Assessing the parametric building model capabilities in minimizing change orders

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Abstract

Design changes during construction, which are typical in most projects, lead to increased cost, loss of productivity and delays. These changes are usually due to approved scope changes or due to design errors and omissions (E&Os) found in the construction documents. Errors and omissions are typically manifested in terms of incorrect or inconsistent dimensions and layouts in the construction documents, or by the lack of timely and correct information that is needed to build the project or to meet the code requirements. Among others, E&Os are usually caused by poor coordination and communication among the many parties involved in the design process.

This paper explores the extent to which change orders resulting from errors and omissions in the design documents are caused by poor coordination and communications, and determines the extent to which the use of the concept of the 3D parametric building model can be used to minimize or eliminate E&Os, hence minimizes total change orders.

The concept of the 3D parametric building model has been implemented in commercial software using object-oriented technology. It creates a centralized database storing all the information about the design components as well as their interrelationships. Thus, whatever change is made is consistently propagated to the entire design object.

The research was conducted through a review of the literature, a case study and a web-based survey among design professionals. The study done by Mokbel [12] revealed that 35% of E&Os are primarily due to poor coordination and that the use of 3D parametric building model has a significant impact on productivity and on improving the coordination of the design process. This model shows promising results in helping to minimize errors and omissions in the design documents.

Keywords: change orders, change orders due to errors and omissions, 3D parametric building modelling, CAD systems, project design coordination, design documents, collaboration.
1 Introduction

Design is a very interactive process. It requires inputs from different design specialists with different levels of technical knowledge. Although these professionals work with different input parameters and perceptions to the design process, they should end with a consistent set of drawings and specifications to communicate the design to the builder. To maintain this consistency between the drawings and to ensure design effectiveness, design team members should efficiently communicate with one another during the process. Poor coordination can have adverse impact on the design outputs and may result in many errors and omissions. When detected, during construction, these design errors will result in associate change orders. This category of change orders can represents more than one third of the total changes that might occur during the project. Meanwhile, these can be prevented or minimized if the produced design drawings were free from errors and well coordinated.

In order to eliminate design errors and omissions, any design change should be documented correctly and properly adjusted in all the existing graphics representations of the design. Using conventional 2D CAD software in handling this problem cannot guarantee the consistency of the solution because of the lack of automated coordination in this software. This type of software creates multiple files to store the design. Consequently, it is not very effective when a change occurs, because the user has to effect this change separately in all of the related files. In most cases this does not happen and significant errors and omissions can take place, leaving some documents unmodified.

On the other hand, the concept of the 3D parametric building model has been implemented in commercial software using object-oriented technology. It creates a centralized database storing all the parameters of the design components as well as their interrelationships. Thus, whatever change is made, it is consistently propagated to the entire design object. The authors hypothesized that to minimize or avoid change orders due to errors and omissions; one can use the “parametric” or intelligent building model to coordinate changes between design documents, because it generates only one model for the entire building. It comprises intelligent building components, views, and annotations. These are both parametric and are associated bi-directionally through a high-performance change propagation engine, which supports the management of the design changes. Any design change within any certain document can be rippled with all the necessary modifications instantly and completely throughout the whole documentation set because these are different views of one model.

2 Related work

To better understand the attributes of a collaborative working environment and to propose a workflow model to be used in documenting, understanding and effectively communicating information associated with a change order, an extensive literature review of the current work flow models has been conducted. Some researchers referred to the workflow system as: “An application level
program which helps to define, execute, coordinate and monitor the flow of work within organizations or workgroups. As a result, a workflow system must contain a computerized presentation of the structure of the work procedures and activities, Ellis and Nutt [7]. Others such as Hector and Sikazwe [9] defined it as “the system that is concerned with the automation of processes where documents, information or tasks between participants according to a defined set of rules to achieve, or contribute to, an overall business goal. Whilst workflow may be manually organized, in practice most work flow is normally organized within the context of an information technology to provide computerized support for the procedural automation”.

This review revealed that the way people in the architectural, engineering, and construction (A/E/C) firms interact, collaborate, and communicate throughout the different stages of the construction project’s life cycle can have a profound impact on its success to meet the pre-planned expectations. For that reason, workflow management is an essential technique for providing effectiveness and success of any design changes and consequently to the whole project. Neglecting this process will lead the project participants to compromise and not to obtain the required accuracy.

Finally, the authors came to the conclusion that this coordination issue could be tackled by the automation of design information exchange process through the use of the parametric building model in the production of design drawings.

3 Methodology and concepts

The methodology used in conducting this research included: a literature review; a case study as an example of real-world situations where problems can be directly observed. Then, this situation was recreated in a simulated scenario to develop a clear vision of what could be done to avoid design errors when the 3D Parametric Building Model software Autodesk/Revit ® is used. A comparison between the drawings generated with Autodesk/Revit ® and the original design drawings generated using AutoCAD R.14 was performed to determine whether or not the use of Autodesk/Revit ® would have prevented or minimized the E&Os observed in the project. Finally, an online survey was conducted among industry practitioners in the United States to provide feedback on their experiences with E&Os using CAD and the 3D model.

3.1 Autodesk/Revit ®

Autodesk/Revit ® software is a trademark by AutoDesk Inc. It was used in this study as an example of a software package that supports the parametric building model. It is available at WPI through a grant.

3.2 The role of Autodesk/Revit ® in managing the project information

The role of Autodesk/Revit ® in coordinating the design documents is similar to the project manager role in the construction projects as follows: Through its parametric engine, it enables the project staff to maintain the required
consistency between their different disciplines throughout the project life; it helps the project members to figure out the possible conflicts between the different users. This coordination role of the software is primarily available on both the worksets and the concurrent building assets (CBA) features.

3.2.1 Autodesk/Revit® worksites
A workset is a collection of building elements (such as walls, doors, floors, stairs, etc) in the building. Only one designer may be given privileges to edit a given workset at any given time. All other team members will be locked out from this workset preventing possible conflicts in the project.

Autodesk/Revit®’s worksites can be used to propagate and coordinate changes between designers. Team members can add elements to their worksets and see the latest changes done by other team members to make sure that the project design is progressing in a well-coordinated manner. Besides, they can save their work to a local file on the network or their own hard drive and publish work to the other team members whenever they choose.

3.2.2 Concurrent Building Assets (CBA)
The collaborating users of Autodesk/Revit® are working in an interactive manner. The parties are mutually dependent on the central database that controls the relationship between the different components of the building. This is achieved through the Concurrent Building Assets (CBA) concept. CBAs capture and maximize the value of information by making it available in the format that is most familiar and appropriate to the various professional disciplines in architecture, engineering and construction. An architect, for example, viewing a framing plan or bracing elevation from a structural engineer can choose to see it as an architectural floor plan or building section. That is because all different views originate from the same model, not as separate files.

4 Case study
A $45 million dollar, eight floors’ healthcare facility was chosen as a case study for this study. During the construction of this health care facility there were a number of change orders that increased both the initial cost and schedule of the project. Among those change orders, there were six change orders due to design E&Os with a total cost impact of 2% of the original estimate and a total delay of 167 days. After analyzing the workflow model of the project and how the information had been exchanged it was found that the main reason behind those E&Os was poor coordination among the different design team members. In turn, this resulted from ineffective communication and erroneous interpretation of the design information. Those change orders were classified as follows: 1-E&Os due to incompatibility of design documents within the same design discipline, 2-E&Os due to incompatibility of design documents among design disciplines.

4.1 Simulation of same-discipline conflict
In the original design there was an incompatibility between some of the doors’ sizes in the architectural drawings and those reported in the schedules. This
mainly resulted from the architect’s mistake of drafting the restroom’s door with a smaller width (0.92 m) than the standard code required width (1.19m). Later, he discovered this error and edited the door’s width in the drawings but he forgot to transfer this modification to the doors’ schedule. The estimator prepared the bill of quantities from the doors’ schedule and the job was bid for the smaller size. This error was repeated in all the restrooms of the hospital (260 restrooms).

A simulated scenario of the above situation was created using Autodesk/Revit ®. The typical plan view of the patient’s room was first drafted. Once the plan view was drawn, the schedule of the doors was automatically generated by the software. The door size was changed to simulate the real situation of that change, hence the doors schedule was automatically updated, unlike the case in the original drawings generated using AutoCAD, in which the architect has changed the door’s size in the drawings to meet the code requirements, but forgot to transfer this change to the door schedules. Figure 1 shows both cases.

![Figure 1: Restrooms’ doors and automatically generated schedules before and after editing.](image)

4.2 Simulation of interdisciplinary conflicts

In the original design there were various related to interdisciplinary poor coordination. These could have been avoided by working with AutoDesk/Revit ®’s worksites feature during the design. In this way the building model can be subdivided into subsets according to the building systems (Architectural, Mechanical, Structural, etc) at which all users can work collaboratively. With
worksets, the parametric change engine performs the coordination work that the conventional CAD systems leave to the architect.

First of all, and before enabling the sharing of the model, the leader of the design team members should assign one workset to each one of them; detect each area, the bounds of the scope, and each detail that each designer will be responsible for. Each design member is then responsible for staying within the original bounds doing his own work (write, edit, view). This simple step will help to avoid many of the problems often associated with poorly coordinated design drawings, which when left uncorrected will inevitably lead to increases in costs and construction duration. This feature will “force” the interaction to take place only within the model. All team members are “forced” to communicate their decisions. In the same time the parametric technology will maintain the necessary consistency among the different views of the model (plans, sections, schedules, etc.). Figure 2 shows an example of how the project worksets have been arranged.

![Figure 2: Project’s worksets.](image)

Each workset records all changes made to the shared model over the course of the project, along with the comments made by all team members when they saved their changes. This information can be exported to a text file for further reporting and analysis.

Autodesk/Revit® will then propagate changes made to the whole model and makes the necessary coordination. If one of the users tries to make a change to a workset that is editable by another user, a warning message will pop up to identify that this workset is not editable. If this user tries to make it editable, another warning will appear (see Fig 3).
In contrast to a drawing file–based environment, where the architect changes should be tracked through each drawing file and each file should be updated manually, in the model-based environment the Autodesk/ Revit®’s parametric change engine takes care of these updates and propagates them to all views since they are all multiple representations of the same model.

Figure 3: Warning message.

5 Survey

A web-based survey questionnaire was conducted among the top Engineering News Record (ENR) design firms and among Autodesk/ Revit®’s users as a supporting step to seek factual information and knowledge on change orders that are resulting from poor design coordination, on their percentage to the total change orders, and on how the use of CAD design packages influence both the coordination process and the percentage of the design errors. A statistical analysis has been done for the collected data.

5.1 Survey results

From the analysis of the survey results, it was found that three fourth of the respondents were architects with significant experience in the engineering design profession. Most of them are involved in private projects rather than public projects. The analysis of the responses of the ENR design firms and the Autodesk/Revit® users’ group regarding the effect of the use of CAD packages in the design showed different patterns. In the ENR design firm’s sample, 66%
of the respondents expressed that the CAD packages (2D drafting, 3D modelling) they are using have minor to no impact on the coordination process. While 24% and 10% articulated that the impact was moderate to major respectively. On the other hand, in the Autodesk/Revit ® users’ group, who are using the parametric building modelling, 63% described the impact as extreme to major, 29% as moderate, and 8% as minor. As far as its impact on the coordination process, their responses replicated that it has been enhanced to a varying extent: 50% said that it has extreme to major impact, 35% said it has moderate impact, and the other 15% went with the minor impact.

From the above, it can be concluded that the designers that are using the parametric building technology in their projects have started to gain some benefits through enhanced productivity and better coordination throughout the design documents, which helped them to reduce the errors and omissions change orders.

Actually, the results of the survey indicate that by introducing this model-based software in construction projects, the power of coordinating the information across the entire design can be better realized. However, the respondents expressed that they do have some problems associated with the use of this model such as some limitations in the software or its inability to adopt the unique nature of the construction projects. They also mentioned that the software was mainly suitable for vertical construction rather than horizontal construction. Yet, these problems are expected since this model-based software is newly introduced in the construction industry, and these will be tackled in the new versions of the packages.

Finally, it is observed that there is a correlation between the percentage of change orders due to errors & omissions in both of the case study and the survey results.

6 Conclusion

This study strongly suggests that the use of the parametric building model can dramatically reduce the number of Change Orders due to E&Os in design
documents. It allows the design team members to spend more time on the tasks that add more value to the project design and less time on tedious coordination with other disciplines’ drawings. This is in contrast with the use of the conventional CAD applications.

References


