Constructability State of Practice Report

James B. Pocock[1]; Steven T. Kuennen[2]; John Gambatese[3]; and Jon Rauschkolb[4]

Abstract: This report reviews guidance on constructability programs from a variety of sources and presents the current practice of constructability. The advice of several organizations and researchers is summarized to describe expectations for ideal constructability. Actual current constructability practice, based on results and analysis of a Constructability State of Practice survey, is described. Approximately 100 owners, architects, engineers, consultants, contractors, and construction managers answered the survey's ten questions and provided written comments. The results provide a picture of current constructability practices in the architecture, engineering, and construction (AEC) industry and progress in recent years. Major conclusions include: (1) constructability has gained acceptance throughout the industry; (2) constructability efforts are clearly beginning in early project phases; (3) a wide variety of constructability techniques and new technologies are being implemented; and (4) obstacles to improving constructability remain, but may be changing. Finally, recommendations are provided based on areas where constructability practice can still be improved. This report is relevant to both industry practitioners and researchers.

DOI: 10.1061/(ASCE)0733-9364(2006)132:4(373)

CE Database subject headings: Constructability; Construction management; Design; Design/build; Project management.

Introduction

In 1991, ASCE's Construction Management Committee wrote that "the extent to which a real constructability program exists in various corporations varies from extremely sophisticated, excellent programs to none at all" (ASCE 1991). In 1993, the Construction Industry Institute's (CII) Constructability Implementation Task Force concluded that "industry-wide constructability implementation is progressing slowly and lacks structure" (CII 1993). Though numerous researchers have investigated constructability, it has been over a decade since the last focused look at constructability in the industry. This report by the Constructability Committee is aimed at building on the work of the Business Roundtable, the Construction Industry Institute (CII), the American Society of Civil Engineers (ASCE) Construction Division (now the Construction Institute), and other researchers in trying to assess how far constructability has come in recent years.

In response to the continued interest in the area of constructability, the American Society of Civil Engineers (ASCE) Construction Institute formed a committee in 2002 consisting of representatives from industry and academia. This Constructability Committee was created to:

> *provide a forum for the communication and discussion of topics related to the constructability of civil engineering projects; advance the engineering and construction industry's knowledge and state of practice of constructability; and act as an industry resource for constructability information, education, and research* (Construction Institute 2003).

Since its inception, the committee has produced an online constructability reference catalog (Construction Institute 2004) to provide practitioners and researchers a comprehensive listing of articles and works that relate to constructability. After publishing this current state of practice report, the committee will make available constructability guidelines for the construction industry.

This report is based on results and analysis of a "Constructability State of Practice" survey conducted by the ASCE Construction Institute's Constructability Committee. The Web-based survey was hosted in the spring and summer of 2003 by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL). A copy of the complete survey is provided in the Appendix. Initial results of the survey were presented in a paper at the ASCE Specialty Conference on Management and Leadership in Construction, in March 2004 (Pocock et al. 2004). Further analysis in this report of numerical responses and written comments provides a more comprehensive picture of current constructability practices in the architecture, engineering, and construction (AEC) industry. This report provides the current state of practice by describing the following:

- The definition of constructability;
- Project phases at which constructability efforts usually begin;
- Constructability methods used during design and construction;
- Who requires constructability and who performs it;
- The major benefits of constructability and problems it could prevent;
- The major obstacles to implementing constructability;

[1]Associate Professor, Dept. of Civil and Environmental Engineering, U.S. Air Force Academy, CO 80840. E-mail: james.pocock@usafa.af.mil

[2]Assistant Professor, Dept. of Civil and Environmental Engineering, U.S. Air Force Academy, CO 80840. E-mail: steve.kuennen@usafa.af.mil

[3]Assistant Professor, Dept. of Civil, Construction, and Environmental Engineering, Oregon State Univ., Corvallis, OR 97333. E-mail: john.gambatese@oregonstate.edu

[4]Associate Engineer, Schnabel Engineering, Inc., 405-A Parkway Dr., Greensboro, NC 27401. E-mail: jrauschkolb@schnabel-eng.com

Note. Discussion open until September 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on December 7, 2004; approved on August 11, 2005. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 132, No. 4, April 1, 2006. ©ASCE, ISSN 0733-9364/2006/4-373–383/$25.00.

- Differences between owner, designer, and builder views of constructability; and
- Progress in constructability practice and where improvement is needed.

Major conclusions include: (1) constructability has gained acceptance throughout the industry; (2) constructability efforts are clearly beginning in early project phases; (3) a wide variety of constructability techniques and new technologies are being implemented; and (4) obstacles to improving constructability remain, but may be changing.

This report is relevant to both industry practitioners and researchers. Industry practitioners will be interested in constructability's benefits and the problems it could prevent, as well as obstacles to constructability. In particular, practitioners will want to know what constructability methods are most commonly used during design and construction. In addition to these issues, researchers will want to know about progress in constructability practice and where improvement is needed. Specifically, researchers will be curious to know who requires constructability and who performs it, as well as differences between owner, designer, and builder views of constructability.

Constructability Background

In 1983, the Business Roundtable published a series of studies collectively called the Construction Industry Cost Effectiveness Project. This group of construction users intended the studies to motivate the construction industry to improve its work methods and cost effectiveness. In its summary report, "More Construction for the Money," the Business Roundtable defined a problem and proposed actions to address it (Business Roundtable 1983):

> **Problem:** There is a lack of knowledge by owners with respect to opportunities for cost reductions and shortened schedules by integrating advanced construction methods and material into the planning, design, and engineering phases of the project.
>
> **Action:**
>
> *By Owners Individually:* Write contracts that give contractors an incentive to mesh engineering and construction expertise with the process called "**constructability**," which can often save 10–20 times the cost it adds to a project.
>
> *By Owners Jointly:* Make concerted efforts to help overcome the shortage of experts in "constructability" by helping to develop training materials and encouraging universities and colleges to add this facet of construction management to their undergraduate curricula.
>
> *By Academia:* "Constructability" skills need to be added to undergraduate curricula in construction management.

Because the Business Roundtable team included representatives from owner corporations, the construction industry, public institutions, and academia, its products were widely circulated and received national attention. For the first time, "constructability" was in the collective vocabulary of the U.S. construction industry.

The Construction Industry Institute (CII) grew out of the Business Roundtable's effort. Based at the University of Texas, CII also includes many owner and construction companies as well as public and academic institutions. For many years, CII led the way in constructability research and guidelines for implementing constructability. Contractors, government institutions, and individual researchers at universities began to apply the Business Roundtable and CII guidance and to publish their results.

By 1991, this body of work had grown to the point that the Construction Management Committee of the ASCE authored its "Constructability and Constructability Programs: White Paper." This paper recognized the value of constructability and summarized the best practices for implementing constructability programs as follows:

> [T]he integration of experienced construction personnel into the earliest stages of project planning as full-fledged members of the project team will greatly improve the chances of achieving a better quality project, completed in a safe manner, on schedule, for the least cost (ASCE 1991).

This endorsement by the ASCE provided further emphasis and credibility to constructability, as demonstrated by the concerted industry effort and academic research since then.

Constructability Guidance

The benefits of constructability can be realized through an array of proactive measures. The Constructability Committee of ASCE's Construction Institute maintains a comprehensive online catalog of documents and articles that are designed to aid members of a project team in implementing constructability measures (Construction Institute 2004). These documented efforts address the recommended processes, procedures, timelines, and players necessary to effectively implement constructability, and the barriers that prevent the realization of possible benefits.

To gain the greatest benefit from constructability, a process should be in place at the onset of the project (ASCE 1991; CII 1987; CII 1993) with a defined set of rules for how to implement constructability. The benefits of constructability are realized to their greatest extent when measures are taken early in the project life cycle (ASCE 1991), in the planning stages, not as a review of the project design (CII 1987). Dedicated efforts should continue through the various stages of the entire project (Fox 2002).

O'Conner and Miller (1994), as well as the Construction Industry Institute (CII 1987), stress the need to start a project with a self-assessment of how constructability is approached in the company. A constructability team is an important asset and should include personnel from owners, designers, contractors, subcontractors, vendors, and consultants (Radtke and Russell 1993). However, it is critical that an experienced construction person, a "Dean of Constructability," be a full-fledged member of the project team from the onset of planning (ASCE 1991; CII 1987). Because of the required initial investment, constructability efforts require high-level corporate recognition and backing (O'Connor and Miller 1994).

From the onset of a project, constructability is most effective if it is included as an integral part of the project execution plan and project procedures (CII 1987; CII 1993). Radtke and Russell (1993) offer a Project-Level Constructability Model Process adapted from the Construction Industry Institute (CII 1993). This process outlines three milestones of the process: obtaining constructability capabilities, planning constructability implementation, and implementing constructability. The process of constructability can be enhanced with checklists, workbooks, and review of lessons learned (CII 1987). The Construction Industry Institute

J. Constr. Eng. Manage., 2006, 132(4): 373-383

developed guidelines to implementing constructability for this purpose (CII 1987), and Gugel and Russell (1994) proposed a model for selecting a recommended approach to implementing constructability. While implementing constructability, there are many aspects of the project that can benefit constructability efforts, including project delivery systems, contracting strategy, construction sequence, and prefabrication and assembly (ASCE 1991).

Barriers to implementing constructability still exist and must be identified during the project (Radtke and Russell 1993; O'Connor and Miller 1994). The Construction Industry Institute outlined top barriers and suggested remedies in their 1993 review of constructability implementation. Barriers identified in this review include complacency with the status quo, reluctance to invest initial resources, lump-sum competitive bidding, lack of mutual respect between designers and constructors, and the delay of construction input into the process (CII 1993).

More recently, Uhlik and Lores assessed constructability practices among general contractors (Uhlik and Lores 1998), and Arditi et al. analyzed constructability in design firms (Arditi et al. 2002). Uhlik and Lores surveyed 72 general contractors in the southeastern United States, while Arditi et al. surveyed 134 heads of design firms across the United States. This report compares the results of both these studies to the writers' findings.

Research Methodology

The writers and several other members of the Constructability Committee drafted the survey questions based on their personal experience in the AEC industry. The intent was to assess the current state of constructability practice in the United States. The length of the survey was intentionally limited to encourage maximum participation. All members of the committee had an opportunity to review the draft survey and offer suggestions before it was finalized. To provide quick dissemination of the survey to a wide audience and to ease data reduction, the survey was conducted online. The online survey was hosted by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) during the spring and summer of 2003.

Survey Participants

The Construction Institute publicized the survey nationally in its newsletter and provided a link from its own website to the survey. Approximately 100 owners, architects, engineers, consultants, contractors and construction managers from across the United States answered the survey's ten questions and provided written comments. Those taking the survey can be divided into three main groups: (1) construction contractors and construction managers (38%); (2) engineers, architects, and design consultants (33%); and (3) owners and owner's representatives (28%). The respondents represented large and small owner corporations, consulting firms, architecture and engineering firms, and construction contractors. Several also represented municipal, county, and state institutions, the Army Corps of Engineers, and the Naval Facilities Engineering Command. In short, the respondents represented a cross section of the entire industry.

After the raw survey data was collected, the writers analyzed it by question and also by separating the respondents into three groups—owners, designers, and builders—and comparing their responses. The writers compared the results to accepted constructability guidance and to similar studies in the past to draw conclusions about the current state of constructability practice and to highlight areas for improvement.

Statistical Analysis

Statistical analysis was used to find the confidence intervals of differences between owners, designers, and builders. Specifically, the following equation was used to determine the 95% confidence interval, as recommended by Navidi (2006):

$$\tilde{p}_x - \tilde{p}_y \pm 1.96 \sqrt{\frac{\tilde{p}_x(1-\tilde{p}_x)}{\tilde{n}_x} + \frac{\tilde{p}_y(1-\tilde{p}_y)}{\tilde{n}_y}}$$

where $\tilde{p}_x$=approximate probability of one group (e.g., builders) selecting a specific response; and $\tilde{p}_y$=probability of another group (e.g., owners) selecting the same response. The confidence interval tells us whether differences between the two groups are statistically significant.

State of Practice Survey Results

Constructability Definition

Initially, the survey asked about the definition of constructability. CII defined constructability in 1986 as "*the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives*" (CII 1986). In 1991, the Construction Management Committee of the ASCE Construction Division stated:

> *Constructability is the capability of being constructed. A constructability program is the application of a disciplined, systematic optimization of the construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledgeable, experienced construction personnel who are part of a project team. The program's purpose is to enhance the project's overall objectives* (ASCE 1991).

For the purpose of the survey, the Constructability Committee offered a definition (and spelling) similar to those used by both the CII and ASCE:

> ***"Constructability is the integration of construction knowledge and experience in the planning, design, procurement, and construction phases of projects consistent with overall project objectives."***

Those taking the survey were asked, "If you do not agree with the definition, how would you change it?" Most persons completing the survey agreed with the definition, but 15 respondents offered comments on changing or improving it. These included the following:

- The need to consider local construction practices;
- It should stress practicalities of construction;
- It should include technological innovation;
- It should include postconstruction operation and maintenance;
- Can the project be built correctly as designed?
- It should describe the efficiency of design and construction; and
- It should also include development of construction methods.

Two respondents advocated spelling constructability as "con-

J. Constr. Eng. Manage., 2006, 132(4): 373-383

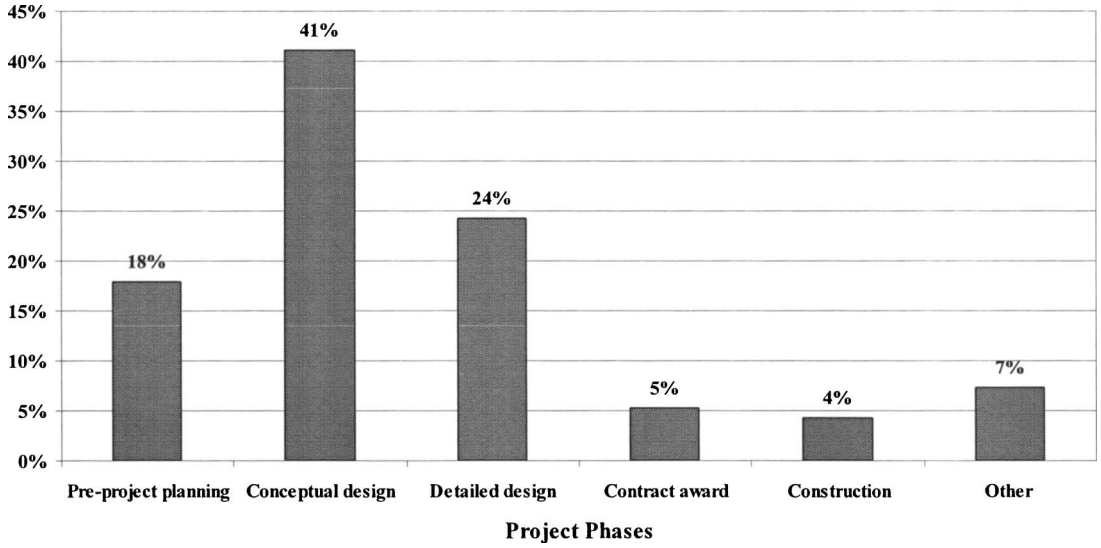

Fig. 1. "During which project phase do constructability efforts typically begin?"

structibility." Although some continue to argue this point, both CII and ASCE have used the "constructability" spelling since the mid-1980s.

Timing of Constructability Efforts

The first survey question about constructability practice was, "During which project phase do constructability efforts typically begin?" ASCE's constructability White Paper (ASCE 1991) stated the standard for ideal constructability: "The maximum benefits to be derived will result when the people with construction knowledge and experience become involved at the very beginning of a project." Although constructability efforts during detailed design and construction are always needed, the survey results are promising because they indicate constructability beginning somewhat earlier in the process than has been described in previous publications on the issue. The respondents said that constructability begins in preproject planning (18%), in conceptual design (41%), and during detailed design (24%). These results indicate that 83% of the respondents said constructability efforts begin before construction, while only 9% begin at contract award or during construction. Fig. 1 provides a more detailed breakdown.

One of the written comments was that, on public projects (which typically employ the design-bid-build project delivery method), constructability efforts start in the bid phase, while on private projects they can start at conceptual design. Another respondent noted that the timing of constructability efforts depends on the size and complexity of the project.

Constructability Mechanisms

The next question was, "During **design**, what mechanisms are most commonly used to address constructability on your projects?" Using a constructability review (35%) or a checklist to avoid common construction errors (29%) might be considered something of a standard practice in many design firms or organizations. A constructability review was understood to mean an internal review by someone in the design organization with a construction background, looking for constructability issues in the design as it is completed. But the use of a construction expert as a member of the design team (33%) or to review the design (57%) goes a step further toward ideal constructability methods, because it implies a higher level of construction expertise, perhaps directly involved in the design. Because constructability programs have the greatest potential for impact early in the project process, these results are very promising. As for other methods, 49% responded that they use peer reviews, while 13% said "other," 10% said "none," and 5% use the Construction Specifications Institute (CSI) Manual of Practice (Fig. 2). Peer review means having another design professional review the design team's work, usually as design milestones are completed.

The written comments offered several other constructability review methods not listed in the question. These included:

- CII and corporate guidelines with results documented for future use;
- Independent technical reviews;
- "Things to look for" checklist;
- Superintendent or experienced field people;
- International Organization for Standardization (ISO) certified Quality Operating System;
- Dr. Checks (a government Web-based tool for collecting and managing project design review comments);
- Trained facilitators; and
- 3D animated modeling.

Another respondent pointed out that, "For design-bid-build projects, architects and engineers appropriately do not want to be responsible for 'means and methods' of construction."

The survey asked the same question about constructability mechanisms, but during **construction**. Among the responses, 73% answered that they "use appropriate construction means and methods," 49% said they use pretask planning, and 49% coordinate construction trades, while 33% said they use "innovative" construction means and methods and 31% use an expert in preconstruction planning. At the low end of the scale, 13% said "other," 8% said they hire a consultant, and 7% said "none." An insightful written answer was, "At this stage of a project, the major … cost and schedule beneficial opportunities for constructability input have already passed." It may be useful in the future to find out more about these means and methods, especially those builders consider to be innovative.

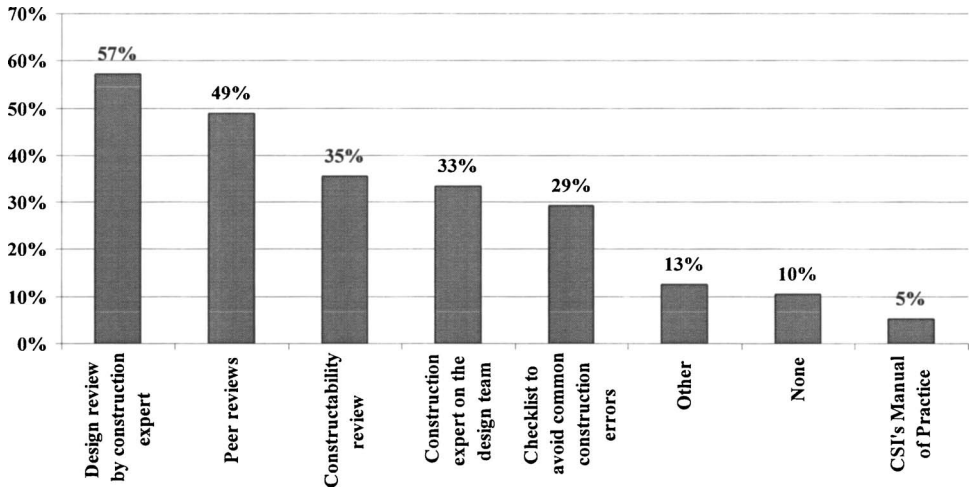

Fig. 2. "During design, what mechanisms are most commonly used to address constructability on your projects? (check all that apply)"

Constructability Responsibilities

Two questions addressed who performs constructability reviews and who requires it. The first of these reads, "For the form(s) of constructability you selected above, who usually performs this role?" As might be expected, those with the most construction experience tend to perform in the constructability review role. More than half (53%) answered contractors, 49% said construction managers, and 19% said subcontractors. But designers and owners are directly involved in implementing constructability measures too, with 75% of respondents stating that architects, engineers, or design consultants perform constructability and 39% listing owners or owners' representatives, while only 11% said "other."

The survey also asked, "For the form(s) of constructability you selected above, who usually requires constructability?" One might expect that owners are chiefly behind the requirement for addressing constructability on projects, and 73% said owners or owners' representatives. But it seems that builders have their own reasons, because 83% said contractors, construction managers, or subcontractors require the consideration of constructability. Designers have a significant interest in constructability as well, with 55% responding architects, engineers, or design consultants, while only 6% said "other."

Two written responses were: "The more aware and educated those listed above are in the practice and benefits arising from early application of constructability to their projects, the more likely they are to require constructability input to their project" and "Some clients require it. Most must be sold on the benefit."

Value of Implementing Constructability

The survey investigated the value of implementing constructability to respondents by asking them, "What are the major benefits of implementing constructability?" The survey offered six possible benefits and all received very strong, and fairly even, support. The benefits listed included "minimizes contract change orders and disputes" (89%), "reduces project cost" (82%), "enhances project quality" (81%), "reduces project duration" (70%), "increases owner satisfaction" (60%), "enhances partnering and trust among project team" (58%), and "other" (7%). The respondents clearly see a wide range of good reasons for implementing constructability efforts.

Two written answers that were not listed in the question were reflected in the following comments: "Safety" and "Provides a plan that can be constructed and operated by normal and reasonable people, and that can be afforded by the owner." One of the more interesting comments was, "The skills required of a constructability practitioner to enhance partnering and trust among project team are the ones receiving the least emphasis and training but have the most unrealized potential." There is some agreement between these results and those of Arditi et al. (2002). They concluded that better relationships, fewer lawsuits, a better reputation, professional satisfaction, and efficient design are the primary benefits of constructability.

Considering the value of addressing constructability from another viewpoint, the survey asked, "What problems in construction that you observe *could be prevented* by improved constructability?" Unlike most questions on the survey, this one did not offer suggested answers but asked respondents to write their own answers. Their comments are listed in Table 1. The five most commonly cited problems were change orders (23%), delays (20%), cost overruns (16%), conflicts and poor communication (15%), and RFIs (requests for information) or design errors (14%).

These problems correspond to many of the difficulties encountered using the traditional process (i.e., without constructability) as noted by Uhlik and Lores (1998). The most commonly mentioned difficulties were "specifications problems," "unrealistic schedule," "problems with physical interference," and "tolerance problems."

Obstacles to Constructability

Finally, the survey asked, "What are major obstacles to implementing constructability?" The survey offered ten possible obstacles and, unlike the first question about value, there was a significant difference in the frequency of answers. Six of the obstacles were viewed as significant (Table 2). The most commonly cited obstacle was "Lack of open communications between designers and constructors" (64%). Clustered together were "Inadequate construction experience" (45%), "Difficulty coordinating disciplines" (44%), and "Lack of resources" (42%). Grouped next were "Project delivery methods" (27%), "Contract type" (25%), and "Not part of current process" (21%). "Too costly" (13%),

J. Constr. Eng. Manage., 2006, 132(4): 373-383

Table 1. "What Problems in Construction That You Observe Could Be Prevented by Improved Constructability?"

Problem	Percent of respondents
Change orders	23
Delays	20
Cost overruns	16
Conflicts/poor communication	15
RFIs/design errors	14
Claims/disputes	9
Unforeseen conditions	5
Trade coordination	5
Lack of work space	5
Material waste	4
Poor quality	4
Contractor-designed work	3
Safety	3
Outdated specifications	3
Repeated problems	2
Contractor risk	2
Poor planning	1
Inaccurate bids	1

"inconsistent terminology" (13%), and "lengthens the project" (6%) were not considered as significant as other obstacles. Only 11% said "other."

This question received the most written responses. Among them were:

- Substantial pressure on public owners to reduce costs at every step of the capital project process. This results in squeezing the designer, who cuts out constructability as a way to get the fee down to some "acceptable" level.
- Codes do not require constructability.
- We ignore people at the crew level.
- Design engineers lack experience and are defensive.
- Engineering education doesn't emphasize constructability.

These results echo several of the CII's (1993) findings, which listed complacency with the status quo, reluctance to invest initial resources, lump-sum competitive bidding, lack of mutual respect between designers and constructors, and the delay of construction input into the process (CII 1993). However, these results do not match up with those of Arditi et al. in their study of design firms, which identified faulty working drawings, incomplete specifications, and adverse relationships as the primary constraints hindering constructability (Arditi et al. 2002).

Table 2. "What Are Major Obstacles To Implementing Constructability? (Check All That Apply)"

Obstacle	Percent of respondents
Lack of open communications between designers and constructors	64
Inadequate construction experience	45
Difficulty coordinating disciplines	44
Lack of resources	42
Project delivery methods (e.g., design-bid-build)	27
Contract type	25
Not part of current process	21
Too costly	13
Inconsistent terminology	13
Other	11
Lengthens project	6

Within the definition of constructability used in this study, "adverse relationships" are a common obstacle to constructability. Overall, it seems that many of the traditional obstacles to constructability remain.

Comparisons between Owners, Designers, and Builders

Owners

For this analysis, the responses from those who identified themselves as owners or owner's representatives were combined. Owners not only initiate the project, they see themselves as initiating constructability too. Fig. 3 shows the owner's viewpoint of when constructability efforts typically begin on projects. More than 88% said that they were the ones who usually required addressing constructability on their projects. Because they are involved in all project phases, owners are in a good position to say when constructability efforts begin. Their view was significantly different than the overall survey results on this question.

The owners and the total group of survey respondents see a similar percentage of constructability efforts beginning during pretask planning or construction. The major difference is in the conceptual and detailed design phases. In the overall survey results, 41% of the respondents said constructability efforts begin during conceptual design, but only 29% of the owners agree. More than half the owners (53%) said constructability does not begin until detailed design, while only 24% gave this response in the overall survey. Thus, owners do not see constructability efforts beginning quite as early as does the total group. Even so, 97% of the owners said constructability efforts typically begin before contract award, which is an improvement over past practices.

Designers

For this analysis, "designers" includes respondents who identified themselves as architects, engineers, and consultants working primarily in design. The designers definitely see constructability efforts beginning earlier than do the owners (see Fig. 3). While even fewer designers than owners (6% versus 15%) say constructability efforts begin during preproject planning, 59% of designers report constructability efforts beginning during conceptual design, with only 28% saying it begins during detailed design. This difference on conceptual design between designers (59%) and owners (29%) was found to be statistically significant using a 95% confidence interval, according to the method of statistical analysis described previously. This is similar to, and even higher than, the 51% of design firms beginning constructability reviews during conceptual design reported by Arditi et al. (2002). The conceptual and detailed design categories in this study are almost the reverse of the owners' view (see Fig. 3). The difference for the detailed design phase was also found to be statistically significant.

This difference between owners' and designers' perspectives of when constructability efforts typically begin may be due to constructability processes that owners are unaware of. Designers may actually begin internal constructability efforts during conceptual design as a standard practice, without involving the owner.

There is some indication of this in how designers answered question 4: "During **design**, what mechanisms are most commonly used to address constructability on your projects?" Design-

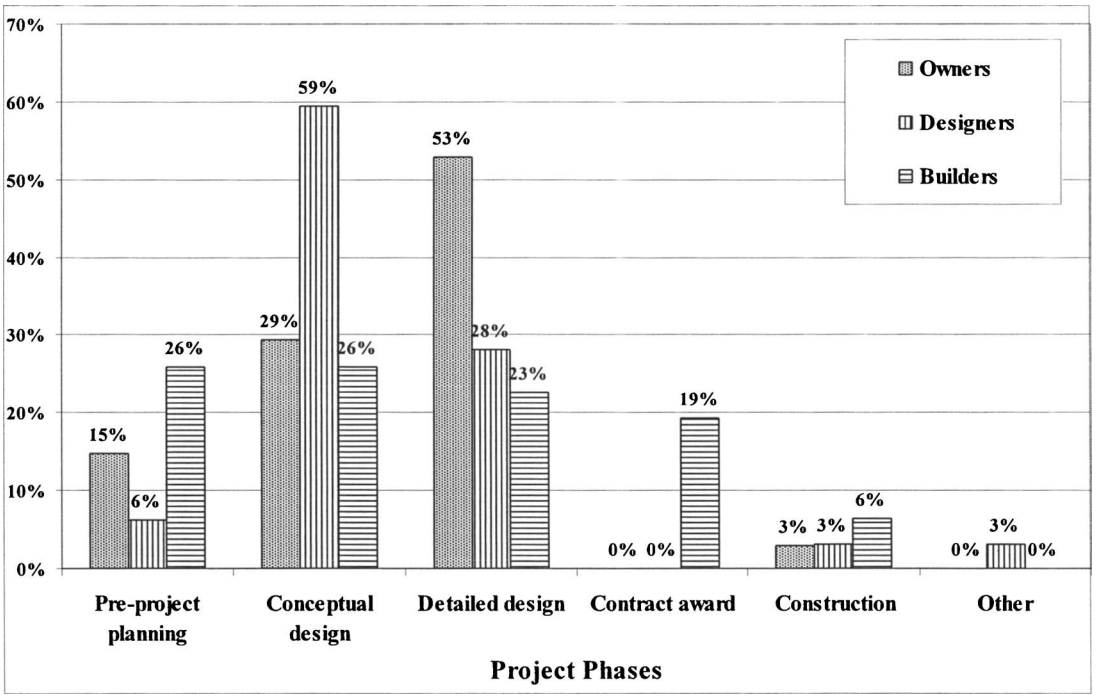

Fig. 3. Comparing when constructability efforts typically begin

ers report that they use a combination of constructability methods during design. Several of these may not be apparent to the owner, depending on the owner's level of involvement in the project.

Designers answered that they used each of the following constructability mechanisms with a significant frequency during design: design review by a construction expert (59%), peer reviews (53%), a constructability review activity on your project schedule (38%), a construction expert on the design team (34%), and implementing a database or checklist to avoid common construction errors (34%) (see Fig. 4). Any of the five mechanisms that are commonly used could be implemented internally without the owner realizing that constructability efforts were already underway. So, despite the owners' responses, it may well be that more constructability efforts begin during conceptual design than during detailed design.

These constructability mechanisms used by designers are similar to those reported by Arditi et al. (2002), with "peer review" and "feedback system" found to be the most common.

These results also show that designers use a variety of constructability techniques. These techniques make use of constructability experts, peers, construction experts, and checklists. Approximately half the designers listed "Lack adequate construction experience" as a major obstacle to implementing constructability. It appears that designers are trying to make up for their lack of construction experience through a combination of constructability experts and methods.

Builders

In characterizing the views of "builders," survey responses of contractors and construction managers were combined. Their responses were very consistent, and their opinions can be summarized as follows:

1. Constructability efforts should start early in the design process. Builders were the only group that said some constructability efforts begin at contract award (19%). This difference was statistically significant. Despite their limited involve-

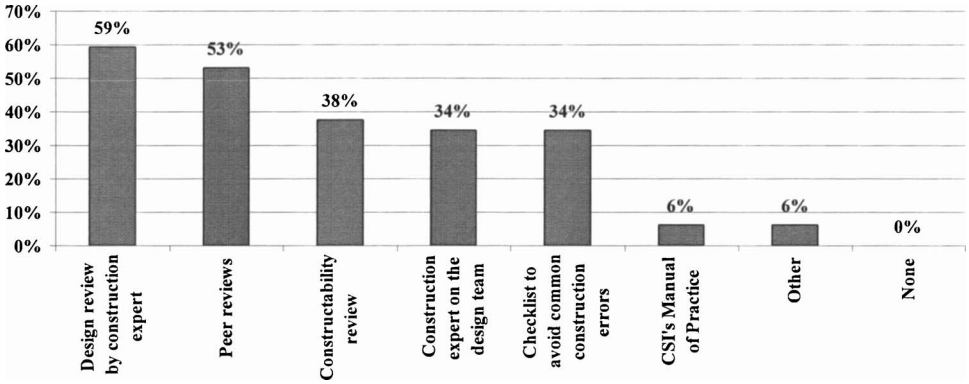

Fig. 4. Designers' responses to "During design, what mechanisms are most commonly used to address constructability on your projects? (check all that apply)"

J. Constr. Eng. Manage., 2006, 132(4): 373-383

ment before contract award, more than half the builders (52%) said constructability efforts typically begin during preproject planning or conceptual design (see Fig. 3). The differences between builders and designers (26% versus 6%) at preproject planning, between builders and designers (26% versus 59%) at conceptual design, and between builders and owners (23% versus 53%) at detailed design were all statistically significant. Because construction managers are usually involved earlier in projects, they tended to see constructability beginning earlier than construction contractors. This is consistent with Uhlik's and Lores' (1998) findings that 96% of general contractors agreed that their participation during design can help produce better drawings, specifications, and buildable projects, and that 81% commonly participate by inserting construction knowledge during preconstruction phases.

2. The potential benefits of a constructability review diminish the later in the design process it is initiated. Many written comments supported this conclusion; for example, "design details are too late coming in for review."
3. The design-bid-build project delivery method allows little opportunity for implementing constructability prior to the construction phase. Contract types, project delivery methods, and "not currently part of the process" made up 35% of the builders' responses to the question on obstacles to constructability. Uhlik and Lores reported that 51% of general contractors said "design without construction input is the traditional form of contracting" and 15% said "owners do not care about constructability in their contracting strategy" (Uhlik and Lores 1998).

These three points are the conventional wisdom on constructability, but they also express builders' frustrations with their traditionally limited opportunities to influence design.

Builders responded that they see a variety of constructability mechanisms used during design and construction, but they clearly see more during construction than design (103 responses versus 51). Builders' most common constructability technique during construction is simply applying appropriate construction means and methods (28%). This is another indicator of the limited opportunity builders have to be involved in constructability efforts in earlier phases.

Although results from construction managers and contractors have been combined, it is worth considering one difference. Constructability reviews and value engineering are a primary focus and function of the construction manager, so it is not surprising that they agree that "constructability efforts typically begin before contract award." However, when general contractors say the same thing, they may be referring to something more. It is typically necessary for a contractor to determine during the bid phase how the project will be constructed. Determination of the best means and methods to build a project, those that utilize the least amount of labor and equipment, is what wins bids. This could be what contractors mean when they respond, "constructability efforts typically begin before contract award." Uhlik and Lores (1998) described a large majority of general contractors engaged in activities during the conceptual phase and design phase that sound routine, but should also be considered implementing constructability, such as suggesting structural systems and analyzing the design to enable efficient construction. In the survey results for this report, builders described constructability efforts during "their" design for items such as cofferdams and steel erection engineering. These types of builders' constructability efforts may be independent of designers' constructability programs.

Builders list the following benefits when constructability reviews are implemented:

- Reduce change orders;
- Alleviate distrust between contractor and engineer; and
- Enhance teamwork among project stakeholders.

This view of constructability benefits has a construction perspective, but these benefits are valuable to everyone on the project team.

Builders agreed with owners and designers that lack of open communication between designers and builders was the largest (22%) obstacle to constructability, but they also considered project delivery methods (15%), contract types (13%), lack of adequate construction experience (12%), difficulty in coordinating disciplines (11%), and not enough resources (11%) as significant obstacles.

The lack of communication and the type of project delivery method are related, because the traditional design-bid-build approach gives the builder little opportunity to practice constructability before the construction phase. It also limits their opportunity to work with the designer and influence the design.

It is not surprising that builders view design engineers as less experienced in construction, but they also see the lack of experience as significant enough to diminish constructability. Uhlik and Lores (1998) reported that 45% of general contractors listed "designers' lack of construction experience and construction technologies knowledge" as a barrier to constructability. Coordinating subcontractors is certainly a construction task. However, in citing coordination of project disciplines, the builders seem to be pointing at a design responsibility that is not consistently achieved.

Comparison to Guidance

Progress in Recent Years

In comparing the survey results with the constructability guidance described earlier, several conclusions can be drawn about the current constructability practice:

1. Constructability efforts are beginning earlier in the project delivery process. Most constructability is beginning in the preproject planning and conceptual design phases. Very few constructability efforts begin after detailed design. This is a major finding of this research.
2. Construction expertise, in a variety of forms, is being applied during early phases of the project.
3. Builders are attempting to apply construction innovations including methods, materials, and equipment to improve constructability.
4. Not only are owners requiring constructability programs on their projects, but designers often do and builders even more so.
5. There is a broad recognition of a variety of constructability benefits.

Room for Improvement

Despite industry progress in constructability practice, there are certainly areas for improvement:

1. Constructability efforts could begin even earlier, during preproject planning.
2. Builders and designers agree that designers lack construction experience.

J. Constr. Eng. Manage., 2006, 132(4): 373-383

3. Builders remain frustrated with their limited ability to influence design.
4. A wide variety of obstacles still impede implementing constructability on projects, such as project delivery methods.

Conclusion and Recommendations

Notable progress has been made in the practice of constructability since the Business Roundtable's 1983 report. The committee received a wide response to the survey from owners, designers, and builders representing the U.S. design and construction industry. Overall, the practice of constructability has improved significantly, with constructability efforts becoming more common through a wide variety of approaches. But there is clearly room for improvement. The survey results show that:

- Constructability efforts are recognized, supported, and practiced by owners, designers, and builders, indicating the acceptance of constructability throughout the industry.
- Constructability efforts are clearly beginning in early project phases; 59% of the respondents said before detailed design. Designers and builders see constructability efforts beginning even sooner than owners do.
- A wide variety of constructability techniques are in use, and new technology is being adapted to aid constructability efforts.
- Obstacles to improving constructability remain, but may be changing as constructability and the industry evolve.

Recommendations

Constructability efforts could still begin more uniformly early in the project delivery process. Owners and designers have the greatest opportunity to make this happen by initiating constructability efforts during preproject planning or conceptual design. Owners should require constructability reviews (particularly for design-bid-build projects) as a distinct task or phase in the scope of work.

The single most frequently listed obstacle to constructability was a lack of open communication between designers and builders. Owners in particular can create opportunities for more open communication by selecting appropriate contract types, project delivery methods, and project partnering, and by requiring a formal process that incorporates construction experience early in the project.

Engineers and architects should become more familiar with construction practice and management through education and work experience. Universities should continue to strengthen the construction element in architecture, construction, and engineering programs to support the construction requirements addressed in ASCE's proposed "Body of Knowledge" (ASCE 2004). A strong introduction to constructability, construction methods, etc., should be part of an architect's or engineer's formal education. Architectural and engineering firms need to give designers the opportunity to gain construction experience (field testing and inspection) by integrating construction-related tasks into their duties as part of career development.

Although many of the same obstacles to constructability as described in past research were reported in this work, the writers hope that "contract types" and "project delivery methods" will become less frequent obstacles as construction management, design-build, partnering, and other alternatives to traditional design-bid-build continue to become more common practice.

Future Research

In their next effort, the Constructability Committee plans to write constructability guidelines for industry and a "constructable construction documents guideline."

Another topic for future research is to examine how obstacles to constructability have changed as our industry and constructability methods have developed. Researchers could also investigate the impact of evolving construction law on constructability efforts.

It may also be useful in the future to explore the differences between public and private projects that may shed light on other, unrecognized obstacles.

Acknowledgments

The writers wish to thank the following individuals and organizations for their assistance in making this report possible:

- Edward R. Ardery, the author of the ASCE "White Paper" and a current Constructability Committee member, for bringing constructability to the forefront in the industry and academia;
- The U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) in Champaign, Illinois, and in particular, Mr. Bill East, for hosting the survey website;
- Sathyanarayanan Rajendran, a graduate student in the Department of Civil, Construction, and Environmental Engineering at Oregon State University, for his work in summarizing the literature on implementing constructability;
- Captain Patrick C. Suermann, an instructor in the Department of Civil and Environmental Engineering at the U.S. Air Force Academy, for his work in compiling and analyzing designer survey responses and reviewing drafts of this report; and
- Dr. Dan Jensen, Associate Professor in the Department of Engineering Mechanics, U.S. Air Force Academy, for his assistance with statistical analysis of survey data and results.

Appendix. Constructability State of Practice Survey

1. **For this survey, constructability is defined as "*the integration of construction knowledge and experience in the planning, design, procurement, and construction phases of projects consistent with overall project objectives*." If you do not agree with the definition, how would you change it?**
2. **Which of the following best describes your role in the design/construction process?**
   - Owner;
   - Owner's representative;
   - Architect;
   - Engineer;
   - Consultant working primarily in design;
   - Construction contractor;
   - Subcontractor working primarily in construction; and
   - Construction manager.
3. **During which project phase do constructability efforts typically begin?**
   - Preproject planning;

J. Constr. Eng. Manage., 2006, 132(4): 373-383

- Conceptual design;
- Detailed design;
- Contract award;
- Construction; and
- Other (please briefly describe).

For additional remarks or other:

4. **During DESIGN, what mechanisms are most commonly used to address constructability on your projects? (check all that apply)**
   - None;
   - Peer reviews;
   - Follow the CSI's Manual of Practice;
   - Design review by construction expert;
   - A constructability review activity on your project schedule;
   - Construction expert on the design team;
   - Implement database or checklist to avoid common construction errors; and
   - Other (please briefly describe).

For additional remarks or other:

5. **During CONSTRUCTION, what mechanisms are most commonly used to address constructability on your projects? (check all that apply)**
   - None;
   - Apply innovative construction means and methods;
   - Pretask planning;
   - Incorporate construction expert into preconstruction planning;
   - Coordinating construction trades;
   - Hire a consultant;
   - Apply appropriate construction means and methods; and
   - Other (please briefly describe).

For additional remarks or other:

6. **For the form(s) of constructability you selected above, who usually performs this role? (check all that apply)**
   - Owner;
   - Owner's representative;
   - Architect;
   - Engineer;
   - Consultant working primarily in design;
   - Contractor;
   - Construction manager;
   - Subcontractor working primarily in construction; and
   - Other (please briefly describe who).

For additional remarks or other:

7. **For the form(s) of constructability you selected above, who usually requires constructability? (check all that apply)**
   - Owner;
   - Owner's representative;
   - Architect;
   - Engineer;
   - Consultant working primarily in design;
   - Contractor;
   - Construction manager;
   - Subcontractor working primarily in construction; and
   - Other (please briefly describe who).

For additional remarks or other:

8. **What are the major benefits of implementing constructability? (check all that apply)**
   - Enhances project quality;
   - Reduces project duration;
   - Reduces project cost;
   - Enhances partnering and trust among project team;
   - Increases owner satisfaction;
   - Minimizes contract change orders and disputes; and
   - Other (please briefly describe).

For additional remarks or other:

9. **What problems in construction that you observe could be prevented by improved constructability? (please type your answer here)**
10. **What are major obstacles to implementing constructability? (check all that apply)**
    - Project delivery methods (e.g., design-bid-build);
    - Contract type;
    - Not enough resources;
    - Lack adequate construction experience;
    - It is currently not part of the process;
    - Too costly;
    - Lengthens the project;
    - Inconsistent terminology;
    - Lack of open communication between designers and constructors;
    - Difficulty in coordinating disciplines; and
    - Other (please briefly describe).

For additional remarks or other:

11. **Optional: Can we contact you?**
    - Name:
    - Company:
    - Phone number:
    - E-mail address:

References

Arditi, D., Elhassan, A., and Toklu, Y. C. (2002). "Constructability analysis in the design firm." *J. Constr. Eng. Manage.*, 128(2), 117–126.

ASCE Body of Knowledge Committee of the Committee on Academic Prerequisites for Professional Practice. (2004). *Civil engineering body of knowledge for the 21st century—preparing the civil engineer for the future*, Reston, Va.

ASCE Construction Management Committee of the Construction Division. (1991). "Constructability and constructability programs: White paper." *J. Constr. Eng. Manage.*, 117(1), 67–89.

Business Roundtable. (1983). "More construction for the money." *Summary Rep. of the Construction Industry Cost Effectiveness Project*, New York.

Construction Industry Institute. (1986). "Constructability—a primer." *Publication 3-1*, Austin, Tex.

Construction Industry Institute. (1987). "Guidelines for implementing a constructability program." *Publication 3-2*, Austin, Tex.

Construction Industry Institute. (1993). "Preview of constructability implementation." *Publication 34-2*, Austin, Tex.

Construction Institute. (2003). "Constructability committee." ⟨http://www.constructioninst.org/COC.htm⟩ (Dec. 1, 2003).

Construction Institute. (2004). "Constructability committee. " *Constructability Catalog*, ⟨http://www.cecer.army.mil/pl/catalog/index.cfm?RESETSITE=ConstrucCommit⟩ (Nov. 29, 2004).

Fox, S. , Marsh, L., and Cockerham, G. (2002). "Constructability Rules: Guidelines for Successful Application to Bespoke Buildings." *Constr. Manage. Econom.*, 20(8), 117–126.

Gugel, J. G., and Russell, J. S. (1994). "Model for constructability approach selection." *J. Constr. Eng. Manage.*, 120(3), 509–521.

Navidi, W. (2006). "Confidence intervals." *Statistics for engineers and scientists*, McGraw-Hill, Boston, 335–337.

O'Connor, J. T., and Miller, S. J. (1994). "Constructability programs:

Method for assessment and benchmarking." *J. Perform. Constr. Facil.*, 8(1), 46–64.

Pocock, J. B., Kuennen, S. T., Gambatese, J., and East, B. (2004). "Constructability state of practice survey." *Proc., 2004 Specialty Conf. on Management and Leadership in Construction*, ASCE, Reston, Va., 95–108.

Radtke, M. W., and Russell, J. S. (1993). "Project-level model process for implementing constructability." *J. Constr. Eng. Manage.*, 119(4), 813–831.

Uhlik, F. T., and Fores, G. V. (1998). "Assessment of constructability practices among general contractors." *J. Archit. Eng.*, 4(3), 113–123.