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Constructability: The key to reducing investment risk[3]

Abstract

The National Technology Roadmap for Semi-conductors indicates that the growth of the advanced technology factory cost is creating an exponential growth in factory investment risk. Management techniques are needed to help reduce that investment risk. Constructability implementation, if performed right, is a management concept that has been shown to reduce construction costs by 10 to 20 times its implementation cost. A corporate and project level constructability implementation program was developed by the Construction Industry Institute (CII) to help integrate construction knowledge with engineering, beginning at project inception. This article provides an historical base describing the development of constructability, constructability program criteria, and the constructability review process.

Keywords: Constructability development, management.

KONSTRUKSIE-KUNDIGHEID: DIE SLEUTEL TOT 'N VERLAGING IN BELEGGINGSRISIKO

Die *National Technology Roadmap for Semi-conductors* in die VSA vestig die aandag op aanwysers ten opsigte van gevorderde tegnologiese fabriekskoste wat dui op 'n toename in fabrieksbeleggingsrisiko. Bestuurstegnieke is nodig om hierdie beleggingsrisiko's die hoof te bied. Konstruksie-kundigheid, reg aangewend, kan as 'n strategiese bestuurskonsep konstruksiekoste met 10 tot 20 keer die implementeringskoste verlaag. 'n Implementeringsprogram op korporatiewe en projekvlakke is ontwikkel deur die *Construction Industry Institute* (CII) om hulp te verleen met die integrering van konstruksiekennis met ingenieurskundigheid vanaf die uitset van 'n projek. Hierdie artikel gee 'n historiese blik op die basiese vertrekpunt in die ontwikkeling van konstruksie-kundigheid, die kriteria vir 'n konstruksiekundigheidsprogram en die hersieningsproses van konstruksie-kundigheid. Verder word 'n duidelike raamwerk vir die implementering van hierdie konstruksiekundigheidsprogram aangedui, soos dit in ontwikkelde tegnologiese industrieë toegepas word.

Sleutelwoorde: Konstruksie-kundigheidsontwikkeling, bestuur.

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1. Introduction

Construction projects are evolving from a reactive to a proactive environment. Constructability is re-emerging as a proactive program that has shown a positive effect on project quality, cost, and duration. The master builder of historical times combined the architect/engineer and constructor into one entity. During the 1940s and 1950s, the US construction industry experienced a separation of design and construction that resulted in declining construction value and quality (Alaydrus, 1944). The division of the master builder's responsibilities has, over time, created an atmosphere that breeds construction and quality problems, resulting in increased rework and unnecessary cost (Ganthner, 1997). The construction industry as a whole is in the process of reestablishing the historical master builder concept of the architect/engineer and constructor working as one entity. Even though a variety of organizations participate in a project's life cycle, only the owners, architect/engineers, and constructors can ensure a project's success (Ganthner, 1999).

2. The history of constructability

Concerned with identifying the cause of the decline in construction quality and wanting to identify possible solutions, chief executive officers from major US corporations formed the Construction Users Anti-Inflation Roundtable in 1969. In 1972, this organization merged with others to form what is known today as the Business Roundtable (CICEP, 1983).

During the late 1970s, the Business Roundtable funded 23 separate studies, called the Construction Industry Cost Effectiveness (CICE) project, to uncover causes and provide recommendations for reversing the construction industry decline in quality, efficiency, productivity, and cost-effectiveness (Pritchett, 1986). Report B-I of the CICE project, *Integrating Construction Resources and Technology Into Engineering*, addresses the significant savings in both costs and project duration obtainable from the careful interaction of construction with planning, design, and engineering into projects (CICE, 1983).

One case study reported by the CICE project, *Report BI*, was a $45 million new site synthetic detergent plant. The contractual agreement stated that the owner's architect/engineering department would lead conceptual design. Project definition and design were performed by an architecture/engineering firm, and construction management was performed by a general contractor. Both had cost-reimbursable contracts and had no previous experience working together. Constructability implementation began during the project definition and design phase. The integration cost was assessed at $75 000 for personnel and travel associated with the architect/engineering team involvement. Schedule and quality benefits were hard to quantify, but conservatively were identified at $615 000, a return of more than eight to one.

The CICE project report concluded that significant benefits, such as reducing project costs and schedules, could be obtained by the thorough integration of construction expertise with project engineering, if certain barriers are overcome. Some owners do not demand or support an integrated process because they do not understand or appreciate the potential benefits and attractive rate of return on the comparatively small investment. Contractors do not fully implement constructability programs unless they have owner support. Most contracts are not written to provide an incentive for contractors to integrate construction and architecture/engineering. In addition, the report identified a significant shortage of personnel qualified to significantly contribute to the integration process.

From the CICE project research, it was determined that more than half the time wasted during construction could be attributed to poor management practices. In response to the research findings, constructability, the integration of construction knowledge and up-to-date construction technology into architecture/engineering, was recommended. When owners are willing to pay the small extra cost of implementing more sensible methods of construction, they will reap the benefits of more construction for their dollar. For example, emphasis on improved, safe construction methods could result in a cost reduction equal to 8 percent of the direct construction labour payroll.

Improved materials management could save an average of 6 percent of project labour costs. The support of contractor training programs for foremen and general foremen could expect a return of at least three-to-one on the investment. Constructability has been shown to reduce construction costs by 10 to 20 times its implementation cost. In dollars, that would equate to a $1 million return for an outlay of $50 000 on a $30 million project (CICEP, 1983).

The *Construction Industry Institute* (CII) was formed in 1983, with one of its research focal points to improve the construction industry through new management methods and techniques (Oglesby 1989). Member organisations and university faculties participate in specialised task forces to identify needs, conduct research, and implement results. Acting on the CICE project suggestions for the development of constructability training and reference manuals, the *CII Constructability Task Force* was established to identify and sponsor research relating to the integration of construction knowledge and experience into architecture/engineering (Schappa, 1989). Conclusions from this task force were published in several publications by CII in 1986, 1987, and 1993.

3. Advanced technology construction

Construction costs for advance technology facilities could increase from a current $1 billion to an estimated $10 billion by the year 2005. Directly related to this construction cost are the increased requirements of tool operational effectiveness, the ability of tools to process wafers at their maximum capacity throughout the manufacturing process. To meet the tool operational effectiveness requirements, larger, more complex facilities are considered necessary. Facility complexities refer to water, gas, chemical, air, exhaust, and waste distribution systems, in addition to the extensive building automation controls required by the semiconductor production process. Larger factories with more complex systems, coupled with changes in feature size and wafer diameter, significantly increase the manufacturing company's investment risk (NTRS, 1999).

Future manufacturing requirements are also in direct conflict with the time needed for factory construction, tool installation, and factory ramp. In the advanced technology industry, time from factory groundbreaking to first wafer start has doubled over the past 12 years, leading to increased investment risk. By the year 2012, the advance technology industry desires a first wafer start in approximately 12 months from the strategic planning phase, reduced from approximately 24 months in 1997 (NTRS, 1999). This desire implies a design/construction sequence of 9 months. To meet this demand, the elements of factory construction and manufacturing process preparation must be shortened and performed in parallel, as graphically represented in Figure 1. Shortening construction time is expected to decrease overall project cost and thus reduce capital investment risk.

The project life cycle refers to the complete project, beginning with the strategic planning phase and progressing through the conceptual planning phase, schematic design phase, construction, tool install/qualification, and terminating with facility operation/tool ramp. Focus on the strategic planning phase through the construction phase for the constructability program implementation is necessary because CII research indicates that a maximum investment return can be realised during this time frame.

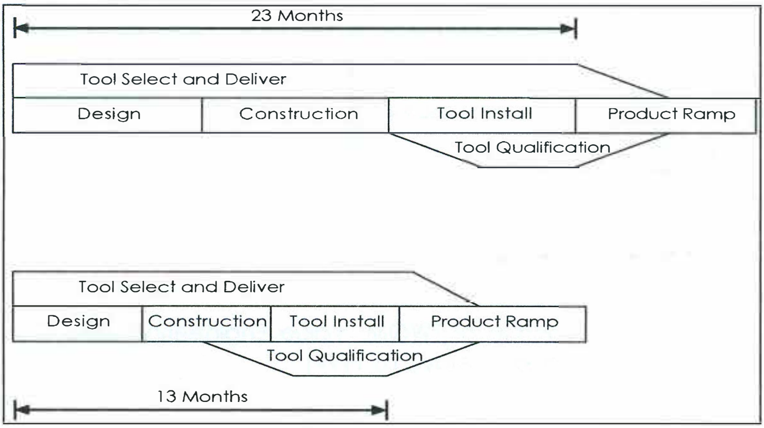

Figure 1: Time to First Wafer Start (Predmore, 1999)

4. TQM, value engineering, and constructability

The objective of TQM, value engineering, and constructability is to deliver a quality product in a manner that will provide the client with the most value per investment dollar. All three are management methods designed to jointly achieve the overall project objective. The difference between these methods is their focus. TQM is focused on installing quality into all aspects of construction. Value engineering is focused on the functionality of the process. Constructability is focused on improving the process of how the facility is built. Total quality management, value engineering, and constructability are not mutually exclusive (Figure 2). Value engineering and constructability are complementary management methods that may be used as elements to achieve total project quality (Alaydrus, 1994).

At some point throughout the project life cycle the owner, architect/engineer, and constructor will each play the role of customer and supplier. The owner supplies the scope to the architect/engineer, the architect/engineer supplies the plans and specifications to the constructor, and the constructor supplies the built facility to the owner (Juran, 1988). The principal focus of TQM is for each supplier to identify and satisfy or exceed the customer's needs in terms of cost, quality, and time.

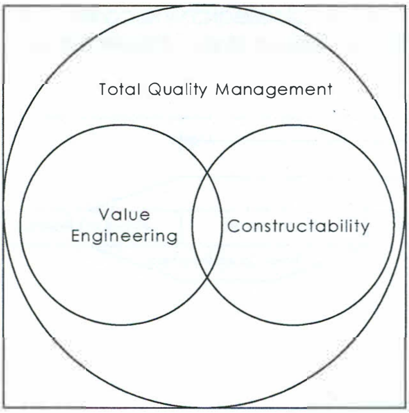

Figure 2: Relationship of TWQM, Value Engineering, and Constructability (Alaydrus 1994)

Characteristics	TQM	Constructability
Performance Driver	Customer	Architect/Engineer's Customer - Constructor
Principle	"Do it right the first time"	Problem Avoidence, Optimize Contruction Process
Growth	Continuous Improvement	Document Lessons Learned

Table 1: TQM and constructability comparison (Alaydrus, 1994)

Criteria	Value Engineering	Constructability
Focus	Overall reduction of life cycle cost.	Optimize construction process in terms of construction cost, schedule, safety and quality.
Implementation	A brainstorming session where life cycle cost alternatives is considered for systems components while maintaining design function.	An integral part of project management and scheduling allowing construction knowledge and experience to be integrated into project planning and design.
Timing	Performed during design phase	On-going from conceptual planning through construction and start-up.

Table 2: Value engineering and constructability comparison (Alaydrus, 1994)

TQM and constructability are proactive approaches stressing commitment from all personnel. Using a teamwork approach, the mutual goal is to instil quality into the final product. Table 1 compares the TQM and constructability working relationships.

The differences between constructability and value engineering are the analysis objectives and the point of application within the total project life cycle. The analysis objective of value engineering is to reduce the facilities total life cycle cost, whereas constructability focuses upon optimisation of the construction process (Table 2) (Alaydrus, 1994).

Value engineering is performed during the document development phase. At this point critical design decisions dictating construction methods have been made with the assistance of a construction expert. Implementation of both methods within the project life cycle maximises overall project cost reduction, time reduction, and quality increase (CII, 1993).

Constructability is most beneficial if performed during the conceptual planning phase before the project scope is defined, because construction knowledge and experience are less restricted by design decisions. The benefit of implementation before project scope definition will be the realisation of maximum cost and time reductions.

5. Constructability

The formal definition of constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives (CII, 1986). Constructability is the process of doing everything possible to make construction easier, improve quality, safety and productivity, shorten construction schedules, and reduce rework (Kerridge, 1993). Both definitions indicate that beginning in the strategic planning stage, project construction methods must be considered and continue to be developed throughout the project life cycle. Too often, construction managers are not involved until the crafts are mobilised to begin site operation. Their efforts are usually concentrated on site with only occasional visits to the architect/engineer's office.

The CICE research indicated that a significant percentage of a project's results are fixed during the first 25 percent of the architect/engineering design and programming. Therefore, the greatest effect potential on a project's overall outcome is before the design phase (Figure 3), when basic decisions are made.

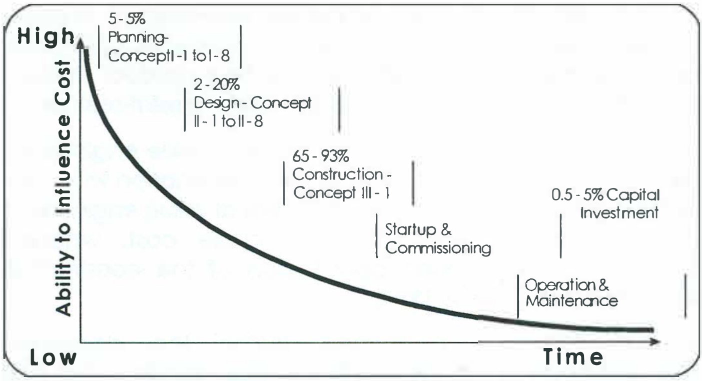

Figure 3: Time/cost relationship of constructability implementation (Russel 1998)

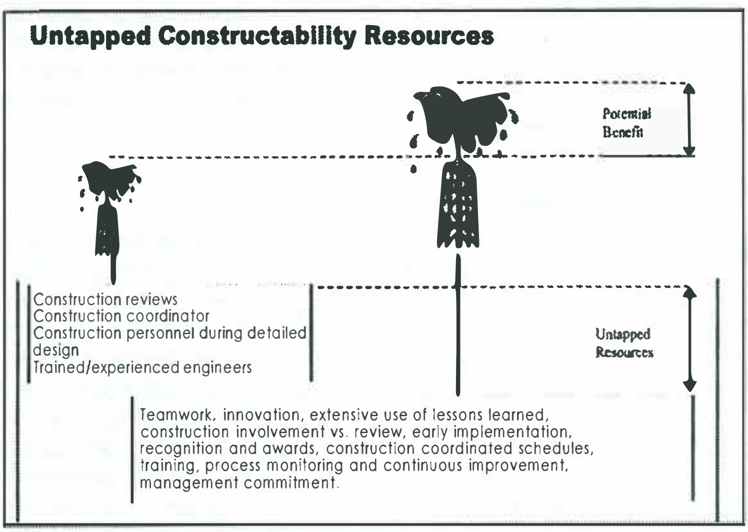

Figure 4: Untapped constructability resources (Alaydrus, 1994)

Constructability programs were originally developed to achieve the level of design and construction integration once achieved by the master builder. The application of construction knowledge and experience to the strategic planning, design, procurement, construction, testing, and start-up project life cycle phases by construction personnel who are part of the project team will enhance the project's overall objectives, by optimising the overall project plan, design, schedule, costs, and building methods (ASCE, 1991).

During the total project process, the architect/engineer (A/E) is responsible for developing a design that, when implemented by the builder, produces a project that meets the owner's needs and expectations (Galvinich, 1995). Many architect/engineers have never been exposed to field operations; therefore, they cannot visualise the labour and equipment sequencing required to construct the project. Project design should incorporate economical building techniques that employ acceptable standard construction methodologies and afford the contractor opportunities to use innovative ideas, materials, methods, and equipment (*Civil Engineering*, 1986).

Most plans and specifications specify material use and end-results. These prescriptive oriented plans and specifications, which restrict the means and methods for accomplishing the work, are in sharp contrast to the master builder concept of architecture/engineering and construction integration.

Due to the rapidly changing technology and the current legal environment, the A/E cannot assume an all-encompassing role. It is to the benefit of all project participants that the constructor be given the opportunity to use his/her full experience and expertise for project construction. When the A/E's only concern is the end result, he/she fails to conceptualise necessary construction methods and processes, and the builder is delegated significantly increased responsibility for the project success. These responsibilities can manifest themselves as conflicting requirements, possible schedule delays, inefficient resource use, and out-of-sequence work producing a devastating effect on the project's schedule and budget (Galvinich, 1995).

6. Constructability program

To help eliminate construction problems, a constructability program must be implemented. A constructability program is the application of a disciplined, systematic optimisation of the construction-related aspects of a project during the planning, design, procurement, construction, test, and start-up phases by knowledgeable, experienced construction personnel who are part of the project team. The program's purpose is to enhance the project's goals by optimising the overall project plan, planning and design, construction schedule, costs or estimates, and construction methods.

Constructability may be implemented in varying degrees of formality. Informal constructability approaches are usually indistinguishable from other construction management activities and include design reviews and construction coordinators. Formal programs usually have a corporate philosophy and a documented program that involve tracking past project lessons learned, team-building exercises, and project planning participation by construction personnel. Figure 4 is a graphical representation of how the resources of a formal constructability approach may yield greater benefits than an informal approach (Alaydrus, 1994).

7. Barriers to constructability

The CICE project research identified seven barriers that reduce the effectiveness of construction integration (CICE, 1983):

- Resistance by owners: Constructability programs add highly visible extra costs to projects but the benefits are less tangible
- Tradition: Construction persons are unaccustomed to being involved during project planning and working in architect/engineering offices
- Resistance by architect/engineers: Construction experts are sometimes perceived as meddling and troublesome during design
- Shortages of qualified personnel: It may be difficult to obtain qualified construction personnel
- Training: Neither industry nor schools are training people in the integration of construction with architect/engineering
- Incentives: The incentives for contractors to expand integration are minimal
- Priority: Integration has a low priority on many projects because owners are unaware of the potential savings.

In an effort to counterbalance the highly visible extra costs of a constructability program, the constructability review fallacy was created. The review fallacy occurs when constructability is approached solely as a design review process, which is inefficient and ineffective. Construction personnel are excluded from the planning and design process, when maximum cost effect occurs, only to be invited to review completed or partially completed designs. This method creates an atmosphere of contention between the architect/engineer and constructor. After a design is partially complete and a review takes place, the architect/engineer has already publicly committed to the drawings. At this point, the construction reviewer will be reluctant to provide input lest he/she is perceived as being overly critical. In addition, at this point within the project life cycle, design changes are an expense of cost and time due to rework.

Constructability viewed in this manner is not an integration of architect/engineering and construction; therefore, it will not produce the results of cost and time reduction. The frequently cited rationale for implementing constructability in this manner is the ease of contracting a constructability service and the tangible deliverables in the form of marked-up drawings. The review fallacy also indicates that the construction industry does not understand how and when a constructability review should be implemented. Industry application of constructability reviews is usually at the completion of design. A review at this time reaps low return because it takes place too late within the project life cycle.

Resistance between constructors and architect/engineers consists of two aspects, the lack of ability to communicate effectively with each other and the timing at which the constructor's perspective is requested. If the constructor and architect/engineer work together during strategic planning, a mutual respect is developed, creating a positive atmosphere. Qualified construction personnel are available, but a contracting method that would allow construction companies to consul, yet not be excluded from the bidding process, has not yet been developed.

CII and many universities currently teach the concept of constructability, but a lack of understanding still exists within the industry that distinguishes between value engineering, constructability programs, and constructability review. The incentive for contractors to offer constructability-consulting services is minimal. A major barrier for the contractor is possible exclusion from the bidding process if he/she offers the consulting services because of the intimate project knowledge he/she would have that would allow him/her to have a competitive advantage. Owners are aware of the potential savings generated from constructability programs, but they want a quick, concise method of implementation in which benefits are tangible.

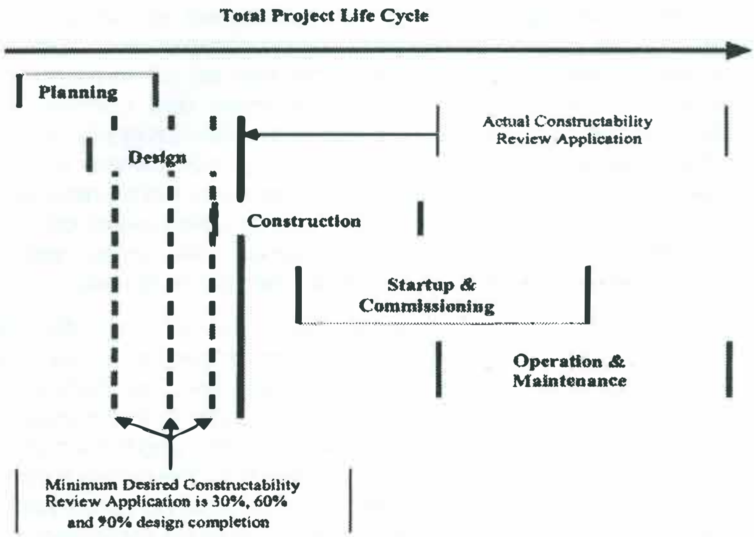

Figure 5: Constructability review inplementation relationship

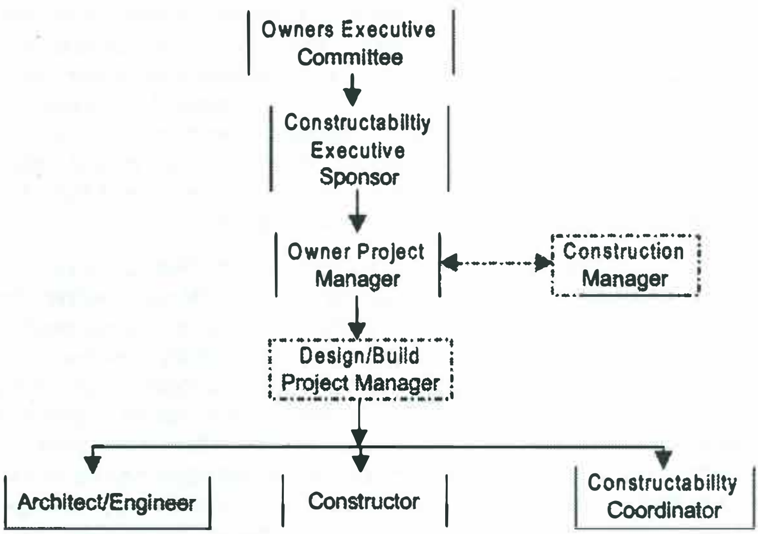

Figure 6: Core project constructability organizational chart

The most effective approach to constructability is owner, architect/engineer, and constructor integration from project inception. This approach creates an atmosphere in which team participants can form the essential bonds of trust, mutual confidence, and good rapport necessary for a successful project. When all team members are present from project inception, idea flow is smoother because the project has not been constrained by tight definitions, and participants are not as concerned with filtering their ideas. The result is minimisation of design rework and improved overall design quality. Personal relationships that are established early within the constructability program foster continued co-operation, communication, and support throughout the project life cycle (CII, 1987).

8. Constructability review

The above problems can be alleviated if a constructability review is performed throughout the design process bringing the constructor and architect/engineer together under the concept of the master builder. A constructability review then becomes an evaluation of design and construction documents to determine bid ability, constructability, and operability. Bidability identifies the degree to which design documents may be understood, estimated, administered, and enforced by checking for completeness and consistency. Constructability identifies the compatibility of the design with the site, construction materials, building technique, schedules, and field conditions. It answers the question: Can it be easily built? Operability identifies the ease with which a completed facility can be operated and maintained in relation to frequency of service, accessibility, and effect of downtime (Kirby, 1985).

It is not always easy to reconcile differences of opinion about design adequacy and constructability when the constructability reviewer confronts the architect/engineer. Maximum constructability review benefits may be realised if conducted from project inception promoting a team atmosphere (*Civil Engineering*, 1986). The improvement of constructability is not limited to just drawing reviews, preassembly of components, or determining more efficient methods of construction mobilisation. It also focuses on the need for and importance of timely construction input through constructability programs (Norwich, 1993). Unfortunately, most construction reviews are performed on completed designs that do not support the concept of early constructability implementation. Once a design system is chosen it should not be changed or radically modified without real cause. It is therefore imperative that construction experts are actively involved, during the early design stages, to review the basic structural/civil systems alternatives being proposed by architect/engineering.

A team of field-experienced construction experts should perform a formal, systematic constructability review of all architect/engineering design documents to ensure that the designs are practical from a constructor point of view. Document critique has two major categories: drawings and specifications for procurement of materials and equipment.

Other factors to consider during the conceptual design reviews are construction manpower availability, plant orientation and layout, in light of available construction equipment, and preassembly of major components in light of available manpower, construction equipment, plant layout, and construction schedule (Falgout, 1982). Figure 5 is a graphical representation comparing the actual and minimal desired application of a constructability review throughout the project life cycle.

9. Developing a constructabilty framework for advanced technology facilities

The development of the constructability framework for advanced technology facilities began with generating ideas to overcome the barriers noted in the CICE research. The CIIS constructability task force issued three documents that presented essential elements and tools necessary for implementing a corporate and project level constructability program. CII's Constructability Program Implementation manuals provided the basic elements necessary for capital investment return; however, the following problems in adapting the program to the advance technology industry were identified:

- Extracting information from the manuals takes too long
- Ascertaining the common thought process throughout the program is difficult
- The tools are cumbersome, difficult to understand, and work independently
- The materials are not presented in a clear and concise manner that is user friendly
- The project manager constructability involvement is not clear and practical
- Constructability reviews are being substituted for program implementation.

The advanced technology industry, which usually uses fast track construction combined with the design/build project delivery method, needs a modified approach to constructability implementation. The focus of the developed program is implementing construction knowledge and experience as early as possible within the project life cycle and capturing that knowledge for future projects. The target audience for the constructability program are those involved in the construction process, from owners to trades.

For this program to work, everyone involved must understand the constructability concept and its benefits. Extracting information from the CII manuals took too long; therefore the advanced technology constructability program was developed as a flowchart with supporting narrative. For ease of use, a flowchart was developed as a graphical guide along with written descriptions outlining, step-by-step, the evolution of the constructability program. The common thought process was to maintain the integration of construction knowledge throughout the entire project life cycle.

The owner's first step in implementing a constructability program is to write a constructability policy statement that clearly states a description of the desired results, the implementation-supporting rationale, the level of corporate commitment, and the programme responsibilities.

The strategic planning phase begins when the owner's executive committee performs feasibility studies to determine the requirements in support of the corporate vision. If project construction is necessary, preliminary project development begins. The preliminary project scope, budget, and schedule development is critical to the owner's decision in support of the corporate vision. A programming consultant may be contracted to gather facts critical to the executive committee's final decision; however, his/her focus is the development of the overall project scope definition in relation to the owner's needs. To reap the large investment return from implementing a constructability program, a constructability consultant should be added to the team during this critical decision period. The constructability coordinator's focus would be the development of the overall project scope definition in relation to the construction process. By adding a constructability coordinator to the team, the owner develops a more complete picture of all parameters that affect the final project cost and schedule, enabling a better final decision.

The owner will determine the project construction priority and the project delivery method based on information provided by the programming and constructability consultants. The constructability coordinator will continue to assist in the subsequent project phases, even if a construction manger is contracted. To help facilitate a smooth project evolution, the constructability coordinator possesses the corporate knowledge of the decisions made during the strategic planning phase and the owner's expectations. A construction manger must focus on the full project development. The construction coordinator will focus on facilitating communication between the architect/engineers and constructors, documenting construction related ideas and decisions for database entry, and ensuring that construction suggestions are incorporated into design.

During the design phase, the constructability coordinator is responsible for overseeing that final construction documents are presented from a contractor's viewpoint that the construction phase can be completed within the given time frame, and that ambiguities that could lead to claims or impede construction productivity are eliminated (Abdallah, 1985).

The constructability coordinator's responsibility during construction will be to facilitate communication between the intent of the architect/engineer and the reality of the field. Because the coordinator has been a member of the decision-making process since project inception, he/she logically has inherent acceptability as a resource to the field organisation. Maintaining the continual service of the coordinator through construction should reduce rework, schedule delays, and change orders that may be related to a lack of communication between the architect/engineer, design intent, and the constructor's interpretation.

The final responsibility of the coordinator is to document constructability ideas to be historically recorded in a database. The main goal of the constructability database is to capture construction knowledge and experience throughout the project life cycle. One form should be used for idea suggestion to easily facilitate documentation. The constructability coordinator should also add schedule and budget effects. The form may also be used to document field feedback and ideas on how specifications and drawings perform under actual project application and what claims were generated.

A suggested core project team organisational chart is presented in Figure 6. It is essential that the architect/engineer, constructor, and constructability coordinator be equal within the project organisation to ensure that construction technology and experience will be incorporated into the engineering and design effort. A contracted constructability coordinator must be separate from the constructor so that the construction knowledge and experience critical to decisions being made at the beginning of the strategic planning phase are available without affecting the bidding process.

Construction of advanced technology manufacturing facilities, that usually uses fast track construction, combined with the design/build project delivery method, needs a streamlined approach to constructability implementation. The developed program focuses on implementing construction knowledge and experience as early as possible within the project life cycle and capturing that knowledge for future projects. The common thought process is to maintain the integration of construction knowledge throughout the entire project life cycle. The target audience for the constructability program are those involved in the construction process, from owners to labourers. For this program to work, everyone involved must understand the constructability concepts and the benefits that can be achieved. For ease of use, a flowchart is used as a graphical guide along with written descriptions outlining the evolution of the constructability program through each phase of the project life cycle.

Within each phase of the project life cycle, the constructability coordinator has designated responsibilities clearly showing how the evolution of construction integration changes with the development of the project. Project managers have extensive responsibilities that do not need to be increased; therefore, constructability implementation, co-ordination, and documentation responsibilities rest upon a designated constructability coordinator. Program focus, coordinator responsibilities, and basic database format must be consistent to facilitate easy learning, understanding, and use. To overcome the constructability review fallacy, the constructability coordinator is a team member equal to the architect/engineer during the strategic planning phase. The coordinator should also have the responsibility of educating the architect/engineer concerning areas that may be in conflict with the construction process as well as with the analysing of architect/engineer output for compliance with construction methods and requirements. This framework incorporates these philosophies into a project level constructability program for use in the construction of advanced technology facilities.

Constructability creates a win/win situation for all members of the project team. With the integration of construction and architecture/engineering, the owner obtains a high quality product for less money and time, the architect/engineer creates a product that reduces conflict and litigation, and the construction trades believe that someone is finally listening to their field experience. It is believed that the use of the developed constructability framework will enhance the ability of the architect/engineer/constructor team to provide higher quality facilities in a compressed time frame, more cost-effectively.

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