SUSTAINABILITY INFORMED DECISION MAKING IN THE CONSTRUCTION SECTOR

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ABSTRACT

In the contemporary world the construction industry is facing continual pressure to increase the sustainability of its practice. In this context, designers and engineering teams are faced with two main issues: (a) the management of the diverse and ever changing body of sustainability related knowledge; and, (b) the need for timely, informed support for the decisions related to sustainability which are made in the pressurized environment of the design and tender stages. While research into these two areas has produced valuable findings and several research software prototypes and commercial offerings, the paper argues that there is merit in viewing decision support and knowledge management as complimentary technologies. The paper reports on a research initiative bringing together a knowledge management environment and a decision support tool to provide designers with an environment that supports sustainability informed decision making, and brings just-in-time sustainability knowledge management into the applications used in architectural design offices.

KEY WORDS

Architectural Design, Decision making, Sustainability.

INTRODUCTION

Sustainability goals can only be achieved if construction activities are informed by new resources of knowledge and expertise. Some of this comes in the form of good practice, standards and enhanced process models, but much will have to come from situated and contextual appreciations of sustainability goals and local practices developed across organizational and professional boundaries.

Sustainable construction can be summarized through the following principles: (a) Minimization of resource consumption, (b) Maximization of resource reuse, (c) Use of renewable and recyclable resources, (d) Protection of the natural environment, (e) Creation of a healthy and non-toxic environment, (f) Pursuit of quality in creating the built environment (Kibert 1994). Within the industry's own discourse, addressing these issues is seen to require

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the adaptation of present practice (e.g. designing and building for ease of demolition as well as ease of construction) as well as the creation and application of new knowledge within new practices, e.g. the adoption of new sustainable ideas and concepts (C-Sand 2003).

In order to effectively promote sustainability, these decisions must be informed by sustainability related knowledge and experience. Architectural practice in particular can take a leading role in driving the sustainability agenda forward through client education and an innovative approach to 'designing in' sustainable solutions and technologies (Hill & Bowen 1997; Roodman et. al. 1995). However, almost invariably, time and finances dictate that design choices made in the initial stages of a project are effectively fixed and cannot be 'revisited' or changed, hence it is crucially important that the correct choices are made at the outset. There are clear synergies possible if decisions taken during the design phase of a project (and indeed throughout its life) are supported and informed by the knowledge resources of the respective project organizations, with the results and reasons for these decisions feeding back into the body of knowledge.

The paper reports on a research initiative bringing together a knowledge management and decision support environment to provide designers with sustainability informed decision making. The paper first summarizes related work in the field. An overview of the knowledge management environment (C-Sand) and the decision support tool (ADS) is then given, followed by a description of their conceptual integration and the resulting Knowledge Informed Decision Making (KIDM) environment. The paper then reports on the validation of the resulting prototype in a laboratory environment. This is followed by a discussion informed by the validation results and the literature. Finally, the paper provides concluding remarks and directions for future work.

RELATED WORK

The research described in this paper fits best into the category of applications known as Group Decision Support Systems (GDSS), which are seen as a development of Group Support Systems (GSS). GSS can be described as interactive computer based environments that support concerted and coordinated effort toward completion of joint tasks (Nunamaker et. al., 1997). There is well-documented empirical support for the benefits of GSS. In an analysis of 54 GSS implementations, it was shown that over 80% of organizations using GSS, showed improved performance (Fjermestad & Hiltz, 2000). Similarly, laboratory research has shown marked potential for improved team performance (Briggs et. al. 2003; Fjermestad & Hiltz, 1999; Easley et. al. 2003).

Group decision support systems (seen as a subset of GSS) are similarly the subject of considerable research in their own right. Even though GDSS are 'infrequently encountered' they have the potential to considerably enhance management meetings (Huber, 1984). Similarly in Dennis et. al. (1988), GDSS are discussed within a wider set of technologies which might support electronic meetings, concluding that GDSS has considerable potential to support management decision making. However, while research has continued, supported by advances in information and communications technologies, collaborative systems designed to support team decision-making are still seen as a relatively recent development (Easley et. al. 2003).

The multiplicity of circumstances governing the decision making processes inherent in architectural design leave scope for numerous misunderstandings, unforeseen difficulties created by inappropriate or ill-conceived changes and decisions which fail to propagate amongst all interested parties. Further, these circumstances are commonly compressed into short timeframes featuring periods of intense activity in which many decisions are made (Cooper et al, 2005). Nevertheless, research has shown the value of computing systems explicitly designed to support decision-making processes within organizations (Kohli & Devaraj, 2004). Accordingly there appears to be value in creating such systems for architectural design with a particular emphasis on minimizing the necessity to break out of the intense bursts of design activity to use and maintain the system.

The field of knowledge management has been the subject of considerable research effort and within the construction sector it has been recognized that its practice is considered to be immature and under-utilized (McGee & Prusak 1993; Laudon & Laudon 1998; Rezgui 2001; Asprey 2004; Sor 2004). These efforts include innovative solutions which attempt to take account of the way that the Design and Construction process is fragmented, involving short-term partnering between actors from a variety of disciplines, sitting at different locations, with varying levels of IT support for their individual business processes (Rezgui, 2001; e-Cognos, 2003; C-Sand, 2003).

The integration of knowledge management with DSS techniques has received increasing attention over recent years (Nemati et. al., 2002). However, while several studies have been proposed, there is little evidence of implementation (either laboratory, or in industry), which integrates knowledge management and decision support into existing desktop applications.

SUSTAINABILITY KNOWLEDGE MANAGEMENT ENVIRONMENT

A service portal (C-Sand) has been designed and developed to promote and disseminate knowledge about sustainable products, techniques and practice in the construction industry. The method employed to achieve these ends is based on intra and inter-organizational knowledge sharing through a set of web based services with a portal user interface. Together, the C-Sand services aim to mimic the social processes of knowledge sharing using implicit networks formed in the system's underlying knowledge model. The services are used first to create representations of real world resources, namely 'knowledge representations' (KR), and then to link these representations to other representations using a construct characterized as a knowledge representation link (KRL). Having defined several types of link within the model, these KRs and KRLs form a number of networks dependent upon the type of link one examines (Ferneley et al 2002).

Once a resource is known to the system (i.e. stored as a KR), it is available as a search result to end-users. The system employs well known ranking and relevance feedback mechanisms on search results in a process akin to bookmarking where a user chooses those results they believe best suit their requirements, rating those resources on a four point scale. The system takes the rated results and creates a user 'interest' from them, which is in turn stored as yet another KR. This new 'interest' KR represents what a particular user regards as a useful set of reference resources in a particular knowledge domain, that being the initial search query. Crucial to the social networking features of C-Sand is the fact that once created, such interests are by default public and can be returned as search results to other users in the same way as any other KR. This gives the entire user base access to a form of peer reviewed set of resources for their search if an interest is returned. Also, from an interest it is trivial to find out who the interest belongs to (its creator) thereby providing access to peers with similar knowledge interests. This feature implicitly identifies communities of practice (Wenger 2000) within the system that may be exploited by its users to further their own physical social networks outside of the system.

Other features of the C-Sand system include:

- Knowledge push facilities allowing one user to 'flag' a resource to another user who may be interested in it.
- · Knowledge pull facilities whereby a user 'subscribes' to a resource in order that the system can inform them of changes to the resource, or rather changes to the system representation of the resource, which may reflect changes to the resource itself or just changes to system metadata.
- Annotation of resources by attaching a KR of the Annotation type to a resource. Such annotations are public and can be viewed by other users, who may also attach a reply thereby creating a kind of threaded discussion around the subject of the resource
- A built in Web Services client that can use arbitrary third party Web Services to extend the functionality of the platform.

The services underpinning the C-Sand portal are decoupled from the user interface such that alternative GUI arrangements can be employed. Further, although the services as instantiated at present use Java RMI for communication, they have been designed to be simple to export as Web Services using an appropriate front-end server implementation. Thus standardized simple communication protocols can be used for interoperation with other systems.

DECISION SUPPORT ENVIRONMENT

Advanced Decision Support (ADS) aims at viewing and recording the evolution of project information over time to better support effective decision making (Rezgui et al 1998a, Rezgui et al 1998b, Cooper et al 2005). The main output from ADS is a proof of concept demonstration platform based on an integration of the ADS prototype and Bentley Systems' Microstation/J CAD application. In the design of the demonstrator, six key issues have been addressed (Cooper et al, 2005):

- Recording the intent behind decisions such that the reasoning for various elements of a design is transparently maintained.
- Tracking dependencies between elements of information and the decisions related to them such that the users of the system can find out what previous activity, if any, is likely to be affected by their current action.
- Notification of changes to information elements to users or indeed other information elements for internal system purposes.

- Ownership, rights and responsibilities must be recorded and maintained in order that users can find out who did what to what and also so that the system can control who has the right to make certain alterations to information elements.
- Versioning of information is required to keep track of which version (or state) of an element relates to which decision and to enable a historic review of and/or return to those states at a later time.
- Schema evolution, which provides for the changing context in which information is created, used and interpreted throughout the course of a project.

The design of the ADS system uses a transaction object to encapsulate data about the operations performed on various information elements (Elements in a CAD model for the purposes of the demonstrator), which are represented by object version objects. Each element is versioned each time an operation is performed on it and the transaction tracks all of the versions of all of the elements involved in a decision. A decision object is directly associated with the transaction for which it is created. This history of operations and versions can be browsed using a purpose designed 'decision browser' and is also brought to bear when any new work involving any of the information elements recorded in an existing decision is performed. It is at this point that the history is leveraged to provide notification that previous decisions may have an impact on the present user's activity with regard to the affected elements.

So the object version, versioned object, operation, decision and transaction classes form the core of the ADS model with several more classes dedicated to notification, rights management and references to external resources. These classes are connected to the design application (Microstation/J in the case of the demonstration platform) via an adapter layer where application specific specialisations of the versioned object and object version classes provide the interface to the application, with other adapter specific classes being used to trap application events, manage the storage of the versions of elements themselves (ADS only holds metadata about the version, not the version data itself), and manage the veto of application events in response to ADS rights management.

The tracking of user activity in ADS can also be leveraged to determine the likely information needs of that user at any given point. These can be turned into queries submitted to C-Sand in order to find relevant related information.

SUSTAINABILITY KNOWLEDGE INFORMED DECISION SUPPORT ENVIRONMENT

The aim in attempting to integrate ADS and C-Sand is to create a Knowledge Informed Decision Making (KIDM). It is essential to deliver timely information right into the application environment in which people perform their daily duties. Thus, possible points of interaction were determined whereby information indexed in C-Sand may be useful to an individual working in an application 'plugged-in' to ADS. Furthermore, the decisions recorded in ADS are indexed as Knowledge Representations in C-Sand in order to make them a part of the searchable and linked information space. The following four points of interaction have been identified:

- Dynamic query of the C-Sand database for items relating to the element currently being edited in ADS: This requires ADS to translate operation invocations into a query for the C-Sand search function. The results would be delivered through ADS into the application that is being used for editing, and then displayed to the user. Users would have the option of selecting a returned item to inspect it in more detail if required.
- Indexing of decisions: When ADS records a decision as a result of user action, it will send the details of the decision to C-Sand where the decision will be indexed in the same fashion as all other resources that are indexed by C-Sand. This provides the ability for those not working in the ADS environment to find and view decisions related to the projects they are involved with.
- Extended decision notifications: When ADS comes across an operation that potentially conflicts with a previous decision, it fires a notification obligation that notifies interested parties within the ADS system of the potential conflict. We propose that it would be beneficial for these notifications to be captured and stored up to the point where a decision is recorded in ADS whereupon C-Sand would flag the new decision to any user subscribed to one of the decisions related to the stored notifications. This widens the notification mechanism to a whole host of users that may be able to provide valuable input or those who are merely interested to know how some aspect of a design is affected as that design progresses.
- Annotation of decisions: This feature would involve linking annotations to decision Knowledge Representations in C-Sand and then presenting the details of those annotations back to users in the ADS decision browser when they view the original source decision. This would provide a means to record and re-present wide ranging discussions related to a decision in both C-Sand and ADS applications.

Realizing these scenarios for interoperation required a degree of modification to both the C-Sand and ADS tools. Firstly, in order to maximize the future utility of the work, it was determined that communications between the applications should employ Web Services protocols, each application being published as a set of service methods available to any Web Services capable client. For the C-Sand kernel, this was a simple task as a single visible service method is used to call all internal methods, which was designed from the outset to be easily deployed as a Web Service. The task was not so simple for ADS however. Although the design of ADS itself exposes well defined interfaces that could be published as Web Services relatively easily, they were not the interfaces we required to achieve the interactions we envisaged. As such it was necessary to build a new component into ADS that exposed methods useable to C-Sand as Web Services and which also incorporated a Web Services client to make calls into the C-Sand services.

DISCUSSION AND CONCLUSIONS

While the research was evaluated in a laboratory-type environment, a number of relevant scenarios have been developed with support from industry end-users to simulate the use of the knowledge informed decision-making environment in a real-world context. From a user perspective, it was found that KIDM was capable of providing real-time, relevant assistance in decision making without requiring the user to explicitly 'search' in the first instance. Of course the value of KIDM depends on the quality of the resources referenced or stored within the C-Sand environment and the timeliness and accuracy with which it is delivered to the user. C-Sand currently employs the simple and popular TF-IDF (Salton & Buckley, 1988) algorithm for document index entry calculation. Further, no scaling or normalization is applied to take account of differing document lengths during indexing or retrieval. As ADS decision descriptions typically tend to be quite short, C-Sand is statistically biased against them and tends to return them with low relevancy during searching activity, for example when an application adapter attempts to find items related to the current focus of editing. ADS itself will notify the user of any affected decisions related to current activity in the current scope (e.g. the project in which the activity is carried out), but relevant decisions from out of scope resources (e.g. different projects that ADS would not be tracking) sometimes tend not to make the 'cut' in returned relevant item lists. This means that some of the benefit of lessons learned is not delivered to the point of need, i.e. the user's application. Applying a normalization function such as Pivoted Document Length Normalization (Singhal et al 1996) should help to ameliorate these effects but we have not had the opportunity to experiment with this to date.

At a fundamental level, KIDM requires that the organizations in question to be prepared to adopt and adapt to new knowledge management techniques and distributed decision making approaches. Moreover, the questionnaire results corroborate existing research in that many construction organizations have a bureaucratic and often authoritarian and hierarchical structure, which can inhibit full adoption of KM practices (Rezgui, 2005). Analysis of existing KM practices within the construction industry has revealed that a specialized management team is often given the responsibility of 'creating' knowledge that the rest of the organization is expected to use. While this can offer some short-term advantages it also carries the risk of regulating and monopolizing knowledge production. Where this is the case, real benefits can be gained by migration from a centralized approach to knowledge creation that empowers individuals. The characteristics of this 'participatory' type of culture, with a flat structure, open communication channels, and participation and involvement in decision-making can enhance sharing of information and facilitate communication both within the organization and within the wider industry.

From a business and end-user perspective, the validation of KIDM has emphasized the potential process benefits that such environments can bring in assisting practitioners in their decision making by capitalizing on the wealth of existing and available related knowledge. In particular the contextual delivery and filtering of those knowledge resources shows promise and is worthy of further work. In terms of limitation of the research, one can argue that the validation process was only conducted in a laboratory environment, and therefore requires further validation in a large-scale real-world setting. This constitutes one future research direction for the authors', who are hoping to report on their additional findings in future publications.

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