Constructability Analysis in the Design Firm

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Abstract: The timely execution of a construction project is very important to the owner, who makes plans and commitments on the basis of the project's anticipated completion date. Failure of design professionals to consider how a builder will implement the design can result in scheduling problems, delays, and disputes during the construction process. Constructability of design is a subjective scale that depends basically on a number of interdependent project-related factors. Many design firms have a formal (explicit) constructability program that is launched as early as the conceptual planning stage of the project. This research examines design professionals' efforts to pursue constructability and provides recommendations for performing constructability reviews in an efficient and effective manner.

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Introduction

The strong markets in the late 1990s have brought a new set of problems. A formal (explicit) constructability program has become indispensable for any design firm that cares about the quality of services it provides, and more importantly, about surviving in today's highly competitive market.

Constructability programs aim at integrating engineering, construction, and operation knowledge and experience to better achieve project objectives. But constructability input has been hindered by the designer's partial understanding of construction requirements, diverging goals between design and construction professionals, and the resistance of the owners to formal constructability approaches because of the highly visible extra cost to projects.

Another aspect of today's construction industry is that firms are trying to adapt themselves into a market that prefers more integrated project delivery options (design-build, construction management, fixed price, lump sum, etc.). In a survey conducted by *Engineering News-Record* (ENR) magazine in 1997, the engineer-constructor discipline dominates the design market with nearly 50% of total billings, compared to other disciplines like engineer, architect-engineer, engineer-architect, and others (*The top 500 design firms source book* 1998b). This distribution indicates that the construction industry is responding to the proven benefits of integration and by implication, to the benefits of highly constructable designs.

Even though the issue of constructability has been discussed in the literature for many years, it attracted special attention after the publication of a report sponsored by the Business Roundtable as part of the Construction Industry Cost Effectiveness Project in 1982 (Integrating construction 1982). Independent studies (e.g., Ireland 1985; ASCE 1991; Russell et al. 1993) confirmed that integrating construction knowledge into design processes greatly improves the chances of achieving a better quality project, completed in a safe manner, on schedule, for the least cost. The Construction Industry Institute issued guidelines for implementing constructability programs (CII 1986, 1987). Attempts were made to develop models to classify constructability knowledge (e.g., Hanlon and Sanvido 1995; Fischer and Tatum 1997) and to automate the process of constructability reviews (e.g., Gray 1986; Skibniewski et al. 1997; Navon et al. 2000). Surveys were conducted to understand the phenomenon better, to identify the barriers to better constructability, and to quantify the advantages obtained from constructability reviews (e.g., CII 1993; Uhlik and Lores 1998; Anderson et al. 1999). Although these surveys reported the contractors' points of view, other studies looked into the constructability issue from the owners' perspective (e.g., O'Connor and Davis 1988; Russell et al. 1994a; Gugel and Russell 1994). Because the common consensus is that constructability reviews must take place in the design phase, the study reported here surveys design firms.

The objectives of the research presented in this paper include assessing the extent to which constructability efforts are pursued by design firms, determining the preferred timing for constructability implementation, exploring the tools utilized by design professionals to achieve better constructability, exploring the factors that promote or constrain constructability, and determining the benefits of a formal constructability program to the designer. The findings of a survey of large U.S. design firms operating on the local, national, and international markets are reported.

Methodology

This research investigates the implementation of constructability reviews in the design phase of a construction project. It encompasses different issues regarding constructability concepts such as the existence of formal constructability programs in design firms, tools utilized, timing of implementation, and the factors that improve or hinder constructability reviews conducted in a design firm. A questionnaire was designed to address these issues and

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was mailed to the presidents of design firms along with a cover letter and a self-paid envelope. A copy of the questionnaire is presented in the Appendix. The collected data were analyzed by means of statistical methods and conclusions were drawn.

The participants of this survey were selected on the basis of their presence in the *Engineering News-Record* (ENR) list of top 500 design firms in the United States (Top 500 design firms 1998). ENR ranks design firms that work in a wide range of markets (general building, manufacturing, power, water supply, sewerage/solid waste, industrial process, petroleum, transportation, hazardous waste, and others). Ranking is defined according to total design revenue (national and international) in U.S. dollars and therefore reflects the volume of design work performed by the firm. This implies that the sample represents the largest design firms based in the United States, with 1997 total billings ranging from \$9.8 million to \$1.652 billion. The respondents were the presidents and vice presidents of these design firms.

The data were split based on two control variables, namely size of firm and type of work undertaken. To test the significance of the differences between sample proportions, an estimate of the population proportion was calculated using the equation

$$p=\frac{N_1P_1+N_2P_2}{N_1+N_2}$$

where N_1 and N_2 are sizes of samples, and P_1 and P_2 are the sample proportions drawn from respective populations. The null hypothesis states that there is no difference between the population parameters. The sampling distribution of differences in proportions is approximately normally distributed with its standard deviation given by

$$\sigma_{P_1-P_2}=\sqrt{pq\left(\frac{1}{N_1}+\frac{1}{N_2}\right)}$$

where $q=1-p$.

Hypotheses were tested using a level of significance of $\alpha=0.01$ (99% confidence level) by using the standardized variable z. For a 99% confidence interval, the critical z values are 2.33 and -2.33.

$$z=\frac{P_1-P_2}{\sigma_{P_1-P_2}}$$

When respondents were asked to rate a factor on a (High/Medium/Low/None) scale, the ranking of the factors was done by assigning numerical values to the ratings (e.g., High$=3$, Medium$=2$, Low$=1$, and None$=0$). The ranking was based on the mean of the values derived for each factor.

To test the significance of the differences of the means of the ratings, a null hypothesis was constructed so that there is no difference between the population means, that is, $\mu_1=\mu_2$ or that the samples are drawn from two populations having the same mean. The sampling distribution of the differences of the means is approximately normally distributed with a standard deviation given by the following expression:

$$\sigma_{\bar{x}_1-\bar{x}_2}=\sqrt{\left(\frac{\sigma_1^2}{N_1}\right)+\left(\frac{\sigma_2^2}{N_2}\right)}$$

where N_1 and N_2 are the sizes of the samples, and σ_1 and σ_2 are the respective standard deviations.

The null hypothesis can be tested against the significance of an observed difference at an appropriate level of significance by using the standardized variable (z score).

Table 1. Characteristics of Respondents

Characteristics of respondents	Frequency	Percentage
Type of service provided		
Traditional (design-bid-build)	88	66
Design-Build	43	34
Construction management	21	16
Type of work performed		
General building	86	64
Engineering (highway, heavy, etc.)	77	57
Industrial (power plants, refineries, etc.)	39	29
Annual sales		
Less than \$15 million	30	22
Between \$15 million–\$20 million	26	20
Between \$20 million–\$45 million	42	31
More than \$45 million	36	27
Geographical location of projects		
Local	76	57
National	90	67
International	71	53

Note: Total respondents 134. Some respondents identified more than one response.

The Statistical Package for Social Sciences (SPSS 1996) was used to analyze the data.

Characteristics of Respondent Design Firms

It was found that 66% of the respondents provide traditional design services, 34% do design-build, and 18% construction management (Table 1). It can be inferred that the traditionally fragmented project delivery option of design-bid-build still counts for most of the contracts, which supports Uhlik and Lores' (1998) assertion that "design without construction input is the traditional way of contracting" and makes the need for formal constructability programs very important. Nevertheless, recent feedback from the industry shows that "innovative project delivery systems are sweeping the industry" (Russell et al. 1998). Among the new delivery options is partnering, which seeks to bring together all key players on a project for goal setting and rapport building. Also, design-build, whose growing popularity is driven by the industry's desire to loosen the stranglehold of litigation, combines the design and construction disciplines and gets projects completed more expeditiously. Constructability is presumably less of a problem in partnering and in the design-build delivery system because designers and construction personnel (including subcontractors) are in constant touch throughout the project.

Table 1 includes information about the type of work performed by the respondents, company size in terms of annual sales, and geographical location of projects undertaken by the respondents. The design firms that took part in the survey appear to be large firms involved mostly in general building and civil engineering projects and active in local, national, and international markets.

The location of a project may have a considerable impact on constructability. Information about materials and skilled labor available at a project location and construction techniques predominantly used in certain regions should be taken into consideration during design. Other considerations might address site accessibility, soil conditions, weather, and availability of preassembly or prefabricated components.

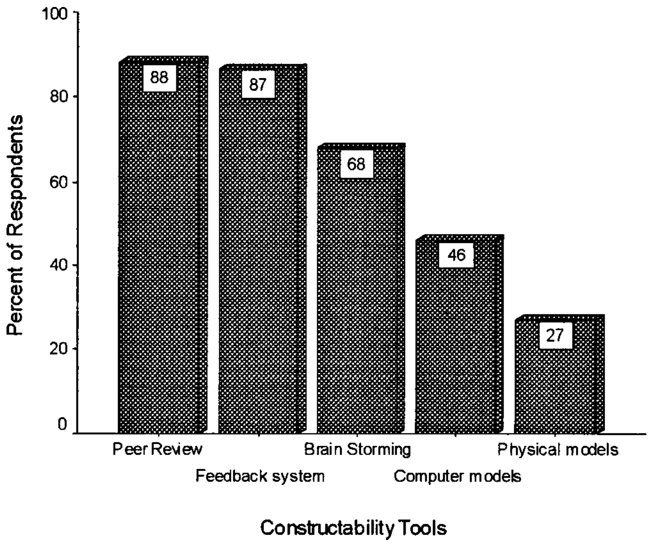

Fig. 1. Utilization of constructability tools

Constructability Reviews in Design Firms

Of 139 respondents, only 5 indicated that they had never heard the term ‘‘constructability’’ before. They represent 4.3% of the total population surveyed. The answers provided by these respondents were not included in the analyses presented in this paper. This finding indicates that most design professionals (95.7%) are familiar with constructability as a concept. A little over half (50.7%) of the respondents indicated that they have a formalized corporate philosophy about constructability in their organization.

The results of Uhlik and Lores' survey (1998) of constructability approaches pursued by general contractors show that 90% of general contractors surveyed did not have formal constructability programs, nor did they take action toward the implementation of constructability programs. There seem to be more explicit constructability programs in design firms than in construction companies, although some design firms perform constructability reviews as part of value engineering or as a component of ‘‘construction cost management.’’ The difference between contractors and designers is probably caused by the general belief (Zimmerman and Hart 1982, Burati et al. 1992) that constructability analysis is particularly valuable in the design phase.

Techniques Used in Constructability Reviews

The findings presented in Fig. 1 indicate that ‘‘peer review’’ and ‘‘feedback systems’’ are the most popular tools used in conducting constructability reviews in design firms with 88% and 87%, respectively, of the respondents using these approaches in their firms.

The popularity of the peer review technique can be explained by the fact that many governmental agencies mandate project peer reviews for specific contracts. For example, the city of Boston requires that prior to the issuance of a building permit for ‘‘complex fixtures or systems’’ an examination by a second engineer be performed. Also, the state of Connecticut requires independent engineering reviews on certain projects that meet established threshold limits (Gustafson 1990). The reason behind the peer review requirement is to benefit from the accumulated construction experience of designers at large.

There are two types of peer reviews: project management and project design. The first focuses on the planning or management aspects of a project; whereas, the latter is an evaluation that focuses on the technical aspects of a project. Peer reviews may involve both of these reviews to improve the quality of a project prior to entering the construction phase. A major advantage of peer reviews is that they uncover and correct design inconsistencies, and they specify alternative construction methods with which the designer was not familiar.

With the rising costs of construction and the increased demand of time constraints on schedules, few members of the construction industry can afford to waste time and resources on errors or ineffective work practices. Therefore, heuristic construction knowledge is gathered and stored on a project-by-project basis in most design firms in order to benefit from past lessons and to avoid the same pitfalls in the future. The feedback process involves the capture and transfer of past lessons learned, using either hard copy records or multimedia tools. In the latter, the computer tool captures, records, and stores constructability concepts and lessons learned, while providing design professionals with easy access and graphical retrieval of concepts and lessons to deepen their understanding of constructability issues (Multimedia 1998).

The least common tool used in constructability analysis is a small-scale physical model (used by only 27% of the respondents). This finding indicates that this once popular tool used to visualize the project is on its way to becoming obsolete (except for highly sophisticated structures like petrochemical plants). The design firms surveyed appear to rely more on computer generated models to pursue constructability of design than building physical models, probably because of cost and time considerations. It is worth mentioning here that design firms utilize various different tools in their pursuit of constructability, depending on the characteristics of the projects undertaken.

Techniques not included in the questionnaire were inserted by the respondents in the ‘‘other’’ category. Some prevalent tools include discussions with contractors, clients, and suppliers; quality assurance/quality control after each design stage; the construction manager participating in design reviews; and design checklist reviews.

Timing of Constructability Reviews

The responses plotted in Fig. 2 show that the developed design stage is where most constructability reviews are conducted (87%). It was also found that 25% of the respondents perform constructability analysis throughout the entire design process (conceptual planning, preliminary design, developed design stages, and after finishing the design). This means that one quarter of the design firms surveyed treats constructability improvement as part of an overall continuous project improvement process, which is the recommended practice by most researchers (O'Connor and Miller 1994).

It is generally thought that constructability reviews should be conducted after plans are completed to a certain level in order for reviewers to have something to work with. An alternative process emphasizes that construction expertise must be brought in before any design is put onto paper. This way, opportunity is provided to the designers to begin their work with certain key issues in mind, issues that can frequently be accommodated without adverse cost to the design (Mendelsohn 1997).

If the sum of the respective bars in Fig. 2 is considered, it can be observed that 51% of the firms start performing constructability reviews as early as the conceptual planning stage, and 80% as early as the preliminary design stage. Four percent stated that their firms conduct constructability reviews only after finishing the design. Only one respondent (0.8%) indicated that his/her firm

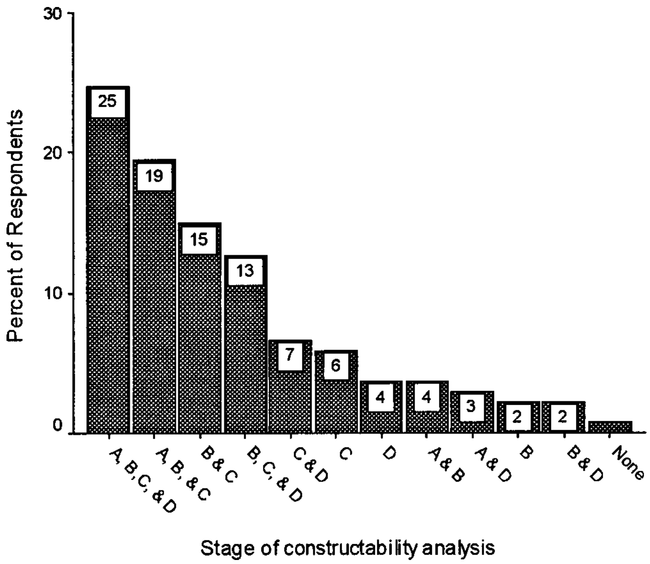

Fig. 2. Timing of constructability reviews: A, conceptual planning stage; B, preliminary design stage; C, developed design stage; D, after finishing the design

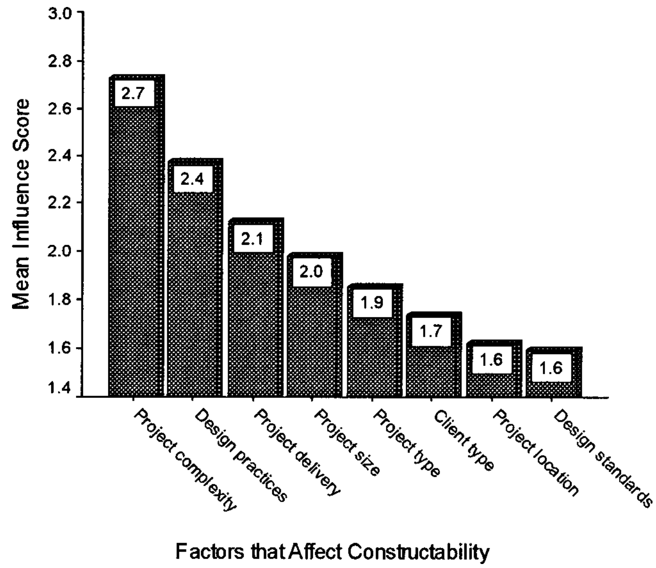

Fig. 3. Factors affecting constructability

never performs constructability reviews. These findings indicate that there is a tendency to perform constructability reviews early in the design process in order to obtain maximum benefits. This finding supports Mendelsohn's (1997) study that recommends that the constructability review process must begin at the earliest conceptual stage to be fully effective.

A constructability review process developed by the Washington State Department of Transportation (WASHDOT) is very similar to the practice reported by the respondents. The WASHDOT process is composed of four constructability reviews performed at various stages during the course of a project. The first review is performed at the completion of the draft project definition report, a comprehensive project report developed during the project definition stage at which time a value engineering study is performed. Then successive reviews are conducted at various points during development of plans, specifications, and estimate.

Factors That Enhance Constructability

The factors that were rated in the survey by the designers are all project related. The factors are plotted in Fig. 3 according to their mean score, which ranges from 0–3 (0 being the least influential and 3 the most influential).

The most significant factor selected by the respondents is project complexity, which reinforces the results of the Construction Industry Cost Effectiveness project, which indicated that the number of construction experts involved in a constructability program should depend on project size and complexity (Integrating 1982). Indeed, the likelihood of constructability problems occurring in the design/construction of industrial facilities such as a petrochemical plant is much higher than in civil engineering projects such as laying a pipeline.

The factor that has the second highest influence on constructability is design practices and philosophy, which shows that constructability is affected largely by the designer's approach to the problem. Constructability can be enhanced by a corporate culture that includes meticulous attention to construction detail, values practical site experience, takes pride in a track record of projects completed with minimum redesign, and rewards architects/engineers who produce constructable designs.

The third factor that impacts constructability is the project delivery system. Whether a constructability program is administered by the constructor or the owner makes a difference (Russell and Gugel 1993). As mentioned previously, design-build practices are also expected to reduce constructability problems as the interface between the constructor and the designer in this delivery system is more rigorous than in the traditional design-bid-build system. Partnering allows long-term relationships between constructors and designers, and as a result, it minimizes constructability problems, because the designer knows well what the partnering constructor requires in the design.

Not surprisingly, the least important factors were marked as project location and design standards. Indeed, design standards are to be adhered to and do not affect constructability as these are universal and have been in the books for a long time. As to project location, the only factor that can be of consequence in constructability would be the designer's ignorance of local construction practices and/or local materials. Given the uniform training of unionized labor and the widespread use of national material brands, it is not surprising that this factor is at the bottom of the respondents' list.

Factors that Constrain Constructability

All the constraints listed in the questionnaire were project related. The factors are plotted in Fig. 4 according to their mean score, which ranges from 0–3 (0 being the least influential and 3 the most influential).

Faulty, ambiguous, or defective working drawings, incomplete specifications, and adversarial relationships were found to be the three major factors that cause constructability problems.

Working drawings are an essential element of construction, bridging the gap between the design set forth in the specifications and the details necessary to fabricate material and install the work in the field. Any faults or ambiguity in working drawings can lead to cost overruns, delays, disruption of construction progress, and consequently, litigation between the designer and other parties involved in the process. This finding reinforces Mendelsohn's (1997) claim that technical contract documents are very important and effective tools in achieving a highly constructable design.

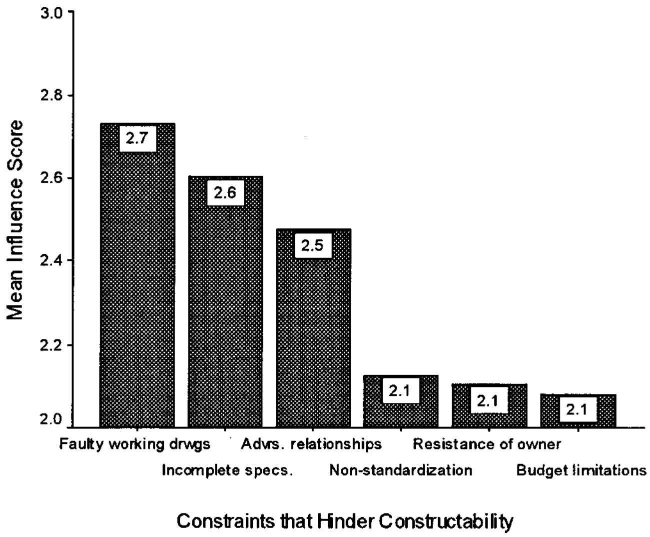

Fig. 4. Constraints on constructability

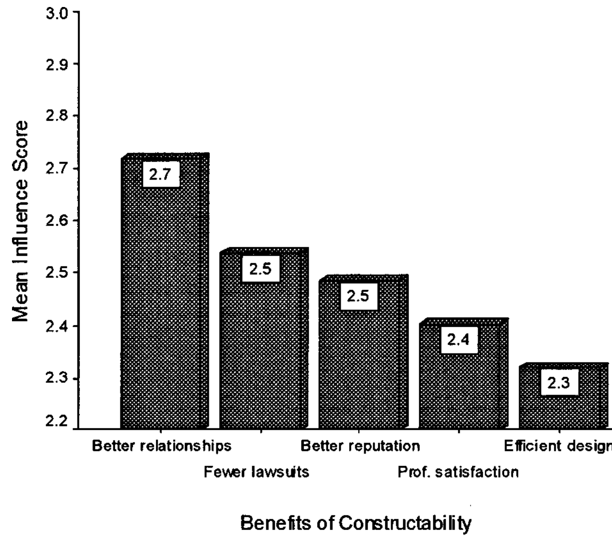

Fig. 5. Benefits of constructability

Specifications can be set as design or performance specifications, design specifications being the "recipe" the contractor is required to follow; whereas, performance specifications dictate what the end result should be without telling the contractor how to accomplish that result. The incomplete specifications factor is the second most important factor shown in Fig. 4 that causes constructability problems. If construction personnel are involved in the preparation of specifications, many on-site conflicts can be avoided.

The construction industry is a fragmented industry where different parties such as the owner, contractor, designer, and subcontractors have differing and sometimes conflicting objectives. This fragmentation is particularly prevalent in the traditional design-bid-build project delivery system where adversarial relationships among the parties has become the norm. The lack of trust, the existence of conflicting objectives, and the common expectation of frequent disagreements result in a general lack of communication which in turn creates constructability problems.

The respondents listed budgetary limitations, resistance of the owner to formal constructability programs, and nonstandardization of design to be the least influential constraints that hinder constructability (Fig. 4). This finding challenges the common perception that owners constitute a barrier to formal constructability programs because constructability programs add a highly visible extra cost to projects, and benefits are less tangible (Integrating 1982). The findings suggest that there is no tendency on the part of the owners to prevent constructability programs, probably because of their proven cost savings.

Benefits of Constructability Programs to Design Firm

A constructability program introduces a cost that is usually added to the design fee and might harm the competitiveness of the firm. Some firms absorb that cost into their indirect expenses to stay competitive, so there should be some benefits to the design firms in return for their investment in a more buildable design.

The most significant benefits listed by respondents are developing better relationships with clients and contractors, being involved in fewer lawsuits, and building a good reputation (Fig. 5). This finding indicates that long-term public relations, litigation-free jobs, and the building of a good reputation are crucial considerations for design professionals, possibly because design work is typically not awarded through lowest offer bidding but by a client who approaches a reputable and competent designer and negotiates an agreement.

A reduction in the number of potential claims and lawsuits against the design firm was marked as the second reward of constructability. This finding can be explained by the fact that design errors (lack of constructability) are the most common cause for contract claims (Diekmann and Nelson 1985). It also strengthens the opinion put forward by Gambatese and McManus (1999) that the implementation of constructability programs can reduce antagonism and disputes between designer and contractor.

The construction business is extremely risky. Much of the preparatory paperwork that precedes construction projects can be viewed as the formulation of risk allocation between the owner, contractor, and designer (Rubin et al. 1983). As claims and disputes increase, the construction industry struggles to find a way to equitably and economically resolve them. A study indicated that fees paid to lawyers and experts in litigation had increased 425% between 1979–1990; whereas, settlements and verdicts had increased only 309% (Marcotte 1990). As a result, the threat of litigation stifles innovation in engineering design. Even as they assess risk carefully on a project-by-project basis, many designers turn down work because of the threat of liability. This shows that the threat of litigation is an important factor in the design profession.

Value Engineering versus Constructability

There is agreement by the large majority of the respondents (91%) that value engineering (VE) cannot replace constructability. This was rationalized by the comments made by respondents to stress the distinction between the two processes, such as "these are two different issues," and "these have different goals," and "VE comes much later in the process."

The primary objective of VE is to reduce the total life-cycle cost of a facility; whereas, constructability focuses on the optimization of the construction process. VE is normally performed during the design phase of the delivery process. An effective formal constructability program ideally begins during the conceptual planning phase and continues through construction. Conducting constructability reviews can act as a precursor to VE, providing information through construction input and lessons learned from past projects so that VE may be more effective. Although constructability reviews and VE might differ in terms of focus, implementation, and timing, activities within the two work processes may complement each other in achieving their goals (Russell et al. 1994b).

Construction Engineers' Involvement in Design

The large majority (95%) of the respondents are of the opinion that construction engineers should be involved in the design phase in addition to other professionals that are already participating in this stage; whereas, the remaining 5% think they do not need to do so. This finding indicates that designers are aware of the need for a construction expert to provide the design team with insights into the construction phase of the project. Although 57% of the respondents believe that construction engineers should be involved regardless of project conditions, 38% indicated that the involvement of construction engineers should depend on the size, complexity, and type of project, with the remaining 5% not seeing any need for a construction engineers' involvement.

Several respondents made remarks like ''sometimes our office engineers do not see things as our construction people do.'' This kind of remark indicates that the designers are not against the potential advisory role that experienced construction personnel might play in their organizations. It emphasizes the fundamental differences between designers and constructors; if nothing else, one can say that a designer has a conceptual mind that relates to intangibles and a constructor has a practical mind that relates to tangibles.

Comparative Analysis

A comparative analysis was performed to test the differences regarding constructability issues between different populations in the collected sample. The sample ($n = 134$) was divided into small and large firms (according to annual sales) to test the effect of corporate size on constructability practices. Firms with annual sales equal to or less than $20 million were considered to be small (56 firms), and those with annual sales of more than $20 million were considered to be large (78 firms). Also, the firms operating in the general building sector (40 firms) and those working in the engineering (highways, heavy, etc.) sector (32 firms) were used as two control groups.

The differences in proportions and means were tested for significance. The underlying null hypothesis was that there is no significant difference between control groups. A 99% confidence interval, i.e., a level of significance of $\alpha = 0.01$, is used in order to minimize Type I error (rejecting a true null hypothesis).

Comparison between Small and Large Design Firms

By using a level of significance of 0.01, none of the null hypotheses were rejected. This result means that for the underlying null hypothesis there is no difference between the population proportions (or means) for small and large design firms in the construction industry.

This finding indicates that the characteristics of constructability reviews (timing, tools used, factors that enhance or constrain constructability, and benefits of constructability) conducted in the design firm are not influenced by the size of the firm (i.e., the volume of work performed).

In contrast, findings by Uhlik and Lores (1998) show that general contractors with larger volumes of work tend to use more resources in the implementation of constructability programs to maintain and increase their volume of work and profitability margins. This difference between designers and general contractors can be attributed to the fact that smaller general contractors do not commonly implement constructability programs at all (Uhlik and Lores 1998); whereas, almost all designers (95.7%) have some sort of constructability program in place. Therefore, it appears that constructability practices vary with company size among general contractors more distinctly than among designers.

Comparison between ''General Building'' and ''Engineering'' Design Firms

The results in Table 2 show that designers in the ''general building'' sector use some of the constructability tools (feedback system, brainstorming sessions, and computer-generated models) significantly more than their peers in the ''engineering'' sector. This finding can be justified by the fact that detailed planning of the interconnection of several activities and specialties is needed more in the general building sector than in the engineering sector. In addition, site layout is a concern in the general building sector because usually the projects are located in urban areas with limited space for construction activities (Uhlik and Lores 1998).

Designers in the general building sector conduct constructability reviews in the conceptual design stage and in the developed design stage more than those in the engineering sector. This finding can be attributed to technical differences between engineering design, which involves more calculations and repetition than architectural design, which requires one-of-a-kind solutions and therefore more constructability reviews especially in the conceptual design stage.

It was also found that designers in the general building sector believe that design practices and philosophies affect constructability significantly more than do the respondents in the engineering sector. This is probably due to the importance of style, art, and fashion in architectural design that is minimal in engineering design.

Conclusion

The maximum benefits of constructability reviews, measured by their ability to influence cost, are obtained in the design phase. Therefore, the study reported here surveys design firms to assess the current practice of constructability reviews conducted in the design of buildings and engineering works. The major findings and the conclusions of the research are summarized as follows:

1. Most design professionals are aware of constructability as a quality indicator of their finished product. About 96% of the respondents are familiar with the concept of constructability.
2. Slightly more than half of the designers indicated that they have a documented, formal corporate policy to conduct constructability reviews in their organization.
3. There is evidence that designers are abandoning the traditional, physical small-scale models in favor of computer-generated 3D models. Only about one third of the designer still use physical models as a constructability tool. This finding is explained by the time and cost savings computer generated models can offer.
4. Peer reviews and feedback systems are the most prevalent tools used to achieve high levels of constructability. The

Table 2. Comparison between "General Building" and "Engineering" Design Firms

Variable	Z score	$\alpha = 0.01$ $Z_{Crit.} = 2.33$ $Z_{Crit.} = -2.33$
Documented corporate philosophy	−0.68	Retain null hypothesis
Constructability tools		
Feedback system	2.40	Reject null hypothesis
Peer review	−1.40	Retain null hypothesis
Brainstorming sessions	1.74	Retain null hypothesis
Computer generated models	3.74	Reject null hypothesis
Small scale physical models	4.90	Reject null hypothesis
Stage of implementation		
Conceptual planning stage	2.03	Retain null hypothesis
Preliminary design stage	3.08	Reject null hypothesis
Developed design stage	3.67	Reject null hypothesis
After finishing the design	−0.69	Retain null hypothesis
Factors that affect constructability		
Project complexity	−0.34	Retain null hypothesis
Design practices and philosophies	2.82	Reject null hypothesis
Project size	−0.42	Retain null hypothesis
Project delivery systems	−1.21	Retain null hypothesis
Project type	2.20	Retain null hypothesis
Client type	0.98	Retain null hypothesis
Project location	2.04	Retain null hypothesis
Design standards and codes	1.38	Retain null hypothesis
Factors that constrain constructability		
Faulty working drawings	−1.32	Retain null hypothesis
Incomplete specifications	−1.09	Retain null hypothesis
Adversarial relationships between parties	1.92	Retain null hypothesis
Nonstandardized design	1.99	Retain null hypothesis
Budget limitations	−0.49	Retain null hypothesis
Resistance of owners to formal programs	−1.39	Retain null hypothesis
Benefits of constructability to design firms		
Better relationships with clients and contractors	−0.56	Retain null hypothesis
Reduction in lawsuits against the design firm	−1.90	Retain null hypothesis
Professional satisfaction	0.26	Retain null hypothesis
Efficient design	−0.60	Retain null hypothesis
Better reputation	−0.33	Retain null hypothesis
Value engineering as an alternative to constructability	1.67	Retain null hypothesis
Construction engineers' involvement in the design phase	−1.68	Retain null hypothesis

popularity of peer reviews is attributed to the fact that some governmental agencies mandate this process for projects that meet established threshold limits.

5. Most designers conduct constructability reviews in both the preliminary and developed design stages. Design professionals operating in the general building sector perform constructability analysis in the conceptual and developed design stages significantly more than their peers operating in the engineering sector.
6. Design professionals believe that project complexity is an essential factor that affects the way a constructability review is conducted in the design stage. Project complexity (technology, materials, and methods of construction) can determine the degree of formality of the program and the number and composition of construction experts needed to achieve constructability goals.
7. Design practices and philosophy usually determine the approach followed in analyzing the constructability of a design. This is more evident in the general building sector (as opposed to the engineering sector) because of the effects of trends, fashion, and style on architectural methodology.
8. Faulty working drawings and incomplete specifications are the major constraints working against constructability of design; on the other hand, owner resistance and budget limitations are perceived by designers as having a trivial effect on constructability. This finding does not agree with the generally held belief that owners are usually reluctant to allow their designers to conduct formal constructability programs because of the highly visible extra cost to their projects.
9. Designers consider developing good relationships with contractors and clients and avoiding litigation to be the best rewards of a highly constructable design. This finding supports the involvement of construction personnel in the design phase, which presumably improves the mutual understanding among the parties involved in the construction project, consequently reducing the chances for future disputes and potential litigation. Indeed, designers agree that the design team should include an experienced construction engineer, especially if the project is large and complex.
10. Value engineering can be a complementary process to con-

structability, but cannot replace it. Ninety-one percent of the designers indicated that VE could not be an alternative to constructability.

In today's competitive world, deficiency of design is one of the major challenges facing the construction industry. Significant savings in both cost and time can accrue from the implementation of established constructability reviews as early as the conceptual planning of especially large and complex projects. Further research is recommended to study the relationship between innovation in design approaches and innovation in construction technologies.

APPENDIX QUESTIONNAIRE

Illinois Institute of Technology
Department of Civil and Architectural Engineering
Construction Engineering and Management Program

Constructability Questionnaire

Company: ______________________________ Name: ______________________________
Title: ______________________________

1. **What best describes your organization?**
   - ❑ Design-build
   - ❑ Design contractor
   - ❑ Construction management

2. **What type of work is your organization typically involved in? (check all that apply)**
   - ❑ Building
   - ❑ Engineering (highway, heavy, etc.)
   - ❑ Industrial (power plants, refineries, etc.)

3. **What are your firm's annual sales? (millions of dollars)**
   - ❑ Less than $15m
   - ❑ Between $15m and $20m
   - ❑ Between $20m and 45m
   - ❑ More than $45m

4. **What are the geographic locations of the projects you undertake? (check all that apply)**
   - ❑ Local
   - ❑ National
   - ❑ International

5. **Constructability has been defined as the extent to which the design of the structure facilitates ease of construction, subject to overall requirements of the completed structure. Have you heard this term before?**
   ❑ Yes ❑ No
   If your answer is "No", do not attempt to answer the remaining questions. Please return the questionnaire in the enclosed self-paid envelope.

6. **Do you have a documented corporate philosophy for dealing with constructability issues in your organization?**
   ❑ Yes ❑ No

7. **What are the techniques used in constructability reviews by your organization? (check all that apply)**
   - ❑ Small-scale physical models
   - ❑ Brainstorming
   - ❑ Peer review
   - ❑ Computer generated models
   - ❑ Feedback system (from past lessons learned)
   - ❑ Others (please specify) ______________________

8. At which stage of the design process do you perform constructability analysis? (check all that apply)

- ❑ During the conceptual planning stage
- ❑ During the preliminary design stage
- ❑ During the developed design stage
- ❑ After finishing the design

9. Rate the following factors with respect to their effect on constructability:

	High	Medium	Low	None
Project delivery system (traditional, design/build, CM)	❑	❑	❑	❑
Project complexity (construction methods and technologies)	❑	❑	❑	❑
Project size	❑	❑	❑	❑
Design standards and codes	❑	❑	❑	❑
Project location (local, national, international)	❑	❑	❑	❑
Project type (building, engineering, industrial)	❑	❑	❑	❑
Client type (public, private)	❑	❑	❑	❑
Design practices and philosophy	❑	❑	❑	❑

10. Rate the following conditions with respect to constraining constructability:

	High	Medium	Low	None
Faulty, ambiguous or defective working drawings	❑	❑	❑	❑
Incomplete or ambiguous specifications	❑	❑	❑	❑
Non-standardized designs	❑	❑	❑	❑
Adversarial relationships between designer and contractor	❑	❑	❑	❑
Resistance of owner to formal constructability program	❑	❑	❑	❑
Budget limitations	❑	❑	❑	❑

11. Rate the following with respect to benefits of constructability reviews to the design firm:

	High	Medium	Low	None
Reduction in number of claims and lawsuits against designer	❑	❑	❑	❑
Better reputation and more workload	❑	❑	❑	❑
Improved efficiency of design	❑	❑	❑	❑
Professional satisfaction	❑	❑	❑	❑
Better relationship with contractor and client	❑	❑	❑	❑

12. Do you think value engineering/value analysis can replace constructability reviews?

❑ Yes ❑ No

13. Do you think construction engineers should be involved in the design phase of the project in addition to architects, structural, mechanical and electrical engineers?

❑ Yes ❑ No

Do you want to get a summary of the results of this survey?

❑ Yes ❑ No

THANK YOU.

Please mail to: **Mr. Ahmed Elhassan**
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