Engineering, Construction and Architectural Management

Development of constructability concepts, principles and practices

A. GRIFFITH A.C. SIDWELL

Engineering, Construction and Architectural Management 1997 4 | 4, 295–310

Development of constructability concepts, principles and practices

A. GRIFFITH* & A.C. SIDWELL†

School of Construction, Sheffield Hallam University, City Campus, Pond Street, Sheffield, S1 1WB, UK, and † Construction Industry Institute, Australia, School of Building and Planning, University of South Australia, North Terrace, Adelaide, South Australia 5000

Paper submitted 2 November 1995; accepted for publication 16 October 1996; discussion open until June 1998

Abstract Constructability is a system for achieving optimum integration of construction knowledge in the building process and balancing the various project and environmental constraints to achieve maximisation of project goals and building performance (CII Australia 1993). Constructability concepts and principles, considered during conceptual planning, design, procurement, construction and use, can make the total building process easier to manage, quicker and more cost effective. When constructability becomes an implied and accepted aspect of the total building process it has the potential to deliver real benefits to clients, consultants, contractors and users. Constructability practices have developed from application and a considerable body of research conducted over the last thirty years. This paper reviews the development of constructability concepts and the identification of the key principles of constructability, and identifies the likely future developments in constructability research and practice. Historically, the attention given to constructability has been somewhat narrowly focused on individual project stages, and therefore, the multi-dimensional aspects of constructability have not been fully considered and the real benefits may have been missed. The findings presented in this paper indicate that the construction industry has begun to address more purposefully the concerns and difficulties of actively managing the interface between the various stages of the building process in addition to considering the facets of the individual stages themselves. In this way, constructability is becoming an important and powerful concept which can be applied beneficially to the total building process.

Keywords *buildability, constructability, construction management, design-construction integration*

INTRODUCTION

The concept of buildability emerged in the late 1970s as a direct result of research and practical applications aimed at improving the efficiency, cost effectiveness and quality of construction projects. In 1983, the Construction Industry Research and Information Association, CIRIA, defined it as 'the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building'. The adoption of buildability in the UK does not seem to have been high. This is believed to be because research was limited in focus with an emphasis on improving site productivity through implementing concepts such as design rationalisation. This restriction, together with the separation of inputs characterising the UK's traditional building process, led to a lack of general interest in and application of buildability concepts.

In contrast, research and construction practice in the USA focused more purposefully on the concept of constructability (CII USA 1987). Interests took advantage of the close link between building owners and contractors, emphasising a management systems approach to think creatively about the practicalities of the building process. Research in Australia adopted a similar management-based approach (CIIA 1993) presenting practical measures to improve the total construction process by focusing on key issues for consideration, rather than recommending specific procedures. The development of constructability principles serves to accommodate variations in organisational cultures, procedures and practices, thereby broadening the appeal of and encouraging the potential for the application of constructability concepts.

THE FOCUS OF THIS PAPER

The aim of this paper is to review critically the concepts and principles of constructability which are recognised today and which evolved from the early research studies into and practical applications of buildability. This focus is pertinent as there has been much creditable research and application of constructability concepts in recent times. Moreover, there remains some confusion in defining the conceptual boundaries of buildability and constructability. Until the boundaries are made clear, difficulties will likely remain in establishing the real benefits available to the construction industry from applying the concepts and principles of constructability.

Objectives

The specific objectives of this paper are:

1 To describe in detail the development of constructability concepts and clearly determine the boundaries of constructability and the boundaries of buildability.
2 To identify and develop the key principles of constructability which allow its concepts to be applied with the maximum potential during any construction project
3 To anticipate likely future developments in constructability research and practice based upon current activities, concerns and issues.

Collection of information

The information for this paper was gathered predominently from the large body of knowledge in the fields of buildability and constructability which has been assembled over the last 25 to 30 years. The information, published extensively in the form of journal papers, books and conference proceedings, reflects research and practice in the UK, USA and Australia, these being the countries where research interest has been at its height. A practical example of constructability from recent research is described, which lends considerable support to the concepts and principles which are presented. These sources of information combine to facilitate a level of insight into the likely future orientation of constructability research and practice.

THE EVOLUTION OF CONSTRUCTABILITY CONCEPTS

Early experience

A UK governmental report in the early 1960s raised considerable concern at the distinct separation between the processes of design and construction, drawing specific attention to the inadequacies of communication and co-ordination which, it was said, was responsible for many of the problems then being experienced within the construction industry (Emmerson 1962). A number of general difficulties were identified, the principal ones being: the poor preparation of drawings and specifications; the inefficiencies of pre-contract design procedures; and the inadequate level of communication between the designer and contractor. Following this theme, a further report (Banwell 1964) suggested that:

> 'design and construction must be considered together and that in the traditional contracting situation, the contractor is too far removed from the design stage at which his specialised knowledge and techniques could be put to invaluable use'

The report called for more attention to be given to pre-contract planning and design formulation and criticised professionalism as being narrow sighted, giving rise to unnecessary and inefficient construction practices. It was suggested that: clients define their building requirements clearly at the start of the design stage; the building process should better integrate the stages of design and construction; and that traditional construction practices should be reviewed to seek inter-disciplinary approach. A subsequent study (Economic Development Council 1967) reported that the recommendations made in the Banwell Report had not been successfully implemented within the construction industry and that flexible approaches to traditional procedures should be sought and new initiatives developed if meaningful change within the industry was to be achieved. The Wood Report in the mid-1970s (National Economic Development Office 1975) suggested that in the decade following the Emmerson and Banwell reports some improvements had been made in the quest for integrating better the processes of design and construction. In general however, the original problems remained and it was suggested that efforts should be directed towards increasing the level of awareness for the problems and designing measures to bring together the design and construction processes such that the construction stage might directly capitalise on design initiatives.

Redefining the problem of integrating design with construction – the concept of buildability

Following the reports of Emmerson, Banwell and NEDO, the Construction Industry Research and Information Association (CIRIA) supported a major research initiative to investigate what they regarded to be, the principal problems of construction practice. Their attention focused on a concept which they referred to as buildability, suggesting that building designs were not providing value for money in terms of the efficiency and effectiveness in the way in which the building process was then being carried out. The report of their investigations, *Buildability: An Assessment*, (CIRIA 1983) presented seven categories of buildability principles to: carry out thorough investigation and design; plan for essential site production requirements; plan for a practical sequence of operations and early enclosure; plan for simplicity of assembly and logical trade sequences; detail for maximum repetition and standardisation; detail for achievable tolerance; and specify robust and suitable materials.

CIRIA stated that their methodological approach provided data that 'were too limited to be certain that the categories identified were final and universal', although they had sufficient confidence to publish the categories as provisional guidelines. It is from this original study that buildability research and practice evolved. The initial CIRIA report was followed by a further study (Adams 1989) in which the original seven categories of buildability principles were further developed to present 16, more definite, principles. This study is most purposeful since, although it still focuses on design, it does begin to widen the perspective of buildability and point the way towards recognising the true complexity and multi-faceted nature of the issues involved.

The first CIRIA study, while laudibly raising general awareness to the concepts and principles of buildability and therefore achieving its basic objective, was unfortunately restricted in focus. A subsequent research study (Griffith 1984; Griffith 1985a) was similarly narrow in scope, but recognised in its findings the fundamental weakness in focusing narrowly on the attributes of design to aid construction on site. It was suggested that concentrating on design was important, but that project site and management-based factors must also be considered. The difficulties surrounding the determination of conceptual boundaries for buildability have been discussed in further studies (Bishop 1985; Griffith 1985b). It was the narrow focus, together with the complexities of the traditional contractual processes, that led to the diminishing interest in buildability concepts within the UK construction industry during the late 1980s.

Developing the concepts of constructability

Whereas in the UK the interaction of design and construction was perceived predominently as a design orientated concern, in the USA a much broader view emerged to establish widely ranging concepts termed constructability. In the early 1980s, concern for the cost-effectiveness and quality of the American construction industry led to the establishment of the construction industry cost effectiveness project study team. Their report (Business Roundtable 1982) concluded that 'the benefits to be gained from "good" constructability [throughout the building process] are approximately ten to twenty times the cost of achieving it'. The Business Round Table initiated the establishment of the Construction Industry Institute (CII) based at the University of Texas at Austin in 1983. Constructability research has been a focus in CII activity and it was they who first defined constructability as 'the optimum integration of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall project objectives' (CII 1987).

Three research projects during the late 1980s characterise the CII's interest in constructability. The first study (Tatum *et al.* 1986) directed attention towards the contribution that could be made by designer and contractor during the conceptual planning stage. Three aspects were identified as being important: developing a thorough project plan; detailing site layout; and considering alternative principal construction methods. The second study (O'Connor *et al.* 1986) examined how construction knowledge could be used to advantage during engineering and procurement. The suggestions made were: design and procurement should be construction-driven; designs should be configured to enable efficient construction; design elements should be standardised and encourage repetition; pre-assembly works should be scoped to facilitate fabrication, transport and installation; designs should promote utilisation of resources; designs should assist construction under adverse weather conditions; and specifications should serve to simplify construction operations. The third study (O'Connor & Davis 1988) addressed the potential for good constructability during field operations. This study identified seven issues important to good constructability and which should be considered on all construction projects: sequencing of site tasks; temporary construction systems; use of hand tools; plant and equipment; pre-assembly needs; temporary support facilities; and post-bid construction preferences.

The CII integrated the information accumulated from these three research studies into the *Constructability Concepts File* (CII 1987). In all, 14 concepts were presented, six for consideration during conceptual planning, seven for consideration during the design, engineering and procurement stages, and one concept for consideration during site operations. The essence of the approach is to consider the Pareto Principle where decisions taken early in a project's life cycle have greater potential to influence the final outcome of the project. (Fig. 1).

Contributions to constructability research have also been made in Australia (Hon 1988; Hon *et al.* 1989). These studies reviewed the contribution of

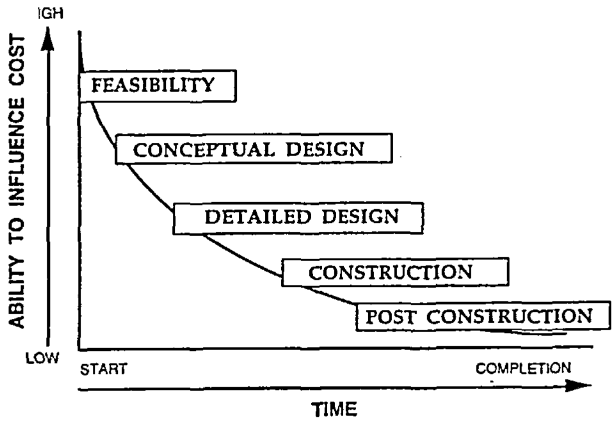

Figure 1 Cost influence curve.

constructability consideration within a project management setting. This was particularly useful since many of the problems seen in the UK studies, arising from the traditional contractual process, were obviated leading to the identification of potential benefits through closer design and construction consideration. Further research (McGeorge *et al.* 1992) propounded that constructability must not just focus on the design and construction relationship, but rather be directed to examining the total building process and the contribution that constructability can make throughout the life cycle of a project. McGeorge *et al.* suggest that constructability is 'the extent to which decisions made during the whole building procurement process, in response to factors influencing the project and other project goals, ultimately facilitate the ease of construction and the quality of the completed project'. They present a three-dimensional model in which participants to the building process, constructability factors, and project stages, interact to give good constructability in the building process.

Building on the suggestions of McGeorge, the New South Wales Government, Australia, developed the *Capital Project Procurement Manual* (CPPM) (NSW Construction Policy Steering Committee 1993). The CPPM sets out a detailed series of constructability considerations under seven principal headings: site factors; design; construction; employee relations; safety; climatic conditions; and procurement methods. The manual further encourages these considerations by incorporating them into an action plan designed to ensure their consideration at each key stage in the total building process.

Establishing the boundaries of buildability and constructability

In reviewing the evolutionary development of constructability concepts it can be clearly seen that constructability differs markedly from buildability in terms of its much wider boundaries. Buildability, as seen through research studies and practical applications, is a concept which focuses predominently on the influence that the designer may impart upon the ease of construction on site. Constructability takes a more holistic perspective, focusing on the consideration of all stages in the total building process. There is, of course, a very real and major implication to constructability as a practical concept for application throughout the total building process. Constructability is fundamentally dependent upon: the client being committed to its inclusion in project development from the outset; the efforts of the project team to avidly pursue its principles; and the early and dedicated involvement of the main contractor. Early commitment to constructability in the project life cycle is also essential as the ability to influence project success will be greater in the initial stages of project development. When constructability is considered early and endorsed by the project team its concepts and principles have the potential to bring tangible benefits to the total building process. The following section develops this theme further and describes how principles of constructability have been developed which are applicable to each stage of the total building process.

THE PRINCIPLES OF CONSTRUCTABILITY

Without doubt, constructability is a complex and multi-faceted phenomenon. Benefits will only be achieved when there is a better understanding of the contributions to be made by considering constructability both within the stages of the total building process and within the interface between the stages. Factors that influence the building process are many and may be generic or project specific and it is these factors that must be considered if good constructability is to be realised in any construction project.

Factors influencing constructability

Constructability may be influenced within the following stages and aspects of construction:

Feasibility, conceptual planning and procurement
Client's corporate objectives; client's project requirements; project strategy; project priorities – time, cost, quality; project team selection; definition of relationships, responsibilities and authority; type of project; location, site conditions and environment; resources; legislation and regulation; climatic influences; project risk; form of contract; contract negotiation; and contract administrative procedures.

Design
Design concepts; specifications; construction details; task dependency; standardisation; tolerances; dimensional co-ordination; and drawings and communication.

Construction and management

Construction knowledge; skill base; construction methods; sequencing; resource deployment; standards and control of quality; organisational structure; management and supervisory style; industrial relations; planning and progressing methods; material procurement; use of plant and equipment; site layout and temporary facilities; and site safety.

Post-construction

Installation and commissioning; operational requirements; user requirements; and life cycle provision and maintenance.

Constructability is a concept that must seek to alleviate the difficulties brought about by the separation and demarcation between the stages of the building process. Moreover, it must seek to resolve the many problems of performance, technology and management that arise during each stage. An approach is necessary which appreciates those many and diverse factors identified in all construction projects while also accommodating project specific factors and appreciating the particular culture of the organisations involved.

Constructability principles

Between 1991 and 1993, the CII Australia collaborated extensively with the CII in the USA to develop a *Constructability Principles File* appropriate for the Australian context (CII Australia 1993). The research team evaluated the concepts of buildability and constructability that had been the subject of research carried out in the UK, USA and Australia over the last 25 to 30 years against a series of local case studies and developed a set of principles tailored to the Australian construction industry. The concepts developed consist of a best-practice, how-to-do-it manual, covering:

1 Implementation advice on how organisations can establish a constructability programme
2 A flowchart indicating the applicability of principles at each stage in the building process
3 Executive summaries explaining the principles of constructability
4 The key principles of constructability
5 A database to record examples of the savings made from implementing constructability.

An important development by the task force is the concept that principles of constructability are not applied sequentially as the building process develops, but rather may be developed during several stages. A flowchart was presented which advises the user which principles are most likely to be relevant at particular stages in the project life cycle. The constructability file presents 12 overriding principles which represent the best in current constructability practice and are aimed at encouraging the project team to apply them, where appropriate, to their project.

The team may find that some principles directly relate to their project while others do not, but the goal of the file is to stimulate thought about constructability and how to make it work. The approach deliberately avoids a checklist approach that likely stifles creative thought, and instead addresses the difficulties associated with implementation by indicating the relative importance of each principle at any particular stage of a typical construction project. The CIIA principles of constructability are described as follows:

Integration
Constructability must be made an integral part of the project plan.

Construction knowledge
Project planning must actively involve construction knowledge and experience.

Team skills
The experience, skills and composition of the project team must be appropriate for the project.

Corporate objectives
Constructability is enhanced when the project team gains an understanding of the client's corporate and project objectives.

Available resources
The technology of the design solution must be matched with the skills and resources available.

External factors
External factors can affect the cost and/or program of the project.

Program
The overall program for the project must be realistic and construction-sensitive, and have the commitment of the project team.

Construction methodology
The project design must consider construction methodology.

Accessibility
Constructability will be enhanced if construction accessibility is considered in the design and construction stages of the project.

Specifications
Project constructability is enhanced when construction efficiency is considered in specification development.

Construction innovation
The use of innovative techniques during construction will enhance constructability.

Feedback
Constructability can be enhanced on similar future projects if a post-construction analysis is undertaken by the project team.

Application of constructability principles

Integration, construction knowledge and team skills consider the importance of including the 'right' team members from the beginning of the project. Corporate objectives considers how constructability may be enhanced when the project team understand clearly both the corporate, as well as project, objectives. Available resources and external factors address the concern that constructability will often be affected by factors over which the project team has little control, but that their potentially detrimental influence can be minimised if identified early. Program considers the importance of establishing a realistic and construction-sensitive schedule for the works, one which has been discussed and agreed to by project team members. Construction methodology, accessibility and specifications are concerned with issues that should be integrated into the final design and project documentation. Construction innovation addresses the use of construction knowledge to improve the effectiveness of site operations. Ideally, the contractor will have been consulted early in the developmental process to facilitate the input of his specialist knowledge and experience. Feedback, the final constructability principle, is concerned with the concept that a construction project evolves through a somewhat cyclic and cumulative process rather than a mere linear process, whereby the knowledge gained on the project can benefit subsequent projects. Two post-construction reviews are recommended, one to evaluate the effectiveness of constructability decisions, and the second to determine the operational efficiency of the total project.

Benefits of implementing constructability

Today, construction clients expect their projects to be completed on time, within budget, and to be of good quality; they demand a high quality of service and real value for money. Moreover, clients expect the final product to be relatively trouble free and inexpensive to use and maintain. They require a system that affords them efficiency and effectiveness throughout the total building process. It is for this reason, if no other, that constructability concepts and principles have an innovative and significant role to play. The CIIA Australia has proposed a systematic approach based on four key components which are illustrated in Fig. 2. These are: acceptance of the cost influence curve; adoption of a corporate program; adoption of a project level program; and application of the *Constructability Principles File.*

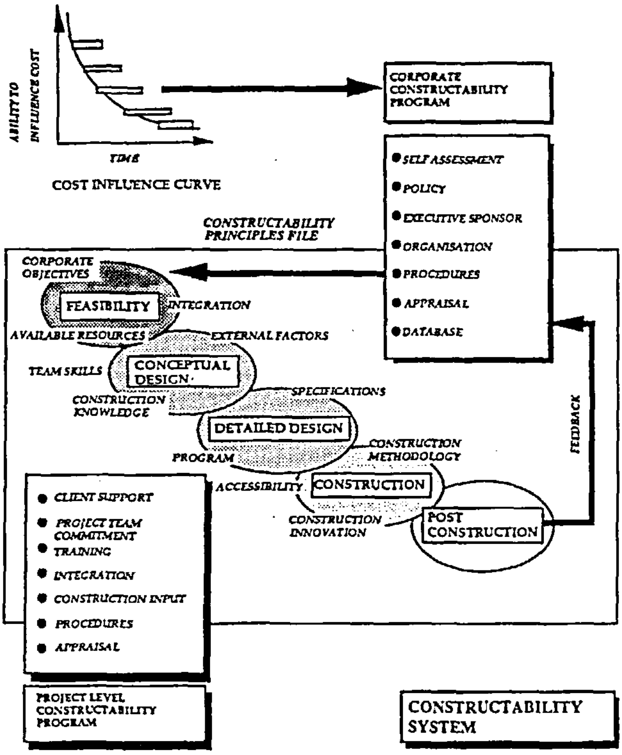

Figure 2 Constructability system (CII Australia 1995).

There are tangible benefits to be gained from implementing constructability in any building project. Some of these benefits may be manifest, others more obscure, some quantitative in nature while others are more subjective. Benefits can also be quite pragmatic, measurable not only in terms of cost, time and quality, but in terms of the physiological and psychological gains for the building team members. The benefits of constructability have become well recognised (CII USA 1987; McGeorge *et al.* 1992; CII Australia 1993; Griffith & Sidwell 1995) and may extend across the total building process and include the following: better conceptual planning; more effective procurement; improved design; better construction methods; more accomplished site management; more effective teamwork; higher job satisfaction; increased project performance; and enhanced recognition for the participants.

Barriers to implementation

It would be unrealistic and therefore irresponsible to suggest that constructability can address all the questions, difficulties and problems that confront any and all construction projects. Creating a building that is easier to construct cannot be the sole aim of the client (Griffith & Sidwell 1995). Each building project is an individual and often unique entity which requires, in its formulation, a multitude of complex and interactive factors to be considered. What constructability can do, is to invite the client and building team to consider, perhaps more so than has been the case in the past, principles which can assist them to create a smoother passage through the management of the project.

It is clear that the fragmented nature of building and the segregated roles of the project team, characteristic in traditional building procurement, present inherent and signifcant barriers to the widespread adoption and developing success of constructability. Moreover, support is stifled by the obstacles to innovation in design, technology and management, brought about through: the low level of awareness; demarcation; the lack of incentives; reticence; and the competitive stance adopted by construction professionals. Such difficulties and the barriers they create to the further development and application of constructability concepts are complex and involved and will not be overcome easily. Better building, through the implementation of constructability, will evolve only from the committed interest of clients and a concentrated effort towards dissolving barriers and encouraging teamwork. Constructability can be assisted by clients and supported by project teams, with a clear direction sought to improve: design approach; *construction techniques*; *construction management*; and use of the finished product. Constructability must become a creative thinking process throughout the total building process.

A CASE STUDY EXAMPLE OF CONSTRUCTABILITY APPLICATION

This section presents a recently completed research case study example of constructability to exemplify constructability consideration within the building process. The example reviewed should not be interpreted as stereotypical of constructability interest and activity, but rather serve as a persuasive indication of the propensities of constructability concepts and principles in application. This case study example of constructability application concerns the procurement, design and construction of a large public arts and entertainment centre, a state government initiative in Australia. The brief for the project called for: a 12,000 seat public arena; backstage facilities and storage; public amenities; corporate suites; and a main foyer and auditorium. Speed of construction was considered to be the overriding priority of the client as was the effectiveness of construction techniques and management as the project held considerable public and political attention at that time. In addition, a project management approach was to be used for the project. At the recommendation of the client, constructability consideration was to be encouraged throughout the total building process. The benefits of constructability emerging from this interest were as follows:

Conceptual planning and procurement

As the project was to be completed to a tight programme schedule and restricted budget, the project management team pursued a novation form of contract – where the client employs a designer to develop the design to a certain point, then calls for tenders and the successful contractor then completes the design and carries out the works. For this project, the design consultant developed the design to the point of novation and then engaged their own subconsultant and a building consultant, appointed jointly by them and the project management team, to specifically assist with project methodology and planning. This approach was highly beneficial as the close interaction between the subconsultant, building consultant and project management team allowed constructability to be a key feature of their organisation and planning for the project. Tenders were requested from a number of contractors and detailed negotiations followed with the lowest bidder.

Design

The selected contractor allowed the project management team to scrutinise the bid during which the high cost elements could be identified and the opportunity explored to make cost savings. From this process a range of design and construction alternatives were suggested, leading to subsequent cost-effective modifications.

Construction

The project was situated on an area of poor ground. As this was identified early on in the conceptual planning stage, project management had taken the opportunity to re-confirm their site investigation survey data such that when the contractor tendered and subsequently carried out the construction works the nature of the ground conditions was known with accuracy. Construction methods that had been considered during the conceptual planning stage were reviewed with the selected contractor and aspects which would encourage good constructability in methods and sequencing were incorporated into the site works.

Construction management

A prominent concern of site management was the method and sequence by which the steel space frame trusses would be set in position for the large span roof. It was impossible to construct the entire roof at ground level and then lift it into position, so it was decided to use multiple and co-ordinated crane lifts to raise and sling the main trusses into position. Specially fabricated working cages were then suspended from the cranes to allow operatives to fix the roof coverings. This method alleviated the need for temporary working platforms which reduced time and costs considerably. Special provision for safe working had to be agreed with site labour and trade unions before the method was implemented.

The benefits of these techniques

The benefits of constructability consideration were clearly visible in this case study. Constructability concepts and principles had been pursued throughout the total building process for the arts and entertainment centre, and post-construction review indicated that the project had been delivered four months ahead of schedule and with overall cost savings approaching 8% of total budget. This case study shows quite unambiguously that there are real benefits to be accrued from the detailed consideration of constructability.

FUTURE DEVELOPMENTS IN CONSTRUCTABILITY RESEARCH AND PRACTICE

This review of constructability concepts, principles and practice has shown that there has, over time, been considerable re-assessment of its form. Interest has grown from the narrow perspective of buildability to the strategic consideration of constructability as a valuable management tool to bring real benefit across the total building process. A truly workable approach to constructability requires recognition that there are many and diverse factors that impinge upon the building processes. These factors were presented earlier in this paper. Constructability will not gain full support within the construction industry until these factors are better understood and until constructability principles are seen in context with them. To develop a conceptual approach which appreciates the influence of these factors and relates them better to constructability will not be an easy task.

Recent research (Chen & McGeorge 1994) states 'that many researchers have recognised the importance of being able to identify all relevant factors ... this has been an ideal which has been too complex to model conceptually and therefore too difficult to implement'. Chen and McGeorge suggest that 'the greatest potential gains will be achieved by better management of information to support project decision making'. They support a systems approach to examine a three-dimensional model in which participants, project factors and project stages are significant to constructability strategies. Further research by Griffith and Sidwell (1995) presents an outline for developing a constructability strategy at each key stage of the construction process. This considers many of the factors suggested by Chen and McGeorge. This approach sought to stimulate creative thought about the nature of each stage such that important questions and considerations about the building process would not be missed and to encourage action to be taken by the respective participants to pursue constructability.

In the strategic consideration of constructability it is likely that future research and practice might focus on: the more holistic view of constructability to develop more encompassing strategies to be developed for considering constructability at each stage in the total building process; the concentration on a fewer number of factors which influence constructability such that greater reliability can be built in to the strategies developed; and the formulation of management methods that are readily adaptable to the individual project situation, including non-traditionally procured projects.

CONCLUSIONS

It can be seen clearly from this paper that constructability concepts transcend the total building process. Constructability has a valuable role to play in conceptual planning, procurement, design, construction and use. The timing of its implementation is crucial to its success as the ability to influence the project outcome is greatest early in the project lifestyle. The application of constructability thinking at the project's inception will therefore maximise its potential to deliver real benefits. Constructability will achieve greater success when its concepts and principles become an inherent and recognised part of the way in which a construction project is conceived, organised and managed. For benefits to be guaranteed, the project team led by the client must have a collective project policy which is actively pursued through a structured programme of measures designed to encourage constructability from day one of the project's conception.

Three factors are significant to the successful implementation of constructability: first, the conscious perception, drive and commitment of the client; second, the earliest possible involvement of construction knowledge, skills and experience in the building process; and third and perhaps the most important factor, the collective response and support of all the members of the project team. Better value for money, improved quality of service and significant savings in project cost and time are shown to be possible through constructability consideration. A strategic approach in the future will likely see constructability being focused on a number of key issues within the construction process – those which have a significant capability to influence the project outcome. Constructability will need to be understood fundamentally within the context of these factors if its concepts and principles are to develop, become applied more widely and have greater success in the future.

References

Adams, A. (1989) *Practical Buildability.* Construction Industry Research and Information Association (CIRIA)/Butterworth, London.

Banwell, H. (1964) *The Placing and Management of Contracts for Building and Civil Engineering Work.* HMSO, London.

Bishop, D. (1985) *Buildability: The Criteria for Assessment.* Chartered Institute of Building (CIOB), Ascot.

Business Roundtable (1982) *Integrating Construction Resources and Technology into Engineering.* Business Roundtable, New York.

Chen, S.E. & McGeorge, W.D. (1994) *A Systems Approach to Managing Buildability.* Australian Institute of Building (AIB) Papers.

CII Australia (1993) *Constructability Principles File.* Construction Industry Institute, Adelaide.

CII USA (1987) *Constructability Concepts File.* Construction Industry Institute, Texas.

CIRIA (1983) *Buildability: An Assessment.* Construction Industry Research and Information Association, London.

Economic Development Council (EDC) (1967) *Action on the Banwell Report.* HMSO, London.

Emmerson, H. (1962) *Survey of Problems Before the Construction Industry: a report prepared for the Ministry of Works.* HMSO, London.

Griffith, A. (1984) *A critical investigation of factors influencing buildability and productivity.* PhD Thesis, Heriot-Watt University, Edinburgh.

Griffith, A. (1985a) *Buildability: The Effect of Design and Management on Construction: A Case Study.* Science and Engineering Research Council (SERC)/Heriot-Watt University, Edinburgh.

Griffith, A. (1985b) Buildability: Time for Re-assessment. *Building Technology and Management, Journal of The Chartered Institute of Building (CIOB)*, Feb, CIOB, Ascot.

Griffith, A. & Sidwell, A.C. (1995) *Constructability in Building and Engineering Projects.* Macmillan, Basingstoke.

Hon, S.L. (1988) *A study of buildability within a project management system.* M.Bldg. Thesis, University of Melbourne, Melbourne.

Hon, S.L., Gairns, D.A. & Wilson, O.D. (1989) *Buildability: A Review of Research and Practice.* Australian Institute of Building (AIB) Papers, Vol.3, AIB, Australia.

McGeorge, W.D., Chen, S.E. & Ostwald, M.J. (1992) *The Development of a Conceptual Model of Buildability Which Identifies User Satisfaction as a Major Objective.* International Council for Building Research Studies and Documentation (CIB) Conference, Rotterdam.

National Economic Development Office (NEDO) (1975) *The Wood Report: The Public Client and The Construction Industry.* HMSO, London.

New South Wales Government Construction Policy Steering Committee (1993) *Capital Project Procurement Manual.* NSW Government Office, Australia.

O'Connor, J.T., Rusch, S.E. & Schulz, M.J. (1986) *Constructability Improvement During Engineering and Procurement.* Construction Industry Institute (CII), USA.

O'Connor, J.T. & Davis, J.S. (1988) Constructability during field operations. *Journal of Construction Engineering and Management*, **114**, (4).

Tatum, C.B., Vanegas, J.A. & Williams, J.M. (1986) *Constructability Improvement During Conceptual Planning.* Construction Industry Institute (CII), USA.

This article has been cited by:

1. Patrick T.I. Lam, Franky W.H. Wong, Albert P.C. Chan, Wilson C.Y. Shea, Jo W.S. Lau. 2012. A scheme design buildability assessment model for building projects. *Construction Innovation* **12**:2, 216-238. [Abstract] [Full Text] [PDF]
2. Terry Williams, Ole Jonny Klakegg, Derek H. T. Walker, Bjørn Andersen, Ole Morten Magnussen. 2012. Identifying and Acting on Early Warning Signs in Complex Projects. *Project Management Journal* **43**:10.1002/pmj.v43.2, 37-53. [CrossRef]
3. Rajendran SathyanarayananConstructability Review Process – A Summary of Literature 6-25. [CrossRef]
4. Franky W.H. Wong, Patrick T.I. Lam, Edwin H.W. Chan, L.Y. Shen. 2007. A study of measures to improve constructability. *International Journal of Quality & Reliability Management* **24**:6, 586-601. [Abstract] [Full Text] [PDF]
5. Patrick T.I. Lam, Franky W.H. Wong, Albert P.C. Chan. 2006. Contributions of designers to improving buildability and constructability. *Design Studies* **27**, 457-479. [CrossRef]
6. A.D. Knight, A. Griffith, A.P. King. 2002. Supply side short-circuiting in design and build projects. *Management Decision* **40**:7, 655-662. [Abstract] [Full Text] [PDF]
7. Y.J. Shen, D.H.T. Walker. 2001. Integrating OHS, EMS and QM with constructability principles when construction planning – a design and construct project case study. *The TQM Magazine* **13**:4, 247-259. [Abstract] [Full Text] [PDF]

Constructability Analysis in the Design Firm

David Arditi, M.ASCE[1]; Ahmed Elhassan[2]; and Y. Cengiz Toklu[3]

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.

DOI: 10.1061/(ASCE)0733-9364(2002)128:2(117)

CE Database keywords: Constructability; Design.

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; Gugel and Russell 1994; Russell et al. 1994a). 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

[1]Professor, Illinois Institute of Technology, Dept. of Civil and Architectural Engineering, Chicago, IL 60616. E-mail: arditi@iit.edu

[2]Graduate Student, Illinois Institute of Technology, Dept. of Civil and Architectural Engineering, Chicago, IL 60616.

[3]Assistant Professor, Eastern Mediterranean Univ., Dept. of Civil Engineering, Famagusta, Northern Cyprus.

Note. Discussion open until September 1, 2002. 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 January 9, 2001; approved on April 17, 2001. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 128, No. 2, April 1, 2002. ©ASCE, ISSN 0733-9364/2002/2-117–126/$8.00+$.50 per page.

J. Constr. Eng. Manage., 2002, 128(2): 117-126

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=sizes of samples and P_1 and P_2=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=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.

J. Constr. Eng. Manage., 2002, 128(2): 117-126

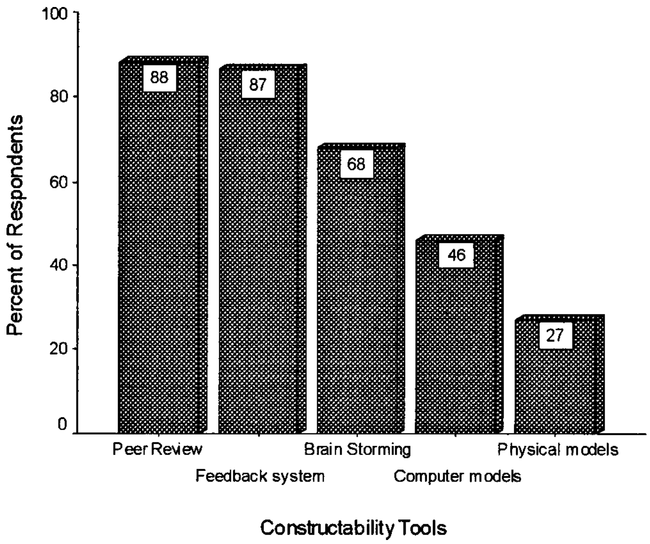

Fig. 1. Utilization of constructability tools

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

J. Constr. Eng. Manage., 2002, 128(2): 117-126

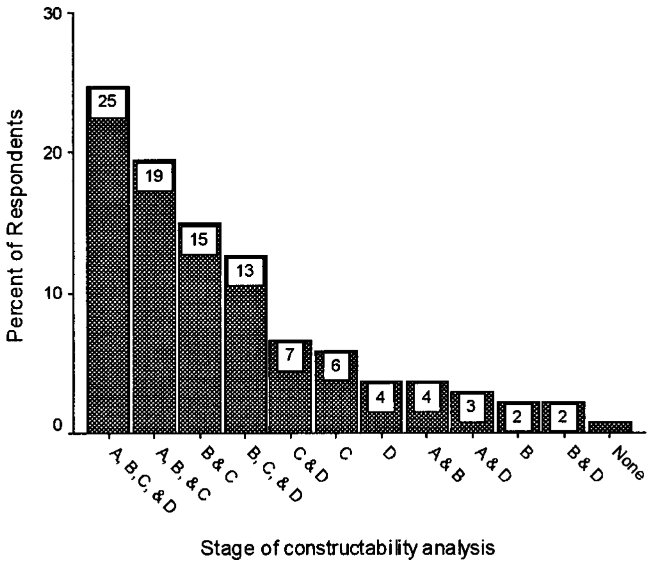

Fig. 2. Timing of constructability reviews: A, conceptual planning stage; B, preliminary design stage; C, developed design stage; D, after finishing the design

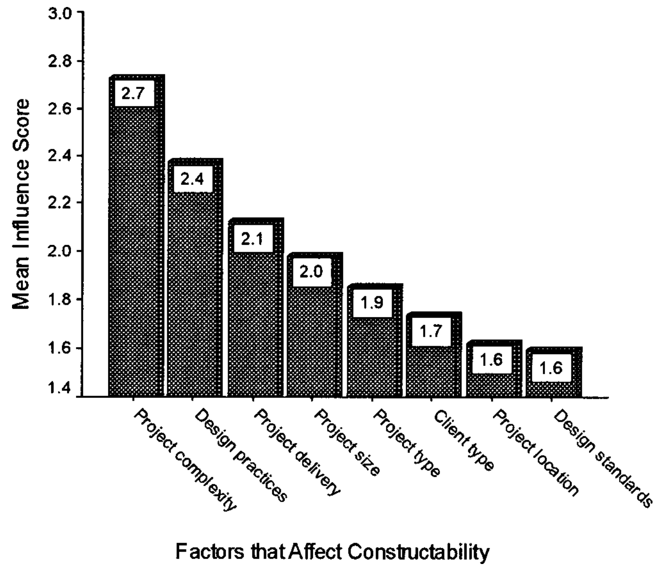

Fig. 3. Factors affecting constructability

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 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 to 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 to 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

J. Constr. Eng. Manage., 2002, 128(2): 117-126

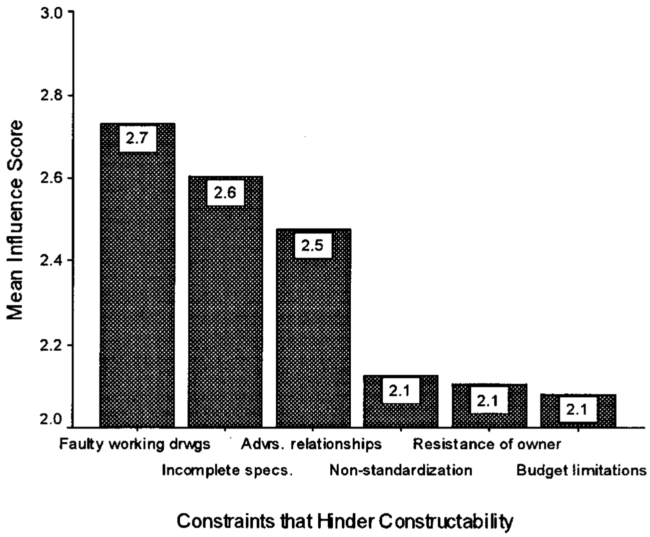

Fig. 4. Constraints on constructability

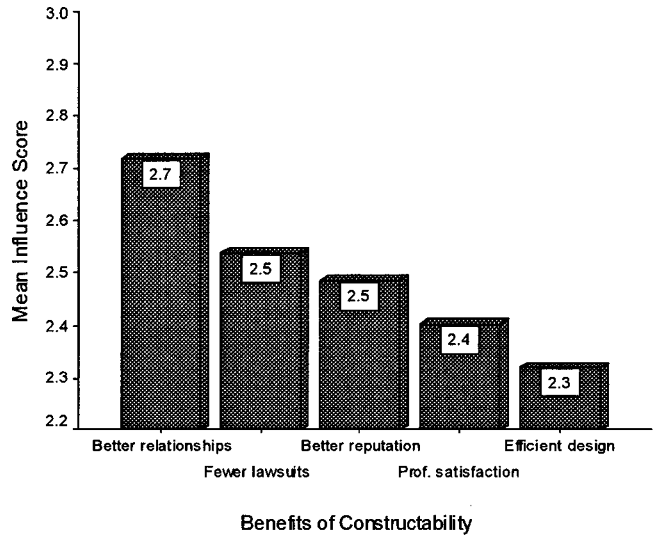

Fig. 5. Benefits of constructability

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.

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 and 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

J. Constr. Eng. Manage., 2002, 128(2): 117-126

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.

J. Constr. Eng. Manage., 2002, 128(2): 117-126

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

Variable	Z score	$\alpha=0.01$ $Z_{\text{Crit.}}=2.33$ $Z_{\text{Crit.}}=-2.33$
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

4. Peer reviews and feedback systems are the most prevalent tools used to achieve high levels of constructability. The 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 constructability, 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) ______________________

J. Constr. Eng. Manage., 2002, 128(2): 117-126

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**
Department of Civil and Architectural Engineering
Illinois Institute of Technology
Chicago, IL 60616

J. Constr. Eng. Manage., 2002, 128(2): 117-126

References

Anderson, S. D., Fisher, D. J., and Rahman, S. P. (1999). ''Constructability issues for highway projects.'' *J. Manage. Eng.*, 15(3), 60–68.

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

Burati, J. L., Jr., Farrington, J. J., and Ledbetter, W. B. (1992). ''Causes of quality deviations in design and construction.'' *J. Constr. Eng. Manage.*, 118(1), 34–49.

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.

Diekmann, J. E., and Nelson, M. C. (1985). ''Construction claims: Frequency and severity.'' *J. Constr. Eng. Manage.*, 111(1), 74–81.

Fischer, M., and Tatum, C. B. (1997). ''Characteristics of design-relevant constructability knowledge.'' *J. Constr. Eng. Manage.*, 123(3), 253–260.

Gambatese, J. A., and McManus, J. F. (1999). ''Discussion of the constructability review process: A constructor's perspective, by Roy Mendelsohn.'' *J. Manage. Eng.*, 15(1), 93–94.

Gray, C. (1986). ''Intelligent construction time and cost analysis.'' *Constr. Manage. Econom.*, 4(2), 135–150.

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

Gustafson, G. D. (1990). ''Why project peer review?'' *J. Manage. Eng.*, 6(3), 350–354.

Hanlon, E. J., and Sanvido, V. E. (1995). ''Constructability information classification scheme.'' *J. Constr. Eng. Manage.*, 121(4), 337–345.

Integrating construction resources and technology into engineering. (1982). *Rep. B-1*, A Construction Industry Cost Effectiveness (CICE) Report, The Business Roundtable, New York.

Ireland, V. (1985). ''The role of managerial actions in the cost, time and quality performance of high-rise commercial building projects.'' *Constr. Manage. Econom.*, 3(1), 59–87.

Marcotte, P. (1990). ''Hastening justice—Biden Committee studies task force plan to cut trial delay.'' *American Bar Association Journal*, 76(40).

Mendelsohn, R. (1997). ''The constructability review process: A constructor's perspective.'' *J. Manage. Eng.*, 13(3), 17–19.

Multimedia constructability tool. (1998). INDOT constructability tool, Civil Engineering Dept., Purdue Univ., West Lafayette, Ind.

Navon, R., Shapira, A., and Shechori, Y. (2000). ''Automated rebar constructability diagnosis.'' *J. Constr. Eng. Manage.*, 126(5), 389–397.

O'Connor, J. T., and Davis, V. S. (1988). ''Constructability improvement during field operations.'' *J. Constr. Eng. Manage.*, 114(4), 548–564.

O'Connor, J. T., and Miller, S. J. (1994). ''Constructability programs: Method for assessment and benchmarking.'' *J. Perform. Constr. Facil.*, 8(1), 46–64.

Rubin, R. A., Guy, S., Maevis, A. C., and Fairweather, V. (1983). *Construction claims: Analysis, presentation, defense*, Van Nostrand Reinhold, New York.

Russell, J. S., and Gugel, J. G. (1993). ''Comparison of two corporate constructability programs.'' *J. Constr. Eng. Manage.*, 119(4), 769–784.

Russell, J. S., Gugel, J. G., and Radtke, M. W. (1993). ''Documented constructability savings for petrochemical-facility expansion.'' *J. Perform. Constr. Facil.*, 7(1), 27–45.

Russell, J. S., Gugel, J. G., and Radtke, M. W. (1994a). ''Comparative analysis of three constructability approaches.'' *J. Constr. Eng. Manage.*, 120(1), 180–195.

Russell, J. S., Jaselskis, E. J., Anderson, S. D., and Hendrickson, M. C. (1998). ''A summary of Construction Congress V.'' *J. Manage. Eng.*, 14(6), 27–30.

Russell, J. S., Swiggum, K. E., Shapiro, J. M., and Alaydrus, A. F. (1994b). ''Constructability related to TQM, value engineering, and cost/benefits.'' *J. Perform. Constr. Facil.*, 8(1), 31–45.

SPSS Base 7.0 for Windows, User's Guide (1996). SPSS Inc., Chicago.

Skibniewski, M., Arciszewski, T., and Lueprasert, K. (1997). ''Constructability analysis: Machine learning approach.'' *J. Comput. Civ. Eng.*, 11(1), 8–16.

''The top 500 design firms.'' (1998a). *Eng. News-Rec.*, 240(16), 75.

The top 500 design firms source book. (1998b). Engineering News-Record, McGraw-Hill, New York.

Uhlik, F. T., and Lores, G. V. (1998). ''Assessment of constructability practices among general contractors.'' *J. Archit. Eng.*, 4(3), 113–123.

Zimmerman, L. W., and Hart, G. D. (1982). *Value engineering—a practical approach for owners, designers, and contractors*, Van Nostrand Reinhold, New York.

J. Constr. Eng. Manage., 2002, 128(2): 117-126