AN INFORMATION SYSTEM FOR THE MANAGEMENT OF CHANGES DURING THE DESIGN OF BUILDING PROJECTS

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Keywords: Construction Industry, Coordination, Information Models, Change Management.

Abstract: Design is an important stage in a project's life cycle with the greatest impact on the overall performance and cost. For several reasons, changes introduced by design participants are imminent. Despite the importance of coordinating these changes among the different participants during the design stage, current practice exhibits severe information transfer problems. Since corrections to finalized designs or even designs at late stages in the process are extremely costly, it is less costly to spend the effort in managing changes and producing highly coordinated and easily constructible designs. To support this objective, this paper presents an information system with a built-in database for representing design information, including design rationale and history of changes, to support the management of changes during the design of building projects. The components of the system are discussed and possible future extensions to the present study are presented. This research is expected to help engineering and design-build firms to effectively manage design changes and produce better coordinated and constructible designs with less cost and time.

1 INTRODUCTION

Undoubtedly, the quality of design has an extensive impact on all subsequent stages of a project’s life cycle, including construction. Producing a quality design is highly dependent upon effective coordination among the diverse participants involved in the process and proper management of changes. The constructability of a project is an important measure of the success of the project (Hegazy et al., 2001). Many of the design decisions and changes made early in the design process affect the construction of the project. It is, therefore, important to incorporate construction expertise in the design process to improve the constructability of the design and help design teams to enhance the buildability of projects (Lam et al., 2006).

Despite the importance of constructability input, the means by which this knowledge is introduced in construction projects is still largely rudimentary (Pulaski and Horman, 2005). As discussed by Pulaski and Horman (2005), current methods typically use design reviews by construction experts. Sometimes tools, such as checklists, are used to help coordinate changes and systematize the process. These methods are relatively unsophisticated, inefficient, and often lead to rework. This, in turn, can result in animosity among team members. While these methods have led to project improvements, it is clear that there have been limited advances in the ways to manage changes more effectively during the design process.

Also, in the current traditional practice, each project stage is isolated and is performed by professionals who are less experienced on successive steps. As such, the information and rationale behind the decisions made at each stage are not transferred to the following stages. Despite any cost savings made by speeding early stages, problems are magnified and passed to other parties later in the process, such as construction and operation/maintenance. With late corrections being extremely costly, it is worthwhile to spend the effort in producing highly coordinated design changes that improves constructability and efficient facility operation. Often, the consequences of coordinating design changes and constructability problems are not discovered until during construction. Some of these consequences include variation orders and contractual disputes, which lead to cost overruns and, often, client dissatisfaction. Unfortunately, with the escalating complexity of building projects and

Zaneldin E. (2009).
AN INFORMATION SYSTEM FOR THE MANAGEMENT OF CHANGES DURING THE DESIGN OF BUILDING PROJECTS.
In *Proceedings of the 11th International Conference on Enterprise Information Systems - Databases and Information Systems Integration*, pages 49-55
DOI: 10.5220/0001865500490055

the tighter constraints on time and cost, coordination-related errors increase in design documents. In recent years, therefore, the A/E/C industry has devoted a considerable attention to design information representation and integration of the design and construction information of building components.

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. Examples of early product models include RATAS (Bjork, 1994) and COMBINE IDM (Dubois et al., 1995). The RATAS model, for example, describes a building project through a hierarchy of relations between objects and uses five abstraction levels: building, system, subsystem, part, and detail. The hierarchical representation of a project's data, such as that used in building product models, can be used to encode the design rationale that is fundamental for design-change management. Examples of early research efforts that focused on recording design rationale include the active design document of Garcia and Howard (1991) and the parameter dependency network of de la Garza and Alcantara (1997). The latter effort presented an interesting data structure that represents building data in a hierarchy and design rationale as a performance criteria (e.g., a certain fire rating is used as the rationale for the design of a certain door). Recently, Shen et al. (2003) developed a model that organizes the construction data into a tree structure and then retrieve information and obtain domain views by specifying the ways of traversing the tree. Staub-French and Nepal (2007) presented a feature-based framework for representing and reasoning about component similarity that builds on ontological modeling, model-based reasoning and cluster analysis techniques. This reasoning process is implemented in a prototype cost estimating application, which creates and maintains cost estimates based on a building product model.

Along with design data representation, present advances in computer technologies, such as electronic mail and the Internet, allow faster and efficient exchange of information and can potentially improve the information-extensive design process. Electronic media can not only convey geometric information such as drawings, but can also transfer text information such as specifications, bills of quantities, conditions of contract, and design rationale statements. Tools such as groupware, videoconferencing, remote access, and file sharing can be used, individually or combined, to provide custom solutions for design coordination and site-to-office communication. Currently, some examples exist of systems developed to allow the access and sharing of project information by participants in remote locations (Nitithamyong and Skibniewski, 2004, Li et al., 2004).

Constructability focuses on optimizing the construction process in terms of construction cost, schedule, safety, and quality. While constructability research is typically centered in the construction community, it is essentially a design process that should be addressed early in design (Pulaski, 2006). Among the constructability-improvement programs currently gaining wide acceptability in construction are Computer-Integrated Construction and Value Engineering. A common characteristic among existing constructability-improvement programs is their focus on the interaction between design, as a single product, and other phases of a project's life cycle, particularly the construction phase. This, however, seems to place less emphasis on the multi-disciplinary nature of the design development process. Design coordination, therefore, is an independent effort deemed appropriate to address the design development process and account for its unique difficulties and challenges. In this sense, design-coordination can be an important complementary task to all other constructability-improvement programs. In this context, several researchers have developed systems to improve constructability. The effort of Arditi et al. (2002), for example, examines design professionals' efforts to pursue constructability and provides recommendations for performing constructability reviews. The work of Chua and Song (2003), on the other hand, incorporates construction program knowledge for constructability analysis.

A common characteristic among existing constructability-improvement programs is their focus on the interaction between design, as a single product, and other phases of a project's life cycle, particularly the construction phase. This, however, seems to place less emphasis on the multi-disciplinary nature of the design development process and the frequent changes introduced during design.

The objective of this research is to utilize recent advances in information technology to effectively manage changes during the design of building projects. A structured information system was developed to build building components, store design information and rationale, and effectively manage design changes made by each party.

Possible future extensions to the present study are also presented. This research is expected to help engineering firms, particularly those involved in design-build and turn-key projects, produce highly coordinated and easily constructible designs.

2 INFORMATION SYSTEM

The information system incorporates four main features: 1) hierarchical representation of design data; 2) storing design rationale; 3) storing active building components of projects in a central repository; and 4) identifying communication paths for automated communication of changes and managing changes with approval mechanism. The main components of the proposed information system are shown in Figure 1. Further explanation of these features is shown in the following subsections.

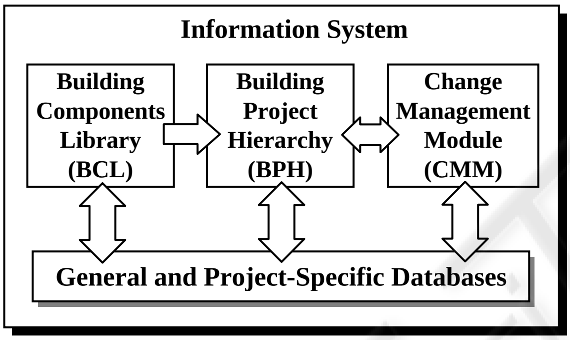


Figure 1: The Main components of the proposed information system.

2.1 Hierarchical Representation of Design Data

Almost all existing design representation models separate the multidisciplinary design information at the system level (e.g., architectural, structural, electrical, and mechanical systems are separate). While this representation is simple and suits the work of individual design teams, it 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 and avoid redundancy by representing building components as smart objects that contain all their multidisciplinary design information.

This is achieved by representing building components in the form of a building project hierarchy (BPH). BPH is a hierarchical representation of design data that unifies the storage and manipulation of building data and avoids redundancy. The novel element in this representation is that building floors are divided into manageable spaces that are considered as smart objects containing all their multidisciplinary design information (Figure 2).

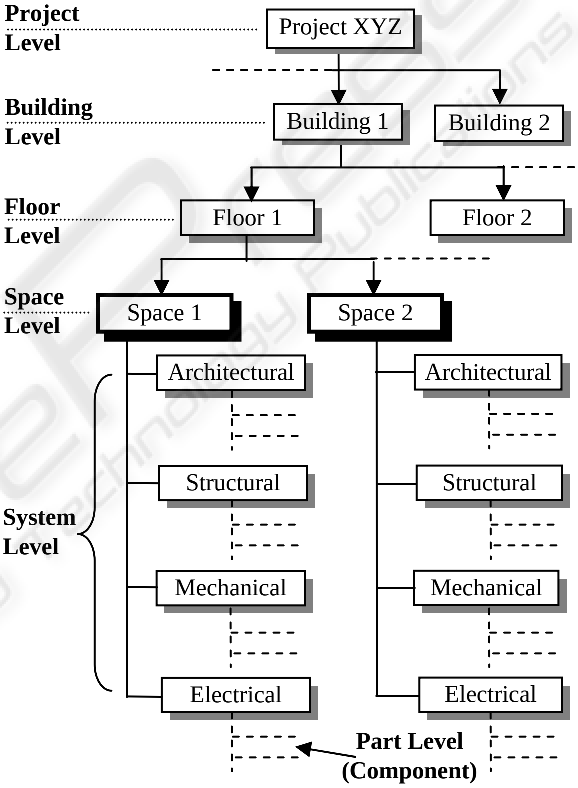


Figure 2: Proposed representation of design data.

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 to suit all parties. Proper database design, a suitable interface, and powerful reporting were also necessary to ensure the success of such unified multidisciplinary representation and, as such, promote coordination and improve constructability. Also, 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 proposed building project hierarchy (Figure 2): 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, etc., and associated attributes. A beam component, for example, has attributes like width, depth, material, reinforcement, code-restrictions, and location-in-wall. The proposed building project hierarchy, as such, provides a unique description for each component in a building project.

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. The structural, mechanical and electrical databases have a similar structure that incorporates a number of tables for saving the sub-trees associated with different space components in the BPH. In this way, a unified BPH representation of the design information for all disciplines is achieved.

2.2 Storing Design Rationale

The hierarchical representation of design data is 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 is represented by recording the performance criteria for each building component. Design rationale is represented by four information items recorded for each component. The four items recorded for a window component, for example, are: (1) a description of the desired performance criteria (e.g., sufficient daylight and wide external view); (2) the minimum and maximum performance values (e.g., between 240 and 260 cm wide); (3) a list of components that affect the current component; and (4) a list of components that are affected by changes in the current component. The third and fourth data items represent important dependency relationships with other components, similar to predecessor and successor relationships in network analysis.

2.3 Central Depository of Building Components

A central depository of all building components is needed to serve as a library that can store components from all design disciplines, along with their attributes and can be accessed by all parties. Since changes to these attributes mean changes to the design that need to be easily monitored, the attributes of any component need to be represented as visible objects. To facilitate the use of the building components library (BCL), it is necessary to pre-identify and store default information related to components from every discipline before putting the library to actual use.

A BCL is, therefore, developed to serve as a central depository of template building components that are used by all parties to facilitate the creation of a complete BPH for a project. Default components from various levels (e.g., floor, space, door, window, wall, beam, column, etc.) 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 add components from the BCL to the BPH.

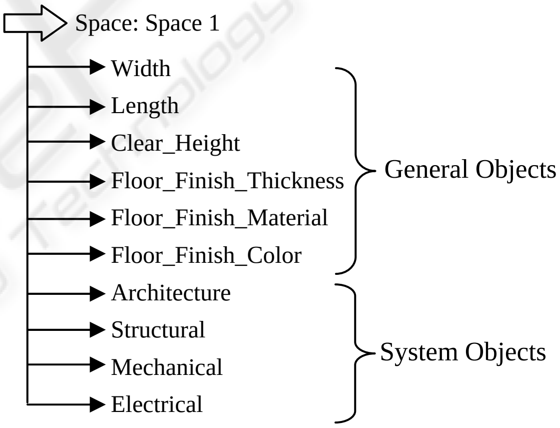


Figure 3: Example of "Space" component in the BCL.

The administrator can add a new default component to the BCL and then specify the design discipline(s) that can use that component. Once the default values for the specification section, design rationale, and route of changes (communication paths) are specified, the default component is added to the BCL and then becomes ready for use by the designers. The different components in the BCL are managed by using a reference to discipline type. In this way, each design discipline can only use the BCL to add components related to its part of the BPH. The information in the BCL, therefore, is maintained with a high level of consistency and security. An example of a "Space" component in the BCL is shown in Figure 3.

2.4 Managing Design Changes

A change management module (CMM) is developed in order to notify affected parties by changes made during the evolution of the design. To facilitate this, it is important to identify the relationships among the different building components in a project and among the various design parties. This helps in determining the proper communication paths to affected parties when a change is introduced. 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.

To allow for efficient management of design changes, building components need to be active and automatically report changes made to their own values to affected parties. This can be done through the development of change-management procedures 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. These reports are important particularly to the design administrator who can use them to track all changes made to a project and follow up pending changes on a daily basis. Also, it is always recommended, throughout the design process, to inform other disciplines of an intended change to any building component, before actually implementing that change. It is necessary, therefore, to send a corresponding change proposal to all other disciplines for approval before applying this change. Accordingly, designers from all disciplines should receive proposals for changes from other disciplines. This change-proposal can then be approved or disapprove by other disciplines.

To facilitate change management, BPH elements are used as active objects capable of automatically communicating changes made to their own values. Various procedures have been incorporated to monitor new and old values of any object attribute (e.g., window width), allow designers to propose new values or obtain approvals from other parties, and track/send/find changes made to a component. The change management mechanism also includes other general procedures that provide effective tracking of all changes made, allow designers to respond to proposed changes and implement approved change-proposals, and obtain various reports on the changes made. These procedures improve coordination and keep project information up to date.

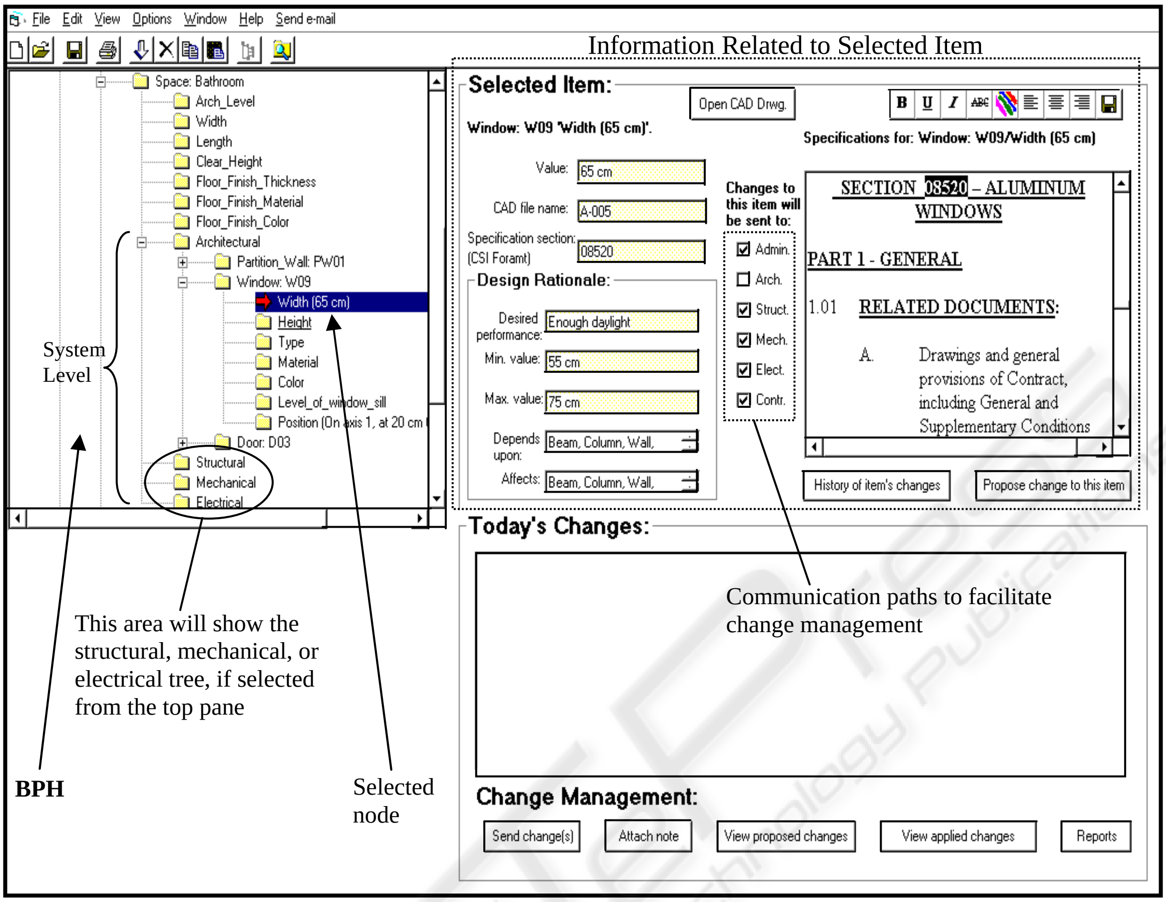
3 DEVELOPMENT OF A SYSTEM FOR CHANGE MANAGEMENT

An information system that incorporates the BPH, the BCL, and the CMM is developed, as shown in Figure 4. The system stores design information and rational for the purpose of managing design changes. When a designer uses the system, all changes made are stored in a temporary “today’s-changes” database. This information is then transferred to the project’s “changes” database at the designer’s request. The “changes” database includes two tables; one for “proposed changes” and the other for “applied changes”. The reporting system queries the databases to provide the user with useful information regarding pending changes and the history of changes made during the design evolution.

A BPH for a project can be created using the template building components stored in the BCL. The process of building a BPH for a project continues until a complete BPH is created. During this process, designers may introduce changes to their initial design values. To start a new project, the architect can use the system to create the BPH by answering four questions related to: 1) new project name; 2) number of buildings in the project; 3) number of floors in each building; and 4) number of spaces in each floor. A corresponding default BPH with a roof component will be created along with its underlying databases for the architectural, structural, mechanical, and electrical designs. If the newly-created building contains more than one floor, a stair component is automatically added to the BPH.

To refine the initial BPH as per the detailed project information, the architect can change the default names of the components (nodes) and use the BCL to add new components to the BPH. Upon completion of this process the system’s main screen will appear as shown in Figure 4, where the BPH is shown in the left side of the screen, the BCL and communication paths in the middle of the screen, and the CMM in the bottom left side of the screen.

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. On the other hand, adding a higher level component (such as “space”) requires adding various default nodes that relate to the corresponding architectural, structural, mechanical and electrical systems. The “bathroom” space in Figure 4, for example, is inserted initially as a default component from the BCL with its sub-nodes, including the



Window: W09 'Width (65 cm)'.

Value: 65 cm

CAD file name: A-005

Specification section: (CSI Foramt) 08520

Design Rationale:

Desired performance: Enough daylight

Min. value: 55 cm

Max. value: 75 cm

Depends upon: Beam, Column, Wall,

Affects: Beam, Column, Wall,

Changes to this item will be sent to:

☑ Admin.

☐ Arch.

☑ Struct.

☑ Mech.

☑ Elect.

☑ Contr.

Specifications for: Window: W09/Width (65 cm)

SECTION 08520 – ALUMINUM WINDOWS

PART 1 - GENERAL

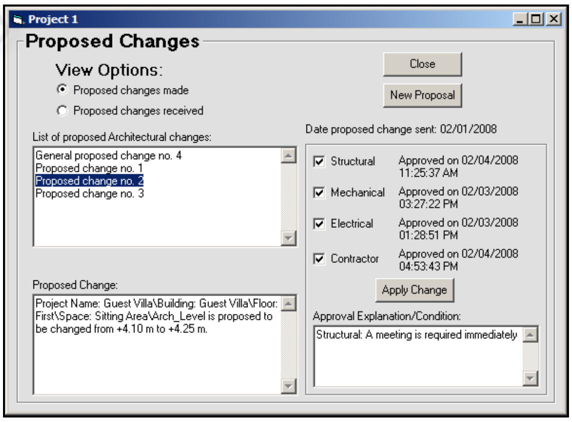
1.01 RELATED DOCUMENTS:

A. Drawings and general provisions of Contract, including General and Supplementary Conditions

Figure 4: Main screen of the proposed information system.

system nodes. When the "structural" node of the "bathroom" space is highlighted, its associated structural tree is read from the "structural" database and automatically displayed at the bottom of the screen. In fact, when any node is selected, all of its values appear on the screen and allow the designer to edit/modify information related to CAD and specification documents, design rationale, and communication paths (e.g., see the top right side of Figure 4).

At the early stages of generating a new project, it may not be practical to send every change made to the BPH. The architect, for example, may frequently change the dimensions of spaces or levels of floors (Figure 5) before deciding on their final values, and only then need the communication process start with other disciplines. To allow this flexibility, the proposed system permits the design administrator to turn the send-changes action on and off.



Proposed Changes

View Options:

● Proposed changes made

○ Proposed changes received

List of proposed Architectural changes:

General proposed change no. 4
Proposed change no. 1
Proposed change no. 2
Proposed change no. 3

Proposed Change:

Project Name: Guest Villa\Building: Guest Villa\Floor: First\Space: Sitting Area\Arch_Level is proposed to be changed from +4.10 m to +4.25 m.

Date proposed change sent: 02/01/2008

☑ Structural Approved on 02/04/2008 11:25:37 AM

☑ Mechanical Approved on 02/03/2008 03:27:22 PM

☑ Electrical Approved on 02/03/2008 01:28:51 PM

☑ Contractor Approved on 02/04/2008 04:53:43 PM

Approval Explanation/Condition:

Structural: A meeting is required immediately

Figure 5: Approvals of other parties to proposed changes.

Many changes are generally introduced during the design process, and it is possible that some designers may not implement some of them in a timely fashion. To avoid this, a warning system tracks all changes made to a project and continuously reminds designers to respond to pending change-proposals and applied-changes that affect them. Sequential query language (SQL) statements are used to automatically query the changes database and obtain the status of all change-proposals and applied-changes. If a response to a proposed change is not provided, different messages (depending on the amount of delay) will be sent to remind designers to respond. Similarly, if a designer did not provide a date to implement (respond to) a change or did not implement a change on time, reminder messages will be sent accordingly.

4 CONCLUSIONS

In a multidisciplinary environment such as the design process for building projects, changes are eminent, and properly managing these changes is a key to controlling the project and ensuring a consistent and well-coordinated design. This paper presented an information system to store design information, record design rationale, and effectively manage design changes. The proposed system incorporates a central building components library (BCL) that is used to create a complete building project hierarchy (BPH). The novel aspect of the proposed BPH is its representation of multidisciplinary design data within each building space. In addition, each building component has preset communication paths that help to automatically communicate changes made to any component to all affected parties. The role of the design administrator in this system is as a central coordinator. The model helps the design administrator keep track of changes, follow up on pending changes, and coordinate proposed changes. The use of the proposed information system to manage multidisciplinary design changes in a collaborative environment will be investigated as a future work. Furthermore, the information system needs to be validated through a case study and real-life experimentation. An effort is currently under way to set up the system on a design firm’s local area network and experiment with it for actual projects being designed by the firm. The results of this validation work will be reported in a later paper.

ACKNOWLEDGEMENTS

The investigator would like to express his sincere appreciation to contractors, consultants, and design firms who participated in providing information related to design data and coordination-related problems that helped in developing the change management mechanism.

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