Determining the Impact of CADrafting Tools on the Building Delivery Process

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ABSTRACT

Computer aided design (CAD) is intended to change the way design and construction are carried out. At a minimum, this implies savings realized in terms of time spent and improvement of the quality of designs produced. To test this idea, we hypothesized that computer aided drafting and design operations may be instrumental in reducing the number of change orders issued and help control cost overruns by improving the accuracy of construction documents. We compared change orders in projects designed in the conventional media against ones developed with computers. We found that there is evidence supporting our hypothesis. Furthermore, in the process of investigating this question, we found that computer applications to improve the management of existing building information (as-built drawings, building system related information, and the like) represent even more critical needs than those that can reduce change orders through more accurate design drawings.

Key Words

drawing accuracy; change orders; design errors; as-built drawings; scope changes

INTRODUCTION

What purpose a computer aided architectural design tool should serve has been discussed extensively. Still, researchers who have been working in developing "intelligent" tools to assist designers in their tasks are faced with the fact that "dumb" drafting packages dominate the use of computers in the architect's workplace [AIA, 1991]. While the use of computers as drafting tools is increasing, it is claimed that architects are reluctant to use them in the "true" sense of the term: computer aided design. The explanation of this claim is more complicated than what is often given as designers' unwillingness to compromise their creativity. Traditionally, electronic drafting tools have been considered as a direct, one-to-one substitute for manual drafting, an unavoidable part of the design process. The benefits of computation in this case are easier to measure since the objective is to produce more accurate drawings in less time.

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The integration of CAD tools over the whole span of the design process, on the other hand, is not an obvious task. Neither is it desirable nor is it efficient in the long run to look for a one-to-one mapping between existing processes and computer aided ones. CAD tools are here to change the way things are done from the traditional modes of design activity; that is, if we are to realize any substantial benefits (Akin and Anadol, 1992).

There are a number of diverse issues related to the organization and human resources of the architect's workplace that the implementers of CADrafting tools need to consider together with the "dumb" *versus* "intelligent" characteristics of systems. These technical and non-technical issues have already been recognized in the implementation of new technologies in business, mechanical engineering, manufacturing [Forester 1989, Long 1987, Mumford 1983, Robertson et al 1992]. In this study, we set out to identify methods to successfully integrate CAD tools such that there is measurable benefit to the practice. The work presented in this paper is a benchmarking study for comparing manual and automated projects to identify if and at what stage CAD tools have an impact on the building delivery process. If there is evidence that CAD tools have in fact made a contribution, the next step is to look at the way those tools have been integrated in the workplace. This work also involves the development of a method for undertaking this task.

WORK ON CHANGE ORDERS

Akin [1991] has reported that some architects claim that projects carried out with CADrafting systems in some cases produced better crafted buildings. Based on this, the hypothesis that CADrafting systems, when used centrally as a clearing house of design information, can help produce more accurate working drawings has been proposed. This suggests that change orders originate from design errors in the first place. Let us examine this question first.

A report prepared by the Committee on Construction Change Orders [NRC, 1986], formed upon request from the agencies that sponsor the Federal Construction Council, explains that federal agencies have been receiving criticism from Congress and other government officials for excessive changes to their construction contracts. This has led the agencies to impose strict and costly controls on the changes they make which in some cases have jeopardized the functional performance of the new buildings. The committee has analyzed how the agencies record and report the changes and have made recommendations on adopting uniform standards. As a minimum, the agencies have been advised to develop statistics, on the basis of completed projects, on the number, dollar amount and percentage of original contract amount of modifications to their construction contracts and the reasons causing the change orders. The committee has advised the use of five broad categories of reasons in preparing the statistics: *design deficiencies*, *criteria changes*, *unforeseen conditions*, *changes in scope* and *other*. The statistics provided for this study by two of the federal agencies show that changes related to *design deficiencies* are the most frequent and most costly among the five categories. Although the objective of this study is different than ours, the statistics requirements, the categorization of changes proposed by the committee and the results of statistics analyses are similar to the ones with which we worked in this study.

Golish [1992] is presently working on another project to "analyze and categorize current Corps of Engineer projects to determine where most errors occur in the design/documentation process" and also to "determine to what extent automation ... and standardization ... have reduced errors in the process." His method involves analyzing and categorizing reviews and comments given to a number of Corps projects and then reviewing these projects after construction "to determine other errors missed by reviewers which result in change orders." He has broken down the types of problems to which reviewers point out in projects into three main categories: *criteria, design issues and documentation. Design issues are further broken down to scope, design analysis, design configuration, product/system selection* and *coordination*. Documentation related problems are also further classified into *coordination, omissions/errors, format/presentation of information, terminology* and *estimates*. It is worthwhile to note that, some of what Golish has categorized as problems encountered prior to construction, we have in fact observed manifested during the construction phase in the form of change orders.

Ibbs *et al* [1986] have studied the impact of various contract clauses on project performance. Examining the "change family" of clauses in contracts, they have listed fifteen types: *work scope definition, design changes, construction changes, quantity variations, workmanship variations, schedule intervention, errors and omissions, as-built drawings, correction of damage/other's work, subsurface investigation,* force majeure, *unforeseen conditions, design rework, equipment/material rework, construction rework*. Among these reasons of change, they have named work scope definition, design changes, construction changes, workmanship variations and design rework as the "most problematic" contract clause types with regards to the general measures of project performance such as cost, schedule, safety and quality. Among these measures, we have observed that the impact of changes on cost leads to similar observations.

OBJECTIVES

Thus, this paper aims to:

(a) determine the overall percentage increase in the contract amount due to change orders,

(b) categorize the reasons for changes,

(c) identify how many in each category of change exists,

(d) identify the impact of these categories of changes on overall increase in cost, and

(e) observe the implications present in the statistics for manual and automated projects.

We are interested in comparing two groups of projects, CADrafting *versus* manual ones, on the basis of the change order statistics derived from our observations. We are looking for any evidence which shows that there is in fact a difference between the two groups. We expect that use of CAD tools leads to see less number of changes and less increase in cost. In this respect, we will especially be scrutinizing those categories of changes that can be traced back to the design phase of the project.

METHOD

The study was conducted in two main steps: data acquisition and data analysis. The data acquisition phase involved the selection of offices, selection of projects, examination of written project records and interviews with the project managers of the selected projects. There were two offices involved in our study. One was the design and construction office at the physical plant of a private university and the other was a private architectural office. Throughout the paper, the former is referred to as "Office-A" and the latter is referred to as "Office-B." We have chosen these two particular offices primarily because they represent the two different categories of design delivery methods: Office-A predominantly uses manual methods and Office-B works with computer aided design tools. We should add that both offices were very cooperative in making their resources accessible for the collection of data. The selection of projects was primarily driven by the intention to sample the two different categories. The second important criteria was that all projects we study would be completed projects, their written records would be filed and accessible. Both Office-A and Office-B projects were renovation jobs, completed in what has been referred to by both offices as a "compressed construction time frame." This was not a premeditated choice on our part but did provide uniform grounds for comparison.

The examination of written project records involved the examination of the budget breakdown and most importantly the change orders issued for each project. We focused on the change orders issued to the general contractor. In each case, the final amount of the contract signed with the general contractor reflected more than half of the project's budget while the contracts signed with the subcontractors provided little or no information on changes. Since a change order often consists of a number of items, when looking at the type, number and cost of changes, we took these individual items into consideration rather than the change order documents, in lump sum.

Next, we consulted the project managers of each project to find out about the reasons for the change order items. Through these interviews, we developed eight categories for the reasons of change:

(a) The category of *incomplete as-built drawings* refers to the changes caused by inadequate or missing information because the as-built drawings of the building were incomplete.

(b) The category of *design errors* refers to errors of omission, errors of commission and the combination of the two made by the designers during the design phase of the project. There are yet other subcategories these three can be broken down into but within the scope of this study, we will only be referring to the main *design errors* category.

(c) The third category, *site conditions*, refers to the unforeseen conditions that were discovered during construction. This is distinct from the "as-built" category as it involves aspects of use and equipment installations not normally included in as-built drawings.

(d) The fourth category, *user requests*, are mainly changes in the scope of work requested by the user of the building or space that was being constructed. This category includes the cases where the user makes a change in his decision about the scope of the work or requests some part of the design to be demolished and reconstructed. We separated this from the next category, changes in scope, since this is initiated by the user/owners of the space and not by the construction managers.

(e) *Changes in scope*, is the collection of changes that were often initiated by the project manager. Such changes include repairing the damage done by others, extra work needed in anticipation of future additions, and improvements of performance of the facilities.

(f) *Contingency*, refers to anticipated additional work and for which necessary funds were allocated at the time the contract was prepared.

(g) The seventh category, *credits*, refers to the deductions in the contract amount due to elimination of work or savings realized through existing resources and value engineering.

(h) Finally, the eighth category, *combination*, refers to the reasons for change in which a combination of any of the seven categories mentioned above are relevant.

In the data analysis phase, we developed summary tables for the data collected and made observations on the trends present by the data. In the following section, we will discuss some of these findings.

RESULTS AND OBSERVATIONS

A total of eight manually delivered projects were examined from Office-A. The numbers of change order items issued to the general contractor for all projects totaled 196 and cost $250,318 which represents a total original contract amount of $2,307,771 to a final $2,558,089 after the change orders. This means a 10.85 percent increase in the contract amount. The final total budget for these projects was $3,721,344 representing additional appropriations made in each account once the initial construction phase was completed (Table 1).

Table 1. Office-A Projects, Statistical Summary

	590237	592108	590135	590124	590124	590129	591111	590129	TOTAL
Total Budget ($)	1,212,500	550,940	424,735	404,299	360,680	283,810	247,260	237,120	3,721,344
Original Amount ($)	795,100	283,500	297,571	278,650	161,250	177,800	143,600	170,300	2,307,771
Number of Changes	68	22	23	5	20	12	31	15	196
Cost of Changes ($)	76,392	23,873	41,780	34,679	25,157	10,838	28,933	8,666	250,318
Final Amount ($)	871,492	307,373	339,351	313,329	186,407	188,638	172,533	178,966	2,558,089
Percentage Increase	9.61	8.42	14.04	12.45	15.60	6.10	20.15	5.09	10.85

There was only one project from Office-B and it was delivered using computer aided design tools. Fifty-nine change order items were issued, costing $240,304. The original contract amount, $2,284,383, increased by 10.52 percent to $2,524,687 (Table 2). Although several other projects were also available for our analysis none fit all of the selection criteria we used in this study.

Table 2. Office-B, Project 91200, Statistical Summary

Original Amount ($)	2,284,383
Number of Changes	59
Cost of Changes ($)	240,304
Final Amount ($)	2,524,687
Percentage Increase	10.52

Looking at the classes of reasons for change, in Office-A projects, the most frequent and most costly reason for change is the class of design errors (Table 3). Second in this ordering is the class of changes in scope. The third most frequent and costly reason is the class of user requests.

This ordering changes in the Office-B project where the most frequent and the most costly reason for change is the class of user requests. The second most frequent and costly reason is the class of design errors. Third in the Office-B ordering is the class of unforeseen site conditions (Table 4). In a preliminary way this supports our hypothesis that the use of CADrafting may be responsible for the reduction of design errors, particularly when it is organized centrally and serves as a clearinghouse for design information generated concurrently.

Table 3. Number and Cost of Reasons for Change in Office-A Projects

	as-built	d-errors	site	user	scope	contin.	credit	comb.*	TOTAL
Number	5.5	70.5	15.5	36.5	55	9	4	17	196
Cost ($)	1,965	131,723	18,438	36,860	56,886	8,946	-4,500	50,907	250,318
% in Total Increase	0.08	5.71	0.80	1.60	2.46	0.39	-0.19	N/A	10.85

* These are also included in the categories of which they consist.

Table 4. Number and Cost of Reasons for Change in Office-B Projects

	as-built	d-errors	site	user	scope	contin.	credit	comb.*	TOTAL
Number	0	23.2	10.3	24.5	1	0	0	2	59
Cost ($)	0	87,478	35,104	95,658	22,064	0	0	21,873	240,304
% in Total Increase	0.00	3.83	1.54	4.19	0.96	0.00	0.00	N/A	10.52

* These are also included in the categories of which they consist.

During the interviews with the project managers, we took note of the observations they had made on the nature of the changes to their projects. One comment Office-A project managers agreed on was that most of the time, the changes were due to either changes in scope or user requests. Changes due to design errors did not occur as often but they did tend to cost more. After classifying the changes to Office-A projects (Table 3), we observed that this informal conclusion held. The sum of the number of changes due to changes in scope and user requests (approximately 91 changes) was higher than those due to design errors (approximately 70 changes). On the other hand the sum of the cost of changes due to changes in scope and user requests had less impact on the total increase in contract amount (37 percent of the total increase) than the cost of changes due to design errors (53 percent of the total increase). The project manager of the Office-B project had stressed the fact that user requests and unforeseen site conditions were the predominant reasons for change both by number and cost. We observed that the total number and cost of changes caused by user requests and unforeseen conditions was in fact higher than those caused by design errors (Table 4).

Considering that all of these projects were renovation jobs and from the observations of the project managers, we were expecting those changes due to incomplete as-built drawings and unforeseen site conditions to be much higher than what is reflected in the data. However, this does not overrule the possibility that these two categories might be among the underlying reasons for some of the change order categories. In fact, for both offices (Table 3 and Table 4), the sum of the costs of incomplete as-built drawings, unforeseen site conditions and design errors had a higher impact on the total increase in contract amount (61 percent of the total increase for Office-A and 51 percent for Office-B) than the sum of the costs of user requests, increases in scope, contingencies and credits (39 percent of the total increase for Office-A and 49 percent for Office-B).

Based on the small sample of projects we studied, especially in Office-B, it is somewhat premature to make comparisons between manually delivered projects and those that incorporated CAD tools. It is still useful to mention the trends that are evident in the data. For example, although the sum of the costs of incomplete as-built drawings, unforeseen site conditions and design errors had a higher impact on the total increase in contract amount in both offices, the impact on Office-A projects (61 percent of the total increase) is higher than the impact on the Office-B project (51 percent of the total increase). To establish that this difference is an indication of the positive contribution of CAD tools, more detailed comparisons looking at the subclasses of changes are needed. For example, comparisons can be made on the basis of design errors due to concurrent engineering where different parties might be working on incompatible aspects of the same design. We observed that Office-B shared the computer files of the architectural base drawings with the engineers which eliminated replication of data and also enabled these parties to act on the same information, consistently.

CONCLUSIONS

It is no great revelation that advanced CADrafting tools should be integrated in the architect's workplace. To see the impact of computers in this process, there has to be an understanding of the design delivery processes and the design agents involved as well as the potential role CAD tools might play in all of this. The benchmarking study represented by this paper is aimed at identifying if and at what stage CADrafting tools may have an impact on the building delivery process. While limited by the sample of data we collected, the preliminary results indicate that CADrafting tools, even if dumb, can make a difference in controlling the numbers of change orders issued, provided that the CADrafting systems serves as a clearinghouse for design information. This confirms earlier findings [Akin, 1991].

The ultimate goal of our study has been to analyze the ways computer aided design tools are integrated into the workplace with respect to relevant technical, organizational and human resource issues. We hope to extend the preliminary findings in these directions, in the near future.

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