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INTEGRATING CONSTRUCTION
RESOURCES AND TECHNOLOGY
INTO ENGINEERING

A CONSTRUCTION INDUSTRY
COST EFFECTIVENESS PROJECT

INTEGRATING CONSTRUCTION

RESOURCES AND TECHNOLOGY

INTO ENGINEERING

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I

SUMMARY

Owners' dollars create and control the services and capacities provided in the marketplace by the construction industry.

Significant savings in both costs and the time required to complete projects can accrue from the careful interaction of planning, design and engineering with construction into the creation of projects, especially large ones. But these opportunities are largely ignored by many owners in all segments of the construction industry. Opportunities to reduce project costs and schedules by using existing and new construction technology are lost because construction too often is relegated to operate as a production function separated from financial planning, scheduling and engineering or architectural design.

Some owners and contractors are incorporating their construction resources into engineering with a "planned constructability program." In these programs, a construction specialist, working with the engineering team as the project is defined and designed, can cut costs by 10 to 20 times the added cost of extra personnel. On a $30 million project, an extensive constructability program may cost $50,000, but can bring savings of $1 million. Costs and schedules are trimmed by:

— Arranging the optimum preparation of both engineering details and the sequence in which they are prepared so as to avoid delays in construction on the site.

— Taking advantage of the latest construction technology as part of the design.

— Developing work-simplifying methods and minimizing labor-intensive design.

— Devising design and procurement strategies to suit the unique logistical requirements of each project. This involves making the optimum use of shop rather than field fabrication, preassembly, use of modular-sized units, and designing to allow for the use of facilities and equipment that do not press the limits of safe and efficient construction.

— Optimizing plant layout with respect to construction, maintenance and operation.

— Giving the project team fast reports on the construction cost impact of design changes.

To realize the full benefits of constructability programs, it usually takes at least one full-time experienced construction person, assisted by others on a part-time basis, working on the project throughout its entire engineering phase. Too many engineers are not up-to-date about how to build what they design, or how to design so buildings and/or process equipment can be erected in the most efficient way. To succeed, constructability programs must be ***fully*** supported by the owner, the engineering group and the construction organization.

Many projects have lacked effective constructability programs due to a lack of appreciation for the potential to save significant money. Tight limits on project costs often restrict the staff needed for constructability, delaying the involvement of construction experts until the design is so far along that changes would be so disruptive as to increase costs. Such limits lessen input and waste great opportunities for cost savings.

To broaden and strengthen the integration of project planning, design and construction, we recommend that:

— Owners, engineers and constructors take steps to become more aware of the methods and benefits of a fully integrated project.

— Materials be developed for training all concerned in how to integrate construction into the planning and design of projects.

— Universities that offer undergraduate level programs in construction add courses that reflect an awareness of the methods and benefits of integrated construction planning.

II

OBJECTIVES

This report is intended to:

— present the results of a comprehensive fact-finding study of current philosophies, practices and problems involving the integration of construction expertise into the planning and engineering stages of projects.

— present recommendations aimed at optimizing the process by which facilities are designed and constructed by fully integrating construction technology with planning and design.

III

HOW STUDY WAS MADE

This report was prepared by a team of seven, representing owners and contractors. The research consisted mainly of interviews with owners, architect-engineers, engineer-constructors, and contractors in the commercial power, light industrial and heavy industrial segments of construction. Team members interviewed 35 companies in their inquiry as to how and to what degree construction is integrated with planning and design.

Because of certain unique characteristics found in commercial construction, a special report on that sector was prepared (see Appendix 1).

IV

FINDINGS

What Integration Is and Does

To be effective, integration with construction must be thorough enough to have an impact on engineering. The construction experts must:

- Participate in conceptual development and planning for the project;
- Participate in making decisions;
- Participate in design reviews, scheduling and cost estimating;
- Be consulted about construction-related problems;
- Be supported by the project management so that their contributions become part of the design.

Figure 1 shows a typical sequence for a construction project. All too often construction managers are not involved until work crews are mobilized to begin operations at the site. They concentrate their efforts at the construction site and make only occasional visits to the engineering office.

Figure 2 shows the schedule when integration is included. Construction experts play an active role in the engineering process from the beginning of its definition through the design. A significant percentage of project results are fixed during the first 25% of the engineering effort. Therefore, the potential for greatest impact is ***before*** basic decisions have been made and designs begun. Construction ideas are less disruptive then, and the opportunity for significant cost and time savings is greatest.

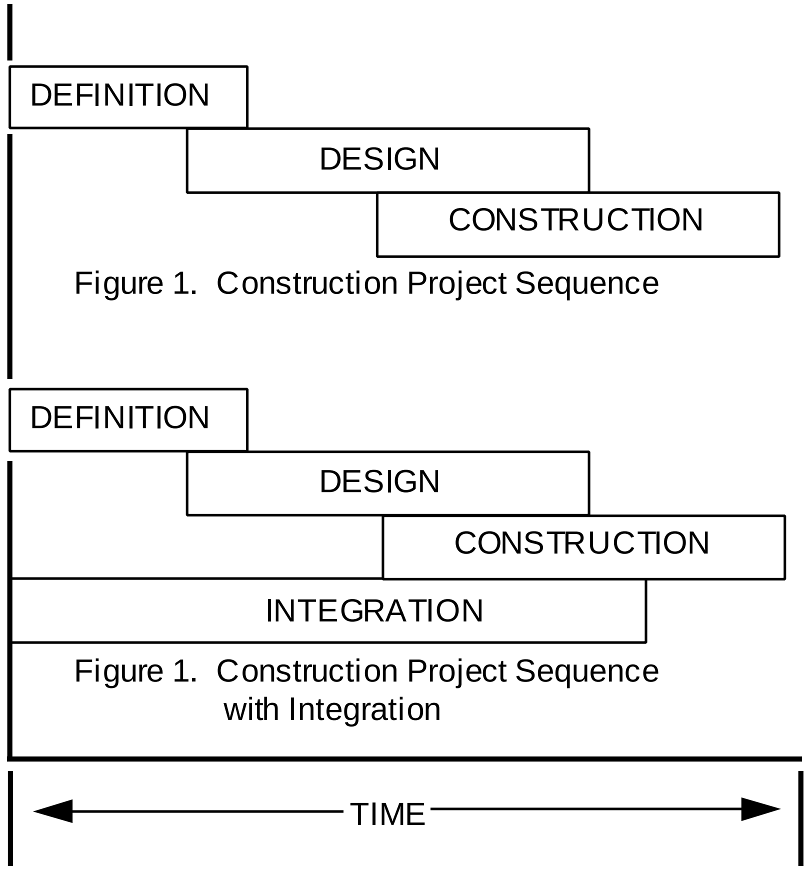


Figure 1. Construction Project Sequence

Figure 1. Construction Project Sequence with Integration

Integration is frequently carried out through a "constructability" program —that is, the planned involvement of construction in the engineering process. The number of construction experts involved in such programs depends on the project's size and complexity, and the skills of the people. To make a positive contribution to the design effort, it usually requires at least one full-time person assisted by other part-time construction people throughout the engineering phase. Integration assures that the engineering fits the technology of the construction contractor for the project.

Construction technology[1] has changed little in the last several years. Research and development has lagged behind that in many other industries. One major reason is the contractor's role in a typical construction project. All too often, he builds from a complete set of drawings without having been able to influence what has been designed. This arrangement limits his incentive to develop and apply new technology, partly because methods that may be the key to saving time and cost on one project may not apply to others. Constructability programs help construction organizations apply cost-savings methods to the design of new projects. In turn, this provides an incentive for further development of new methods[2] .

The State-Of-The-Art

Currently, the degree of involvement in the engineering process varies widely.

Three common arrangements:

- ***Minimum Integration*****—**The construction site manager is not assigned to the project until groundbreaking. Before groundbreaking, the owner's home office construction manager may assist with engineering problems. After groundbreaking, the construction site manager may visit the engineering office occasionally. Most joint action involves schedule coordination and problem solving

- ***Average Integration*** **—**The engineering project manager and several of the design engineers are experienced in construction. The contractor's staff is also involved part-time before groundbreaking for cost and schedule coordination and constructability input. This type of integration is typical of design/build organizations.

- ***Thorough Integration*** **—** The construction organization assigns one or more persons to work full-time with the engineering team from the beginning of engineering presentations, constructability and cost analysis, and schedule coordination.

[1] Construction technology is defined to include the methods, control systems, organizations, materials, equipment and labor skills needed to build facilities.

[2] See Report B-2, *"Technological Progress in the Construction Industry"*, The Business Roundtable, 1982.

Training

Most owners and contractors do not have formal training programs in the skills required to develop experts in "constructability". Construction experts picked for this kind of liaison work with engineers should be experienced personnel with good communication and interpersonal skills. The program's success depends on the skills of the people involved and the support of the project management.

Who Makes It Happen?

In-depth integration demands full commitment by the owner. The on-site construction manager usually leads the integration process. He must be supported by the home office supervisor, by on-site craft superintendents and field engineers, and cost or schedule engineers wherever located In-depth integration also demands full commitment from the engineering contractor because of the need for more people to be involved at a higher level.

Potential Impact

The interaction of construction expertise and engineering, thoughtfully and wisely carried out, can make improvements large and small in the way projects are built. These include:

— ***The overall approach to a project,*** including the decision on the type of contracts to be used—lump sum or reimbursable —and whether to use a single design/build firm or separate firms for different parts of the work.

— ***Subcontracting strategies,*** e.g. customizing design packages to fit the contracting plan by preparing an early plan for project subcontracting.

— ***Engineering presentations,*** that is, customizing the engineering output to meet the needs of physical construction. This eliminates wasted engineering effort for unused details and assures that the construction organization will have all the information it needs.

— ***Constructability:*** teamwork between construction experts and engineers should yield designs requiring the least costly methods for on-site construction. This can be expanded to offsite construction of modules or other cost-saving alternatives.

— ***Schedule integration:*** making sure the field organization gets the right engineering information and on-time equipment deliveries to avoid wasting labor at the site.

Barriers To Integration

Several barriers frequently curtail the use of integration:

— Resistance by owners: Constructability programs add highly visible extra cost to projects; benefits are less tangible.

— Tradition: Construction people are unaccustomed to being involved early and working in engineering offices.

— Resistance by engineers: Construction experts are sometimes perceived as meddling and troublesome during engineering.

— 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 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.

Cost And Benefits

The cost of integration is minimal and consists mainly of salaries for the construction experts involved plus their travel expenses. The payoff comes in improved project economics, more effective use of field labor, work simplification, a shorter schedule for project completion, and the application of new technology. Typical savings have been 10 to 20 times the added personnel costs. For example, on a $30 million project, in-depth integration may cost $50,000, but the resulting savings can reach $1 million. Cost and schedules are reduced by:

— Optimizing the engineering and construction relationship.

— Optimizing engineering details and sequence to meet construction's needs.

— Using the latest appropriate construction technology as a part of the design.

— Developing work-simplifying methods and minimizing labor intensive designs.

V

CONCLUSIONS

Significant benefits can be obtained by the thorough integration of construction expertise with project engineering. The benefits consist of reducing project costs and schedules, through the increased use of new construction technology.

Some owners do not demand or support an integrated process because they do not understand or appreciate the potential benefits and the attractive rate of retum on a comparatively small added investment.

Contractors do not fully implement constructability programs unless they have owner support. Moreover, most contracts are not written so as to provide an incentive for contractors to integrate engineering and construction.

There is a shortage of personnel qualified to make a significant contribution to the integration process.

VI

RECOMMENDATIONS

To broaden and strengthen the integration of project engineering and construction, It is recommended that:

- —***Owner Awareness:*** Owners take steps to become more aware of methods and benefits of a fully integrated project. They should require engineering and construction contractors to implement this integration.

- —***Training in Constructability Skills:*** Materials be developed for training in constructability skills. This would include an introduction to the latest technology of construction me thuds, materials and equipment, and to proven methods for incorporating new technology into the design and planning process.

— ***University Education:*** A plan be developed to alert the academic community to the need to include constructability in undergraduate curricula. Faculty and students should be aware of the fully integrated process in their classroom and research efforts.

— ***Reference Manual:*** A reference manual be prepared for use by owners, engineers and contractors. It should provide guidelines and suggestions for establishing constructability programs. Typical material in the manual might well include:

— Models covering various types of construction, owner capabilities and contracting methods.

— Suggested constructability programs for typical industrial projects (see Appendix 1).

— References to published papers covering constructability.

— Case studies (see Appendix 2).

APPENDIX 1

INTEGRATING NEW TECHNOLOGY AND CONSTRUCTION INTO COMMERCIAL BUILDING

This addendum explains some of the differences between a commercial project and a power, process or heavy-industrial project, and why early integration of new technology and "constructability" into design and construction helps the owner save money.

There is a major difference between the commercial construction and the sectors involving power, process and "heavy industry". The ***commercial sector*** views the ***building*** as the most important product of the design process, with aesthetics and function playing a major role. In contrast, the ***power, process and heavy industry*** sectors place major emphasis on the ***product*** produced by the equipment, which is merely shielded from the elements by the building.

For this reason the commercial sector appears to handle a successful project somewhat differently in that each major project is usually treated as more of a "one of a kind" entity with a more truly integrated project process than other sectors of the construction industry, with an ongoing yearly design/build volume. This is good and bad, in that a well represented and coordinated commercial team can achieve great success, but a mismatched group can yield disastrous results, often before remedial action can be taken.

Who makes integration happen?

In the commercial sector the most successful project team for a major project ($50 million and larger) appears to be composed of the following members who are assembled at the project feasibility evaluation:

1. Owner's representatives
2. Developer/consultant
3. Architect/engineer—of national renown.

After a project is deemed a "go", a well-recommended general contractor (GC) is immediately brought on board as either a construction manager (CM) or a GC, and sometimes technical consultants as well as major specialty subcontractors functioning as consultants (i.e., facade, mechanical, electrical, vertical transportation, structure). During the design phase, value engineering and life-cycle costing are employed to evaluate major directions. While no cumulative record is available of cost-time benefits, it is generally agreed that 10 to 20% of project cost can be saved by using this process.

When should the integration process begin?

As early as possible. Large commercial projects created by the most highly regarded design professionals are constantly breaking new ground in the realm of design So they are often advancing the state-of-the art in their quest for design solutions. This process could easily be equated to the space program's creation of many technological innovations, necessary to launch an exploration craft, which later became useful and innovation parts of the everyday world.

One of the most successful ways to incorporate the latest "state-of-the-art" capability (new technology) into the project process is accomplished by the close interaction of the architect, engineer, general contractor, specialty contractor, material supplier and the developer in creating a set of carefully prepared specified performance criteria as is evidenced by the following:

Carefully Prequalified Architect/Engineer	*Carefully Prequalified Contractor Lump Sum Bid and Negotiated Specified Performance Criteria*	*Carefully Prequalified Specialty Sub-Contractors and Materials Suppliers*
	Interaction	
	Specified performance criteria should be based upon regular, general and specific research in areas of structure, facade, roofing, vertical transportation, interiors, mechanical and electrical systems, etc.	

Performance criteria is that which is established by the design professional and their consultants to state the desired goal within aesthetics criteria but does not state the methods by which that goal is reached. Therefore, the use of performance specifications requires a clear and careful balance between the architect/engineer and the subcontractor and material supplier with a qualified testing agency as the ultimate authority on the proof of performance and in settling of disputes between the designing parties. The general contractor and, in some cases, the developer, serve as a filter and buffer for the owner regarding:

— Subcontractor and material supplier prequalification and buyout.

— Subcontractor supervision, coordination and management.

— Financial project management.

— Long term liability.

Constructability is attained by four sources:

1. The architect/engineer during the design research and development phase.

2. The general contractor if he is brought in during the design phase either as a construction manager or a general contractor, but only partially if he is brought in complete with contract documents on a negotiated basis. With lump sum bidding, the constructability technique is used only if the contractor encounters a problem, is specifically questioned, or is given a change order.

3. Subcontractors if they are brought in early as consultants. When subcontractors are brought in after a package award, unless it is a performance award, they will mainly suggest changes to save their own time and money.

4. The developer, particularly with close financial and schedule supervision and with the know-how of his construction and maintenance staff.

Costs and returns

The cost of integration includes some of the following fees for personnel and travel expenses:

— Architect/engineers early involvement fee

— Developers' management fee

— Consultants' fees

— Contractors' preconstruction fee

— Subcontractors generally come on board early to work towards a guaranteed maximum upset price (GMP) which can be overturned when the package is bid if the low bid is less than the GMP.

— Material suppliers usually participate at no cost as long as their product is one of those specified or they could bid on the project.

— A safe guess on the cost of the preconstruction services just listed for a $50 million project is roughly $1.5 million. This might well save 20% of the project cost, or about $10 million, for a net savings of $8.5 million on the $50 million volume of construction.

APPENDIX 2

CASE STUDIES
THE INTEGRATION OF PLANNING, DESIGN, AND CONSTRUCTION

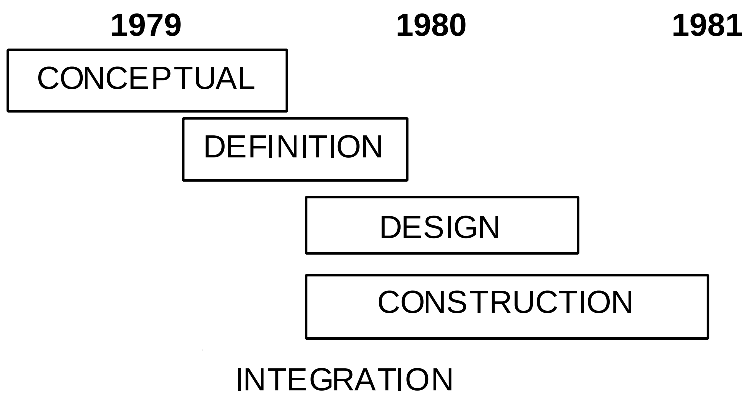
Case Study No. 1

Project: $12 million addition to a food-processing plant
Contracting arrangement: All phases of engineering through the detailed design were completed by the owner's engineering department. The construction was managed by a general contractor on a cost-reimbursable contract The contractor used lump sum subcontractors for all the civil work

and self-performed the process installation.

Staffing for integration: The general contractor's site operations manager was identified as the constructability coordinator and was assigned full-time at the engineering office for four months and traveled from the construction site for two months. Specialists from the contractor's home office and the site organization were called in to consider specific technical problems.

Timing:



Roles and responsibilities: The major responsibilities of the constructability coordinator were to:

— Review all proposed design packages to identify potential cost or schedule-savings and work with engineering to devise improvements.

— Coordinate the content of all packages of engineering issued in order to meet the subcontracting strategy.

— Coordinate the timing of engineering issues and equipment deliveries to dovetail with construction needs.

— Call in specialists to study specific technical problems.

The constructability coordinator's role was actively supported by the owner's project manager and the construction manager. This contributed to the success of the effort.

Cost and benefits: The cost of the constructability program was $32,100 for personnel and travel. The conservatively identified benefits produced a cost savings of $542,482, including:

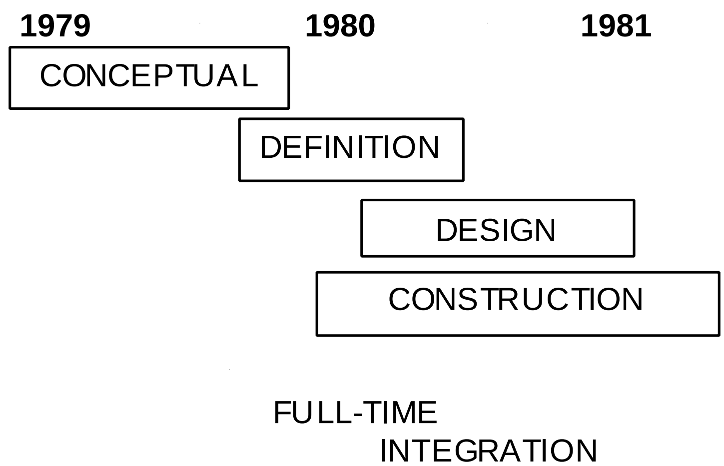
Change tank bottom from sloped to flat with sumps	$ 12,030
Eliminate grinding welds smooth on all tanks	145,065
Change nozzles from stainless to carbon steel on a tank	4,940
Use prefabricated trench instead of formed trench	1,080
Use standard screed instead of vibrating screed for concrete placement	5,000
Use rock anchors instead of through bolts on packing building footings	1,660
Reduce size of anchor bolts and base plates on pipe supports	275
Use glass fiber instead of concrete housing for fire hoses	300
Use angle at edge of slab rather than standard formed edge	450
Use channel frames for doors, eliminating the need for temporary masonry supports	1,300
Move pipe-bridge columns outside of odor control building	300
Modify foundation slightly for redesigned caustic tank	1,500
Ship column in one piece instead of welding it at site	3,700
Modify pipe supports to simplify erection	800
Modify process building slab-on-grade	960
Extensive use of local subcontractors for civil work	183,000
Run ground level instead of elevated pipe bridges; attach off building instead of running across roof	38,900
Hanging tractor-aisle piping beneath beams	1,056
Relocate tank piping to ground level and locate vertical runs adjacent to tanks	1,490
Use standard fire-protection industry standards	18,000
Reroute underground piping to east side of guard house	29,723
Manage painting scope and method	75,000

Case Study No. 2

Project: $45 million new site synthetic-detergent plant.
Contractual agreement: Conceptual engineering was led by the owner's engineering department. Definition and design were completed by an engineering contractor and construction was managed by a general contractor The engineering and construction contractors were separate firms with no previous experience working together. Both had costreimbursable contracts.
Constructability staffing: The main effort at constructability was during the definition and design periods. The general contractor assigned one person, full time for nine months as constructability coordinator, housed in the engineering contractor's office. The coordinator was a qualified site manager and had extensive international experience.

Specialists from the field organization, the contractor's home office, the owner's staff and vendors were brought in to work on specific technical problems.

Timing:



Roles and responsibilities: The constructability coordinator's re sponsibilities during definition were to:

- — Coordinate development and evaluation of design/construction alternates to reduce project costs and optimize quality.
- — Coordinate design presentation with the field organization.
- — Interpret construction schedule and logic to and from the task force.
- — Develop the format and coordinate the implementation of the constructabil ity program.
- — Be a resource to the field organization.

During the design phase, the constructability coordinator's responsibilities were to:

- — Monitor the construction plan and the engineering presentation to assure their compatibility.
- — Question the reasons for using standard practices, drawings, etc. with the goal of devising lower cost and/or higher quality elements of the design.
- — Approve all engineering before it was issued.
- — Advise and consult about quality-control specifications for construction.
- — Coordinate the development of engineering-materials and construction-methods studies.
- — Inform the general contractor of all decision on a timely basis.
- — Work out items in the detailed engineering-construction schedule through the project engineer.
- — Act as a consultant on the master-milestone schedule
- — Interpret construction-schedule and logic for the task force.
- — Be aware of the engineering schedule and priorities for making suggestions to facilitate construction.
- — Open doors between engineering and construction personnel; after the design is completed, be involved only as required.

— Help coordinate the flow of information and people between engineering and construction for scheduling, engineering presentation, technical consultant, and constructability.

— Be involved in making decisions for all engineering issues impacting construction.

— Be available for special construction studies or preplanning activities.

Costs and benefits: The integration cost $75,000 for personnel and travel, working with the engineering team. Many of the schedule and quality benefits of the program are hard to quantify. Conservatively identified cost savings totalled some $615,000, a return of more than eight to one. Some of the cost-cutting steps and methods developed and implemented by the team are:

Combined most major field-erected equipment into one lump sum package	$285,000
Revised building and equipment foundation design to minimize excavation and formwork	75,000
Maximize steel and equipment shop painting	35,000
Designed many large pieces of equipment to maximize shop fabrication	20,000
Many (12-15) minor studies were done around civil/ structural details, equipment installation details, etc.	50,000
Develop detailed construction schedule early in the definition phase of engineering to define early construction priorities and long lead-time materials	
Early equipment installation planning to (a) optimize shop assembly, (b) identify field problems early, (c) level crafts	25,000
Piping: (a) material standardization (b) alternate material studies	25,000