An Information Model to Facilitate Sustainable Design of Building Projects in the UAE

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Abstract: As urbanization increases in UAE, the demand for housing and infrastructures also grows. The challenge is to continue to build but in a different way considering more energy-efficient sustainable buildings. Producing a sustainable design is highly dependent upon effective participation among the diverse parties involved. In the construction industry in the UAE, these parties are fragmented due to the multistage nature of construction projects and multidisciplinary participants, particularly during the design stage. The decisions made during this stage have an extensive impact on subsequent stages of a project's life cycle. Having a sustainability expert during the design stage is important and the awareness of sustainability requirements by all design participants is of equal importance. In this research, recent advances in information technology are used to develop an information model that will improve the sustainability of building during the design stage. An information framework for storing design information and sustainability performance criteria is developed, allowing design participants to collaborate in an integrated environment. This research is expected to help designers produce sustainable designs for building projects.

Keywords: Sustainable Design; Information Models; Building Projects; Design Rationale; Construction

I. INTRODUCTION

Typically, buildings are designed to meet building code requirements, whereas sustainable building design challenges designers to go beyond the codes to improve overall building performance and minimize life-cycle environmental impact and cost [1]. Buildings are responsible for almost half of carbon emissions, half of water consumption, about one third of landfill waste, and 13% of all used raw materials [2, 3]. With its introduction in 2000, the Leadership in Energy and Environmental Design (LEED) Green Building Rating System [4] helped to spark a revolution, articulating a new set of integrated, measurable goals that changed the way we approach the design, construction, and operation of buildings. In the US, for example, buildings account for fully 39% of carbon dioxide emissions. As a result of this, the research in this direction has moved steadily forward over the past ten years, evolving the way building performance is measured and rated [4]. Other rating systems are also available but differ in terminologies, structure, performance assessment methods, and relative importance of the environmental performance categories. A comparison of the structure, assessment methods and implementation characteristics of the various rating methodologies can be found in a report by Cole [5]. In recent years, great progress has been made in improving the sustainability of buildings and their contents through a range of initiatives. As reported by [6], an estimated $15 billion worth of green buildings are in design or under construction in the U.S., representing around 15% of total public construction.

Several governments, globally, has opted to adopt the concept of 'Building a better quality of life – A strategy for more sustainable construction' [2, 7]. This provides the first step to improving standards in the industry. However, there is still a lack of research in this direction. Achieving sustainability through conservation, recycling, and research in the development of new materials and technologies and in the communication of design information are the next great challenges for the construction industry. Manoliadis et al. [8], for example, developed a methodological framework to investigate the most important influences on sustainable construction showing significant trends towards land use, energy, and resource conservation. Pulaski et al. [9] presented a study that examines the integration of sustainable design and constructability on the US Pentagon renovation. Griffith [10], on the other hand, presented a study to examine the concept and principles of integrated management systems, its potential application and contribution to sustainable construction, and the issues that it raises for the future management of the construction processes.

Although the process of sustainable design has experienced some major changes [11], there is still much to be done in order to manage sustainable construction knowledge and address issues such as capturing, storing, and transferring design knowledge. Also, there is very little understanding of the best ways to capture knowledge and ensure that it is readily available to other parties. In recent years, the A/E/C industry has devoted a considerable attention to focus in building sustainability issues, information representation, and integration of design information. Various researchers have developed models and tools to manage the large amount of design and construction data. Accordingly, a set of product models were developed to structure project information in a hierarchical representation of a project's. Examples include the work of Staub-French and Nepal [12], Shao and Liu [13], and Nitithamyong and Skibniewski [14].

Few studies have been made to integrate building data with sustainability knowledge, despite the many efforts and

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initiatives that have been undertaken within the industry itself and in the academia to develop mechanisms and tools for managing knowledge within design and construction firms. According to an article published in October 2009 [15], all new buildings in the UAE have to be constructed in accordance with 'green building' standards from January 2008. Since then, the UAE government moved towards enforcing sustainable design and changed the way firms do design. This challenge requires making designers aware of the importance of this issue and, at the same time, developing a system that is efficient and easy to use by design participants. A structured sustainable design approach is, therefore, needed to better facilitate the communication among all participants and with a sustainability expert in order to have buildings with minimal negative environmental impacts [16].

The main objective of this study is to develop an information model in order to capture and retrieve relevant design knowledge to increase the understanding and awareness of sustainability requirements among engineering and design-build firms in UAE. This will also support the UAE government efforts in designing and constructing all new buildings to sustainable construction standards. It will also help in the development and implementation of standards and make use of the best suitable technology to enable the country achieve the required change in this regard. The effort of this research will also enhance the companies' competitiveness in local and global markets in the near future. For such a goal to be possible, changes to the current practice during the design process of building projects needs to be performed.

II. INFORMATION MODEL

A model, which was initially developed by Zaneldin 2009 [17] and Zaneldin et al. 2001 [18], was modified and used in this research. The model incorporates five main components: 1) a building project hierarchy to represent design data; 2) a storage of design rationale; 3) a library of active building components with communication paths; 4) a sustainability feedback mechanism; and 5) change management mechanism. Each of these components is elaborated in the following subsections.

A. Hierarchical Representation of Design Data

Existing models to represent design data separate the different multidisciplinary design information at the system level. This representation eventually separates related design information and, as such, may lead to conflicts in coordinating the multidisciplinary work. A certain building space, for example, has to be included four times under the four branches of the architectural, structural, mechanical, and electrical systems of a building hierarchy. This indicates redundancy and can create coordination problems. It is important, therefore, to unify the storage and manipulation of building data in order to avoid redundancy by representing building components as smart objects that contain all their multidisciplinary design information.

In this paper, a building project hierarchy (BPH) was adopted from Zaneldin et al. [18]. In this representation, the building floors are divided into spaces that are considered as smart objects containing all their multidisciplinary design information, as shown in Fig. 1. As such, each building space in the BPH contains all information related to its architectural, structural, mechanical, and electrical designs. In this representation, proper multi-user access and modification rights were established for the unified BPH model to suit all parties. Proper database design and powerful reporting were also necessary to improve sustainability.

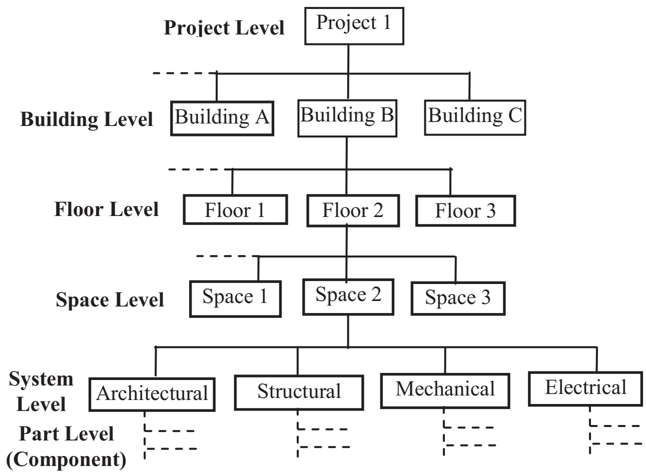

Fig. 1. Representation of Design Data.

The proposed BPH allows designers from all disciplines to instantly view the components of all other disciplines in the same hierarchy. Six levels are used in the building project hierarchy (Fig. 1): 1) Project Level; 2) Building Level; 3) Floor Level; 4) Space Level; 5) System Level; and 6) Part Level. The "Part Level", for example, includes the majority of the detailed building objects, such as walls, doors, windows, beams, columns, footings, etc., and associated attributes. A "beam" component, for example, has attributes like width, depth, material, reinforcement, code-restrictions, sustainability requirements, and location-in-wall. Each component in the BPH stores its sustainability requirements and, as such, it promotes a sustainable and environmentally friendly design. The BPH data are saved in four separate databases for the architectural, structural, mechanical and electrical designs, with the architectural database having links to the other databases to facilitate the generation of the whole BPH tree during project loading.

B. Storing Design Rationale

Designers from all disciplines normally use certain criteria and rationale while they perform a particular design. The hierarchical representation of design data, such as that used in building product models, can be used to encode the design rationale that is fundamental for design-change management. This is important so that the reasoning behind the design is available when any future changes to building components are contemplated. Design rationale can be represented by recording the performance criteria for each building component.

C. Central Building Components Library (BCL)

The BCL is a central depository of template building components that are used by all parties to facilitate the creation of a complete BPH for a project. Each building component has its own attributes, including the sustainability requirements of the component. To facilitate the use of the components' library, it is necessary to store default information related to components before putting the library to actual use. Default components from various levels are stored in the BCL. Each building component in the BCL is assigned a default specification section, design rationale, and communication paths. Only the administrator can modify the BCL, while other parties can only use it to add components to the BPH. The administrator can add a new default component to the BCL and then specify the design discipline(s) that can use that component.

D. Sustainability Feedback

It is necessary that, during the design process, a sustainability expert is consulted for sustainability feedback and to approve the design and make sure that it follows sustainability requirements. During the design process, designers may introduce changes to their initial design values and, before they can apply these changes, the sustainability expert should be consulted for sustainability feedback. The sustainability expert in this case can also act as a sustainability checker.

E. Change Management Mechanism

Changes made to any building component should be communicated to affected parties. In order to notify affected parties by changes made during the evolution of design, it is important to identify the relationships among the different building components in a project and among the various design parties including the sustainability expert. It is also important that building components be active objects that can automatically send changes made to their values to affected parties through their preset communication paths. Change management procedures were developed for proposing changes, sending changes, and providing reports that can be viewed by all disciplines, such as the history of all changes made throughout the design evolution. Such reports are important particularly to the sustainability expert who can use them to track all changes made to a project. Also, it is always recommended to inform other disciplines of an intended change to any building component before implementing that change.

All changes made are stored in a temporary database and then transferred to the project's database at the designer's request. When designers specify a certain sustainability-related attribute to a component, the sustainability expert will be notified immediately. Many of such attributes may change and it is possible that some designers may not implement some of them in a timely manner for many reasons. To avoid this, a warning system was developed to track all changes made to a project and continuously reminds designers to respond to pending proposed changes and applied changes.

III. Project Initiation with Sustainability Checks

During building a BPH for a project, designers will receive feedback from the sustainability expert. Designers may also introduce changes to initial design values. Before they can apply these changes, the sustainability expert is consulted for feedback and approval. To start a new project, the architect can use the model to create the BPH. A default BPH with a roof component will be created along with its underlying databases for designs of all disciplines. If the building contains more than one floor, a stair component is automatically added. To refine the initial BPH as per the detailed project information, the architect can use the BCL to add new components to the BPH. Upon completion of this process, created the BPH will appear as shown in the screen capture of Fig. 2.

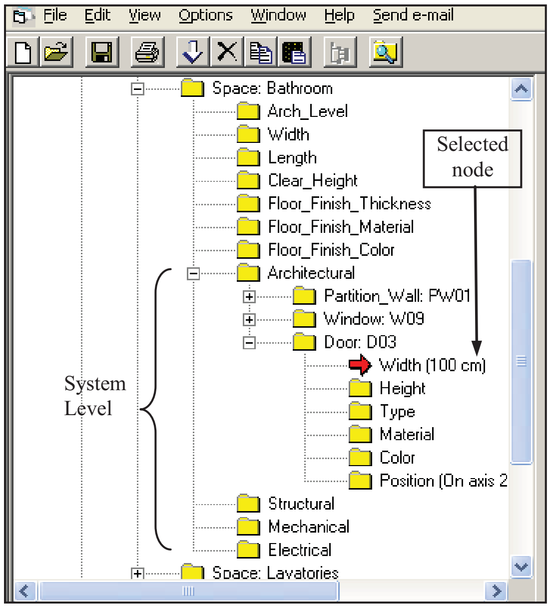

Fig. 2. The Created BPH for a Project.

Adding lower-level components (e.g., door, window, beam, column, etc.) from the BCL to the BPH is simple as this activity relates to a single design discipline. Adding a higher level component (such as "space"); however, requires adding various default nodes that relate to the corresponding system. The "bathroom" space in Fig. 2, for example, is inserted initially as a default component from the BCL with its sub-nodes. When any node is selected, all of its values appear on the screen and allow the designer to edit/modify its information related to its CAD and specification documents, design rationale, communication paths, as shown in Fig. 3 for the selected item in Fig. 2, which is the width of door (D-03) of the architectural bathroom space.

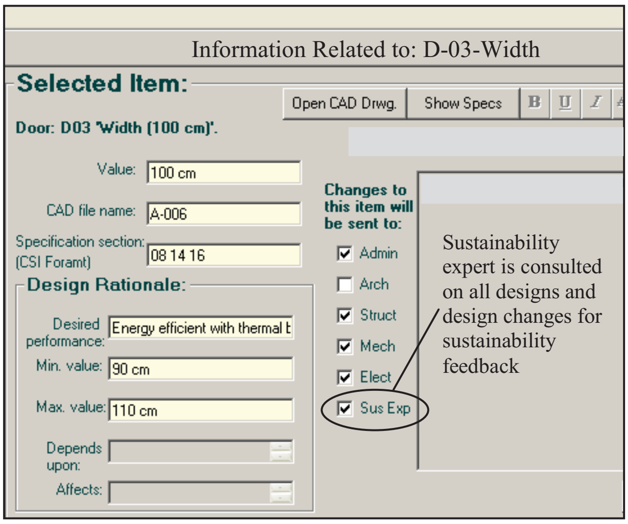

Fig. 3. Information of the Selected Item in the BPH.

IV. Application Example

A real-life application example for a residential building is presented to demonstrate the importance of the model and its benefits over current professional practice to improve sustainability of building projects. The design firm provided a set of documents including specifications and CAD drawings for all disciplines but does not have an expert for sustainability.

Assume that, during the design and after the architect finalizes the plans, engineers from other disciplines start designing their systems. Also, assume that the sustainability expert is available in the firm and was initially satisfied with the designs of all disciplines. As the actual design progresses into the detailed stage, several changes were introduced by the architect. One of the main changes is to remove the external stone cladding and replace it with paint. Also, the architect changed some window types and widths and added two aluminum/glass doors. Without using the proposed model, these changes may not be communicated to the project manager or the sustainability expert, who may consider them significant.

To simulate this situation and illustrate the effectiveness of the proposed model over current practice, the proposed model was used to store the design data of this building and introduce some of the actual changes made to the building. Using the default components of the BCL, a complete BPH for this building was readily created in the server machine by specifying the number of floors in the building and the number of spaces in each floor. Some components were then input for each discipline. The default names of the components were changed by the architect and other engineers to reflect the actual names of these components. As shown in Fig. 4, the generated BPH shows some of the ground floor and first floor spaces.

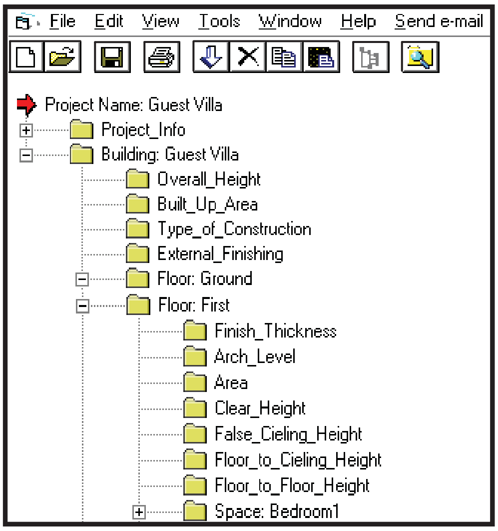

Fig. 4. Part of the BPH of the Example Building.

The structural components of the building were also input easily. To further refine the initial BPH as per the detailed project information, all design participants used the BCL to add new components to their part of the BPH. Changing widths of windows in the BPH by the architect, for example, will automatically and instantly send the new values to the sustainability expert as well as all affected parties. The sustainability expert was also notified with all changes for sustainability feedback. The sustainability expert immediately informed the architect that his change proposal of removing the external stone cladding and replacing it with paint is not recommended since it will reduce the sustainability of the building. This is because it will change the u-value and may disseminate more heat to the building and, accordingly, consume more energy. The architect proposed another solution to reduce cost and the proposed change was approved by the sustainability expert.

The proposed change management module is essential to get approvals for proposed changes, make sure that designers respond to changes, and implement approved changes. This will increase the level of coordination among all parties, help update project information, and improve sustainability. Upon implementing the approval process, the structural, mechanical, and electrical parties and the sustainability expert approved the proposed changes and the architect was notified of their approvals, thus allowing changes to be applied.

Automatically, the BPH nodes representing the changed components were changed to reflect their new values and the changes were automatically added to "today's changes" database. Applied changes were then automatically sent to all affected parties, including the structural engineer to make proper design modifications. The model tracks the responses made by affected parties to all applied changes and uses its warning system to remind them of the need to respond to pending changes. The reporting system of the present model is also important to help the design administrator (who can also be the sustainability expert) to follow up on pending changes and track the history of all changes made to the project. The proposed model provided various reports to allow all designers to view some or all of the changes related to their design. The design administrator may then use these reports to follow up on pending changes on a daily basis and track the history of all changes made to the building in particular and to the project in general.

The problems discussed earlier (the changes made by the architect that may affect the sustainability of the building) did not happen using the proposed model as the architect was required to use the "Approval Process" before applying these changes. Using the proposed model, these changes were efficiently communicated to affected parties, including the sustainability expert. The architect could apply these changes only after proposing them and getting the approvals of all affected parties and the approval of the sustainability expert. The sustainability expert, who was instantly notified by these changes, advised the architect to select another system that is more efficient in terms of sustainability and more cost effective (other than replacing the existing cladding system with paint, which was not approved).

The data of this example reflects a common situation in the traditional project delivery process in which design parties make designs that may not be environmentally friendly. It also reflects the fact that designers may make changes that may affect the sustainability of buildings without informing other parties considering these changes as insignificant and, thus, proceed with these changes without informing other disciplines. This may equally affect all design disciplines and cause sustainability problems, if not properly communicated to get the feedback of a sustainability expert.

The example presented in this section serves to prove the validity of the proposed model and its applicability in practice. When presented to a number of academic researchers and industry professionals through a live demonstration, very favorable responses to the model's performance and capabilities were obtained.

V. Conclusion

This research presented a new approach that uses recent advances in information technology to facilitate design coordination and improve sustainability of building projects. The proposed information model can be used to store building information, record design rationale, and effectively manage multidisciplinary design changes in a collaborative environment. The novel aspect of the proposed BPH is its representation of multidisciplinary design data within each building space. In addition, each building component in the model is active and has preset communication paths that help to automatically communicate changes made to any component to all affected parties, including the sustainability expert who also acts as an administrator and a sustainability checker for the project. The model was validated using a real life application example. The expected benefits of the proposed model are improved design, higher consistency, increased productivity and better sustainability of projects.

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