BENEFITS OF CONSTRUCTABILITY ON CONSTRUCTION PROJECTS

By George Jergeas,[1] P.E., and John Van der Put,[2] P.E.

ABSTRACT: This study was undertaken to identify the most significant gaps between the potential benefits of applying constructability principles to Alberta, Canada, industrial projects and the benefits typically realized in industry practice. This study also aims to gain an understanding of the barriers that commonly restrict constructability benefits. The data for this survey was obtained by administering a survey based on the Construction Industry Institute's 17 constructability principles. The results of this study indicate collaborative industry effort should be focused in the areas where the largest gaps currently exist between potential and realized benefits. These include among other things, involvement of construction in the design phase, building mutual trust, respect, and credibility between project planners, designers, and constructors. As the examples cited in this study illustrate, significant gains in project cost, schedule, performance, and safety can be achieved when the above prescription is followed. For example, savings of 30–40% in the total installed cost for facilities are quite readily achievable.

INTRODUCTION

The objective of this study is to evaluate the effectiveness of applying constructability principles on Alberta, Canada, industrial construction projects by comparing the potential benefits of applying constructability principles to the benefits typically realized in practice based on the experience of industry practitioners in Alberta. This study also strives to gain an understanding of the barriers that typically contribute to the gaps between the potential and realized benefits of applying constructability principles.

The Construction Industry Institute (CII) based in Austin, Tex., defines constructability as ''the optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall objectives.'' The CII's fundamentals of constructability are outlined in a set of 17 principles that apply to the conceptual planning, design, procurement, and field operations phases of a project. These principles which are listed in Appendix I, were used as the basis for this study.

While constructability does not necessarily add to or improve the function or operating reliability of a project, the inclusion of construction knowledge and experience into the planning and design of a project can result in reduced installed cost and improved safety during construction (Matheson et al. 1995). Recognizing that field labor and materials comprise the two most significant factors affecting project cost, schedule, and quality performance, a constructability approach will make use of construction-oriented expertise early in the planning and design of a project.

LITERATURE SEARCH

The concept of constructability was introduced by the CII (1986), in which it stated ''Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives'' (CII 1986). Since this definition of constructability, various new definitions have emerged based on the individual project needs and requirements. All definitions focus on the issue that the benefits of constructability can solely be achieved by the integration of the construction knowledge and experience into each phase of the project delivery process. During the course of literature search for this paper, a considerable amount of technical papers and reports on constructability were obtained.

According to Fischer and Tatum, constructability should be an important objective in all phases of the construction project, and designers play an important role in achieving superior constructability. Most projects however, do not receive constructability input although previous research has demonstrated numerous benefits of such an input. One reason for this lack of constructability input as argued by the authors is the lack of formal, explicit constructability knowledge bases that can link constructability issues to design decisions and that can be made available on-line to interested parties in the form of some kind of database. This paper describes research that compiled and formalized constructability knowledge related to reinforced concrete structures. To ensure appropriate and specific constructability input, the authors have classified the knowledge by construction methods and structural elements. To make this specific knowledge available to the designers at the right time during the design development, the authors have further divided it into five groups: application heuristics, layout knowledge, dimensioning knowledge, detailing knowledge, and exogenous knowledge. This classification leads to conclusions regarding the ability to collect and formalize this knowledge and to make it readily available to designers to improve project performance (Fischer and Tatum 1997).

Gugel and Russell present a model for selecting an approach to implement constructability. Constructability can be implemented using an informal or formal approach. Based upon this research, three approaches, one informal and two formal, have been identified and labeled as follows: (1) informal approach; (2) formal project level; and (3) comprehensive tracking. The model consists of a hierarchy of decision levels. Within these levels, there exists three steps: (1) individual assessment of owner and project characteristics resulting in a single conclusion of a formal or informal approach; (2) combining owner and project characteristics into a single conclusion of an informal or formal approach; and (3) if a formal approach is concluded, a decision is needed as to whether it is formal project level or comprehensive tracking. To assess owner and project characteristics, a framework of variables described by parameters has also been developed.

The model hence developed was tested by six owners on seven different projects. The results were consistent with the constructability approach selected by the owner. The model can assist owners in efficiently determining the appropriate means by which to incorporate construction knowledge and experience into the designs of their projects (Gugel and Russell 1994).

[1]Dir. Proj. Mgmt. Specialization, Dept. of Civ. Engrg., Univ. of Calgary, 2500 University Dr. NW, Calgary, AB, Canada T2N 1N4.

[2]General Mgr., Chilean Pipeline Operations, TransCanada International, P.O. Box 90, 645 7th Ave. SW, Calgary, AB, Canada T2P 4G8.

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Gugel et al.'s research has indicated that the owners have been using different approaches for the purpose of constructability implementation. The authors with the help of four case studies present a comparative analysis of three such approaches. The approaches studied are as follows:

1. Using a construction management firm during preconstruction
2. Specialized formal programming
3. Comprehensive tracking

For each of the above approaches the qualitative and the quantitative benefits and costs were identified and compared.

Each approach is presented to enable the project managers to understand the constructability implementation programs and help them decide which approach to be adapted and know in advance various costs and benefits associated with each approach. Also it can help them identify the input required on the project from the owner to facilitate the constructability implementation program (Gugel et al. 1994).

For any constructability implementation program to be successful a strong database for constructability ideas is an important factor. In this paper the authors have discussed and analyzed in detail various project data collection techniques such as voluntary survey questions, interviews, preconstruction meeting notes, and questionnaires with respect to their effectiveness in obtaining the data on constructability.

Using the constructability data obtained from a major refinery expansion project and considering six major types of constructability improvements from both qualitative and quantitative aspects the following two questions were addressed:

1. Which data collection methods are best in soliciting certain types of data?
2. Who can be the most effective contributors in soliciting certain types of data?

Based on the results, a number of recommendations have been made with respect to the collection of constructability implementation data methods (O'Connor et al. 1986).

O'Connor et al. have presented and analyzed seven concepts for improving constructability during the engineering and procurement phases of the project with some applications of each concept. These concepts promote construction-driven schedules, simplified design configurations, standardization of elements, and module/preassembly design, which can facilitate fabrication, transportation, and installation. These concepts also address the accessibility of manpower, materials, and equipment to facilitate construction in adverse weather and specifications improvement (O'Connor et al. 1987).

Radtke and Russell present a process model for the implementation of constructability at the project Level. The model is based on the data obtained from the CII Constructability Implementation Task Force and various constructability-implementation programs currently used in the industry.

The model process provides a benchmark for owners to use on their projects for the purpose of enhancing the constructability on their projects and in turn gaining the maximum benefits from the constructability improvement program (Radtke and Russell 1993).

O'Connor and Tucker provided a definition of constructability as the ability of the project conditions to enable the optimal utilization of construction resources. The authors have analyzed data from a large refinery expansion project for content, and classification frequencies have been observed. By analyzing the engineering rework, it exposes the causes and costs of rework that occurs as a result of constructability issues (O'Connor and Tucker 1986).

ALBERTA CONSTRUCTION INDUSTRY

The construction industry in Alberta employs about 125,000 workers in three principal sectors: (1) industrial; (2) commercial/institutional; and (3) residential. At the time of this writing, there is roughly $20 billion worth of new construction planned in the province over the next 5 years.

The province of Alberta's industrial base is focused on the exploitation of its natural resources with industrial construction concentrated on providing facilities for petrochemicals production, oil and gas production, and transportation of natural gas and petroleum products through pipelines, forestry, mining, and power generation. Industrial construction workers are still predominantly unionized although ''open shop'' (nonunion) contractors have gained an increasingly significant share of the work over the past 10 years. Open shop contractors are already firmly entrenched in the residential and commercial/institutional construction sectors.

Multinational engineering and construction contractors like Bantrel, Fluor, Brown & Root, Stone & Webster, and Delta Catalytic are quite active in the province, particularly on the larger and more complex projects, but they do not dominate the market. Home-grown Canadian and Albertan companies such as Colt, Optima, Flint, Ledcor, and PCL are well respected and maintain leadership positions in the provincial industry. Although not interventionist, the Alberta government takes a very active role to help ensure equal access and fair competition in the industry while also promoting collaboration between owners, contractors, suppliers, and labor with the help of industry groups such as the Construction Owners Association of Alberta to maintain the ''Alberta Advantage'' in construction.

The Alberta construction industry is now in a ''boom cycle'' following a long drought which began in the recessionary period in the early 1980s and lasted until the mid-1990s. The labor supply has managed to keep up with the demand but not without the importation of workers from other provinces and other countries. Not surprisingly, labor costs have been on the increase and some spot shortages of particular trades such as pressure welders and industrial electricians have occurred. This reality has increased the need for industry participants to apply techniques such as constructability to help them manage the installed cost of their projects in order to preserve their economic viability.

METHODOLOGY

The data for this study was obtained through a survey administered to practitioners in the Alberta construction industry as a follow-up to a pilot study investigating the benefits of constructability on industrial construction projects (Jergeas and Van der Put 1999). The survey was sent to 100 randomly selected individuals from among the 400 attendees at the Construction and Engineering Leadership Conferences held at the University of Calgary in 1997, 1998, and 1999 (see Appendix II). A total of 37 people completed and returned the survey. Examples of successful applications of constructability principles were also taken from the available literature (Matheson et al. 1995).

The industry practitioners who provided information for this study represented the following organizations:

Owner Companies	Engineering and Consulting Firms	Government Entities
Enbridge	Delta Hudson	City of Edmonton
Agrium	Colt Engineering	Province of Alberta
Husky	Kent Construction	City of Calgary
Suncor	Bantrel	

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TransCanada Pipelines
Petro-Canada
Alberta Energy Company
Shell
Syncrude
Telus
PanCanadian Petroleum
Nova Chemicals

The survey respondents were predominantly mid- to senior-level executives in the industrial construction sector responsible for the management of large construction projects in the range of \$10–500 million, which span a year or more and involve large organizations. Their average level of experience in the industry at the time of the survey was about 20 years.

For the purposes of this study, the 17 CII constructability principles were grouped into the following seven broad themes:

- Up-front involvement of construction personnel
- Use of construction-sensitive schedules
- Modularization and preassembly
- Standardization
- Designs that facilitate construction efficiency
- Use of innovative construction methods
- Use of advanced computer technology

As shown in Attachment A to Appendix II, the authors grouped together principles that were closely related and defined a theme for each grouping based on the central ideas that the principles in each group conveyed. The rationale for grouping the principles was to make the survey easier to administer and the results easier for the reader to understand.

For each of these seven groupings of constructability principles, the survey respondents were asked to rate (using a 5-point scale) (1) the potential benefit; and (2) the actual realized benefit of applying the principles based on their experience. They were also asked to make note of any barriers that they felt typically make it difficult to derive benefits from implementing each of the principles. Respondents were provided with the following definitions to aid them in completing the survey:

- Potential benefit: The relative impact of applying the constructability principle in terms of cost, schedule, and quality improvements if successfully implemented
- Realized benefit: The degree of success that they or others they work with have had in applying the constructability principle, and actually realizing the expected benefits based on their recent experience
- Barriers: Problems that arise or things that various project participants may do that make it difficult to fully realize the benefits of implementing constructability principles

Regarding the rating scale, respondents were asked to only assign the highest rating of 5 in those cases where the potential or realized benefits are very significant, i.e., original total project cost reduced by 10% or more. An example of the survey form is included in this report as Attachment B to Appendix II.

RESULTS

Individual survey responses were tabulated and mean ratings and standard deviations around the means were calculated for each of the seven constructability principle groupings. The gaps between the potential and realized benefits of applying constructability principles were calculated as well. The results are shown in Table 1. The barriers that the respondents indicated that typically contribute to these gaps are listed in Appendix III. The following sections provide an analysis of the results for each of the potential benefits, realized benefits, gaps, and barriers.

TABLE 1. Summary of Constructability Survey Results

	Potential		Realized		
Constructability principle grouping	Mean	Std	Mean	Std	Gap
1. Up-front involvement of construction personnel	4.46	0.51	3.39	0.94	1.07
2. Use of construction-sensitive schedules	4.11	0.71	3.26	0.95	0.85
3. Modularization and preassembly	3.76	0.86	3.09	1.07	0.67
4. Standardization	3.78	0.83	2.72	0.94	1.06
5. Designs facilitate construction efficiency	4.04	0.85	2.94	1.07	1.10
6. Use of innovative construction methods	3.94	0.83	2.82	0.94	1.12
7. Advanced computer technology	3.49	0.86	2.35	0.81	1.14

Note: Std = standard deviation.

ANALYSIS OF POTENTIAL BENEFITS

As can be seen in the overall survey results in Table 1, the mean ratings for the potential benefits of applying constructability principles are in a fairly tight range from a low of 3.49 to a high of 4.46. Looking at the results, the areas that survey respondents indicated have the potential to yield the greatest benefits are the following:

- Up-front involvement of construction personnel
- Use of construction-sensitive schedules
- Use of designs that facilitate construction efficiency

As noted above, industry experience indicates that if there is to be any significant benefit from construction planning, then the contribution from the construction experts must be made from day 1 of the design process.

For example, in 1994, Colt Engineering installed glycol dehydration facilities in Northeast British Columbia for Talisman Energy, a senior Canadian oil and gas producer. On that project, constructability teams were formed prior to the conceptual engineering stage of the project so that any innovations could be immediately implemented. An example of such an innovation was the use of precast concrete berms rather than earthen berms around produced water tanks resulting in greatly simplified installation (Matheson et al. 1995).

As another example, on the Andrew offshore platform project in the North Sea for British Petroleum, early input from construction contractors was the key to delivering a design that would best suit fabrication methods. The design would incorporate the needs of fabricators and constructors such that changes, that commonly arise during construction, would be eliminated. For instance, the integration of engineers from BARMAC, the jacket fabricator, and Saipem, the installation contractor, helped to focus on design features that would make the structure easier to build and install (Fischer and Tatum 1997).

In the same way that the application of constructability techniques in project planning has the potential to produce significant benefits for project participants, the omission of constructability planning can lead to serious problems. For example, on a recent fiber-optic cable installation project, construction experts were not involved in the up-front planning and the construction schedule did not adequately account for

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the winter weather window. As a result, the contractors were poorly prepared and poorly supervised, which resulted in significant rework and lost productivity. A further complication was the fact that construction began late in the season due to a delay in the resolution of commercial issues. The end result was that the project had to be stopped when it was about halfway completed and the contractor had to be demobilized because the onset of winter weather made the construction site inaccessible.

ANALYSIS OF REALIZED BENEFITS

Overall, when compared to the potential benefits, the mean ratings for realized benefits are generally lower, ranging from a low of 2.35 to a high of 3.39. This indicates that our survey respondents felt that we are failing to realize the benefits we could be capturing in a number of these areas. The areas where the greatest benefits are being realized in practice are

- Up-front involvement of construction personnel
- Use of construction-sensitive schedules
- Modularization and preassembly

An example of the magnitude of the savings that can be realized when constructability principles are applied, can be found in TransCanada Transmission's Swan Hills compressor station project, completed in 1995. On that project, TransCanada was able to build the station for a cost 40% lower than the baseline historical cost of similar facilities as a result of applying constructability. Specifically, the total installed cost including all materials (including the turbine/compressor package and all peripherals), contractor costs, and the owner's engineering and project management costs, was \$7.9 million, compared to the historical cost of \$12.9 million for compressor stations with a power rating of <5 MW.

Major decisions on this project that resulted from application of constructability principles were a more compact site, a simplified site layout, aboveground rather than buried pipe and cable installation, and the use of a rigid frame building rather than masonry blocks. A key to the success of this project was that the team members on this project all had construction experience and construction inspection personnel were involved early and regularly throughout the design phase (Matheson et al. 1995).

An example of a construction project currently underway in central Alberta that is making extensive use of modularization and preassembly is Nova Chemical's Joffre 2000 Project. Part of the project is a 2.8 billion lb/year ethylene plant, which will be the world's largest ethane cracker. This plant is made up of 154 modules each of which weighs about 400 tons. The modules were built by Brown and Root and PCL Constructors in Edmonton fabrication shops and then transported by truck to the Joffre site for final installation. As a result of this extensive preassembly, about 15% of the installation work on the project is being done off-site.

GAP AND BARRIER ANALYSIS

As shown in Table 1, the largest gaps between the potential benefits of applying constructability principles and those actually realized in practice are in the following areas:

- Up-front involvement of construction personnel
- Achieving efficiency in the construction effort
- Use of innovative construction methods and advanced computer technology

The principal barriers that contribute to these gaps are explored in the following sections.

EARLY INVOLVEMENT OF CONSTRUCTION PERSONNEL

Based on a review of the survey respondents' input listed in Appendix III, the major barriers that appear to contribute to the gaps in this area include the following:

- Lack of mutual trust, respect, and credibility between project planners, designers, and constructors
- Traditional contracting practices that bring the constructors into the project only after the design has been substantially completed and the specifications have been developed
- Lack of desire and commitment by the owners to commit funds and resources to implement constructability (often derives from lack of understanding of benefits)

It is clear from these findings that significant potential benefit in terms of cost savings, schedule improvements, and safer work sites are lost on construction projects because of the often seemingly insurmountable barriers between planners, designers, and constructors. Many planners and designers lack the experience to understand how the decisions they make will affect field operations and they perceive constructors as ''doers'' who would be unable to articulately contribute to the planning and design effort. At the same time, many constructors are uncomfortable in office environments and will typically be reluctant to contribute their ideas unless specifically asked.

It is also evident from the results that the predominant contracting approach for industrial projects, which typically follow a design-bid-build sequence, gets in the way of involving construction knowledge up front in the project in a meaningful way. Even when construction expertise is brought in early in the project through the owner's own construction experts or through a third-party construction management consultant, the benefits are often limited because these will typically not be the people ultimately responsible for the actual construction of the facilities. It appears that in order to capture the most significant benefits from applying constructability, the traditional contracting approach has to be cast aside and the construction contractors must be brought into the project from the very beginning before the design, specifications, and procurement strategy have been established.

For example, on the Andrew project, an alliance was formed between BP, Brown & Root (the EPCM contractor), and the various fabrication and installation contractors, where all of the players were selected and in place at the very beginning of the project. This enabled all to make significant contributions to the design of the facilities. For instance, direct input from the topside fabricator's engineers (Trafalgar John Brown) determined the most logical sequence for constructing the deck, based on the ''pancake'' method for fabricating each of the three deck levels separately, followed by vertical stacking. This innovative technique, rather than the alternative of first constructing the entire ''box'' and then procceding to install equipment, allowed each deck to be substantially completed while still at ground level, significantly improving workforce safety and productivity. Innovations like this and many others enabled the Andrew project alliance to achieve a total installed cost for the platform 35% below the owner's original cost estimate (Fischer and Tatum 1997).

As another example, Flint Canada Inc., implemented an innovative set of feedback loops when they were brought into the early planning stage of the pilot plant construction project they did for Syncrude, a Canadian company that converts oilsands into synthetic crude oil. The first loop was a review of the cost estimate between Flint and the owner to create the same project vision and a common understanding by the entire

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project team of the desired end result. The second feedback loop consisted of technical meetings held during the design stage. This was the heart of the constructability process on this project. Flint's knowledge and experience was combined with Syncrude's to refine and improve the final detail design. Last, the third loop was a process to solicit and evaluate constructability ideas during construction. As a result of the effectiveness of this feedback process, the initial project costs for this project were reduced and productivity during construction was improved (Matheson et al. 1995).

ACHIEVING EFFICIENCY IN CONSTRUCTION EFFORT

A review of the survey responses in Appendix III indicates that the major barriers that contribute to the gaps in this area include the following:

- The congestion around some construction sites especially those around existing operating facilities
- Rigid specifications that limit design flexibility prepared by designers who often lack practical field experience
- Lack of communication between designers and constructors who often seem to be working at cross-purposes

With regard to the first issue, with enough imagination and prior planning, solutions can be found to address the very significant problem of congestion around construction sites. As an example, during the peak loading period on the Joffre 2000 project in mid-1999, there were over 5,000 workers on site. The principal construction firms on the project, Stone & Webster and Fluor Daniel, had the primary responsibility to ensure effective coordination of activities on this very congested site where construction was going on right next door to operating facilities. One of the innovations they developed was to transport workers from the camp facilities to their worksites using Travelaire trams, a motorized system that could pull up to five carloads of workers at a time.

On Colt's dehydration facilities job for Talisman, it was realized that a significant amount of work could be removed from the field scope by prefabricating components in a shop environment and by standardizing the design of structural steel supports. This resulted in significant savings in terms of both the project schedule and total installed cost (Matheson et al. 1995).

On construction projects in remote areas like northern Canada, complex construction and commissioning activities undertaken by large workforces in the offshore environment, carry a relatively high exposure to risk. By transferring as many of these tasks as possible to fabrication shops and assembly yards closer to major centers, it is possible to avoid many of the weather-related and logistical hazards associated with construction in such areas.

Successes in realizing efficiencies with the construction effort can only be made possible through close cooperation between all project participants—owner, consultant(s), contractor(s), and suppliers. This will happen by recognizing that individually each of these players may lack some pieces of the puzzle, but that collectively, they can pool their knowledge and their resources to achieve success for all of the participants.

USE OF INNOVATIVE METHODS AND ADVANCED TECHNOLOGIES

The major barriers that restrict the benefits that could be derived from the use of innovative construction methods and advanced technologies fall into the following three areas:

- Risk aversion and lack of trust by owners, lack of knowledge of the latest construction methods and techniques, and the paradigms of ''we have never done that before'' and ''this is what we did on the last job and it worked then, so why do something different now''
- The real or perceived high cost of advanced computer technologies, especially in field locations requiring sophisticated telecommunications links
- The time required to adequately train staff in the use of computer systems that seem to change very frequently and the lack of user-friendliness

On the Andrew project, innovative engineering solutions were encouraged and adopted throughout the project. The project made significant use of electronic interchange of information between designers and fabricators as well, to ensure the timely transmittal of suggestions and ideas between the fabrication yard and the design office (Matheson et al. 1995).

As another example, Delta Catalytic Constructors Ltd., implemented several innovative construction methods during the bidding and construction in 1992/1993 of the No. 2 Road Bridge for the city of Richmond, British Columbia. These methods, that made extensive use of preassembled components and temporary construction materials and systems, contributed to the successful completion of the project well within budget and without a disabling accident or an environmental incident. These methods were employed as a result of an innovative construction team working with a cooperative constructability-minded engineer (PBK Engineering of Vancouver) acting with the full confidence of the owner (Matheson et al. 1995).

Another company that has applied a number of innovations on their more recent construction projects is Syncrude, a northern Alberta producer of oilsands-based synthetic crude oil. In the spring of 1997, Syncrude undertook to stretch the height of the plant's coker by 3 m in order to increase the overall capacity of the process. This was achieved by cutting off the top of the coker, lifting the old piece off, and then inserting an 3-m stretch section and last, a new scrubber section at the top of the unit. This approach allowed the new sections to be fabricated close to ground level and for the majority of the construction work to be completed outside of the downtime associated with the plant's 39-day turnaround.

In the future, Syncrude is looking at even more paradigm-breaking innovations. Although the original synthetic crude production plant Syncrude built was located quite close to the area where the oilsands bitumen was being mined, new mines now being developed are located further and further away from the plant. This has required the development of some advanced slurry transportation technology using pipelines to get the bitumen to the plant.

Syncrude is considering turning this completely around and actually having the plant go to the mine to get the bitumen rather than bringing the bitumen considerable distances to the plant using pipelines or trucks. The concept is that every 3 years or so, the plant would be jacked up, placed on multi-wheeled crawler-transporters, and then the crawlers would move the plant closer to the new mine site.

The kind of working environment that fosters money-saving innovative solutions will not usually just happen by chance. Rather, it appears to be the result of mutual trust and respect between all project participants and the willingness to challenge the ''tried-and-true'' and to try new approaches in the interest of achieving significant gains in project cost, schedule, performance, and safety.

CONCLUSIONS

Based on the findings of this study, it is the opinion of the authors that the most significant gains from the application of constructability principles on Alberta construction projects can be derived by focusing collaborative effort in the following

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area, where the largest gaps exist between potential and realized benefits:

- Ensuring involvement of construction personnel from day 1 of the design. These should be the people who will ultimately be constructing the facilities. Even when construction expertise is brought in early in the project through the owner's own construction experts or through a third-party construction management consultant, the benefits are often limited because these will typically not be the people ultimately responsible for the actual construction of the facilities.
- Building mutual trust, respect, and credibility between project planners, designers, and constructors that can be maintained over the long term by creating shared vision and commitment to the success of the project at the conceptual stage.
- Being willing to cast aside the traditional design-bid-build contracting philosophy in favor of an approach that brings the construction contractor into the project from the very beginning before the design, specifications, and procurement strategy have been established. This requires fostering close cooperation between all project participants, with each pooling their knowledge and their resources in a true partnership working as a team to achieve mutual success.
- Last, being willing to challenge the ''tried-and-true'' and to try new approaches in the interest of achieving significant gains in project cost, schedule, performance, and safety.

As a final thought, in order to truly optimize overall project costs, we would encourage project managers to think about constructability as only one element in a package, which we call ''integrated value management'' (Jergeas and Revay 1999).

The other elements of this package include strategic alliances or partnering, value engineering, and risk management. Having already defined constructability, the following are definitions for the other three concepts:

- Strategic alliances are attempts to establish working relationships between parties through a mutually developed formal strategy of commitment and communication.
- Value engineering is a multidiscipline, systematic, and proactive function targeted at developing a facility design that will yield the lowest life-cycle cost.
- Risk management is the identification of risks and the development of specific plans to either minimize, share, transfer, or accept those risks.

All four of these concepts rely on a team approach and the investment and foresight at the beginning of the project to avoid problems later on in the project.

APPENDIX I. CII CONSTRUCTABILITY PRINCIPLES

Conceptual Planning Phase

1. A formal constructability program is made an integral part of the project execution plans.
2. Early project planning actively involves construction knowledge and experience.
3. Construction personnel are involved in developing the project contracting strategy.
4. Project schedules are sensitive to construction requirements.
5. Basic design approaches consider major construction methods such as modularization or preassembly.
6. Site layouts promote efficient construction (e.g., adequate space for laydown and fabrication yards and efficient site access).
7. Project team participants responsible for constructability are identified early in the project.
8. Advanced information technologies such as 3D computer modeling or field notebook computers are applied.

Design and Procurement Phases

9. Design and procurement schedules are construction-sensitive.
10. Designs are configured to enable efficient construction considering issues like simplicity, flexibility, sequencing of installation, and labor skill and availability.
11. Design elements are standardized including maximum use of manufacturers' standards and standardized components.
12. Construction efficiency is considered in specification development including prior review of specs by construction personnel.
13. Modular/preassembly designs are prepared to facilitate fabrication, transportation, and installation.
14. Designs promote construction accessibility of personnel, materials, and equipment.
15. Designs facilitate construction under adverse weather.
16. Design and construction sequencing facilitates system turnover and start-up.

Field Operations Phase

17. Innovative construction methods are used such as innovative sequencing of field tasks, or use of temporary construction systems, or innovative use of construction equipment.

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APPENDIX II

Date: ____________________

John Van der Put
TransCanada Transmission
4001 Highway 2 South
Athabasca, AB T9S 1A4
(780)-675-6509

Dear: ________________________

You have been selected to participate in a survey on the effectiveness of constructability measures in the Alberta construction industry as part of a research project led by John Van der Put of TransCanada and Dr. George Jergeas of the University of Calgary Project Management Specialization program. The results of the survey will become part of a paper that we plan to submit to a refereed journal.

The Construction Industry Institute (CII) in Austin, Texas defines constructability as "the optimum use of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall objectives." The objective of our survey is to compare the potential benefits of applying constructability measures on Alberta construction projects against the actual benefits, which you have observed are typically realized in practice, based on your experience. We are also interested in understanding the barriers, which you feel typically prevent more successful implementation of constructability measures.

You have been asked to participate in this survey based on your standing as a provider or client of construction services in the industrial, commercial or institutional construction sectors in Alberta. If you are aware of other people in your firm who would also be interested to contribute to this project, please feel free to share this survey with them as well.

In order that we can complete this project in the Fall of 1999, we ask that you return the completed survey to us no later than September 15, 1999. We look forward to your reply and we thank you in advance for your contribution.

Sincerely,

John Van der Put — Dr. George Jergeas

TransCanada Transmission — University of Calgary

ATTACHMENT A TO APPENDIX II

CII Constructability Principles

For reference, the following are the 17 constructability principles developed by the CII in Austin, Tex., grouped under the seven constructability measures used for this survey:

1. Up-front involvement of construction personnel
   - A formal constructability program is made an integral part of the project execution plans.
   - Early project planning actively involves construction knowledge and experience.
   - Construction personnel are involved in developing the project contracting strategy.
   - Project team participants responsible for constructability are identified early in the project.
2. Construction-sensitive schedules
   - Project schedules are sensitive to construction requirements.
   - Design and procurement schedules are construction-sensitive.
3. Modularization and preassembly
   - Basic design approaches consider major construction methods such as modularization or preassembly.
   - Modular/preassembly designs are prepared to facilitate fabrication, transportation, and installation.
4. Standardization
   - Design elements are standardized including maximum use of manufacturer's standards and standardized components.
5. Designs facilitate construction efficiency
   - Designs are configured to enable efficient construction considering issues like simplicity, flexibility, sequencing of installation, and labor skill and availability.
   - Construction efficiency is considered in specification development including prior review of specs by construction personnel.
   - Designs promote construction accessibility of personnel, materials, and equipment.
   - Designs facilitate construction under adverse weather.
   - Design and construction sequencing facilitates system turnover and start-up.
6. Innovative construction methods
   - Site layouts promote efficient construction (e.g., adequate space for laydown and fabrication yards and efficient site access).
   - Innovative construction methods are used such as innovative sequencing of field tasks, or use of temporary construction systems, or innovative use of construction equipment.
7. Advanced computer technology
   - Advanced information technologies such as 3D computer modeling or field notebook computers are applied.

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ATTACHMENT B TO APPENDIX II

Survey on Effectiveness of Constructability Measures

Objective: The objective of this project is to identify the most significant gaps between the potential benefits of constructability measures (based on the Construction Industry Institute's (CII) constructability principles) and the benefits typically realized in actual practice in the Alberta construction industry as well as to gain an understanding of the barriers which typically restrict the successful implementation of constructability measures.

Instructions: For each of the 7 constructability measures listed below, rate 1) The potential benefit and 2) the actual realized benefit of applying the measure based on your experience. Also, please note any barriers, which typically make it difficult to successfully derive barriers from implementing each of the measures. For your reference, Attachment A shows how all of the 17 CII constructability principles have been grouped into the 7 constructability measures we have included in this survey.

Potential Benefit = The relative impact of applying the constructability measure in terms of cost, schedule, and quality improvements if successfully implemented.

Actual Benefit = The degree of success you or others you work with have had in applying the constructability measure and actually realizing the expected benefits based on your recent experience.

Barriers = Problems which arise or things which various project participants may do which make it difficult to fully realize the benefits of implementing constructability measures.

Ratings are on a 5-point scale where a rating of 1 is the low end of the scale and a 5 is the high end. Furthermore, a rating of 5 should only be assigned for those cases where the potential or realized benefits are very significant (e.g. original total project cost reduced by 10% or more).

Survey on Effectiveness of Constructability Measures

Constructability Measure	Potential Benefit	Actual Benefit
1) Up-front involvement of construction personnel	1 2 3 4 5	1 2 3 4 5
COMMENTS:		
2) Construction-sensitive schedules	1 2 3 4 5	1 2 3 4 5
COMMENTS:		
3) Modularization and pre-assembly	1 2 3 4 5	1 2 3 4 5
COMMENTS:		
4) Standardization	1 2 3 4 5	1 2 3 4 5
COMMENTS:		
5) Designs facilitate construction efficiency	1 2 3 4 5	1 2 3 4 5
COMMENTS:		
6) Innovative construction methods	1 2 3 4 5	1 2 3 4 5
COMMENTS:		
7) Advanced computer technology	1 2 3 4 5	1 2 3 4 5

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COMMENTS:

Please provide your return address below if you would like us to send you a copy of our paper once it is completed:

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Please return your completed survey (mail, fax or E-mail) to:

John Van der Put
TransCanada Transmission
4001 Highway 2 South
Athabasca, AB T9S 1A4

Fax Number: (780)-675-6555
E-mail: john_vanderput@transcanada.com

If you have any questions regarding this survey, please call:
John Van der Put: (780)-675-6509
George Jergeas: (403)-220-8135 E-mail: gjergeas@hotmail.com

APPENDIX III. BARRIERS TO IMPLEMENTING CONSTRUCTABILITY PRINCIPLES

The barriers listed under each of the seven constructability principles groupings were taken from the comments provided by the respondents in their completed surveys. Under each grouping, the comments that were more frequently cited are listed first. Also, the number of times each comment was cited is shown in parentheses.

1. Up-front involvement of construction personnel
   - Not having the construction resources available to the design team when it is needed (4).
   - The right people (construction) are not available at appropriate time in design phase (3).
   - Construction personnel possess practical experience but they generally lack the requisite technical and communication skills (2).
   - Reluctance on the part of owners to spend money early in the project (1).
   - Designers request construction input too late (1).
   - Timing of construction contractor selection has often reduced actual benefits achieved (1).
   - Client does not always want to pay for the time spent on this task (1).
   - Project is funded prior to the EPC team award (1).
   - Dividing lines between designers and construction personnel are sometimes too rigid (1).
   - May be limited by the choice of tendering the project (i.e., construction management contracts allow contractor onboard immediately whereas lump sum tenders limit early involvement (1).
   - Limitations of lump sum competitive contracting. The bidders are usually closed mouthed about the methods. In addition, this type of contracting tends to create adversarial conditions between the constructors and the designers (1).
   - Falls short in regard to earlier involvement of trade supervision. While project construction management staff are being involved from day 1, first- and second-level supervisors are rarely consulted even on a daily scheduling basis (1).
   - We see more construction participation on the larger projects than the smaller ones. Need to change the mindset of engineering that construction can bring added value to the process (1).
   - Project contracting strategy usually is not well thought out or reviewed formally for best results. If job is EPCM, sometimes the CM component participates too late to make a difference (1).
2. Use of construction-sensitive schedules
   - Schedule requirements are often out of the control of project personnel (2).
   - Too many variables at the construction stage to foresee during design. Actual benefits will not meet or exceed potential benefits (1).
   - Typically the EPC company is onboard too late to provide the necessary input into the initial schedule (developed by asset team) (1).
   - Difficulty resides in maintaining engineering deliverables to meet construction need (1).
   - Traditional construction/engineering rift where engineering does not accept that project is construction-driven. Fear on such jobs that construction will "sacrifice" engineering to get the job done faster than engineering is capable of supporting. Construction schedules have been known to be issued without any regard to engineering (and vice versa for engineering schedules not considering construction constraints) (1).
3. Modularization and preassembly
   - Modularization is very specific to only certain projects (1).
   - Does not lend itself to very large equipment (1).
   - Need to make sure that a specialist in transportation is consulted up front to identify size/route and other restrictions (1).
   - Need to ensure that the end user knows what he is getting as an end product. Otherwise rework at site will result (1).
   - Problem with this is if engineering or fabrication quality is poor. Field repairs to poorly designed or fabricated items quickly erode any benefits achieved (1).
   - More development is still required to create the "out-of-the-box thinking." We need to move beyond what we are accustomed to and think innovatively (1).
   - Must be a front-end activity and not a detailed design afterthought to be successful. Must be designed into the project at the front end (1).
   - For projects in Alberta, we do a lot of modularization. Sometimes the modular concepts have not been agreed upon early enough to be implemented (1).
4. Standardization
   - It is often difficult to get meaningful vendor input (1).
   - A barrier is the tendency to want to try innovation (1).
   - Company I work for has its own standards. Hard to get acceptance for use of manufacturer's standards (1).

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- Client engineers and operations do not typically buy into it in practice, each operating area has different wants (1).
- Designers often customize too much (1).
- Major clients like to use their own standards (1).
- Manufacturer's standards are not normally accepted in place of client specifications and standards. We do not seem to be able to standardize from one project to the next even though the projects may be very similar (1).
- Different construction companies have different standards (1).

5. Designs facilitate construction efficiency
   - Design engineers lack practical on-site construction experience and their communication skills with other groups are lacking (5).
   - Communication between construction and engineering needs development. Construction personnel do not know how to deal with formative designs (2).
   - Some sites are extremely congested (1).
   - Restrictions imposed by operations on sites with operating facilities (1).
   - Short-sightedness by developers reducing consultant fees resulting in minimal design detailing and poor quality control and specification documents (1).
   - Designers reluctant to change their design to accommodate the field (1).
   - Designers/engineers do not understand the goals and concepts of constructability (1).
   - Designs that are incomplete at the time of issuance of I&C drawings or design changes afterward (1).
   - It is difficult to find people who have knowledge in both the engineering and construction fields (1).
   - Designs are usually done to facilitate operations first and then construction if formal constructability review has taken place (1).
6. Use of innovative construction methods
   - Lack of imagination and resourcefulness among construction contractors (2).
   - Very few advancements in construction methods over the past two decades (2).
   - Need to be built into design process (1).
   - Developers and design/build contractors exploit innovation to be competitive and increase profit margins. There is a lack of incentive for consultants to be creative to save construction costs on other work (1).
   - If designs have been frozen, innovation may be precluded (1).
   - Contractors are reluctant to come up with suggested innovation (1).
   - Tendency to fall back to proven methods (1).
   - Generally, I do not believe that there is anything truly ''innovative.'' Tools may be improved, but the steps we take to engineer and construct a plant has not basically changed for the last couple of decades (1).
7. Advanced computer technology
   - As with modularization, only certain projects would benefit from this technology (1).
   - In piping design, the many changes in software systems and revisions have cost dearly. Staff never get the time to become expert in a system before they move on to a new one (1).
   - CAD systems need to become more user friendly (1).
   - Good but costly. Better than plastic models but not as easy to see all at once (1).
   - Limited to very large projects due to cost of current technology (1).
   - We have not sold the construction community on the benefits and we are not sufficiently disciplined to avoid ''garbage in'' problems (1).
   - There is a need to invest time and dollars in our construction people to get the optimum benefits in order to create ''thinkers'' and not just ''doers'' (1).
   - Although computer systems are getting better, actual practical use and applications are not there yet. Perhaps in the next 5 years (1).
   - Field construction personnel still reluctant to embrace 3D as tool to replace 2D drawings that they insist they must have to be able to build (1).

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