TOWARDS DEVELOPING A SUSTAINABLE BUILDING TECHNOLOGY ONTOLOGY

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Construction has a significant effect on human quality of life in the context of sustainable development. The UK government has long recognised this and is taking the lead towards a more sustainable approach to construction processes. Success towards a more sustainable construction can be achieved if the stakeholders are informed of the new technologies, innovations and knowledge emerging in the sector. Unfortunately, researchers and practitioners have pin-pointed some limitations with the current approaches in the management of knowledge within the construction sector. Interestingly, Semantic Web technologies, the next generation of the Web technologies, can be used to overcome these limitations. Semantic web technologies can considerably improve information representation, sharing and re-use. This paper investigates the extent to which Semantic Web technologies could be used in representing knowledge on emerging sustainable building technologies. This is done by reviewing the current state-of-the art of sustainable technologies in the UK construction industry. Furthermore, it examines the development of an ontology-driven knowledge base and its usage in the development of a semantic web application.

Keywords: ontology-driven knowledge base, semantic web technology, sustainability development.

INTRODUCTION

The causes and impacts of climate change are now too well-documented to dispute. It is now a common knowledge that global warming is being caused by human activities with construction being a predominant component. With respect to this, there has been a global growing quest of the importance of sustainability agenda within organisations as strategies to mitigate the impacts of climate change. The UK construction industry (UK CI) is under growing pressure from various agencies to incorporate sustainable construction practices into its projects in order to meet the housing demand in the country in terms of quantity and quality. This has compounded the burden of the CI which is already struggling to cope with even more complex problems such as project and knowledge management (Dainty 2005; Egan 1998).

Sustainable construction' is defined as the creation and operation of a healthy built environment based on ecological principles and resource efficiency (Kibert 1994). This implies that the implementation of construction methods, materials, components, equipments and processes in projects must have a minimal effect on the built environment and based on sound ecological principles. The integration of sustainable building technologies (SBT) into housing development projects is imperative in sustaining a healthy built environment. Furthermore, the implementation of modern

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Abanda, F H and Tah, J H M (2008) Towards developing a sustainable building technology ontology. *In*: Dainty, A (Ed) *Procs 24th Annual ARCOM Conference*, 1-3 September 2008, Cardiff, UK, Association of Researchers in Construction Management, 627-636.

methods of construction (MMC)-a component of SBT can considerably improve the supply of buildings thereby lessening the pressure on the demand for housing in the UK. Unfortunately, the inception of SBT has been received with mixed feelings (Hall 2006) despite the government's recommendations (Egan 1998; POST 2003). One of the major reasons to the reluctance of the uptake of SBT has been the limited knowledge about SBT (Hall 2006). The advent of MMC and SBT has also brought along huge amount of information from different sources requiring robust knowledge management techniques for human consumption. This paper proposes an ontology-based method in capturing, modelling and representing knowledge in the domain of SBT with a focus on solar energy systems. The restriction on solar systems is due to the huge nature of the domain of SBT, the resource and time constraints. The afore-mentioned aim of this paper is achieved by first establishing a state-of-the-art of SBT and semantic web technology (SWT) and secondly by using the SWT in capturing, modelling and representing knowledge about SBT.

The next section presents an overview of knowledge management in the UK CI. This is followed by a review of the SBT domain and the general ontology mechanisms required for the development of SBT ontology. This is followed by the presentation of a methodology used in developing the SBT ontology. The last two sections of the paper summarises the whole paper by identifying key findings in the discussion section and the achievements in the conclusion section.

AN OVERVIEW OF KNOWLEDGE MANAGEMENT IN THE UK CI

A major challenge of the UK CI is the huge number of documents involved during the execution of construction projects and the fragmentation of the industry rendering information management a very complex task (Ruikar et al 2007; Rees 2006; Pan 2006).Though the development of mechanisms for manipulation (capturing, storage, search and retrieval) of knowledge during construction projects has always been of great importance to construction organisations (Ruikar et al 2007), there is still very limited understanding of the best ways to foster the creation of knowledge, let alone how to capture it. A major difficulty in this area is how to ensure that knowledge is readily available to individuals, project teams and companies (Shelbourn et al 2006). After over 20 years of implementing information and communication technology into building construction, there is no doubt that substantial progress has been achieved, but real improvement in terms of speed and consistency are lacking (Rees, 2006). As argued in Rees (2006), and by the strengths of the semantic web (SW) demonstrated in Davies, Studer and Warren (2006), Alesso and Smith (2006) and from success stories of exemplar projects in the fields of BioInformatics, e-Commerce, etc, the SW is the missing technology, the building construction industry should have had to cure its myriad knowledge management problems. Moreover, the present World Wide Web used by many has made a huge amount of information available and has been a success story in terms of availability of information and growth rate of the number of (human) users. However, this success and exponential growth of information and number of users have rendered the web increasingly difficult to find, to access, to present, and to maintain information of use to a wide variety of users (Fensel et al 2005; Lacy 2005; Antonio and van Harmelen 2004).

To overcome the limitation of the current web technology, the SW-the next generation of the web technology has gradually gained prominence in the scientific research community. As defined by its creator Berners-Lee:

> *"the SW is an extension of the current web in which information is given a well defined meaning, better enabling computers and people to work in co-operation (Berners-Lee et al 2002)".*

In the SW, information is given a well-defined meaning consumable both by humans and machines. One important task of the SWT is its capability to offer both end-users and applications a seamless access to knowledge contained in heterogeneous data sources in specific user communities (Lei, Lopez and Motta 2006). Currently, the web has primarily been designed for human and not computer consumption, as the latter is being used as a carrier of information. The SW addresses this deficit as it overcomes the challenges of automatic-based processing of information on the web (Walton 2007). The global vision of the SW initiatives is to exchange knowledge among community users. It requires a shared mechanism to classify domain knowledge-items or information into interrelated concepts i.e. ontology (Argüello, El-Hasia and Lees 2006). Ontology has been defined as a specification of a conceptualisation (Gruber 1993). In the Artificial Intelligence domain, the main purpose of ontology is to facilitate knowledge sharing (Fensel 2001)

REVIEW OF THE KEY CONCEPTS IN SBT ONTOLOGY

This section explains the top concepts in the SBT ontology. The three main concepts discussed herein are building construction technology (This concept captures the various types of building construction technologies), organisation (This concept captures the various organisations involves in SBT such as research, supply, execution) performing different services on the building construction technology and the standards(This concept captures standards and codes required for the design of each SBT).The organisation concept will facilitate the localisation of each SBT depending on the interest of the inquirer. Design engineers will be interested in the concept standard. Some important facts such as cost, activities involved will be conceptualised through the use of other components of protégé OWL(e.g. data property and object property).The concept of building construction technology has been reviewed in Abanda and Tah (2007). However within the time frame for this research, key components such as object properties, data properties will be restricted to solar energy systems.

Building Construction Technology

This concept consists of the following classes: sustainable energy technology, building construction element, building construction product, building construction material, building construction method, waste minimisation technology, smart system technology, and water conservation technology. The concept has been reviewed in Abanda and Tah (2007). This research extends the categorisation in Abanda and Tah (2007) to include solar energy systems as a key component of sustainable energy technology. The solar energy system is broken down into solar electric system and solar thermal system.

Organisation

This main concept is further broken down into two classes, research organisations and mixed organisations. Research organisations refer to bodies whose main domain of activity is research in solar energy systems. The class research organisation is further decomposed into academic and non-academic organisation. Academic organisation refers to university research in the domain of solar energy systems. Non-academic organisations included reputable institutions such as Building Research Establishment,

Energy Saving Trust, Carbon Trust, etc. On the other hand, mixed organisations refer to bodies whose main interest is not only research but render any solar energy related service. This includes the local authorities, private companies, installers and associations.

Standard

Following the restriction of this research on solar energy systems, the standards reviewed here are applicable to solar energy systems. The two main concepts considered are general standards and reduced standards. The former consider regulations and standards applicable across all micro-generation and renewable energy technologies. The latter considers regulations and standards applicable only to solar electric and solar thermal systems.

REVIEW OF ONTOLOGY DEVELOPMENT

This section reviews the various mechanisms required in creating an ontology in general. It establishes appropriate choices of the ontology language, ontology methodology, and ontology editor suitable in the context of SBT ontology.

Languages for building ontologies

A number of ontology languages have been reviewed including XML, RDF, RDFS, and OWL. Based on this review each of the ontology languages had some limitations. OWL has been chosen as it overcomes the limitations of the preceding languages (i.e. possesses sufficient expressiveness to provide the ontology descriptions required to support the SW)

Methodologies for building ontologies

The advent of common and structured guidelines or methodologies for the development of ontologies has eased the ontology development process. In this research the ontology methodologies in Gómez-Perez, Fernández-López and Corcho (2004) and Antonio and van Harmelen (2004), have been reviewed. The methodology chosen for this study is that of Noy and McGuinness (2001) and has already been used in Abanda and Tah (2007). This methodology is the most popular and widely used in the ontology research community.

Editors for building ontologies

Ontology development is a difficult and time consuming task. It is even more complex when the ontology is to be implemented in an ontology language. In the case of this research the SBT ontology will be implemented in the Web Ontology language (OWL), hence an appropriate ontology editor has been considered. The following ontology development tools were reviewed: KAON (Maedche et al 2003), OilEd (Bechhofer et al 2001), Ontolingua Server (Farquhar et al 1997), OntoSaurus (Swartout et al 1997) WebODE (Arpirez et al 2003) WebOnto (Dominigue 1998) and Protégé-OWL (Protégé website). After a critical comparison, Protégé (see screenshot in Figure 1) was chosen because it offers support to ontology libraries and the OWL language.

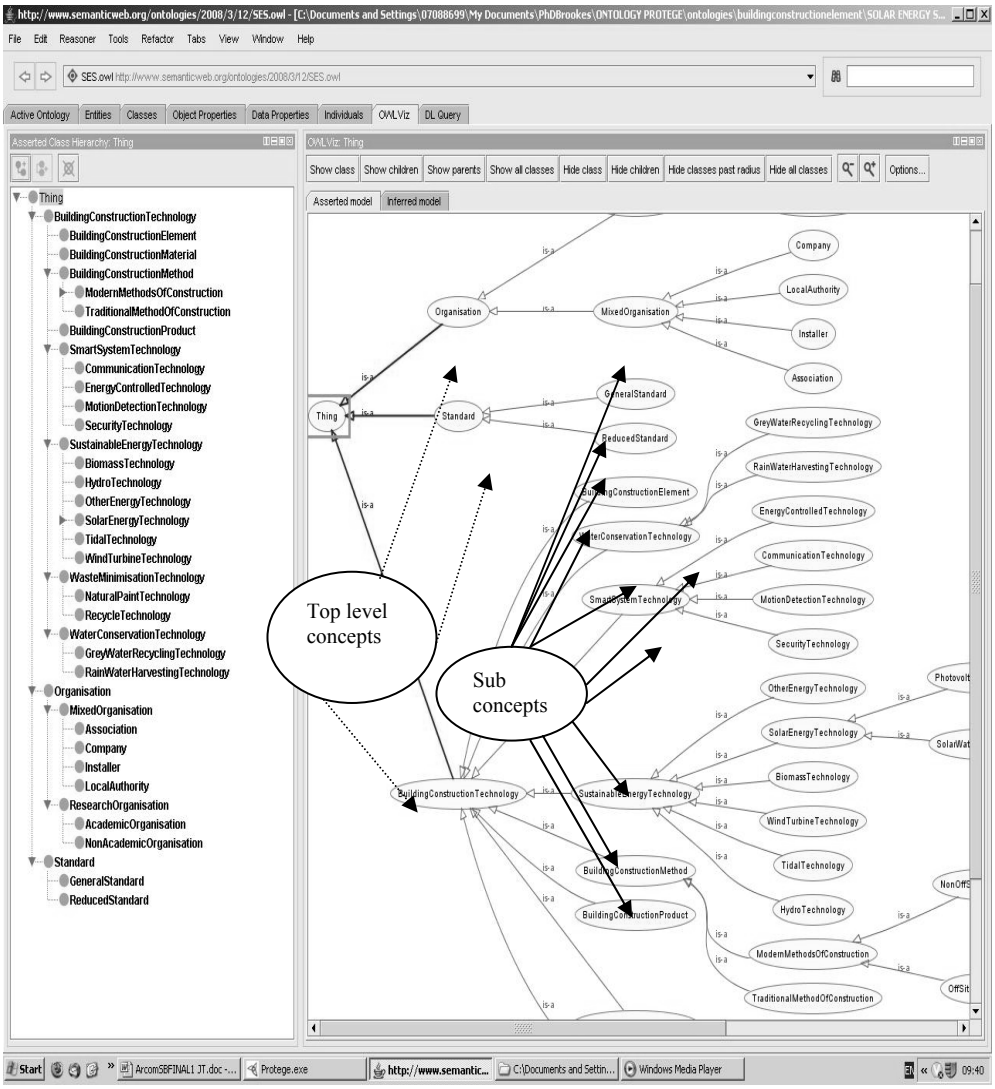

Figure 1: Protégé OWL screenshot showing concept hierarchy of SBT ontology.

ONTOLOGY DEVELOPMENT

The very first step in ontology development is the need to decide on the application domain. The ease or difficulty in the development stages depends on the developer's expertise on the domain of discourse or otherwise the availability of experts in the domain. The elicitation of knowledge and concepts in this domain has been conducted in consultation with experts in the field through a combination of informal discussions and solicitation of documented cases. Furthermore, there is an abundance of information in existing literature on the domain and by carefully reviewing high quality structured data from journals, leading research establishments and other classification systems, the burden of concept validation through a survey, workshop presentations to experts was deemed unnecessary.

Determination of domain and scope of ontology

The domain of the SBT ontology is derived from the combination of both the objectives of this paper presented in the background and the guideline questions for the determination of domain of ontology in Noy and McGuinness (2001). The four principal questions suggested are:

- What is the domain that the ontology will cover?

- For what will the ontology be used?
- For what types of questions the information in the ontology provide answers?
- Who will use and maintain the ontology?

In attempting the above questions and bearing in mind the objectives this study, we arrived at the following answers and hence the domain of the SBT ontology. For the first question, the domain will cover SBT restricted within the boundaries of sustainable construction principles and sustainable development in general. For the second, the SBT ontology will be used for capturing, representing the semantics of sustainable building information for distribution amongst different agents. For the third, the possible types of questions that SBT ontology is likely to provide answers to are, what are the different renewable energy systems in the UK? Where can one obtain further information about sustainable energy systems? What are the existing standards that regulate the different sustainable energy systems? How can one select the most appropriate system for a specific application? How much will it cost? etc. Finally, construction professionals will use the SBT ontology and consideration would have to be given to how the ontology will have to be maintained in practice once developed.

With respect to the above questions and answers, we arrived at the domain to be SBT applied to housing development. Some examples of SBT are water conservation technologies, solar energy systems, volumetric systems of construction, etc.

In determining the scope of the ontology, the method proposed by Grüninger and Fox (1995) based on the design and answering of competency questions helped in limiting the scope of the ontology. Table 1 is an extract of some competency questions and answers.

Table 1: Using competency questions to determine scope and domain of SBT ontology

Competency Questions	Answers
1) Which renewable energy technology is required in a building?	Biomass technology, Wind turbine technology, Solar technologies, etc
2) What are the elements of a Sustainable Building?	Sustainable building materials, Sustainable building methods, etc
3) What are the types of construction methods?	Off-site manufacture, Volumetric and panelised systems, etc
4) What type of material should be used in a building?	Renewable building material, timber, steel, concrete
5) How much is the typical capital costs of a PV system for an existing buildings	£6 000 per kWp (NHBC 2008)

Judging from the above list of questions, the ontology includes concepts like building construction material, building methods, building construction technology, and building construction element.

Re-use of other ontologies

Three key components i.e. elements of buildings (group G), construction products (group L) and materials (group P) from the Unified Classification for the Construction Industry (UNICLASS) (Smith et al 1997) were incorporated into the SBT ontology. One major difference between UNICLASS and other building classification systems in the UK relevant to sustainable building is that, it involves energy and environmental issues.

Enumeration of terms in the ontology

From literature sources, the terms in the SBT ontology are listed without necessarily following an order. Some of the terms are rainwater harvesting technology, grey water recycling technology, wind turbine technology, isAddressOf, researchesOn, hasEmail, etc.

Definition of taxonomy

There are several approaches in developing class hierarchy (Uschold and Gruninger 1996). In this study a top-down development approach was adopted. This approach considers the most general concepts before descending to more specific concepts. In the SBT ontology, the building construction technology, organisation and standard are general concepts. Each of these top concepts further breaks down into more specific concepts. The classes have been organized into a hierarchical order.

This means if a class A is a subclass of class B, then every instance of A is also an instance of B. Figure 1 above shows the asserted hierarchy of the SBT ontology on the left and the graphical representation on the right using the OWLviz plugin.

Definition of properties

Three types of properties have been considered, the annotation properties (a) which comments on some key components of the SBT ontology, the object property (b) which defines the relationship between individuals of the various concepts and data type property (c) which defines the relationship between individuals and data types values. See Figure 2 below.

a) Annotation properties b) Object properties c) Data properties

Figure 2: Properties of the SBT ontology

Definition of Facets

Facets of slots are properties of properties highlighted in the previous step. These facets entail stating slot cardinality, slot value and the class to which the property has been attributed.

Definition of Instances

This step requires creating individual instances of classes which consists of 1) choosing a class, 2) creating an individual instance of that class and 3) filling in the slot values. Figure 3 shows some of the instances of the SBT ontology.

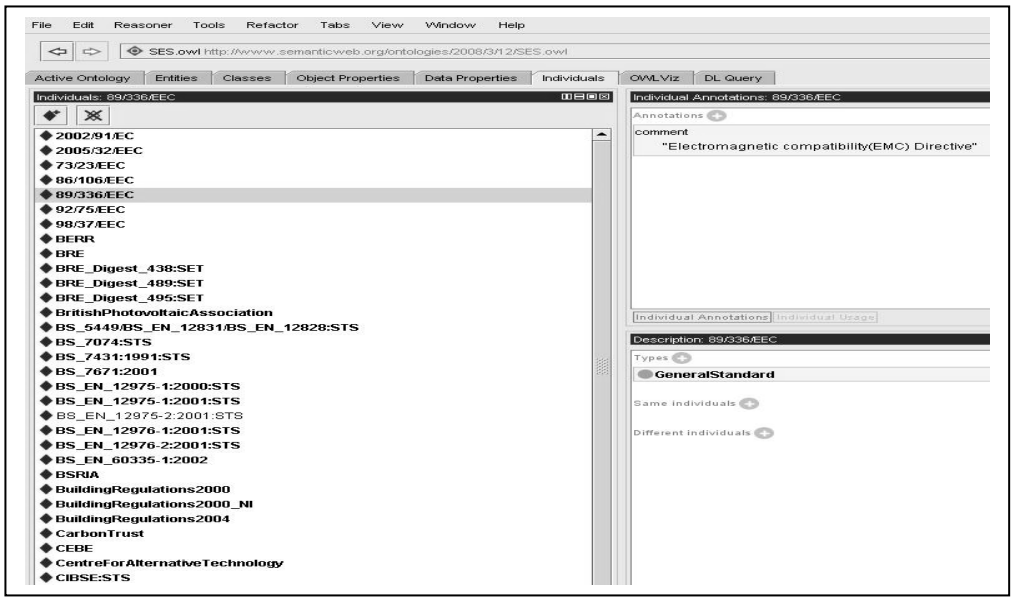

Figure 3: Instances of the SBT ontology

Checking of anomalies

One advantage of protégé OWL over RDF schema is the possibility to detect inconsistencies in ontologies. Some examples of inconsistencies are incompatible domain and range definitions, inverse properties, and cardinality properties. The SBT ontology was checked using the Run ontology test wizard under OWL widget in protégé-OWL. The results from this test wizard were successful confirming the perfect semantics of the SBT ontology.

DISCUSSION AND KEY FINDINGS

Contrary to the usual lack of information in knowledge domains, there is an abundance of information emerging from the domain of SBT. This abundance is overwhelming to construction professionals who desire this to make informed decision in their construction projects. This established the rationale in exploring the extent to which SWT could be used in modelling SBT knowledge. Reviewing both the SBT and SWT led to the identification of the following key findings:

Various organisation used different formats in publishing SBT knowledge;

The definition of SBT terminologies were/are based on natural language posing a lot of ambiguities lacking rich semantics; and

The review of methodologies, tools and languages used in eliciting, modelling and representing ontological knowledge reveals that they depend on the purpose of the ontological knowledge base, the ease of integration with SWT, and availability.

CONCLUSION

In this paper we have reviewed both the SBT and SWT in relation to knowledge managing in the UK CI. Based on this review the above key findings were identified. To overcome the gaps in these findings, key ontology models with rich semantics were developed to capture the knowledge about SBT. These models were used in the development of the SBT ontology. This was achieved by reviewing and making appropriate choices of the ontology modelling language, the ontology editing tool and the knowledge engineering methodology. This work will serve as the groundwork for the future implementation in a SW environment.

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