Comparative Analysis of Three Constructability Approaches

By Jeffrey S. Russell,[1] John G. Gugel,[2] and Michael W. Radtke,[3] Associate Members, ASCE

Abstract: Recent research has identified different approaches owners use to implement constructability. This paper provides a comparative analysis of three such approaches studied in four case studies. The three approaches are: using a construction management firm during preconstruction (referred to as constructability services), specialized-formal programming, and comprehensive tracking. To conduct the comparison, six attributes are used: initiation of constructability input, documented benefit/cost data, extent of owner participation, formalized procedures, methods to track lessons learned, and designated constructability coordinator(s). For each approach, the quantitative and qualitative benefits and costs are presented and compared. Each approach is presented to assist project managers in understanding implementation of constructability. This understanding can provide project managers with answers to the following questions: Considering owner organization and project characteristics, what approach is most suitable? What are the benefits and costs associated with each approach? What action can the owner take to facilitate constructability input?

INTRODUCTION

Constructability, as defined by the Construction Industry Institute (CII), Austin, Tex., is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives ("Constructability" 1986). Constructability has been an evolving work process. A recent trend toward quality awareness has heightened the need for soliciting input from those involved with construction (the immediate customer of planning and design) prior to the start of construction. Such early involvement of construction knowledge and experience reduces the likelihood of creating designs that cannot be efficiently built, thereby reducing design rework, improving project schedule, and establishing construction cost savings.

Recent advances that impact constructability implementation can be categorized as either administrative solutions or implementation methods. Examples of administrative solutions include developing sample constructability implementation guidelines, increasing communication between project participants through partnering agreements or organizational alliances, increasing use of design-construct organizations, and an increasing trend toward turnkey contracting. Examples of constructability implementation

[1]Asst. Prof., Dept. of Civ. and Envir. Engrg., Univ. of Wisconsin – Madison, 2258 Engrg. Hall., 1415 Johnson Drive, Madison, WI 53706.

[2]Design Engr., UOP, 25 E. Algonquin Rd., Des Plaines, IL 60017 – 5017; formerly, Grad. Res. Asst., Dept. of Civ. and Envir. Engrg., Univ. of Wisconsin – Madison, Madison, WI 53706.

[3]Field Engr., C. G. Schmidt, 4199 N. Richards St., Milwaukee, WI 53211 – 0609; formerly, Grad. Res. Asst., Dept. of Civ. and Envir. Engrg., Univ. of Wisconsin – Madison, Madison, WI 53706.

Note. Discussion open until August 1, 1994. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on June 22, 1992. This paper is part of the *Journal of Construction Engineering and Management*, Vol. 120, No. 1, March, 1994. ©ASCE, ISSN 0733-9364/94/0001-0180/$2.00 + $.25 per page. Paper No. 4267.

methods include incorporation of production concepts such as prefabrication, preassembly, and modularization. Each of these methods of construction employ "assembly-line" techniques, resulting in reduced project schedules by allowing multiple activities to proceed concurrently. Increased safety and quality are obtained by performing fabrication at lower elevations and in a controlled work environment. Implementation, however, requires designers to make special provisions to accommodate these methods and must be incorporated during conceptual design.

This paper provides a comparative analysis of four case studies. The case studies demonstrate three approaches to integrate construction knowledge and experience into the planning and design phases. The three approaches are: using a construction management firm during preconstruction (referred to as constructability services), specialized-formal programming, and comprehensive tracking. Example applications of each approach are presented to assist project managers in understanding implementation of constructability. This understanding can provide project managers with answers to the following questions:

1. Considering owner organization and project characteristics, what approach is most suitable?
2. What are the benefits and costs associated with each approach?
3. What action can the owner take to facilitate constructability input?

The four case studies arose from research conducted by the writers under the direction of the CII Constructability Implementation Task Force. The research effort consisted of three phases: questionnaire survey, personal interviews, and case studies. Phase 1 began in February 1991, when the writers mailed a six-page questionnaire survey to 1,591 organizations in the U.S. construction industry. A total of 263 usable responses were received, representing a 16% response rate. Phase 2, personal interviews, began in July 1991 and was completed in November 1991. In total, the writers and researchers from the University of Texas at Austin met with 83 industry professionals while conducting interviews with 62 different organizations. Phases 1 and 2 were used to identify four case studies aimed at providing benefit/cost data associated with implementing constructability. The writers conducted the final phase from January 1992 to March 1992. A complete description of the research results from Phases 1 and 2 can be found in Russell et al. (1992b)

The four case studies included one commercial office building development, one consumer-products–manufacturing facility, and two petrochemical projects. Case-study data were collected by personal interviews ranging from 6 to 8 hr long. Table 1 presents the salient characteristics of the case studies.

ATTRIBUTES OF CONSTRUCTABILITY APPROACHES

The four case studies can be categorized into three of eight approaches identified as means of implementing constructability (Russell et al. 1992a,b). The three approaches described here are ordered in increasing formalization, resources required, and long-term benefit accrued through documenting lessons learned.

The first approach, using a construction management firm during preconstruction (referred to as constructability services), treats constructability

J. Constr. Eng. Manage., 1994, 120(1): 180-195

TABLE 1. Case-Study Characteristics

Case study (1)	Facility type (2)	Construction contract type (3)	Estimated total project cost (millions of dollars) (4)	Project Duration (Months)		Constructability approach (7)	Individuals Interviewed	
				Design (5)	Construction (6)		Organization represented (8)	Representative's project role (9)
1	Commercial office building	Reimbursable guaranteed maximum price	Greater than 100	16	32	Constructability services	Owner	Senior project manager, project manager
1	Commercial office building	Reimbursable guaranteed maximum price	Greater than 100	16	32	Constructability services	Construction management firm	Project executive, project engineer, project superintendent
2	Manufacturing	Reimbursable time and material	Greater than 100	14	16	Specialized-formal program	Owner	Resident construction manager
2	Manufacturing	Reimbursable time and material	Greater than 100	14	16	Specialized-formal program	Design-construction firm	Constructability coordinator, controls manager
3	Petrochemical	Reimbursable cost plus fixed fee with incentives	Greater than 100	24	24	Comprehensive tracking	Owner	Project manager
3	Petrochemical	Reimbursable cost plus fixed fee with incentives	Greater than 100	24	24	Comprehensive tracking	Engineer	Project manager for area 1
3	Petrochemical	Reimbursable cost plus fixed fee with incentives	Greater than 100	24	24	Comprehensive tracking	Constructor	Constructability coordinator for area 1, constructability coordinator for area 2, field constructability coordinator
4	Petrochemical	Reimbursable time and material with incentives	Less than 5	6	11	Comprehensive tracking	Owner	Corporate constructability coordinator

input as a service. Since constructability is viewed as a service rather than a program, benefits and costs attributable to constructability are often considered inseparable from additional services such as value engineering and project planning.

The second approach, specialized-formal programming, is a project-level program that obtains construction input during the conceptual design phase. Under many circumstances involving this approach, construction personnel assist the owner in establishing the program's philosophy, procedures, and tracking systems. Selected projects are typically limited to application of this approach. Consequentially, formal corporate-level documentation of lessons learned and benefit/cost data are not routinely performed.

The third approach is comprehensive tracking. This approach includes aspects that differentiate it from specialized-formal programming: (1) Corporate commitment, philosophy, and procedures are captured within a corporate implementation manual; (2) lessons learned on each project are documented and entered into a corporate database for future reference; and (3) benefit/cost data are recorded. These data are used to document benefits for the purpose of marketing the program and monitor the program's maturity.

A comparative analysis of three approaches found in four case studies has been conducted. The comparison presented in Table 2 considered six attributes: initiation of constructability input, documented benefit/cost data, extent of owner participation, formalized procedures, methods to track lessons learned, and designated constructability coordinator(s).

Initiation of Constructability Input

Timing of construction input is a critical consideration. The "ability-to-influence-cost" curve presented by CII ("Constructability" 1986), indicates

TABLE 2. Attributes of Constructability Approaches

Name of attribute (1)	Constructability services for case study 1 (2)	Specialized-formal programming for case study 2 (3)	Comprehensive Tracking: Case study 3 (4)	Comprehensive Tracking: Case study 4 (5)
Initiation of constructability input	35% predetailed design	0% of detailed design	8% of detailed design	75% predetailed design
Documented benefit/cost	Qualitative	Qualitative and select quantitative	Quantitative	Quantitative
Extent of owner participation[a]	Low	Medium	Medium/high	High
Formalized procedures	No	No	Yes	Yes
Method to track lessons learned	Individual's experience	Individual's experience	Database	Database
Designated constructability coordinator(s)	No	Yes	Yes	Yes

[a]Attribute measured as either low, medium, or high.

J. Constr. Eng. Manage., 1994, 120(1): 180-195

that the greatest ability to reduce project cost exists during the planning and conceptual design phases of a project.

Table 2 presents the relative timing as a percent complete of the design phase when construction knowledge and experience was implemented. Constructability services provided the earliest constructability input, followed by comprehensive tracking and specialized-formal programming approaches. This result can be explained through the relative roles of the constructability input sources and the formality inherent within each approach.

In case study 1, the constructability source, a construction management firm (CM), acted as the owner's agent. The CM assisted the owner in making key project decisions. The CM services supplemented the owner's limited resources available for early project planning and design evaluation. An added service provided by the CM facilitated early constructability input. In contrast, the three remaining case studies involved large industrial owners. These owners possessed adequate in-house engineering and project management expertise to provide constructability input. Outside sources of construction knowledge and experience were not sought to assist the owner in making key project decisions, but rather to implement constructability within a formal program.

Documented Benefit/Cost

For an owner, benefit/cost data can be an effective means to convince upper management to release funding earlier within the project life cycle. For organizations marketing constructability as a service, such data can demonstrate the service's benefit.

The four case studies provided a range of documentation including both quantitative and qualitative cost and schedule savings. Case study 1 failed to maintain a constructability log or track cost savings. Case studies 2, 3, and 4 maintained a log that documented constructability ideas. Case study 2 maintained a log for a six-month period at the end of the design phase and start of the construction phase. Quantitative estimates were provided for select ideas. On the other hand, logs maintained for case studies 3 and 4 provided quantitative estimates for ideas throughout the design and construction phases.

Extent of Owner Participation

In case study 1, the owner's lack of in-house construction expertise prompted a construction manager to be hired. Construction involvement through the CM during the predetailed design phase provided input. Consequently, the owner's participation in the constructability process was low. In case study 2, the owner's philosophy toward constructability defined the method and identified individuals responsible for implementation. Individuals involved in the constructability process were personally interviewed by the owner. The interviews scrutinized individuals' experience, communication skills, and ability to participate as a team player.

In case study 3, the owner secured the project's constructor to develop and implement the program. Owner participation included: working jointly with the constructor to develop written constructability procedures, developing a formal team-building program, and implementing an incentives program that used integrated project goals between the designer and constructor. The constructor led the program by scheduling constructability activities; tracking lessons learned; and collecting, analyzing, and submitting

J. Constr. Eng. Manage., 1994, 120(1): 180-195

constructability ideas for approval. Estimates regarding the total effort-hours expended on constructability attributed 6.7% to the owner's organization.

The owner in case study 4 assumed the lead role in program implementation. An owner representative acted as a constructability coordinator. Within the owner's process, the roles of the constructor and subcontractors were to provide constructability ideas. Analysis, implementation, and tracking of ideas were performed by the owner. In this case, estimates regarding the total effort associated with the program attributed 90% to the owner's organization.

Formalized Procedures

A program's use of documented procedures establishes a formal method of tracking effectiveness. Case study 1 had no written procedures for the program. This program relied upon the experience of the CM firm's personnel. In case study 2, the owner had a 75-page constructability manual. This manual identified roles and responsibilities of the constructability team members, described appropriate timing of constructability activities, and identified barriers to implementation.

The manual for case studies 3 and 4 included a description of constructability, identification of roles and responsibilities of constructability team members, an organization chart, and forms for soliciting and tracking ideas and lessons learned. In case study 3, the owner and constructor combined manuals (each exceeding 100 pages) to create a 10-page project-specific manual. In case study 4, the owner developed a prototype nine-page project-specific manual.

Method to Track Lessons Learned

Beneficial by-products of a constructability program are the lessons learned captured during the process. Case studies 1 and 2 relied primarily on the constructability team member's past experience to provide lessons learned. The team members failed to document lessons learned, so the benefits were limited for use on future projects. In case studies 3 and 4, the organization leading the constructability effort maintained a computerized database system that categorized and stored lessons learned. These lessons are retrievable for future projects and may change the current corporate design and construction processes.

Designated Constructability Coordinator(s)

Designation of a project constructability coordinator assists in program implementation and monitoring. The number of coordinators and time commitment to a project often depends on project total cost, number of major design consultants involved, and the distance between the project site and participants.

Case study 1 failed to designate a constructability coordinator. The project executive, project superintendent, and project engineer from the CM each served as sources of input on an ad hoc basis. Project coordinators were designated for case studies 2, 3, and 4. Case studies 2 and 4 had one designated constructability coordinator while case study 3 had three coordinators.

BENEFITS OF CONSTRUCTABILITY IMPLEMENTATION

Constructability benefits can be delineated as quantitative and qualitative.

J. Constr. Eng. Manage., 1994, 120(1): 180-195

Quantitative

Quantifying benefits and costs attributable to constructability requires comparison of the traditional design method to the recommended constructability approach. The economic value depends on numerous factors such as project management capabilities, skill level of craftsmen, equipment use, and weather conditions. As the project progresses from conceptual planning through to construction, the cost advantage of quantified estimates reduces.

As design definition becomes more complete during the conceptual design phase, it is easier to capture quantitative estimates of constructability benefits. Proper monitoring of these benefits necessitates formalization of the selected approach. A common industrial method of tracking benefits was a constructability idea log containing ideas and cost savings. These logs documented changes from traditional design or construction methods and techniques. The cost-estimation technique used to quantify the savings was an order-of-magnitude estimate. The estimated savings were reviewed and approved by several members of the constructability team. Case studies 2, 3, and 4 maintained logs that included cost savings. It is important to note that these estimates only reflect quantified savings and disregard benefits such as enhanced communication, coordination, quality, or safety.

Table 3 presents quantitative estimates of cost and schedule savings. These values are based on documented estimates of benefits solely attributable to constructability. In each case, the coordinator established an estimate of the cost and/or schedule savings related to each constructability idea.

The constructability coordinator in case study 2 maintained a constructability log for only 40% of the original project duration where a total of 94 ideas were collected. Fifty-three percent of these ideas were related to cost reduction. The single largest cost saving idea included relocating an existing product conveyor operating in a building under demolition without requiring plant shutdown. This idea was estimated to have saved $50,000. 15% of constructability ideas resulted in schedule reduction. Documented ideas reduced the total project cost by 1.1%, and resulted in completing the project on schedule. An acceleration program was implemented for an increase in direct construction cost of 9.0%. The owner's experience in implementing schedule acceleration programs without constructability increases direct construction cost by an average of 25.0%.

The combined logs of each constructability coordinator in case study 3 included a total of 327 constructability ideas. Eighteen percent and 1% of

TABLE 3. Quantitative Impact of Constructability

Project objectives (1)	Constructability services for case study 1[a] (2)	Specialized-formal programming for case study 2 (3)	Comprehensive Tracking	
			Case study 3 (4)	Case study 4 (5)
Reduction in total project cost (%)	—	1.1	1.1	10.7
Reduction in total project schedule (%)	—	—	10.0	5.0

[a]Estimates unavailable due to lack of documentation.

the ideas contained quantified cost- and schedule-reduction estimates, respectively. The single largest idea that contributed to both cost and schedule reduction was using modularized techniques to construct the facility's 152.5-m (500-ft) main pipe rack. This idea resulted in a total project cost and schedule reduction of $546,000 and two months, respectively. Documented constructability ideas reduced the total project cost and schedule by 1.1% and 10.0%, respectively.

In case study 4, the owner's constructability log contained 80 ideas. Seventy percent of the ideas provided cost savings representing a 10.7% reduction in total project cost. This significant savings in comparison to the other case studies is attributed to two program characteristics: relative "maturity" of the programs and relative size of the projects.

The organizations involved in case studies 2 and 3 had corporate constructability manuals containing numerous examples of lessons learned. Many of these lessons have been integrated into the owner's project planning process and are no longer considered constructability savings.

Case study 4 marked the start of the owner's program. Given the premature stage of the program, it is reasonable to expect large reductions in total project cost. As the program is implemented on more projects and the lessons learned are routinely applied to the owner's project planning process, reported incremental constructability savings are expected to decrease.

Another factor believed to have contributed to the cost reduction obtained in case study 4 was the project's small size. Project size influences the percent reduction in total project cost by the manageability of a smaller project and relative scale. The limited scope of the project permitted team members to envision the complete project, thereby focusing on constructability issues that had the highest potential impact. In case study 4, the percent reduction of cost represented by each idea was distributed over a smaller total project cost. For example, the single largest constructability savings idea logged represented a $25,000 reduction in total project cost. Total project costs in case studies 2 and 3 exceeded $100 million, compared with less than $5 million for case study 4. In fact, case studies 3 and 4 differed in total project cost by a multiple greater than 200.

Qualitative

For case study 1, the qualitative benefits are shown in Table 4. The benefits are not solely the result of constructability. Other construction management practices such as value engineering contributed to realizing the benefits.

Similar qualitative benefits were found in case studies 2, 3, and 4. Representatives from these case studies believed that constructability contributed to the safety performance on each project. Case studies 2 and 4 reported Occupational Safety and Health Administration recordable incident rates of 1.9 and 10, which are below industry standards by 87% and 32%, respectively. Case study 3 reported zero lost time accidents in a total of 4,000,000 field effort-hours. Safety was enhanced through rigging and erection studies, and a reduction of work performed on scaffolding achieved through use of preassembly, prefabrication, and modularization techniques.

Quantified Costs of Constructability

Table 5 presents quantified costs and corresponding benefit/cost ratios associated with implementation. To enable a consistent comparison, costs

J. Constr. Eng. Manage., 1994, 120(1): 180-195

TABLE 4. Qualitative Benefits—Case Study for High-Rise Commercial Building

Project objective (1)	Enhancement (2)
Cost	Returned more than 0.5% of original GMP construction contract amount to owner under a shared savings agreement.
Schedule	Project completed within original schedule duration of 30 months; a 12% reduction when compared with industry average tracked by construction management firm.
Quality	Project recognized by being awarded a local builders association's quality award. Additional quality awards were given to fabricators of building's stainless steel cap and exterior stonework.
Aesthetics	Savings accrued through preconstruction efforts were used to finance a 33% increase in building cap's budget required to preserve building's desired aesthetic characteristics.
Safety	Set precedent for slurry drilling caissons in geographic area and for alternative methods of caisson bottom inspection. This eliminated risk of releasing methane gas.

TABLE 5. Quantitative Costs of Constructability Implementation

Measure of cost (1)	Constructability services for case study 1[a] (2)	Specialized formal programming for case study 2 (3)	Comprehensive Tracking: Case study 3 (4)	Comprehensive Tracking: Case study 4 (5)
Additional effort-hours (% of total construction fixed-hours)	—	—	0.40	1.14
Estimated total program cost (% of total project cost)	—	0.09	0.11	1.10
Quantified benefit/cost ratio	—	10:1	10:1	10:1

[a]Unavailable due to lack of documentation.

are calculated using two measures: constructability effort-hours as a percent of total construction field-hours, and program cost as a percent of total project cost. The effort-hours are based on project participant's estimates of time expended on activities related to constructability. The estimated cost includes salaries of input sources, out-of-town living expenses, cost of tracking ideas, and maintenance of a lessons-learned database.

Constructability Effort-Hours

Figs. 1(*a*) and 1(*b*) present constructability participation time lines. The predetailed design phase includes conceptual planning, process design, preliminary engineering, conceptual design, preschematic design, schematic design, and design development subphases. The detailed design phase refers to actual design and development of construction plans and specifications. The construction phase began with field mobilization and site work, and

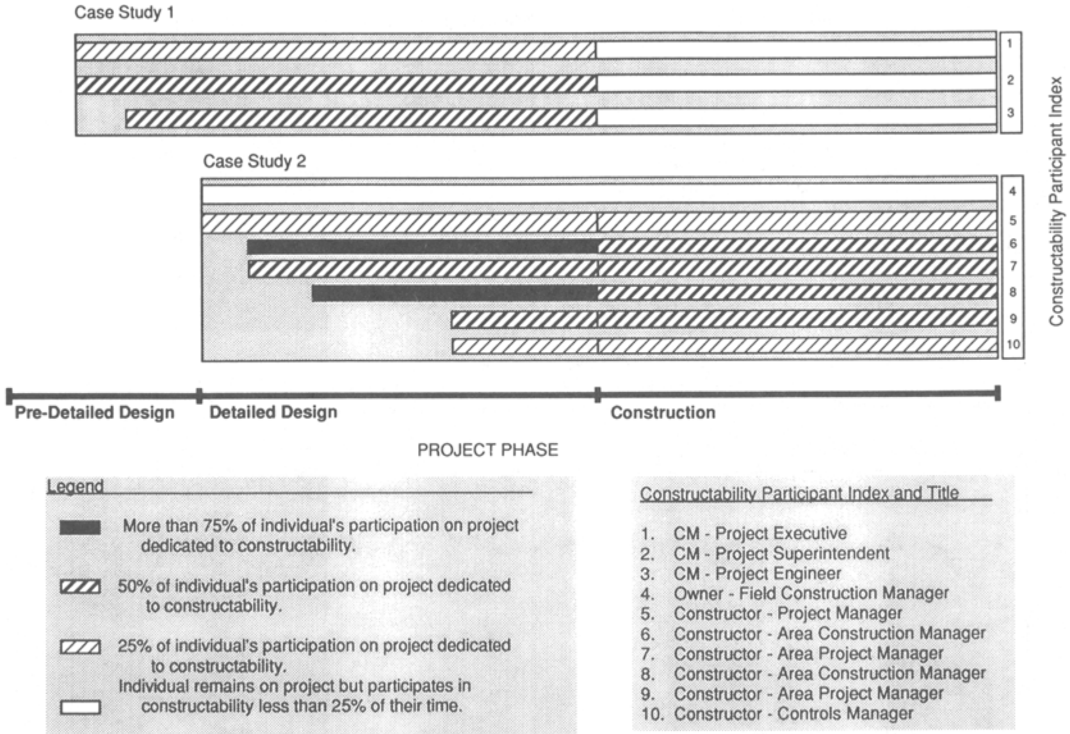

FIG. 1(*a*). Constructability Participation Time Lines:Case Studies 1 and 2

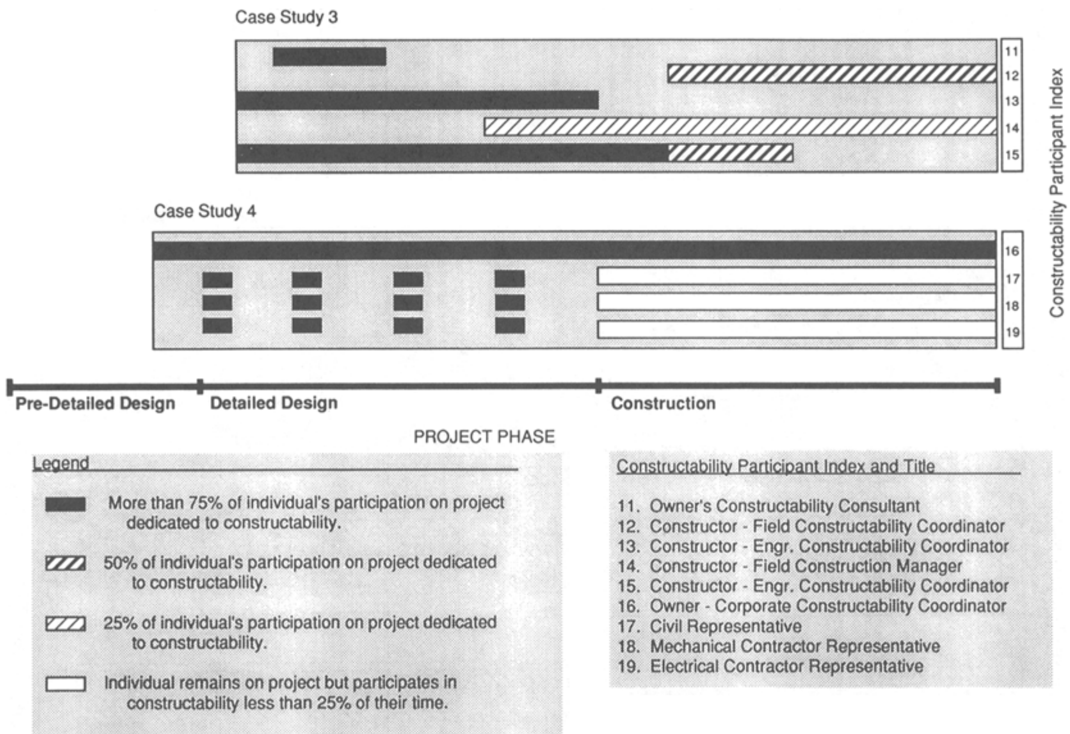

FIG. 1(*b*). Constructability Participation Time Lines:Case Studies 3 and 4

finished with either mechanical completion or issuance of certificate of occupancy.

Personnel in case study 1 were involved during schematic design corresponding to approximately 35% completion of the predetailed design activities. At this time, the CM's project executive and project superintendent conducted constructability activities on a part-time basis. The project engineer started seven months later. These three remained on the project through completion of construction. Constructability input included formal design reviews, cost estimation of design alternatives, value engineering, subcontractor work packaging and prequalification, and schedule development.

In case study 2, constructability was initiated during conceptual planning [corresponding to 0% predetailed design in Figs. 1(*a*) and 1(*b*)] through the early involvement of the owner's resident construction manager. Personnel from the construction division of the design-construct firm started the program at 0% complete of detailed design or five-and-a-half months prior to the start of construction. An area project manager and an area construction manager, who later became the project constructability coordinator were added to the project. An additional area construction manager also participated in constructability. The project controls manager and an additional area project manager began participating in the constructability effort one month prior to the start of construction. These seven individuals represented the core constructability team. As a team, they provided input to design development, reviewed design documents, conducted "model-review" meetings using a scale model representing the facility, collected and evaluated constructability ideas, and maintained a project constructability savings log.

The formalized comprehensive tracking approach, implemented by the constructor on case study 3, began at 8% of detailed design. At this time, two full-time constructability coordinators were assigned to the design-engineering offices. One month later, the owner hired an outside constructability consultant to participate in constructability for a two-month period. The field construction manager started to provide constructability input six months prior to the start of construction. When construction was approximately 20% complete, the field construction manager was joined by one of the original constructability coordinators and a new field constructability coordinator. Each of these coordinators expended approximately 50% of their time during construction on constructability. The coordinator who arrived to the construction site from residence in an engineering office departed the project six months later, and the field coordinator remained on the project until completion of construction. These five individuals from the constructor's organization comprised the core constructability team.

Project participants were capable of providing estimates of effort-hours expended on program implementation. Additional estimates regarding the owner's and designer's effort expended through constructability participation were also obtained. The combined constructability effort consisted of approximately 14,900 effort-hours, or 0.40% of the total (direct and indirect) construction field-hours.

One benefit associated with an owner-implemented constructability program (case study 4) was the potential to incorporate constructability concepts during conceptual planning activities. This project was the first to implement the owner's program. The corporate constructability coordinator did not become involved until 75% of the project's predetailed design phase was

J. Constr. Eng. Manage., 1994, 120(1): 180-195

complete. The constructability coordinator was also responsible for several additional small projects (i.e., with typical total budgets of each less than $10 million). Approximately 5% of the coordinator's time was devoted to constructability. As detailed design was performed, several constructability meetings were held between the owner (also acting as design engineer) and representatives from the general and mechanical constructor's organizations. Effort-hours expended to implement the program including the effort of owner and constructor representatives totaled approximately 400 hr or 1.14% of total (direct and indirect) construction field-hours.

Estimated Total Cost

The estimated total cost of each approach is presented as a percentage of total project cost (see Table 5). These estimates provide guidance with respect to incurred costs.

Quantified Benefit/Cost Ratio

Three case studies maintained a log of ideas, estimated benefits, and costs for constructability implementation. Such data enabled a benefit/cost ratio to be calculated. A benefit/cost ratio of 10 to 1 was found for all three case studies. These ratios are based only on documented and quantified estimates of constructability savings. When one accounts for unquantifiable improvements such as construction sequencing, procurement strategies, and enhanced project coordination resulting from constructability participation, it is believed that the reported benefit/cost ratios are underestimated.

PRACTICAL APPLICATIONS

This section summarizes the practical applications associated with each of the three constructability approaches. The applicability of constructability approaches and steps taken by owners to facilitate constructability are discussed.

Applicability of Constructability Approaches

In case study 1, construction knowledge and experience was used to supplement the private developer's limited in-house project management capabilities. This program had no designated constructability coordinator, nor tracked benefits or costs attributable to constructability. Such tracking, however, may not be appropriate for a real-estate developer involved in a diverse set of projects ranging from shopping malls to office buildings. Investment in development and maintenance of a constructability lessons-learned database may be of limited value to the owner. On the other hand, constructors or construction management firms involved in this type of work may benefit from formalizing a constructability program. Such a program can be marketed as a service provided by these organizations.

In case study 2, the owner had previously documented and convinced themselves of the economic benefits of constructability. The owner has integrated the concept of constructability within the facility delivery process as part of their corporate philosophy. This owner elected to use a project-specific constructability program. The owner hired a design-construct firm to implement the program and track constructability savings. Lack of a lessons-learned database was offset by selecting a design-construct firm with whom the owner has a partnering relationship. In addition, the owner was insistent on obtaining project personnel with extensive experience on the owner's projects; 70% of the construction project team had worked on previous owner projects.

In case study 3, both the owner and constructor were familiar with constructability concepts and recognized the benefits of early construction input. The owner also recognized the benefit of employing an outside constructor experienced in constructing facilities of this type for other owners. The constructor was the best source of lessons learned and derived the most benefit from tracking cost and schedule savings as both a marketing tool used to demonstrate program effectiveness and a measure of the program's maturity.

The owner-performed comprehensive tracking approach used in case study 4 appears to be appropriate for owners involved in constructing facilities of a similar type. The project employing this approach included a small (total project cost below $5 million) standardized type of facility that the owner routinely builds throughout the U.S. Detailed design is frequently performed by the owner's own in-house staff. Due to the small size of these facilities, the source of constructors is often restricted to construction organizations within the local geographic area. Based on these items, the owner, being experienced in this facility type and serving as the designer, was the most logical organization to coordinate the constructability effort. Lessons learned, captured on a computerized database and maintained by a corporate constructability coordinator, provide maximum future benefits. Tracking of benefits and costs attributable to constructability serves as a useful measure of the program's maturity.

Steps to Facilitate Constructability

Owner organization and project characteristics should be considered prior to selecting a constructability approach. This enables the owner to determine the most appropriate approach to implement. The four case studies used three approaches to constructability implementation. Each case study used a different project participant to implement constructability: a construction management firm, a partnered design-construct firm, an experienced constructor, and the owner's own in-house corporate expertise. Appendix I lists additional steps taken by each owner to facilitate implementation.

CONCLUSION

This paper has compared four case studies that implemented three approaches to integrate construction knowledge and experience into the planning and design phases. The three approaches were: using a construction management firm during preconstruction, specialized-formal programming, and comprehensive tracking. Six attributes were used in the comparison: initiation of constructability input, documented benefit/cost data, extent of owner participation, formalized procedures, methods to track lessons learned, and designated constructability coordinator(s). The quantitative and qualitative benefits and costs were presented and compared. It is the writers' hope that this information will assist project managers in understanding what approach to implement and the benefits and costs associated with each approach.

ACKNOWLEDGMENTS

The first writer sincerely thanks the Constructability Implementation Task Force members, the Construction Industry Institute, and the National Science Foundation (grant No. MSM-9058092, Presidential Young Investigator Award), for financial support of the research described here. The writers also wish to thank the numerous individuals who provided the data analyzed in this investigation. Without their knowledge, expertise, and willing participation, this investigation would not have been possible.

APPENDIX I. OWNER PROVISIONS FACILITATING IMPLEMENTATION

Case Study 1

- Used guaranteed-maximum-price contract that included a shared savings incentive.
- Used a five-page contract clause included within terms-and-conditions of CM's contract that identified constructability activities to be performed as part of preconstruction activities.
- Used two competing construction management firms throughout the predetailed and detailed design phases. The additional CM was used to oversee the preconstruction effort provided by the CM implementing constructability on the project.

Case Study 2

- Conducted personal interviews of key individuals providing constructability input. Interviews focused on an individual's experience, ability to function as a team player, and communication skills.
- Constructed one field office to serve as project headquarters for all owner and constructor representatives.
- Insisted on minimal project team turnover.

Case Study 3

- Hired outside constructability consultant in addition to constructor's constructability coordinators.
- Assisted in joint development of project-specific constructability procedures.
- Implemented a formal team-building program.
- Implemented an incentives program that used common schedule milestones between engineering and construction to generate sense of interdependency between two organizations.

Case Study 4

- Supplied the corporate constructability coordinator.
- Maintained a corporate computerized lessons-learned database.
- Implemented an incentives program that offered constructor's 50% of documented constructability savings.

APPENDIX II. REFERENCES

"Constructability: A primer." (1986). *Publication 3-1*, Constr. Industry Inst., Univ. Of Texas at Austin, Austin, Tex.

Russell, J. S., Gugel, J. G., and Radtke, M. W. (1992a). "Benefits and costs of constructability: Four case studies." *Source Document 83*, Constr. Industry Inst., Univ. of Texas at Austin, Austin, Tex.
Russell, J. S., Radtke, M. W., and Gugel, J. G. (1992b). "Project-level model and approaches to implement constructability." *Source Document 82*, Constr. Industry Inst., Univ. of Texas at Austin, Austin, Tex.