d) What special features distinguishes KE from other disciplines? and e) Why is SSM considered as the most suitable and efficient method for KE problem-solving in a spatially distributed and shared domain specific context? In conducting this literature review, both journal and conference articles were sourced manually from several online databases and selected based on the criteria stated above, through a multi-step manual filtering process with independent validation at each step. Duplications and overlapping of selected papers were manually sorted out. The use of manual processes ensured rigor, relevance and credibility was maintained during the selection process. The full texts of selected papers were then independently analyzed by the researchers to ensure it meets the quality assessment criteria presented in Table 1, for inclusion. This was also used to validate the articles selected for this review study.

Table 1. Quality Criteria [25]

1	Is the paper based on research (or is it merely a ‘‘lessons learned” report based on expert opinion)?
2	Is there a clear statement of the aims of the research?
3	Is there an adequate description of the context in which the research was carried out?
4	Was the research design appropriate to address the aims of the research?
5	Was the recruitment strategy appropriate to the aims of the research?
6	Was there a control group with which to compare treatments?
7	Was the data collected in a way that addressed the research issue?
8	Was the data analysis sufficiently rigorous?
9	Has the relationship between researcher and participants been considered to an adequate degree?
10	Is there a clear statement of findings?
11	Is the study of value for research or practice?

4. DISCUSSION OF FINDINGS

This section discusses the findings of this literature review study. The findings are presented in five sub-domains, guided by the scope and research questions the study attempts to address; the techniques currently used for knowledge elicitation, the current methodological approaches used in KE, the role of ontology in KE, the special characteristics of KE, and finally presents a strong argument as to why Soft Systems Methodology (SSM) is the most suitable and efficient method for knowledge engineering problem-solving in a spatially distributed and shared domain specific context.

4.1. Knowledge Elicitation Techniques

Knowledge elicitation is a very important aspect of KE. Knowledge elicitation is the process of extracting domain specific knowledge with regards cognitive issues underlying human performance [26-27]. First used in expert systems and now in KE, several studies have been seeking the best approach to developing knowledge bases into applications or systems such as intelligent tutoring systems, training or educational systems, expert systems, adaptive user-interfaces, etc. In other words, knowledge elicitation is a sub process of knowledge acquisition, even though the two are interchangeably used, and all of which make up KE. The new drive for KBSs have raised concerns in both basic and applied sciences on the best way in which knowledge can be effectively and efficiently elicited from an expert. [28] and [29] criticized the use of cognitive theory for knowledge elicitation stating that although it addresses the knowledge issue, the aspect of its representation and varied conceptualization of the structure of the knowledge (schemata, prototypes, semantic networks, etc.) were not addressed, and which of course, is the main focus of KE. Early studies on knowledge elicitation focused on direct extraction but this was quickly put aside because of the complexity that characterized the problem context [30]. Other limitations of early knowledge elicitation techniques include bias, error, flawed verbal reporting of experts [31]. Recent approaches to knowledge elicitation make use of model constructed to reflect the expert’s knowledge [32], with focus on formal and symbolic representation of knowledge, and how such representations are actually obtained. Thus, our focus here shall be narrowed to recent knowledge elicitation techniques employed in the acquisition, analysis and modelling of knowledge. A summary of these techniques is presented in Table 2 while its applicability is depicted in Figure 1.

1) Limited-information and constrained-processing tasks techniques: used in cases where setting information and/or time constraints on the expert may help improve task performance. E.g. the use of the 20 questions technique in order to efficiently access vital domain information in prioritized order.
2) Protocol-generation techniques: this makes use of different methods of interview such as structured, semi-structured and unstructured; different reporting techniques including shadowing and self-reporting; and through observation methods.
3) Sorting techniques: Mostly used to gain knowledge into the way concepts are ordered and compared by individuals such as their priorities, properties and classes.
4) Matrix-based techniques: This has to do with using grid constructions to map problems against plausible solutions. Some examples of this technique include, employing the grid technique in eliciting,

rating, analyzing and categorizing of concept properties or using frames to represent concept properties and repertory.

5) Protocol analysis techniques: this technique employs the use of text-based information and interview transcripts to identify different knowledge types such as their relationships, goals, attributes and decisions. It is usually used to link knowledge modelling techniques with protocol-based methods.
6) Diagram-based techniques: Employed when the focus of knowledge elicitation is on the why, what, who, when and how of tasks and events. They are useful for generating concept maps, process maps, event diagrams and transition networks.
7) Hierarchy-generation techniques: This approach is usually used for building hierarchical structures and taxonomies like decision trees. Laddering is a typical example of hierarch-generation technique.

Table 2. Summary of Elicitation Techniques and their Associated Tools

Technique	Employed in	Tools
Limited-information and constrained-processing tasks techniques	Cases where vital information needs to be extracted in a prioritized order under limited time and information	Set no. of questions e.g. the 20-question tool
Protocol-generation techniques	Familiarization with the knowledge-identification activities of the domain in order to gain initial knowledge specification of the domain	Structured, semi-structured and unstructured interviews, observations, self-reporting and shadowing
Sorting techniques	Mostly used in unfamiliar domains to gain knowledge of concept properties, classes and priorities	Graphical tools used for creating new features and piles
Matrix-based techniques	Mostly used in unfamiliar domains to gain knowledge of concept properties and repertory	Graphical grid presentation/editing tools and cluster analysis software
Protocol analysis techniques	Used in unfamiliar application domains for checking task templates and inference generation and task specifications for cases where no models exist	Text tools for marking up interview transcripts
Diagram-based techniques	Employed in unfamiliar domains where the focus is on gaining information into the concept properties of events and tasks	Graphical tools for creating concept maps, process maps and event diagrams
Hierarchy-generation techniques	Used for preparatory work when trying to capture the useful hierarchies concept properties in a particular domain schema	Graphical tools used for the construction of multiple hierarchies and taxonomies

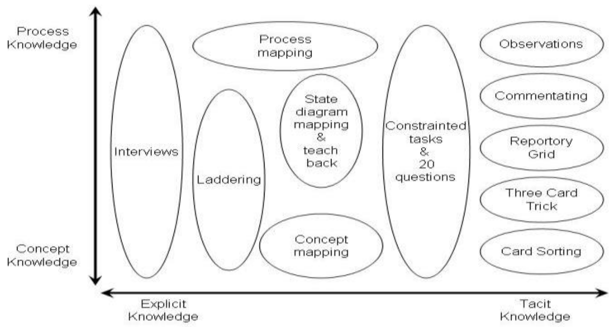

Figure 1. Applicability of Knowledge Elicitation Techniques

4.2. Current Methodological Approaches used in knowledge Engineering

Several methods have been applied in an attempt to structure development and use of knowledge bases since the advent of KE, although recent approaches focus more on the need for flexibility and adaptability in problem solving methods within a highly complex and changing environment [33-34]. Majority of the existing approaches are mere modifications of agile software engineering methodologies such as the widely used CommonKADS [35][5], Generic Task approach [36], Protégé [37-38], Role-Limiting Methods [39-40], KADS [41][5] and Components of Expertise [42-43]. One common characteristic among all these methodologies is in their use of the knowledge role concept. Agile methodologies are more appropriate for small co-located structures and for developing applications that are not life-threatening [44-45]. The need for a more adaptive methodology that can meet the challenges of problem solving in uncertain and highly proliferating context requirements gave birth to the development of ontologies. Very recently, the use of ontologies took center stage for problem-solving in knowledge engineering. The ontology paradigm makes use of model constructions to depict the real world problem situation within a domain-specific context. However, knowing the appropriate level for a detailed knowledge structuring a priori has remained a challenge in the use of ontologies [40]. Some methodologies have however been proposed to help address evolution issues and interactivity and collaborative issues in ontology construction [46-47].

4.3. The Role of Ontology in Knowledge Engineering

The 1990s witnessed an increasing role of ontologies particularly in the field of computer science. Several definitions of ontology exist but the most commonly used is that defined by [13], which states that "ontology is an explicit specification of a shared conceptualization that holds in a particular context." Ontology was introduced in the early 1990s to facilitate knowledge sharing but was not widely adopted in the knowledge engineering field until the mid-2000s, when it was used to address the growing need for concept sharing in the WWW and later paved way for the Semantic Web [48]. Context plays a very important role particularly in the reuse of ontologies partly because different individuals have varied conceptualizations of the real world, thus making it necessary to explicate the context within which the ontology exists if others are to understand and make use of it [49]. [50] proposed a theory to define context space. However, in reality, most human activity systems are bounded with very complex and highly unstructured contexts. This is a very limiting factor when it comes to the use of ontology in solving unstructured problems or human activity problem situations [51]. [52] specified ontology into five different knowledge representation roles:

1. A surrogate for the things in the real world
2. A set of ontological commitments
3. A theory of representational constructs plus inferences it sanctions/recommends
4. A medium for efficient computation
5. A medium for human expression

The main problem here is that only roles 1, 2 and 5 actually apply to ontology-specification languages used in knowledge representation [53]. This implies that ontology specifications do not consider any specific paradigm for reasoning. [13] proposed the use of Ontolingua on KIF as mediators between different knowledge representation languages to enable ontology frame style to be defined into classes, subclasses, etc [54]. The purpose of Ontolingua was to enable the sharing of ontologies between users by providing library services. This concept has since been widely adopted in many W3C projects such as the OWL used for the semantic web. However, OWL-DL which is a subset of OWL makes use of fragmented description logic to guarantee computability among users. This brings us back to our earlier statement that ontologies are not specific to a reasoning mechanism. This shows that there is a bias in the reasoning paradigm of DL when OWL is used to model the real world [55-56]. Also, additional reasoning knowledge is always required when DL is used for ontology validation [57]. Lastly, the new rule language separately being defined by the W3C to compliment the present OWL further exposes these limitations [58-59]. Some authors have proposed the use of [60] KIF as a possible way out given that it is less biased and is able to specify reasoning in a single language [61-63]. However, this is still a proposition as not many studies have been conducted in this regard.

4.4. Specific Characteristics of Knowledge Engineering

Knowledge engineering tasks are characterized by specific features that limit the type of methodology that can be used for problem solving. Some of these characteristics arise from the fact that knowledge engineering services are often needed where communities and users need to collaborate semantically in a spatially distributed domain, as is the case with virtual organizations. This borderless characterization among actors in the knowledge engineering process makes it difficult to apply agile methodologies which depend so much on evolving strategies and sophisticated versions of small incremental changes. Also, the spatial separation of actors in a knowledge engineering setting makes it imperative to employ formal knowledge tools to facilitate interaction and collaboration, especially in a distributed and shared environment, which is a lacking phenomenon in most agile methods where clients work closely (in terms of physical closeness) with domain experts in small groups. The form of knowledge representation varies for teams that are co-located and that which is spatially distributed. The use of verbal communication for interaction and text documents for implicit knowledge representation seems more suitable for co-located teams as in the case of agile methodologies, whereas a more efficient means of communication and collaboration medium such as the Internet and WWW will be more appropriate for larger team groups whose members may be widely dispersed in a distributed and shared context. Despite this fact, there is a big challenge in integrating the large number of domain experts into the knowledge engineering process. This is a major difference between software engineering and knowledge engineering tasks. The former is characterized by small team groups that require instant verbal communication and division of functions in the software development task, whereas in the latter case, the knowledge engineers, domain experts and users of the KBS form a very large group of spatially dispersed individuals, integrated through collaborative and interactive technologies, in a specific, distributed and shared domain.

4.5. Why SSM is a More Suitable Methodology for Knowledge Engineering

The sharing of knowledge whether in the office, or classrooms, or media, or in the streets, has been an existing phenomenon since the creation of man. Nevertheless, there is a major distinction between knowledge-giving (as in the aforementioned) and knowledge-sharing. Knowledge-sharing is a complex task that involves the exchange of knowledge in a two-directional way and is often characterized by practical barriers that needs to be identified and overcome. Some of these barriers become more pronounced when the parties involved in the exchange of knowledge are confined in a spatially distributed domain-specific context. Some studies have identified these barriers to include perceived power loss [64], job insecurity [65], lack of motivation [66], resistance to change [67], and inconsiderate language use [68]. Most of these barriers are soft issues common with any human activity system. Therefore, the ability to manage knowledge (knowledge management) plays a very critical role in KE. Knowledge management (KM) is basically about the processes involved from identifying knowledge goals to maintaining and evaluating repositories of knowledge [69]. A key part of KM or KE is in the knowledge elicitation process. These soft issues are always an obstacle to knowledge elicitation. Thus, the ability to identify what knowledge to elicit and properly highlighting the type of barriers that pose a challenge to eliciting the knowledge, is a big step in the right direction with regards to knowledge elicitation.

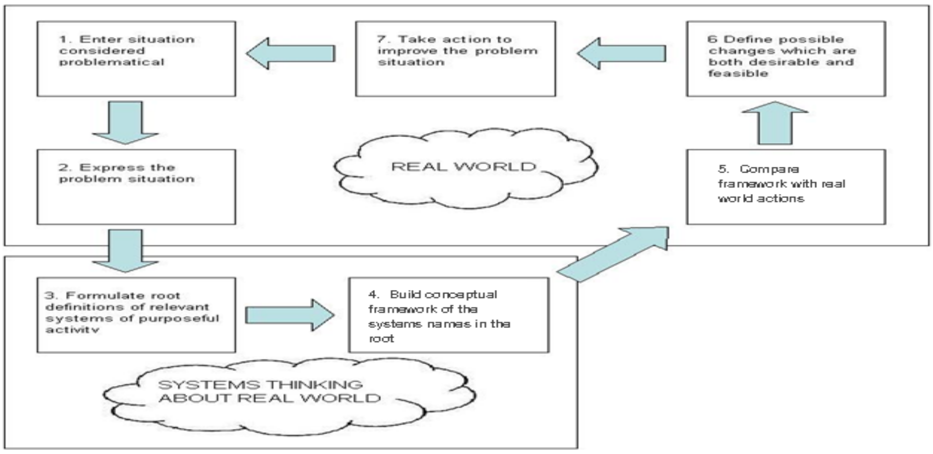

Figure 2. The Seven Stages of SSM

SSM makes use of knowledge concepts to highlight non-technical and fuzzy issues in web environments [70]. [71] proposed a new approach for addressing soft aspects of a system, which he termed soft systems methodology (SSM), based on soft systems theory (SST). This approach is based on the theory of systems thinking where the analyst or knowledge engineer leaves behind his preconceptions about the problem situation and tries to define the problem based on a world view (weltanschauung). This theory assumes that everybody is right based on theory perception of the problem and attempts to unify all these divergent views into a weltanschauung where all the actors share a common view through a seven stage process (see Figure 2). The problem [71] tried to address was how to represent expert ideas in an unstructured problem situation into a structured one by making use of rich picture constructs, models and frameworks to represent the real world problem in order to elicit the expert's knowledge. He argues that individuals in a human activity problem situation all have different perceptions of the problem, approaches to addressing it, benefits and risks derived as a result of addressing it, and all within a constantly changing environmental context that may include physical, economic, and geographic, and which the knowledge engineer must considered while finding a solution to the problem. This was a lacking phenomenon in the PCP hierarchy that focused basically on the perception of individuals without taking into account the unstructured and proliferating environment under which such individuals operate [72]. Thus, SSM provides widely applicable techniques and structures for knowledge engineering tasks. However, the burden of analyzing these findings are left to the knowledge engineer or analyst to bear as there is no computer program available to automate the SSM process.

SSM was first proposed by [71], and [73] as an alternative method for solving information systems development issues. SSM addresses both structured and unstructured problem cases. It employs SSADM, a technical version of SSM, for cases with clearly defined and structured system issues and SSM for fuzzy, undefined and unstructured problem situations [74], though the main reason for its development was to tackle the shortcomings which existing methodologies at the time faced in addressing soft and complex issues [75]. SSM focuses on stakeholder perspectives and engages the user right from the beginning of the problem-solving process, a lacking phenomenon in most of the approaches used in KE. SSM makes use of very easy to use tools to capture and represent the real world scenarios through rich pictures and root definitions (CATWOE) in such a way as to encourage continued user engagement. [76] noted that one of the major contributions of SSM in problem solving is in the procedural stages used by SSM to transform a problem situation from an unstructured, through structured to the desirable change. A process they termed mirroring stages of SSM. Another important contribution made by SSM is that unlike other methodologies, it does not lay emphasis on only the technical issues but rather enhances the problem situation by giving precedence also to the cultural and social perspectives, and derives the final solution based on the requirements of the user [69]. The role of users in knowledge elicitation and KBSs cannot be downplayed as they form an important group of stakeholders that supply user requirement knowledge [77-79].

5. CONCLUSION

During the last three decades, several studies have been devoted to seeking better and more efficient ways of developing KBSs. From the early days of AI and expert systems, to the more recent KE, several methodological approaches have been developed and tested on how best to elicit and transfer expert knowledge for the construction of KBSs. With the proliferation of information due to the daily advances being recorded in Internet and web technologies, the traditional concept of "knowledge role" metamorphosed from static (symbolic level) to a more dynamic (knowledge level), thereby requiring new methods of knowledge elicitation and representation techniques. The introduction of ontology in the KE field attempted to address this challenge at the knowledge level but was inadequate and inefficient for the construction of KBSs in an uncertain and distributed networked environment. Although still evolving, SSM can arguably be said to be the most appropriate method for constructing KBSs through a knowledge engineering domain-specific problem-solving approach. SSM has been described in several ways by different studies. Although generally regarded as a learning system, its wide applicability and acceptability has largely been credited to its ability to address soft unstructured problem situations in environments characterized by high levels of uncertainty and complexities, which is a common phenomenon in most human activity systems. SSM is a very flexible methodology, which can be adapted to suit the nature and context of the problem being solved either by structuring an unstructured problem or simply by reaching a consensus among major stakeholders. This paper therefore proposes SSM as a viable methodology for constructing KBS's in dynamic and uncertain environments.

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