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Issues in Designing Ontology for Waste Management: A Systematic Review

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Abstract
Abstract: Effective knowledge management is important for every domain and for this purpose, ontologies have been used for many years as a prominent conceptual tool. However, there is no systematic review approach that provides clear information on how ontologies have been designed in the WM (Waste Management) domain. This type of review would be useful to assess whether ontologies in WM are being designed according to latest ontology engineering disciplines. We have used our findings in designing, developing and testing an ontology-based waste management system for Kemaman Municipal Council (KMC), Malaysia. We conducted a systematic review of the literature of empirical studies of waste management (WM) ontologies, published in major waste management and ontological engineering journals from 2002 to 2017. This systematic literature review resulted in the identification of few facts. Firstly, most of the researchers did not apply any merging or integrations of sub-domain ontologies. Secondly, only a few researchers used predefined methodologies to design ontology for WM. Finally, ontology applications in this domain are still at an infancy stage, and as such, it would be a good direction at this moment in time, to establish systematic guidelines from a design perspective, for ontology development for WM.

Keywords: *Ontology in waste management, ontology-based waste management, ontology and waste*

I. INTRODUCTION

Waste management is the collection, transportation, and disposal of waste together with monitoring and regulation of the waste management process. Systematic monitoring in the collection process is an important aspect of waste management. Waste collection efficiency can be improved with the help of effective communication and coordination among stakeholders, which include waste management contractors, collectors, supervisors, financial officers and waste managers. A problem with the traditional WM process is that the control decisions are usually made by Administrative staff of the domain on the basis of their experience and individual knowledge. And these decisions may affect the overall waste management process in negative ways at times. Ideally, the control decisions should be taken on the basis of shared knowledge of the domain experts. Unfortunately, this shared knowledge is neither explicitly represented nor fully captured.

Information technology (IT) can help to meet the aforementioned requirements. Latest IT collaboration systems can help to improve information sharing among stake holders. For example, [1] tests on how knowledge sharing can improve employee creativity at both, the employee and the team level. However, IT solutions on their own are not always enough to achieve required goals, especially in the case of complex systems. For tasks such as knowledge sharing, information backup, information recovery, strategic managerial decisions, and many more, IT solutions need suitable information infrastructures and information. For the purpose of systematic and intelligent decision support, it is good to have a knowledge base or domain ontology that can gather, combine, store and exchange knowledge on waste management.[2] defines ontology as an "explicit specification of a conceptualization" of a domain of interest, which serves as a kind of conceptual model for that domain. From this angle, the role of ontology is important because it formally describes the domain of interest, provides a formal explicit specification of a shared conceptualization & facilitates communication between humans and machines, and helps in interoperability between information systems.

Today, many applications prefer to process information through ontologies; processing through ontologies makes information understandable for humans as well as machines [3]. Development of ontologies and their applications has been attracting great interest, such as [4], which investigates the added value of an ontology to the task of review-level aspect-based sentiment analysis. Ontologies facilitate communication, improve decision making, provide controlled vocabulary, support the reuse of knowledge, promote sharing of knowledge, and facilitate storage of data and information [5].

With this in mind, the purpose of this research is to discover the methodologies that are being designed and the techniques which are being used for developing waste management ontology. Let us consider some questions arising from a focus on ontology development for waste management:

Q1: What types of ontologies are being developed for waste management domain?

Q2: What are the most frequently adopted methodologies and what are the best practices in those methodologies?

Q3: What types of IT principles are being applied to ontology in the waste management domain?

Q4: What types of merging/modularization are being adapted in designing ontology for Waste Management?

The outline of this paper is as follows. In section 2 we describe theoretical basis for waste management and designing ontologies in WM, and section 3 describes the approach based on established systematic literature review method. The results are presented in Section 4 and the discussion in Section 5. Section 6 concludes this paper.

II. LITERATURE REVIEW

The primary focus of this section is to describe the main concepts with their theoretical context. Concepts related to waste management have been described in first sub-section, and the second sub-section describes IT & ontologies, and their role in waste management.

a. Waste Management

Waste management is important in the effective use of resources and energy. All types of waste include a range of material resources and embodied energy. There is a great interest in optimizing energy flows, designing less risky ecosystems and safer health systems for humans [6]. Some applications have been developed for sustainable waste management, such as accounting systems for energy flows, material flow analysis, etc. [7].

b. Role of ontologies and Information Technology in WM

The use of machine-readable ontologies is highly recommended by recent researches, because ontologies process information through structured description of information [8]. Ontologies provide a common information structure, the ability to reuse knowledge, and explicit assumptions [9]. Making knowledge machine-readable and helping human beings by knowledge sharing, are also benefits of ontologies[2]. Consequently, many computing fields prefer to use ontologies, such as intelligent information integration, knowledge engineering, natural language processing, e-commerce, software engineering, and databases [10]. [11] presents an improved definition of ontology which states that "ontology is a formal specification of a shared conceptualization". [12] defined ontology as: "ontology is a formal explicit specification of a shared conceptualization". Here, “formal” describes that declarative ontology must be machine readable and “shared” describes that the ontological knowledge is consensual.

III. REVIEW METHOD

A systematic review of the literature is a method for identifying, evaluating and interpreting the empirical studies available on a topic, a research question or a phenomenon of interest. There are several reasons for conducting a systematic review, the most common among which, are the following [13]:

- To support the generation of new hypotheses.
- To review existing evidences about a treatment or a technology;
- To identify gaps in current research;
- To provide a framework/background for new research activities;

Although the works of [14], [15], [16], [17] have described in various ways, the stages of the examination method presented by [18] for general applications are relatively similar. In this article, the review process follows the following steps[17]: review planning, identification of research, selection of primary studies and classification.

a. Revision Planning

Researchers conducting a systematic literature review must answer their academic research questions. According to previous studies, such as [19], [20], [16], we postulate the four research questions discussed in the following subsections to study the design of ontologies in the field of waste management.

b. Research Identification

Our systematic research began with the identification of keywords and search terms. We used general keywords and combined search to identify as many relevant documents as possible. The following electronic databases were used to search key words: ScienceDirect; Business Source Premier; Inspec; Springer Link; AIS (Association for Information System) Electronic library; Scopus; ProQuest Science Journals; Google scholar; ISI Web of Science; ACM Digital library; DBLP; IEEE Explore; and Wiley Online Library.

c. Selection of Primary Studies

After the articles had been identified, the first thing was to remove duplicates and titles that were clearly not related to the examination. This produced a result of 60 articles. Subsequently we obtained the summary of these articles and all the authors read all the summaries, with the following exclusion criteria:

- Exclude if the focus of the paper was clearly not related to waste management.
- Exclude if the focus of the paper was clearly not on designing ontologies in waste management problems.
- Exclude if the focus of the paper was clearly not on IT applied in conjunction with ontologies in waste management area.
- Exclude if the paper is of literature review.

The final number of articles selected for review was 9. The overall process was substantially consistent with Fig.1, also used by [20]

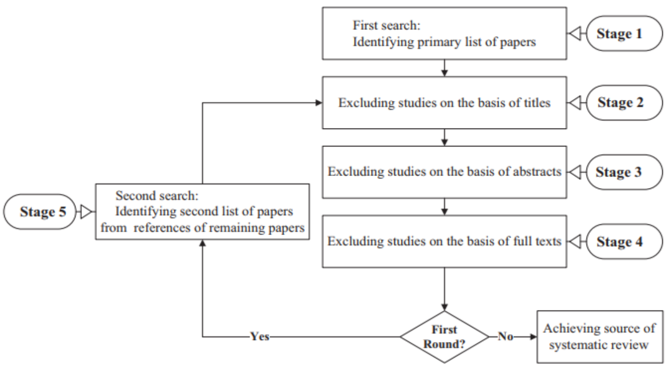

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Fig.1. Stages of the study selection process adopted from [20].

d. Classification

After reading selected documents, ontology classifications were made based on ontology type, complexity of ontology structure (heavy or light), and the level of generality as shown in Table I. Identification of the use of ontologies in conjunction with a type of IT in waste management had been made. Column for table of classification are, structure complexity, level of generality, methodology, IT applied, and merging.

Table I: Classification of Ontologies.

Structure Complexity	Level of Generality	Methodology	IT Applied	Merging/ Modularization	Reference
Light-weight	Domain Ontology	No Information	RFIDS and sensors	Not Applied	[21]
Heavy-weight	Upper, Domain Ontology	No Information	Web application	Not Applied	[22]
Light-weight	Application Ontology	[9]	protégé Using GrOWL Plugin	Not Applied	[23]
Heavy-weight	Upper Ontology, Task Ontology	No Information	OWL DL, SPARQL, JavaScript, Turtle format	Do integration	[24]
Light-weight	Application Ontology	No Information	SWI-Prolog for development	Not Applied	[25]
Heavy-weight	Task ontology, Application ontology	[2]	OntoCAPE ontology	Not Applied	[26]
Light-weight	Application Ontology	No Information	Developed Smart Waste Management Web Based System	Not Applied	[27]
Heavy-weight	Application	No Information	RFIDs, Protégé	Not applied	[28]
Heavy-weight	Application, Task	[30]	Protégé and OWL	Manual merging	[30]

IV. RESULTS

In this section, we discuss about classification of ontologies. The ontologies are classified based on merging, IT applied, the methodology used in designing WM ontology, level of generality and structure complexity. The way IT and ontologies help in waste management process, has also been elaborated.

a. Light-weight Ontologies

Ontologies which include concepts and relationships between concepts without a mechanism of inference, are classified as light-weight ontologies [10]. Objectives of such ontologies are: definition of common domain vocabulary, knowledge structure, knowledge recovery, and searching of knowledge. Upper Ontologies. Upper or Meta-Level ontologies include general purpose concepts that are independent of the domain and can be applied universally (Action, Role, Entity etc.). [22] Selected flexible ontologies to implement share and reuse, also in combination with web technologies and applications. [24] Proposed an upper ontology that guarantees consistency and integration of waste type ontologies, waste management methods and waste management topics, through the use of the common concepts of domain for the definition of ontological components.

b. Heavy-weight Ontologies

Ontologies that include concepts, relationships between concepts and axioms with inference mechanisms, are classified as Heavy-weight, [10]. These ontologies help in the discovery of new knowledge and in the promotion of semantic research.

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Domain Ontologies. [21] presented an automated approach to the analysis of online environmental communication using a Web operating technology.[22] selected flexible ontologies to implement, share and reuse, also in combination with Web technologies and applications The distinction between endurant and perdurant is based on the behavior of entities over time. Endurants are entities that can change over time, are completely present in every moment of their existence and have no temporal parts, but their parts are indexed in time and take part in the perdurants as described by [29].

Task Ontologies. [24] proposed an ontological waste structure that represents different types of waste (different negative effects, different aggregation states, etc.) and possible ways of managing it. [27] presented an ontological design mechanism in which the main components of the environmental domain are gathered from the sources of knowledge and listed in a glossary.

Application Ontologies. [23] proposed an agent-based architecture that provides a hierarchical structure for managing multi-individual and heterogeneous software environments. [25] proposed a mechanism to address similarity measures in CBR and the representation and storage of knowledge. [26] proposed an ontology that is used to organize the information describing the process in the hierarchical classes, and establish relations between its parts. [30] used the OWL ontology language and the protected development tool.[28] have suggested to make wastes smarter, as that would allow them to deal with any problems very effectively. [27] presented an ontological design mechanism in which the main components of the environmental domain are gathered from the sources of knowledge and listed in a glossary.

V. DISCUSSION

The monitoring of waste management includes several intelligent components and entities of the real world. Data integration on waste from smart devices and the other Real databases can be achieved using the Ontology approach. Data integration is essential for different entities and attributes of a waste management system, as described by [31]. The absence of agreed guidelines and methods hinders the development of shared and consensual ontologies within and between teams. It also hinders the extension of an ontology provided by others and its re-use in other ontologies and final applications. Because of the importance of ontology design in the field of waste management and the difficulties encountered in disseminating and sharing this knowledge, the purpose of this article was to list the problems encountered in the design process of ontologies in this domain.

a. Types of Ontologies in Waste Management

There are barriers that prevent the design of an appropriate ontology. However, this research highlights some articles that have designed the ontology for waste management. As far as level of generality is concerned, most researchers focused on application ontologies. [26], [23], [28], [27], [25], [30] designed application ontologies. [22], [24] proposed upper ontologies. [22] proposed domain and upper ontologies and [26], [32], [24] presented task ontologies. Light-weight ontologies have been proposed in [21], [23], [25], [30], and heavy-weight ontologies have been designed in [26], [28], [22], [27], [24]. The distinction between endurant and perdurant is based on the behavior of entities over time. Endurants are entities that can change over time, are present in every moment of their existence and have no temporal parts, but their parts are indexed over time and take part in perdurants. [26], [23], [32], [28], [25], [30] designed endurant ontologies, whereas [24], [26], [32] presented perdurant ontologies.

b. Methodologies

Most of the papers under discussion here, did not mention about methodologies. Only a few of them followed a methodology for developing an ontology; such as [2], [32] and [33] who formalized the waste management theory that would help in designing a WM ontology.

c. IT applied in Waste Management Ontology

IT and ontologies facilitate to create, acquire, transform and discover domain knowledge. Low cost knowledge discovery , and document extraction can be done with the help of Text-mining techniques [21]. Different researchers designed ontologies and used these ontologies as knowledge bases for the WM domain. For instance, [23], [28], [34], [24], [35], [30], [36] designed WM ontologies for Information Systems.

d. Ontology Merging and Integration

Most researchers did not discuss the merging or integration of ontologies. Only in [24], [22], an upper ontology was designed to support the integration of sub-domain ontologies in the field of waste management. For the purpose of integration, [37],[38] discussed the importance of a UFO (Unified Foundational Ontology) as a base upper ontology. This provided the extensibility, scalability and accumulation of support for sub-domain ontologies.

VI. CONCLUSION

When we discuss about the type of structures used in ontology, heavy-weight ontologies are more frequent than light-weight ontologies. When the level of generality is assessed, we find that there are a few researchers like [22] and [24], who had designed upper level ontologies. Upper ontologies play a key role in the integration of sub-domain ontologies as discussed in [37],[38]. It can be seen that most of the researchers focused on endurant entities of the WM domain and designed endurant ontologies, but put less or no effort on perdurant entities. For the second question, when type of methodology is evaluated, we find that most of the researchers did not use any predefined methodology; however, a few used predefined guidelines, such as [2], [9], [27]. The types of IT tools and languages used by researchers were: RFIDs and sensors, Web applications, SWI-Prolog and PSSP language, Protégé, OntoCAPE and GrOWL Plugin, OWL, OWL DL, Turtle format, and SPARQL. For the fourth question, when type of merging or integration is evaluated, it is found that only a few of the researchers used the concept of merging or integration, while most of the researchers did not apply any merging or integration of sub-domain ontologies. For integration or merging of ontologies, domain ontology uses upper ontology as a base ontology. Upper ontologies help to integrate sub-ontologies. The most important function of ontologies is to organize and query domain knowledge. Ontology-based IT solutions can improve the overall waste management process. Although ontologies in waste management attract only a few researchers, we were able to find some research articles on this topic. After searching through 11 different relevant databases, we found only 9 relevant articles about ontologies in waste management. It is clear to us that it is important to propose a methodological approach in designing ontologies, mainly domain ontologies for WM. Since the ontology applications in this domain are still at an infancy stage, it would be a good time and direction to establish systematic guidance from a design perspective of ontology development for WM.

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