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Sustainable building technology knowledge representation: Using Semantic Web techniques

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ABSTRACT

The global quest for sustainability in the exploitation of resources and the need for carbon foot-print reduction has resulted in the development of a large number of innovations and a huge amount of knowledge on sustainable building technologies. Unfortunately, users are being overwhelmed with information overload in this area such that it is difficult for them to make informed choices. The emergence of Semantic Web technologies, the next generation of Web technologies, promises to considerably improve representation, sharing and re-use of information to support decision-making. This paper explores the extent to which emerging Semantic Web technologies can be exploited to both represent information and knowledge about sustainable building technologies, and facilitate system decision-making in recommending appropriate choices for use in different situations. This is done by undertaking a literature review of emerging Semantic Web technologies and emerging innovations in sustainable building technologies. To demonstrate what can already be gained from the Semantic Web, a conceptual model for representing information about photovoltaic system, a major type of sustainable building technologies has been developed. The model is used to develop and test a prototypical ontology in Web ontology language representing knowledge in the photovoltaic system domain. The ontology has been extended to include Description Logics that provide a reasoning mechanism to facilitate system decision support.

1. Introduction

Society and governments around the world are encouraging the development and use of innovative sustainable building technologies to improve the performance of buildings and mitigate the effects of climate change. This has resulted in the development of a wide range of different innovations with a large amount of information and knowledge on sustainable building technologies. Information and knowledge about these innovations are being made available to users through the Web to facilitate accessibility and use. Although the attraction of the Web lies in its simplicity and ease of accessibility [1], the share wide ranging nature of these innovations means that internet searches often overwhelm individuals and practitioners with millions of pages that they have to browse through to identify suitable innovations to use on their projects. Users are therefore unable to make informed choices and have to rely on specialists with experience on a limited range of innovations for advice. It has been widely acknowledged that the solution to this problem is the use of a machine-understandable language with rich semantics for some or all of the information on the Web [1–4]. This has led to the emergence of the Semantic Web, the next generation of the Web, which promises to considerably improve information representation, sharing, re-use and automated processing by software agents to make inferences [1–4]. Key to this, is the use of a common language or an ontology [5] for representing knowledge from different sources to facilitate decision-making. The aim of the work presented in this article is to explore the extent to which emerging Semantic Web technologies can be exploited to both represent information and knowledge about sustainable building technologies and to facilitate system decision-making in recommending appropriate choices for use in different situations. An overview of Semantic Web technologies and sustainable building technologies is presented. A conceptual model, developed to facilitate abstraction and representation of this information and knowledge is presented. The outcomes of the exploratory work that has been undertaken to identify and use various Semantic Web techniques and tools for the representation of knowledge and making inferences from the knowledge are discussed. The exemplar inferences discussed include inferences that facilitate the selection of photovoltaic systems and the selection of their corresponding suppliers.

2. An overview of Semantic Web technologies

The emergence of the World Wide Web (WWW) has brought exciting new possibilities in information access and electronic

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business. The WWW has grown to be the largest distributed repository of information ever created. Estimates reveal that the Web currently contains about three billion static documents and being accessed by over 500 million users from around the world [6]. Web content consists largely of distributed hypertext and hypermedia, accessible via keyword-based search and link navigation. Simplicity is one of the Web's major strengths and an important feature in its popularity and growth. It is this simplicity that has fuelled its wide uptake and exponential growth. However, it is this very simplicity that is hampering further growth and exploitation of the Web. The explosion in the range and quantity of Web content also exposes serious shortcomings in the hypertext paradigm [1]. It is increasingly difficult to locate required content through existing search and browse methods [1–3]. Finding the right piece of information is often challenging. Search engines can assist in finding material containing specific words, but it is very easy to get lost in the huge amounts of irrelevant material. Selecting the relevant material out of the million Web pages on the computer screen becomes a nightmare and manually unachievable as this requires users to read through a large number of retrieved documents to extract the right information. Currently it has been hypothesized that the solution to this problem lies in the 'invention' of the machine-understandable semantics for some or all of the information on the WWW. The realisation of such a Semantic Web requires developing techniques for expressing machine-understandable languages (or ontologies) and making them available on the Web.

According to the WWW Consortium [7], the goal of the Semantic Web is to allow data to be shared effectively by wider communities, and to be processed automatically by tools as well as manually. The vision of the Semantic Web is very ambitious and will require solving long-standing research problems in knowledge representation and reasoning, natural language computing, computer vision and agent systems [8]. However, considerable progress is being made in the infrastructure required to support the Semantic Web, particularly in the development of languages, tools for content annotation, design and deployment of ontologies. Although the realisation of the Semantic Web is still a long way into the future, our aim in the work presented in this paper is to explore the extent to which we can apply emerging developments in this area in order to provide decision support and recommendations of appropriate innovations in sustainable building technologies for use in a particular situation. Nonetheless, based on this exploratory study, some existing essential Semantic Web components have been implemented in developing a prototype ontology in the domain of photovoltaic system. The development of the prototype ontology was facilitated by the protégé-OWL editor. To demonstrate the usefulness of ontologies, some exemplar queries have been formulated, executed and results presented. This was undertaken through the use of Description Logics (DL). A key to the Semantic Web technology is an ontology language which is the subject of the ensuing section.

2.1. Ontology and Web ontology language

In the early 1990s, researchers in the Semantic Web recognised the need for an ontology Web language and several proposals for new Web ontology languages emerged. These included Simple HyperText Markup Language (HTML) Ontological Extensions [9], the Ontology Inference Layer [10] and DAML + OIL (DARPA Agent Markup Language + Ontology Interchange Language) [11]. The WWW Consortium set up a standardization working group in 2001 to develop a standard for a Web ontology language (OWL) having recognised that an ontology-language standard is a prerequisite to developing the Semantic Web. This resulted in the development of the OWL ontology-language standard in 2004 exploiting earlier work on OIL, DAML and DAML + OIL. A key feature of OIL is its basis in DL, a family of logic-based knowledge representation formalisms descended from Semantic Networks and KL-ONE [12] but that have a formal semantics based on first-order logic [13]. All these formalisms adopt an object-oriented model in which the domain is described in terms of individuals, concepts or classes, and roles or properties. For example, in the photovoltaic system domain, a particular system on the market may be called PS-EMS1. In this case, the concept could be "PhotovoltaicSystem", the individual is "PS-EMS1" and the role "isTypeOf" describes the relationship between the concept and the individual. In a strict object-oriented paradigm the term 'classes' is used for concepts, 'properties' for roles and 'instances' for individuals. DL can be used to create a knowledge-base. The formal semantics allows for the development of reasoning algorithms that can be used to make correct inferences and answer complex queries about a domain.

2.2. Ontology applications

The OWL is being used in fields as diverse as biology [14], medicine [15], geography [16], geology [17], agriculture [18], defence [19] and construction [20]. The application of OWL is particularly common in the life sciences where it is used by developers of several large biomedical ontologies such as Biological Pathway Exchange [21], Gene Ontology [22], Systematised Nomenclature of Medicine [23], the Foundational Model of Anatomy [24] and the US National Cancer Institute thesaurus on cancer terminology [25]. The main output of the TOronto Virtual Enterprise (TOVE) is a set of integrated ontologies for the modelling of both commercial and public enterprises developed at the University of Toronto [26]. The TOVE project ontology is one of the best that defines the role or workers or agents in an organisation or an enterprise [26]. The Dutch government has several ontology driven applications on the internet that inform the public about rights and duties that are relevant for certain life events [27]. Some examples of life events are "the death of a close relative" and "working and studying" [27]. In Australia, efforts to structure various biological databases into a single representation format and to represent the mapping between various biological information using the power of OWL and Extensible Markup Language to discover data semantics in complex biological data known as BIOMAP Project is currently being undertaken at Murdoch University [28]. Most ontologies are typically developed through collaborative endeavours within a given community aimed at facilitating information sharing and exchange. This is certainly the case with the Industry Foundation Classes (IFC) and its associated ifcXML by the buildingSMART initiative [29] and the derived Web ontology language (ifcOWL) [20] in the construction industry for application in the building information modelling domain. In the following section we discuss the sustainable building technologies domain and the prototypical ontology being developed to explore the potential application of the Semantic Web techniques in this area.

3. An overview of innovations in sustainable building technology

There exists a broad range of products that fall within the sustainable building technology domain. There are many different characteristics which products may exhibit to demonstrate a degree of sustainability. Some products may be capable of being installed or assembled on site with minimum impacts on the environment. Some may be more energy efficient. Some may eliminate the use of fossil fuels. Some may include high proportions of recycled materials. Some may use natural sustainable materials. Some may promote water efficiency and some may reduce carbon