CONTRIBUTION OF SEMANTIC WEB TO COLLABORATIVE DESIGN

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Abstract. This paper focuses on a lightweight ontology-based knowledge management system, which is a prototype that aims at enhancing the collaborative activities in the early building design phase. Technologies with respect to de facto standards proposed by industry group W3C are implemented to develop this knowledge management system. Resource Description Framework (RDF) associated with its Schema (RDFS) is selected as the ontology language used in the system. RDF(S) with its embedded reasoning techniques provides a rich set of constructs to facilitate the generation of ontologies so that the annotated information can be machine readable. Approaches of how the domain knowledge is represented in RDF(S)-based ontology, is shared and retrieved among stakeholders of building project will be described and illustrated in the paper. A proposition with respect to the contribution of this prototype system to collaborative activities undertaken in the early building design phase will also be discussed in the paper.

1. Introduction

Building industry produces a mass amount of information that has very high reuse value of tacit and explicit knowledge, which is the important strategic resource of an organization (Nonaka & Takeuchi, 1995; Grant, 1996). Reuse and share of knowledge plays a vital role for improving collaboration amongst the involved stakeholders throughout the building life cycle, which may cause positive impacts such as shortening the time-span of building production as well as betterment of building quality. Considering that (external) knowledge could be defined as information that can lead to effective action (Davies, Fensel & Van Harmelen, 2003), it has been mandatory practice for the building industry to organize the vast amount of information with particular mechanisms in order to facilitate future reuse and

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retrieval when the need arises. Organizing the mass quantity of information particularly those generated during the early design phase has however been realized as an uneasy task (Fruchter, 2002). The fast developing information and communication technology (ICT) has contributed its efforts tempting to enhance the collaboration amongst the A/E/C professionals by managing the existing information base more effectively and efficiently.

1.1 WHAT IS THE PROBLEM?

The building industry is very project-oriented in nature, and it is organized on actor streams wherein actors are involved in several projects at the same time (Zarli et al, 2002). Actors involved in the same project are sometimes thousand miles apart and practicing different working methods in accordance with their respective roles. In addition, most projects can be characterized as virtual organizations that are only established on temporary contract basis and therefore merely maintain short-term business relationships. All of these factors have created the dilemma upon the building sector that extra resources are required respectively to manage each project. Consequently, the project-related machine stored knowledge would no longer be contained in one centralized repository but distributed in heterogeneous databases that belong to different individuals, discipline groups, project-teams and organizations. Even though the concurrent ICT enables the formation of virtual project teams that can work across geographical and time constraints through virtual workspaces, integrating the heterogeneous information sources particularly ones that contain weakly structured information remains an uneasy task in the building sector (Christiansson, 1998). The wide use of low-level technologies mostly adhering to hyperlinks and keywords search (Ding et al., 2003), and the lack of meta-level data structures (Christiansson, 1998) are the main reasons behind this non-integrating phenomenon.

1.2. AIM AND OBJECTIVES

These trends have motivated the formulation of a hypothetical Semantic Web based knowledge management system, which is subject to overcome the dilemma of information and knowledge integration in the A/E/C sector and furthermore significantly extend the collaboration support amongst the project stakeholders. This article focuses on depicting how the design knowledge is represented in RDF(S)-based lightweight ontology. Approaches used for handling design information based on the underlying ontology model will also be illustrated. A proposition with respect to the contribution of this hypothetical system to the collaborative activities undertaken in the early building design phase is also discussed in this paper.

2. Dissemination of Design Information in Collaborative Design

Collaboration is defined as a team of people working together with shared goals for which the team attempts to find solutions that are satisfying to all concerned (Kvan, 2000). The main concern of collaboration with respect to collaborative design particularly in the early design phase is to transfer know-how (Chiu, 2002). Activities involved in this phase involve client briefing, data collection, architectural program formulation, and schematic design. In this phase, the most important decisions are made. These decisions are critical to the evolution and quality of the final design of the project.

Communication problem arises when the possibility of different cognitive processes of different individuals on representations occurs in the collaboration (Catledge & Potts, 1996). As a consequence, design specialists in a collaborative design team do not only require tools that can assist them in drafting but also in communicating. Communication is the key to the success of design projects, it is therefore always important to have some quality communication means that may allow collaborators to communicate their design information quickly and efficiently. Communication means that have been implemented by the A/E/C professionals consist of different varieties, range from the conventional face-to-face conversation, the use of telephone and fax machine, to the use of the contemporary Internet technology. A quality design information management system may be claimed as the prerequisite in prior to the start of any design project for allowing proper dissemination of design knowledge. The effectiveness of a design information management system is very much dependent on the communication means chosen for sharing the information generated throughout a design project. The system must be able to manipulate (capture, store, index and retrieve) information that is disseminative through the different types of communication means used.

The principle of effective communication in collaborative design is to share design information efficiently. It is very important to ensure that collaboration in the early design phase is effective because the most important decisions are usually made here. Activities involved in this phase are critical to the evolution and quality of the final design. The human contacts made in this early phase may be characterized to either asynchronously or synchronously (Chiu, 2002). Asynchronous communication mainly focus on the dissemination of the transcribed verbal description such as meeting minutes and telephone memos, sketches, orthographic drawings, schedules/programs and photographs. Project participants sometimes prefer to have synchronous communication particularly when the needs of oral explanation arise. As a consequence, face-to-face design meeting remains scheduled on regular basis as one kind of collaboration activities with respect to the design project.

The exponentially growing Internet is an inherently rich information source that serves as a global database provided with an infrastructure to link various resources that are distributed globally. Numerous technologies have been developed to enable organizations in various sectors of specialty to utilize the Internet for different functionality-specific applications including knowledge and/or information management. Internet-based applications are no longer a new topic in the A/E/C sector for the project team members are increasingly geographically distributed (Christiansson, 2002). Different groups worldwide from this sector have built numerous internet-based functionality-specific applications to utilize her inherent interoperability and communication capabilities. The ideal vision of using internet-based knowledge/information management system is apparently to have all of the scattered pieces of information electronically and well structured in order to facilitate the manipulation procedures. This is however not the case in reality. Information produced at the design stage, in particular, the early design stage remains partially paper-based, weakly and /or even un-structured. Attempts of digitalizing paper-based information by using for example the scanning machine have been conducted tempting to improve the efficiency of information handling. The scanned-in image files remain improperly structured with its information embedded implicitly. The weakly structured information contains lots of redundancies that are manipulated by the low-level technologies that mostly involve hyperlinks and keywords search only (Ding et al., 2003). These shortcomings have motivated the introduction of an enhanced Internet, the Semantic Web, to improve the information management efficiency (Bernes-Lee et al., 2001).

3. Semantic Web and Ontologies

The Internet associated with its most popular application, the WWW, provides interconnected infrastructures that are commonly used to facilitate the accessibility of digital resources. However, this web technology has severe shortcomings that arise from its simple underlying structures and protocols. The current WWW works well for posting and rendering all kinds of web contents but provides very limited support for processing them. This is because most web contents are stored in natural language chunks, which makes them very much dependent on the human users during search, access, extraction, interpretation and processing. Meanwhile, the growing use of WWW has increased the difficulty to manipulate the exponentially increasing amount of information. In response to this, the vision of a Semantic Web was created by Tim Berners-Lee in order to enable automated information access and use based on machine-processable semantics of data. Semantic Web was defined by him as "*an extension of the current web in which information is given well defined meaning, better enabling computers and people to work in co-operation*" (Berners-Lee et al., 2001). To accomplish this vision, efforts to link the existing web contents to semantic descriptions followed by the creation of a set of applications that can utilize this newly created metadata are desperately in need, which thus stimulate a new research horizon (Fensel et al., 2002; Semaview, 2002).

Ontologies are decentralized vocabularies of concepts and their relations to which the existing web contents can refer. These decentralized vocabularies do not only define the meaning of web page contents but also the contents of other information resources, including documents (paper-based) and databases. Ontologies are therefore the kernel of the Semantic Web that allow computers to better categorize, retrieve, query and deduce information from the WWW than the current web technology (Ding et al, 2003; Fensel, 2001). The concept of ontology applied in Artificial Intelligence is to facilitate knowledge sharing and reuse (Fensel, 2001). As defined by Gruber (Gruber, 1993), ontology is a formal explicit specification of a shared conceptualization. Thus, it should be machine-readable (Ding et al., 2003; Fensel, 2001), and supports machine-processable semantics of information sources (Ding et al., 2003).

4. Evolution of the Collaboration ICT in the A/E/C Sector

To date, the favorable collaboration ICTs used within the A/E/C sector are the project extranets (project websites), workflow management tools and groupware applications for collaborative working. These concurrent technologies improve the performance of shared virtual workspace, and thus encourage the formation of geographically distributed virtual project teams in this sector (Christiansson et al., 2002). In this respect, knowledge will be stored in heterogeneous databases that belong to different individuals, discipline-groups, project-teams and organizations, and will no longer be contained in one centralized repository.

Project extranet, tempts to integrate the heterogeneous information sources, and builds on client-server and web browser technology, has been implemented to enable the distributed project team members to share, view and comment on project-relevant information. This tool remains widely used though limitations from its purely document-centric characteristic and limited workflow support have been identified. To overcome the limitations of project extranet is somehow necessary to accommodate the increase of information generated throughout the project life, particularly in the early creative design phase, wherein fragmented design knowledge capture is of importance.

The awareness of project extranet no longer being the best solution has motivated the A/E/C sector to broaden the horizon of communication capabilities that are supported by the Internet. Under the circumstances, several EC funded projects have been conducted tempting to lead to a change of paradigm. For example, Diversity, which is a project that aims at supporting and enhancing concurrent engineering practices through allowing teams based in different geographical locations to collaboratively design, test and validate shared virtual prototypes (Christiansson et al., 2002); and e-Construct, a project with the aim to improve internet-based communication in e-Commerce and e-business in the context of communication across national and organizational barriers. With respect to this, a common communication-oriented language, namely bcXML was defined based on Extensible Markup Language (XML) with building construction meaning aimed at e-Commerce transactions (e-Construct, 2001). E-COGNOS, which aims at offering a generic, a modular and an open solution for knowledge management in the context of collaboration between actors in a construction project (e-COGNOS, 2001) has also started in year 2001. The insights of these examples generally imply that there is an evolution tendency from the *document centric* Internet to a *meaning centric* Semantic Web. This evolution may meet the requirement of knowledge management that practices in the building sector, which is mostly informal and people-centered wherein abstract concept and meaning are of interest.

5. Methodology

A semantic web based knowledge management system is being developed to enhance collaboration in the early design phase of a building project (Lai et al, 2002; Lai et al., 2003). The system is primarily devised to integrate pieces of information generated at the iterative early design stage in order to provide decision making support in a multi-actors environment where information is archived in heterogeneous sources. The system is also capable of providing fast and precise semantic search, and to capture the intent and rationale behind decisions made during the early design process.

Case studies were undertaken to observe several design meetings in order to investigate design information flow and its management as well as to examine how the design team members communicate amongst themselves effectively during decision-making process at the early design stage of building project. Several short interviews were also conducted with some key personnel of the design team as to complement the observation context, which was outlined hereafter.

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5.1 SCENARIO OF THE CURRENT PRACTICE IN DESIGN INFORMATION MANAGEMENT

This section delineated the results of investigation based on a series of observations and interviews in order to portray the current system being used by the A/E/C professionals during the early design phase in regard to handling project-related design information.

Design information was communicated amongst meeting participants via various types of representations including 2D drawings (sectional drawings, plan drawings, elevation drawings), presentation model, 3D computer images, hand sketches and so forth. Most of the design information was maintained in both digital and paper forms, and therefore both digital and paper-based archive systems were used. Hand sketches were the mainly used representations at this stage to communicate design ideas. Computer 3D images were used when design process began to move forth to the schematic design stage. Apart from graphical drafting tools, designers preferred simple tools that they could use for the purpose of managing design information without special training. Word processor, spreadsheet tool, calendar, e-mail facilities and simple electronic filing system were commonly used by designers.

Face-to-face meeting was the preferred communication means by project participants when oral explanations with visual presentations were needed. Other means of communication used apart from face-to-face meeting were faxes, telephone and e-mails. The use of e-mails has been increasing after Internet-based communication means has been widely adopted within the A/E/C Sector. Progress meetings were conducted on regular basis at two levels, company- and project- level respectively. Different information management systems built on different filing structures were used separately by project participants. Repetition of workload was therefore necessary for the meeting participants to coordinate design information that was produced at two different levels and stored in various corresponding company-level repositories. Meeting agenda was made only for the first progress meeting. Meeting minutes were produced after the completion of every project-level and company-level progress meeting by a specific meeting participant, for instance the project manager. Meeting minutes were then used as agenda to guide the discussion topics of the next meeting. Progress report was another type of design information produced on a regular basis to allow the project's client to keep track of the design progress.

Project web was the project-level mechanism used in the case studies to collect project-related information. This project web functioned as a centralised repository to allow project participants to coordinate and share the increasing amount of project-related information. Digitalised information, such as design drawings, progress reports and meeting minutes

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were available in this information pool. During the interviews, interviewees delineated the limitations of project web in relation to information dissemination. Information was categorized based on the preferences of the web master, and was archived under different electronic file folders that were created based on the predefined categories. The semi- and unstructured information such as briefing notes, design rationale, and e-mail messages, was usually not stored in the project web. In general, e-mail messages were collected in another project-level digital information source while the paper-based information was kept in company-level paper-based archives such as file cabinets. Drawings were generated at every stage with respect to the design change, but only the final version was uploaded to the project web. In brief, such descriptions reflected the implication of fragmentary communication and information flow.

The significant shortcoming of the project web in use was the dependency of inefficient human efforts in processing such as searching, browsing and extracting the stored information. Meeting participants were required to spend rather long time to read a specific piece of information in order to comprehend its context during the discussion. It was also observed that meeting participants faced the difficulty to find a specific piece of document during the meeting, particularly when the need of that document arose at random. On the other hand, the person who was responsible for making meeting minute tempted to capture the discussion content on papers. The captured information would then be transformed to digital format with word processor tool after the completion of meeting, which resulted in repetition of workload.

A hypothetical infrastructure, a prototype system, is developed to alternate the conventional notes-taking approach used for capturing the discussion content of a meeting. The prototype system is envisioned able to model and analyze the discussion content based on an underlying ontology model so that the discussion content is organized in a semantic-based network. RDF(S), the de facto standards proposed by the industry group W3C(W3C, 2002) are adopted as the core to develop the ontology model of the prototype system mainly due to the availability of several open source RDF(S) tools.

6. The Prototype System

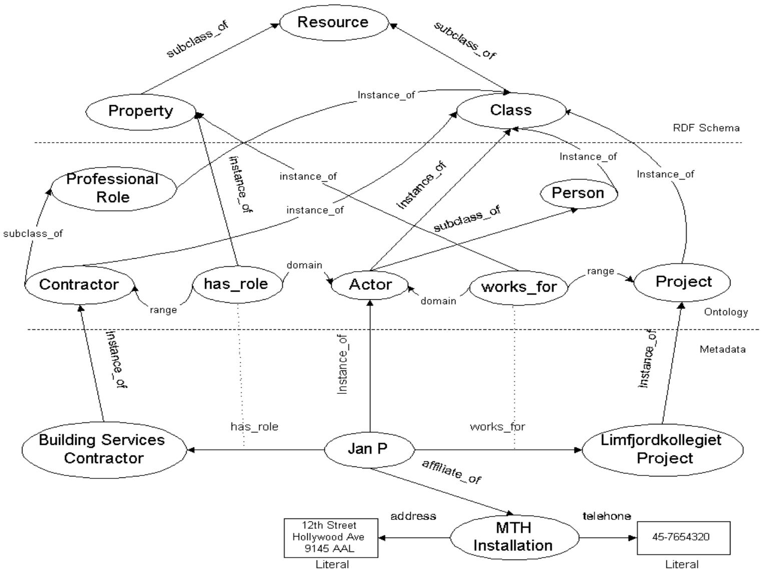

Figure 1. Excerpt of the RDF(S) based lightweight ontology and its instance data

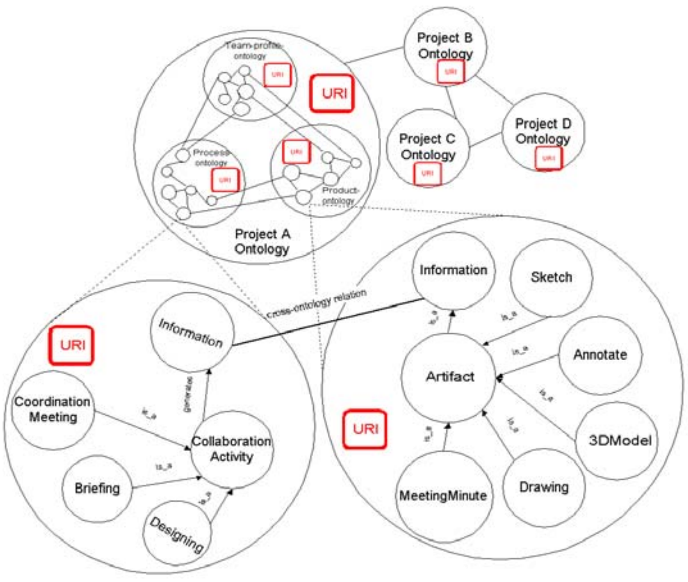

Figure 2. Domain knowledge was represented by modular basis ontology network

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Figure 3. The form-filling UI of the prototype system

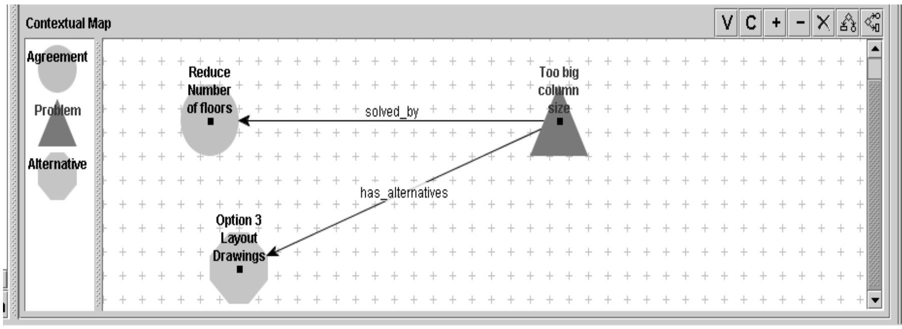

Figure 4. The Contextual Map of the prototype system

Figure 1 illustrated the excerpt of the RDF(S) whereof the prototype system is built. The system is developed with high flexibility concerning the scalable possibility to accommodate new ontologies in the future. Such ontologies should be defined in a way to capture the domain knowledge that corresponds to design information management and dissemination. Currently, this early prototype system is devised to support progress meeting which is one of the collaborative design activities. The prototype system is envisioned to fulfil the following tasks:

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1. To integrate information that is distributed in heterogeneous sources without using one central repository to reduce repetition of workload.
2. To capture and store discussion content wherein design rationale and decision intent are intrinsically encompassed.
3. To organise the captured information in a way that is both human and machine readable
4. To contextualise the captured information in representation that may improve the human's efficiency to interpret its implicit meaning.

The ontology model of the prototype system remained under development when this article was prepared. At this stage, the underlying ontology model consists of few modular components, which respectively is ontology, for example the "team-profile ontology" and the "early-design-process ontology" (see also Figure 2). These modular components respectively describe another aspect of interest, for instance the "team-profile ontology" describes the profile of the design team. These ontologies are linked with each other to provide the expandable capability of the prototype. The graphical presentation illustrated in Figure 2 shows the modular characteristic of the ontologies network, each of which is accessible through the uniquely specified URI (Uniform Resource Identifier). The modular characteristic permits the scattered information including the existent data and the respective ontologies not to be collected under one central repository.

Protégé-2000, an open source ontology editor is used to develop the form-based user interface of the prototype system. This user interface is to facilitate the system user establishing RDF data file based on the lightweight ontology model. Sesame (detail see http://sesame.aidministration.nl), an open source RDF(S) based repository and querying facility is used as the development base of the prototype system. RQL, query language used in Sesame, is also implemented in this prototype system as the means of accessing information in RDF (S) (detail see Broekstra & Kampman, 2001).

The form-based user interface is developed as the mechanism to annotate the content of the meeting minutes with a set of metadata that was pre-defined in the ontology model, including Infoblock Author (denotes the person who raised the discussion issue), Discussion Date, Text (denotes the discussion content), Title (denotes the title of the discussion issue) and so forth. With this set of metadata, the content of the meeting minutes could be semantically structured, and become readable to the machine and easily interpretable to the human. As shown in Figure 3, for instance: <has_action_taker>Joe Young</has_action_taker> illustrates that "Joe Young would take the action" on "something" that was discussed in the

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meeting. The form filling user interface was chosen because form-filling has been a familiar activity for most computer users. The filled-up form represents a dynamic meeting minute with all of the annotated information populates in the RDF(S) based repository. The annotated information can be stored separately from its corresponding ontology. Queries can be established by system user to initiate semantic search (for detail please see Lai et al, 2003). The searched result, which is a list of URIs, is accessible by the system user provided that all of the relevant repositories are connected to the Internet.

7. Discussion

A lightweight ontology based prototype system is being developed at its infancy stage in order to test the formulated hypothesis that a Semantic Web based knowledge management system may contribute to possibly improve collaborative design. At this stage, the reasoning structure of the prototype system is being evaluated by populating instances to the underlying ontology model via the form-filling user interface. The interim findings has identified that the current metadata initiatives are insufficient for the prototype to fulfil all of its tasks. These initiatives focus on the encoding of primary content attributes of resources (e.g. documents, datasets, etc), such as author, date, location ID, and so forth, with the purpose merely to improve information retrieval and interoperability. In order to fulfil all of its tasks, the prototype system is devised one step forward to take the challenge claimed by Goel (Goel, 1995), which is to provide possible means for analyzing the contents from group discussions so that the idea flow can be traced.

Ideas with respect to various issues were generated, shared, and discussed during design progress meeting. These ideas comprise newly defined or existing design problems, propositions to solutions, as well as the solutions themselves. The relationship between these ideas was implicitly written as plain-text messages in the conventional meeting minutes. The implicit relationship between these ideas can be made explicit by contextualizing them from the following perspectives as proposed by Shum et al. (2002) so that the flow of ideas can be traced:

1. The intellectual lineage of ideas, for instance, where has this idea come from, is this idea a problem or proposition, has this problem been solved, are there any precedent cases?
2. The impact of ideas, for instance, what was the impact of this proposition to its problem and to other proposition?
3. Inconsistencies, for example, did the solution gain unanimous agreement from the project team, what was the reason given as opposition?

Contextualizing information in such a way is similar to overlaying interpretation of contents explicitly based on the semantic network derived from the underlying ontology model. As shown in Figure 4, the contextual map, which is part of the prototype system devised for this purpose, allows system users to model the semantic relationships between information graphically by binding the different sets of annotated ideas with context dependent relations (or properties as defined in RDF(S)). For instance, a plain-text statement *"Reducing the number of floors is the agreement made to solve the problem of having too big column's size"* could be represented by a set of RDF triple as *"<Problem>Too big column's size</Problem>* ***solved_by*** *<Agreement>Reduce number of floors</Agreement>"*. <Problem> and <Agreement> denoted the subject and object of the triple respectively while the phrase ***solved_by*** denoted the predicate (or property) of the triple. This set of RDF triple could also be briefly written as *(Problem, solved_by, agreement)*. <*Agreement*> and <*Problem*> were two of the examples of metadata used in the prototype system to annotate the content of information, and *solved_by* was the example of relations used to disclose the semantic relationships between information. Briefly, disclosing the semantic relationships between information graphically as illustrated in Figure 4 may reduce the time users will spend to digest the non-relevant information and therefore enable the users to manage information of interest more efficiently.

8. Conclusion

Design rationale and decision intent are intrinsically embodied in the discussion content of the design progress meeting. Discussion content has been conventionally captured in meeting minutes simply as a piece of plain-text document that is circulated amongst the project stakeholders. Sources of design information that is referred to during discussion are usually specified in this plain-text record. By making use of the technologies of Semantic Web and ontologies, the conventional meeting minutes is envisioned able to be upgraded to a dynamic and semantically structured medium. The implication is that this medium may handle the mass quantity of design information effectively by eliminating the extra workload, either real or perceived, of having to use extra applications to run a project-oriented knowledge (information) base, such as the project web. Further research will investigate in the issues of practicality of this hypothetical system with respect to bridging the islands of information containers that existed amongst the groups of organisations in the A/E/C sector.

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