Total Constructability Management: A Process-Oriented Framework

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Constructability, as defined by the Construction Industry Institute (CII), is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives [18]. Constructability is also defined as a measure of ease or expediency with which a facility can be constructed [10][12]. Finally, constructability is often portrayed as integrating construction knowledge, resources, technology, and experience into the engineering and design of a project.

Since CII formalized the term in 1986, extensive research has been conducted to document constructability concepts, develop implementation steps, identify barriers to implementation, and to quantify cost/benefits attributable to constructability. In the early 1990s, comprehensive research on constructability was undertaken by Vardhan and Yates. Contributions of this three-stage research are summarized below:

1. Analysis of data on constructability obtained from a survey of 61 architects, engineers, contractors, and project managers [22].
2. Development of a design process for implementing constructability during the architectural building design process [23].
3. Investigation into implementation of constructability concepts to provide additional insights regarding the importance of implementing constructability during design processes [24].

Despite the dissemination of constructability research documents, concepts, and roadmaps through the CII and other professional journals, effective implementation remains a complex issue among owners and engineering and construction firms. This issue is complex because effective implementation requires integration of construction knowledge and experience into multiple phases of the project development process.

Research is being conducted to examine the issue of integration. This research explores strategies that will provide a framework facilitating integration of constructability concepts with project development process phases—planning, design, construction, and maintenance/operation. Another research objective is identification of modeling techniques that can be used with the framework to describe when, where, and how integration should occur. This article presents the underlying concept behind the research. However, we first provide a brief review of recent constructability research and case studies that were published after the constructability research by Vardhan and Yates [24].

Recent Constructability Research

Even though constructability has had a positive impact on project performance parameters (cost, quality, and schedule), constructability programs often evolved through trial and error and suffered from the lack of a formal comprehensive approach. Limited data was available on implementation requirements and few informational tools existed to aid implementation efforts. This prompted the CII to focus more on implementation by sponsoring research under the guidance of the Constructability Implementation Task Force. For similar reasons, the Wisconsin Department of Transportation (WISDOT) sponsored research to develop a constructability work process for transportation facilities. In 1991 the American Society of Civil Engineers (ASCE) published a white paper on constructability. A summary of the results and findings obtained by the

CII, WISDOT, and the ASCE investigations is provided below.

1. *Constructability: Program Assessment and Barriers to Implementation* [13]. To develop tools to aid constructability implementation efforts, CII researchers from the University of Texas at Austin interviewed personnel from 62 companies performing constructability programs. Summary results include the following:

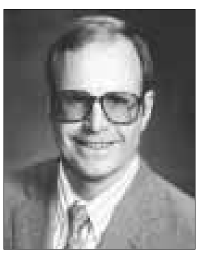
- Fifteen significant corporate and project parameters required for effective constructability implementation were identified, based on successful constructability programs. A Constructability Program Evaluation Matrix was then proposed that defines five distinct levels of program maturity—no program, application of selected supports, informal program, formal program, comprehensive formal program.
- Research identified 18 prevalent barriers to constructability implementation. The seven most significant barriers are complacency with the status quo; reluctance to invest additional money and effort in early project stages; limitations of lump-sum competitive contracting; lack of construction experience in the design organization; designer's perception that "we already do it"; lack of mutual respect between designers and constructors; and construction input requested too late to be of value.
- Barrier-breakers for these seven most common barriers are proposed. For example, to change complacency with the status quo, a recommended barrier-breaker is to designate a strong program champion.

2. *Project-level Model and Approaches to Implement Constructability* [14]. As part of the CII investigation, researchers from the University of Wisconsin-Madison collected data from 262 organizations by means of a questionnaire. This research concluded that:

- Approximately 78 percent of owners, designers, contractors, and professional construction management firms surveyed have either informal constructability programs or none at all. As a result, these organizations experienced difficulty in consistently applying constructability concepts on projects; in estimating the cost effectiveness of early involvement of construction personnel; in generating, storing, and efficiently retrieving constructability lessons learned from previous projects; and in creating a team environment between designers and contractors.
- An organization's approach to constructability implementation is highly dependent on the project type, contract strategy, and variety of projects handled by the organization.
- Organizations tend to evolve through various constructability approaches before achieving the optimal type of constructability program.
- Constructability planning must be integrated into the project execution plan.

3. *Benefits and Costs of Constructability: Four Case Studies* [15]. Using data from questionnaires, personal interviews, and case studies, CII researchers from the University of Wisconsin-Madison provided a comparative analysis of three different approaches owners used to provide constructability input to their projects. These three approaches were referred to as constructability services, a specialized formal constructability program, and a comprehensive tracking approach. This research also compiled

About the Authors



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quantitative and qualitative benefits attributable to each of three approaches studied in four case studies. Additionally, benefits-costs and performance implications are provided. A reduction of 1.1–10.7 percent in total project cost was reported as a direct result of implementing constructability. Program cost ranged from .09–1.1 percent of total project cost—giving an approximate 10:1 benefit-to-cost ratio.

4. *Constructability Implementation Guide* [20]. This comprehensive implementation guide by CII summarizes the research discussed in items 1, 2, and 3 above. The guide provides a methodology for implementation referred to as a "Constructability Implementation Roadmap." An explanation of each component of the roadmap is provided. Nineteen constructability implementation tools are offered that aid in developing and sustaining an effective constructibility program. The tools contain barrier assessment forms, concept application matrices, suggested policy statements, and so forth. Case studies of successful project constructibility programs are also included. Quantified costs and benefits are discussed.

5. *Investigation of Constructability Concepts and Tools for Highway Construction* [16]. This research developed a "Highway Constructability Work Process" for transportation facilities. The process is divided into two phases: pre-contract award constructability and post-contract award constructability. Each phase has specific steps described in some detail. The pre-contract award stage is linked to project planning and design while the post-contract award phase relates to project construction. Twenty-seven different tools are presented that can aid in implementation. One tool shows specific points in the WISDOT project development process where other tools and lessons learned should be applied. A case study application of the process is also described.

6. *The Construction Management Committee of the ASCE Construction Division's White Paper on Constructability* [21]. This paper stressed the importance of integrating constructability with project development phases as suggested by the following statement:

> *"… an effective constructability program requires corporate backing of the program. Procedures that accomplish this integration of engineering and construction have to be provided and used as an integral part of any project implementation plan. Constructability has to be considered as an equal discipline to civil, mechanical, and electrical engineering, etc., so that the organization as a matter of course includes the constructability elements in all phases of the project."*

Current research on constructability provides general steps toward implementation and many tools. A need still remains for a framework and tool that clearly links constructability process steps to specific project development process phases and activities within these phases.

Framework for Modeling the Constructability Process

A major challenge of successful implementation is how to effectively integrate construction knowledge and experience into various phases of a project development process. This issue of integration is very complex and dynamic. A robust process-oriented framework is proposed for portraying when, where, and how integration should occur. This framework must capture inputs, process steps, and outputs, in addition to factors that cause variation in the process itself. Variation occurs as a result of differing organizational environments, project characteristics, project organization approaches, and data acquisition and utilization policies. The framework must also demonstrate how different processes are linked together. The benefit of a process-oriented strategy is a framework that can be adapted to fit the unique characteristics and requirements of each project and each organization. A detailed approach to constructability can then be derived from the framework and existing research.

In this article, we propose a conceptual framework for integrating the constructability process with the project development process. This framework is referred to as Total Constructability Management (TCM). TCM is defined as *the optimal integration of constructability concepts into the various phases of a project development process by using a total quality management customer-oriented focus.*

TCM and Total Quality Management

Total Quality Management (TQM) principles and concepts provide an approach for understanding and describing a process. TQM is generally accepted to be a people-oriented, measurement-driven, customer-focused management philosophy using a structured, disciplined operating methodology [3] [7]. This philosophy stresses a systematic, integrated, consistent, organization-wide perspective involving all employees. The primary emphasis of TQM is total satisfaction for both internal and external customers, within a management environment that seeks

Table 1. Similarities Between TQM and TCM

TQM	TCM
• TQM promotes integration and coordination of productive activities within the organization. It envisions the integration of engineering, manufacturing, marketing, finance, and accounting functions to provide better quality to the customer.	• TCM is a framework to integrate constructability and quality into various phases of project development—planning, design, construction, and maintenance/operation.
• TQM encourages self-management and participative decision making, thereby constituting a substantial change in the manager's role.	• TCM helps dismantle the traditional barriers between design and construction teams by increasing lateral flow of information and ideas.
• Under TQM, shop-floor teams become involved in communication and coordination with teams in other departments and units.	• Under TCM, construction teams become involved in communication and coordination with design and procurement teams.
• Under TQM, the requirements of the final customer drive a demand-pull sequence of relationships, where the goal of each stage is to satisfy the requirements of the subsequent stage.	• TCM focuses on customer needs as well. For example, a customer focus in a design team ensures that drawings are based on constructor and vendor requirements.
• Helps decrease costs by reducing wasteful activities, rework, scrap, and after-sales repairs.	• Helps decrease costs by reducing design rework, change orders, and schedule delays.
• TQM results in a flatter organizational structure. It helps change managers' priorities: their decision-making and control functions shrink, and their roles as consultants and coaches grow.	• TCM strives for the same goal by encouraging experienced managers to come out of their control functions, and to provide invaluable hands-on input during the various phases of a project.

continuous improvement of all processes. Thus, TQM has a process focus.

TQM philosophy also emphasizes the use of teams, often multifunctional in makeup, to facilitate improvement from within the organization. It stresses optimal life cycle cost and uses measurement to improve key work processes. TQM advocates developing positive work relationships between employees, suppliers, and customers.

Each attribute of TQM mentioned above is vital to TCM if a constructibility process is to be effective and applied continuously by participants throughout the project development process. As a consequence, constructability can be viewed as a subset of TQM. A conceptual framework for integrating constructability with various phases of a project development process can be successfully built upon the basic tenets of TQM. Table 1 demonstrates how TCM is related to TQM tenets.

Conceptual Representation of the TCM Framework

A conceptual representation of the TCM implementation strategy is shown in Figure 1. In Figure 1, influence of both constructability and TQM are depicted in terms of basic principles and concepts, current approaches, and tools and techniques. Other factors influencing an innovative constructability process are project and organizational characteristics. Project development process phases—planning, design, construction, and maintenance/operation—are also shown. Linkages between project development process phases and the constructability process are shown with decreasing strength of influence over time.

Information and expertise is available for each component of the TCM framework depicted in Figure 1 from the following sources: the six studies discussed in earlier section entitled "Recent Constructability Research"; TQM [3] [4] [6] [7]; other constructability studies [9] [10] [19]. This information forms basic building blocks for developing a constructability approach specifically applicable to any particular type of organization and project. Another characteristic of the TCM framework is the ability to portray the effect of decreasing influence of the constructability process during each phase as the

Figure 1. Generalized Representation of Total Constructablility Management Framework

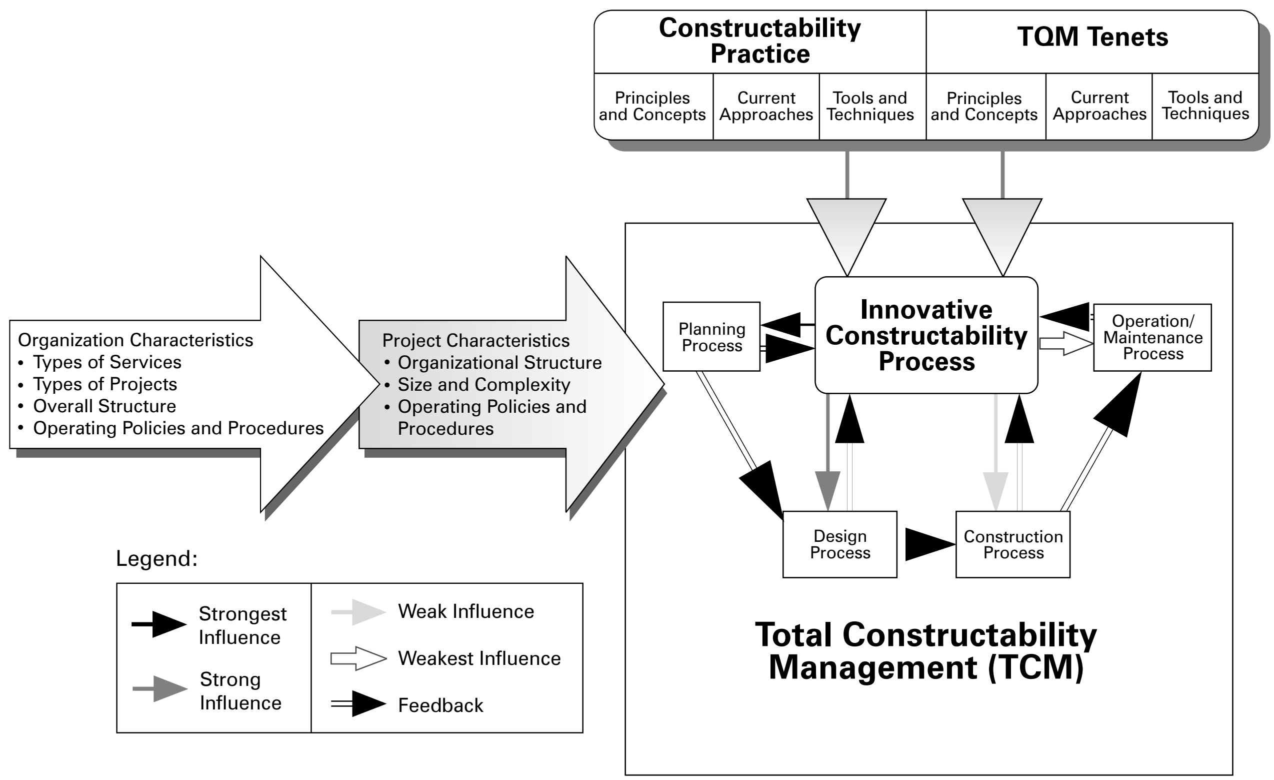


Figure 2. Context (Boundary) of Total Constructablility Management Framework

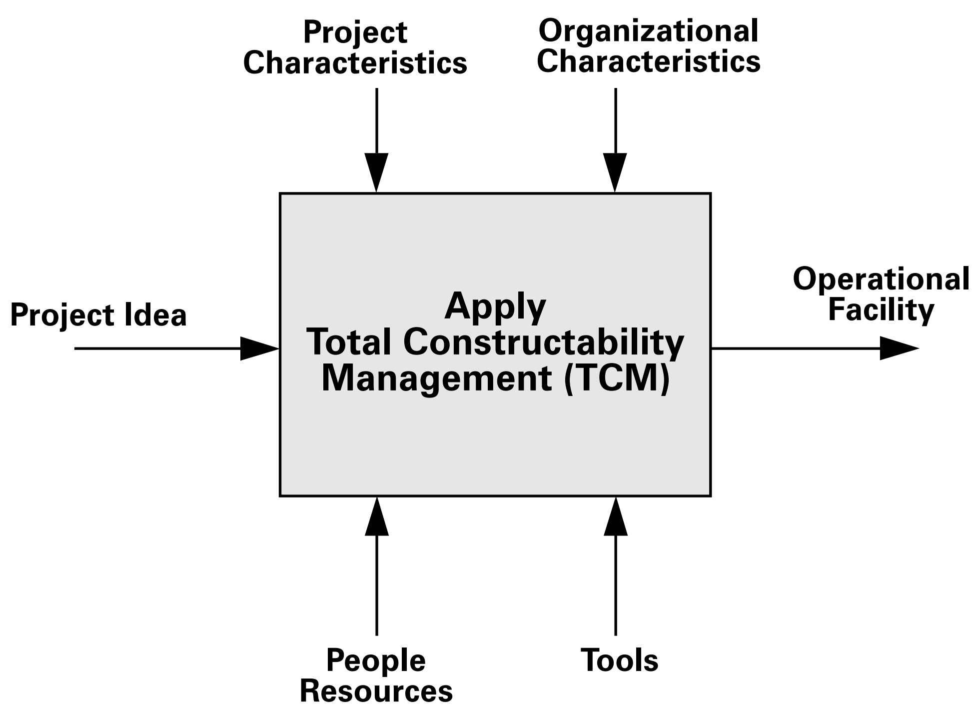
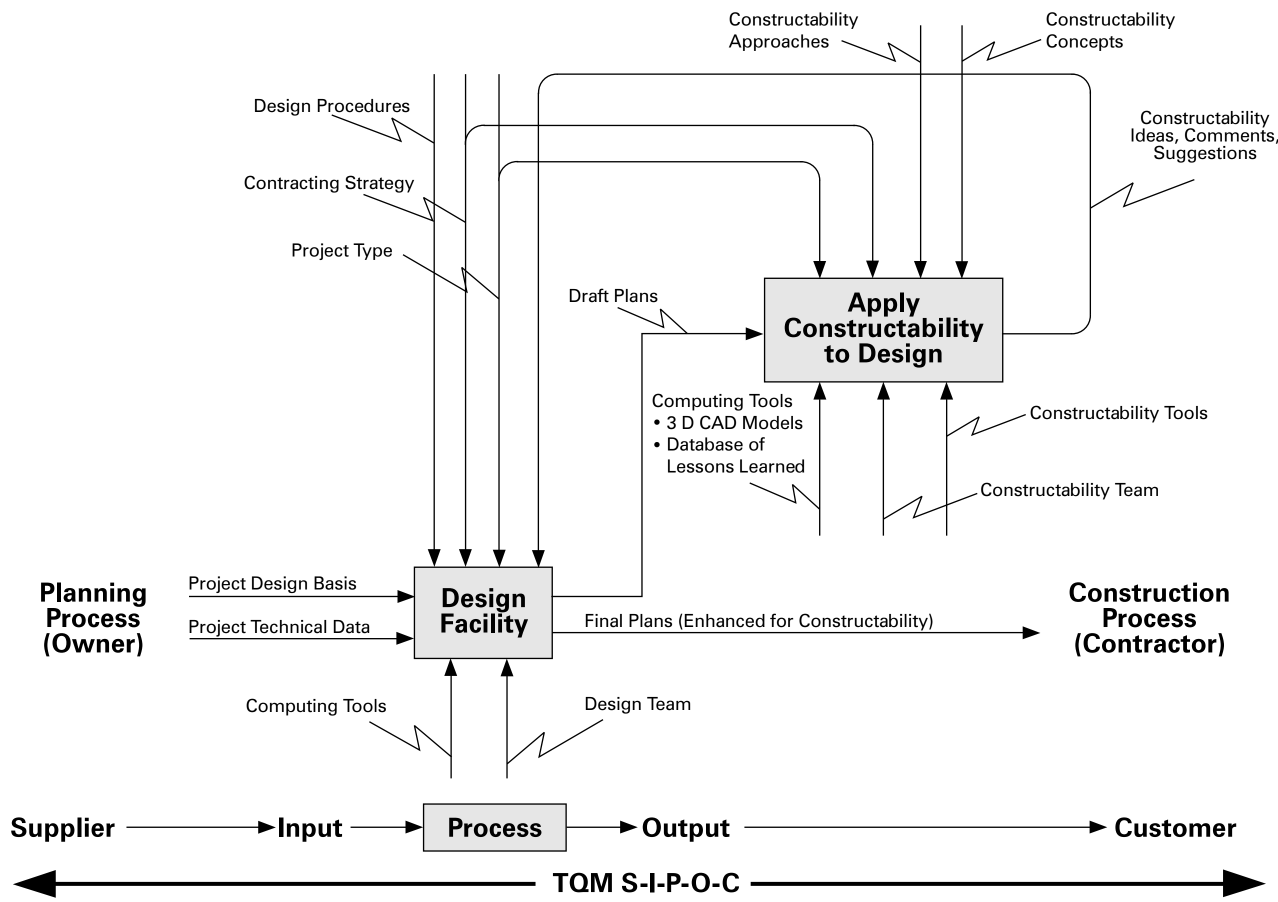


Figure 3. Application of TCM Framework During Design



project moves through its life cycle. For example, input from an innovative constructability process during the planning process will have a high impact on reducing cost and schedule of the project [20]. This impact will substantially decrease during the construction process. Therefore, the constructability process is applied differently in these two phases, and must be modified accordingly.

Illustration of TCM Framework

A primary objective of TCM is to produce an operating facility that is efficient, high in quality, meets technical design requirements, and is profitable. To accomplish this in a cost effective and timely manner, integration of construction knowledge and experience must occur from project inception with an idea that is transformed, over time, into an operating facility. Within this boundary, applying TCM is constrained by project and organizational characteristics. Resources used to perform TCM include people, computers, and constructability implementation tools. This context for TCM is illustrated in Figure 2.

At a lower level of abstraction than is shown in Figure 2, TCM is illustrated in Figure 3 in terms of two components—*Design Facility* and *Apply Constructability to Design*. These two activities are performed concurrently during the design process of project development. The basic representation is portrayed as a Supplier-Input-Process-Output-Customer (SIPOC) chain. In Figure 3, the supplier to the design process is the planning process, consisting of concept development and project feasibility analysis. Generally, the owner performs the planning process and provides the project design basis and key technical data as inputs for design. These inputs are transformed by the *Design Facility* process with final plans, enhanced for constructability, as key outputs. The customer of the *Design Facility* process and user of the output is the contractor responsible for construction.

As depicted in Figure 3, draft plans are also outputs of the *Design Facility* process only used internally by the project. These draft plans become inputs to the *Apply Constructability to Design* process where they are evaluated in terms of their ease and efficiency of construction. Constructability ideas, comments, and/or suggested changes are process outputs. The supplier of constructability comments is the constructability team and the customer of these outputs will be the design team. The design team must incorporate constructability ideas into the design to achieve the external output of the design process—final plans that are enhanced for constructability. Thus, there exists an internal SIPOC that identifies the interface between design and the application of constructability, facilitates the lateral flow of information, and ultimately promotes the integration of construction knowledge and experience into facility design. This SIPOC is most effective when iterative over the duration of the facility design phase.

There are other factors that influence both design and constructability processes as noted in Figure 3. These factors can cause variation in the process and must be considered when applying the TCM framework. Organizational characteristics will determine types of services provided and areas of expertise, as well as the resources that are brought to bear on design and constructability. As an example, state transportation agencies design and build highways. Many perform in-house design while others out-source design. This impacts the agency organization in terms of expertise required for projects, design procedures used, and contracting strategy for procuring design. This will also affect the detailed steps and procedures that describe the *Apply Constructability to Design* process.

Organizational characteristics naturally influence project characteristics such as the specific type of project, the design team selected, and manner in which this team is structured to incorporate a constructability team. These issues are determined procedurally through the constructability approach adapted by the organization for projects. The type, nature, detail, and how constructability ideas, comments, and suggestions are acquired, as shown in Figure 3, depend to a great extent on resources such as the use of CAD for constructability analysis, a computer-automated database for retrieving appropriate lessons learned from past projects, constructability tools, and the project contracting strategy that may influence the makeup of the constructability team.

A comprehensive application of constructability, based on the TCM framework, can be developed that portrays inputs, process steps, and outputs with a focus on the customer of each step. For example, using the CII roadmap [20], *Apply Constructability to Design* process might be decomposed into *Obtain Constructability Capabilities, Plan Constructability Implementation,* and *Implement Constructability*. Example steps for these stages would be to *Develop Project Constructability Procedures* and *Integrate Them into Project Activities* and to *Apply Constructability Concepts and Procedure,* respectively. An appropriate decomposing of *Design Facility (Perform Preliminary Engineering, Develop Plans and Specifications,* and *Review and Approve Final Design)* must occur simultaneously so that appropriate points of interface can be determined, allowing for the timely integration of construction knowledge and experience. TCM also provides a framework for considering other factors acting on processes as a result of both organizational and project characteristics. These characteristics will vary and will influence the transformation of inputs to outputs associated with project development phase processes and constructability as it is integrated into each process. Finally, TCM provides insights into developing a constructability process based on existing constructability practices and TQM tenets that can lead to continuous improvement as new projects are started and others are completed.

To support actual application of the TCM framework, a process modeling tool is recommended. This tool must possess capabilities to model, in detail, the attributes of TCM shown in Figures 2 and 3 and discussed in this section. The next section presents one process modeling tool that has the potential to fully develop the TCM framework.

Process Modeling Tools

Chung [6] and Gibson [8] examined different process modeling tools. Both researchers concluded that the tool selected should be hierarchical, modular, standardized, and capable of representing complex processes common to design and construction of capital facilities. Moreover, we suggest that the tool must clearly separate inputs that are transformed by a process and those that either guide the process or are used to facilitate the transformation of inputs to outputs.

The IDEF0 modeling technique described by Mayer [11] is recommended as a tool to model the constructibility process for two primary reasons. First, IDEF0 meets the above-mentioned criteria. Second, IDEF0 has been used successfully by researchers and construction companies to model construction processes [8] [17].

IDEF0 uses Cell Modeling Graphic Representation. The "box and arrow" graphics show the function (or process) as a box and the interfaces to or from the function as arrows entering or leaving the box. Functions (i.e., boxes) operate simultaneously with other functions, with the interface arrows "constraining" when and how functions are triggered and controlled.

A function is described as a series of activities that takes an input, modifies the input, and produces an output (i.e., a process). Input arrows represent information, data, or objects that are transformed by the function. Output arrows reflect objects, information, or data produced by the function (i.e., inputs that are transformed by function performance). Control arrows, entering the top of the box, describe data or information that governs the accomplishment of the function or influences function output. Finally, mechanisms (arrows entering from the bottom of the box) are people or devices such as computers that carry out the function.

IDEF0 provides ideal modeling capabilities for extending the TCM framework to a detailed approach for constructability implementation. The use of mechanisms allows for the representation of key project team personnel who carry out the process. Mechanisms are also computer automated systems like CAD or a lessons-learned database. Moreover, the use of controls in IDEF0 modeling facilitates the portrayal of data or information that may constrain the transformation of inputs to outputs such as contract type or a specific company policy. Both mechanisms and controls provide a vehicle to represent different characteristics from the project environment that influence process performance. This feature will facilitate analysis of how the transformation of inputs to outputs might be affected by changing these characteristics. Finally, two distinctly different but related functions can be modeled using IDEF0, then linked via inputs and outputs as shown in Figure 3. This occurs at each level of decomposition.

A key requirement of a robust process-oriented framework is the capability to model different project characteristics and effects of organizational constraints. IDEF0 can identify the types of key factors that impact a process. However, an analysis such as that demonstrated by Anderson and Woodhead [1] [2] is necessary. For example, Anderson and Woodhead's [2] network modeling technique, which is similar to IDEF0, demonstrates how a project management decision-making process, such as project scheduling, is influenced by changing project characteristics. These characteristics are a function of the project environment. Anderson and Woodhead's project environment corresponds to projects constructed at the small, medium-sized, and large firm levels. Under their approach, the basic functions that comprise the project scheduling decision process are similar at each firm level. The manner in which the functions are performed changes when moving from the small to the large firm project environment. Changing function performance results from the influence of project size, type, technical complexity, location, and contracting strategy. Changes are manifested in differences in inputs and outputs for each project scheduling function. Variation in inputs and outputs are, for example, caused by different policies, information systems used, and the roles of key project team players associated with projects common to each firm level.

The IDEF0 modeling tool facilitates extending the TCM framework to a detailed application level. By using this technique and analyzing the impact different attributes have on process functions, similar to the Anderson and Woodhead approach, a dynamic and fully integrated process for implementing constructability can be achieved. Research is currently under way to develop a comprehensive Total Constructability Management application.

Summary

We have described a framework for developing an innovative constructability process for enhancing project plans, specifications, and contract documents. The framework is based on the concept of Total Constructability Management and is built on existing constructability research and basic tenets from Total Quality Management. Identifying key interface points between project development process phases and the constructability process is a critical feature of the TCM framework. Once these interface points are identified at each level of decomposition, a comprehensive model can be developed that portrays inputs, process steps, and outputs, with a focus on the customer of each process step. By expanding the process depiction to specifically identify organizational and project-driven characteristics (such as design and construction teams, analytical computing tools available, and contracting constraints), a timely and efficient transformation of inputs to outputs can be achieved. A process modeling tool, IDEF0, is proposed in conjunction with the Anderson and Woodhead network approach to fully develop the TCM framework. A robust and flexible constructability process can then be designed to help eliminate barriers to implementation, to fully integrate construction knowledge into the project in a timely fashion, and to set a benchmark for continuous improvement.

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