CIFE CENTER FOR INTEGRATED FACILITY ENGINEERING

Requirements and Tools for Transferring Construction Experience Between Projects

by

Mark C. Reuss

C. B. Tatum

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Author: Mark C. Reuss, Field Engineer, Bechtel
Former Research Assistant, Stanford University

C. B. Tatum, Professor of Civil Engineering, Stanford,
phone 415/723-3926, email: tatum@cive.stanford.edu

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Abstract: Recent advances in computer tools and increased use of these tools for design offer excellent means for transferring design experience between projects—it is possible to start with the electronic model of the last job. However, industry professionals are frustrated regarding the difficulty of capturing construction experience and transferring it to later projects. Advanced information technology offers assistance with this critical need for integration. The research project described in this report increased understanding of the types of information to share between projects and demonstrated that microcomputer database tools can capture this information and make it available for future projects. The research method involved developing a classification of possible types of knowledge, expanding and refining this classification based on documents concerning experience transfer in design and construction firms and interviews, developing a prototype computer application to capture this information and make it available for new project teams, and testing this approach on an active construction project. This research also resulted in conclusions regarding the content of construction experience, capturing and gaining access to this information, and the feasibility of using computer tools.

Subject: This report describes examples of current approaches for transferring experience between construction projects and reports the results of developing and testing a classification for knowledge from construction experience and a database application to capture and disseminate this knowledge.

Objectives/Benefits: The objectives of this research project were to define the types of information regarding construction experience on projects that would assist in design, procurement, and construction on later projects; to investigate alternate means to capture this information during the ongoing construction phase of a project; to evaluate alternate ways to represent and retain this information in a computer application that would make it readily available to future project teams; and to develop and test a prototype computer application for construction experience transfer.

Methodology: The method for this research involved reviewing current methods for experience transfer in firms, developing an attributes matrix to classify information from construction experience, obtaining data regarding construction experience from industrial and building firms, investigating alternate means of capturing the information and making it available for future projects, and developing and testing a prototype computer application to collect and transfer construction experience between projects

Results: The major results of this project include a summary of current practices for experience transfer, a classification system for the knowledge from this experience, and a prototype database application that uses the classification to capture construction experience and make it available for future project teams.

Research Status: This report and its companion (TR No. 81) give the results of this completed project. The project increased understanding of construction experience and demonstrated the feasibility of using hardware and software normally available on construction sites to capture this knowledge and make it available to improve performance on future projects. Based on findings from this project, successful development of multimedia tools in CIFE, and member interest ways to improve experience transfer, this topic may merit additional CIFE research project in the future.

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Appendix A: Construction Lessons Learned Concepts

Ch. 1 Problem and Research Plan

1.1 Need, Current Approaches and Problems

Recent advances in computer tools and increased use of these tools for design offer excellent means for transferring design experience between projects. It is possible to start projects with the electronic model of the last job. But feedback from actual use of the design is often not captured in electronic format, creating a potential for repetitive design errors. In addition, there is a strong frustration among industry professionals regarding the difficulty of capturing construction experience and transferring it between projects. This research project was designed to increase understanding of the types of information that should be shared between projects and to evaluate the possible use of database software to assist with this critical information need.

To transfer experience between projects, managers often transfer people. Many operations and project managers strongly desire new methods. They can easily identify many examples of beneficial transfer of construction experience between projects, but are very frustrated that intervention by senior management is often required to make this happen. The level of computer skills available at the construction site is rapidly increasingly and managers want to take advantage of this in transferring experience. However, they are keenly aware that standards for careful selection, classification, and storage of the information are needed, and that any computer applications must be flexible and easy to use.

Despite this well recognized need, several barriers inhibit the transfer of experience between construction projects. Physical separation and organizational fragmentation present significant obstacles. Many managers and supervisors in engineering and construction believe that each project is very different from others and therefore only limited benefits result from transferring experience. The frantic pace of the project site and the competitive nature of the industry limits the investment of time and resources in programs designed to benefit future projects. "Paperwork" is an anathema to many in construction; field people frequently regard efforts to transfer experience as an additional administrative burden rather than a new information system that brings real benefits.

1.2 Definition and Scope of Construction Experience

Construction experience, as used in this research, is knowledge based on methods to perform construction, field operations and results of prior projects. This knowledge provides technical, operational, contractual, or administrative guidance for subsequent projects. Construction experience transfer is the use of knowledge from lessons learned on prior projects to maximize achievement of current project objectives.

This project focused on the conceptual issues involved in the description, capture, and use of knowledge concerning construction experience. The scope included information regarding construction experience in industrial and building construction. The data elements in the database focus on power plant projects.

1.3 Purpose and Objectives of the Research

The purpose of this research was to increase understanding of the types of information needed for construction experience transfer between projects and to evaluate the feasibility of using computer tools to capture this information and make it readily available for new project teams.

The following objectives structured this research project:

- define the types of information regarding construction experience on projects that would assist in design, procurement, and construction on later projects
- investigate alternate means to capture this information during the ongoing construction phase of a project
- evaluate alternate ways to represent and retain this information in a computer application that would make it readily available to future project teams
- develop and test a prototype computer application for construction experience transfer.

This research related to other projects in Stanford's Center for Integrated Facility Engineering (CIFE) by using information technology to support integration. The project responds to an often stated managerial frustration regarding the difficulty of transferring construction experience between construction projects. Engineering and design now use databases and 3D CAD models to make experience from prior projects easily available. The prototype system developed in this research is a starting point for gaining similar advantages from information technology in transferring construction experience—a very different and less understood type of knowledge. By making construction experience from prior projects available during the design and procurement phase of projects, this research also supports CIFE's goal of increasing vertical integration.

1.4 Research Method and Activities

1.4.1 review experience in firms and summarize current knowledge of the information requirements for construction experience transfer

Project reports and other forms of documentation that exist in owners' and contractors' organizations provided important background for this project. The researchers located and reviewed available types of documentation regarding experience on specific projects and the types of information needed for construction experience transfer. This information included feedback to design from engineer-constructors, technical issues described by design-build contractors, experience in contract management in owner's organizations, and experience with risk management, new materials, and difficult installations from management contractors.

The company documentation reviewed during this research included information from Bechtel, Chevron, Critchfield Mechanical, Fluor Daniel, Korte Construction, Pankow Builders, and Turner Construction.

Other published background reviewed during this project included other database applications in design and construction, such as structural failures, product information, project control, and building codes.

1.4.2 develop an attributes matrix for access to information required for construction experience transfer

Based on the background literature and documents from firms, the researchers developed an attributes matrix for access to the types of information needed to effectively transfer construction experience between projects. As further described in Chapter 4, this matrix includes elements related to facility type, construction engineering and management, organization, physical environment, and construction phase. The attributes matrix formed the basis for a database application to evaluate the feasibility of capturing and accessing construction experience. The researchers expanded and refined the matrix based on the different types of data regarding experience transfer obtained during the research.

1.4.3 obtain data from documents and interviews and analyze to develop a structure of knowledge for construction experience transfer

The researchers investigated several types of firms and projects to collect data for expansion and refinement of the attributes matrix. As further described in Chapters 2 and 3, this data collection and analysis involved review of documents regarding lessons learned and interviews with managers responsible for this activity in several firms. The firms used both computerized and manual systems to capture construction experience. The information from firms allowed refinement of the attributes matrix and provided entries for the database application to test it.

1.4.4 investigate alternate means of capturing the information contained in the classification and alternate computer applications to make it available for future project teams

The researchers considered several computer tools to capture construction experience and make it available to future projects. This included PC database software for IBM compatible and Apple computers. Based on ease of data entry and capability for easy searching, we selected a commercial database initially developed for the Apple Macintosh but now also available for PC's. This system and the reasons for its selection are further described in Chapter 4.

1.4.5 develop and test a prototype computer application for construction experience transfer between projects

Following evaluation and selection of the best software, the researchers built a prototype application to demonstrate the feasibility of capturing and providing the information needed for experience transfer between construction projects. The application included the major types of information contained in the structure of knowledge for construction experience transfer. As further described in Chapter 4, we tested the application by loading information from several cogeneration projects. We also conducted a field test of the prototype at a project site.

This research is an exploratory investigation to begin consideration of the major topic of construction experience. The background related to this topic includes published summaries of experience from individual projects and lessons learned programs in companies. The increased understanding of construction experience gained in this research provides a basis for both development of computer systems to transfer construction experience and future research regarding extended application of information technology in the collection and transfer of construction experience.

1.5 Reader's Guide for the Report

Managers interested in the conclusions concerning the potential to use computer tools for capture and dissemination of construction experience should start with Chapter 5. Chapter 3 then gives further insight concerning the two types of knowledge from construction experience identified in this research. For a description of the prototype database application see Chapter 4.

Researchers interested in the background for the project will find this information in Chapter 2. Chapter 3 describes the data elements and concepts that make up construction experience and Chapter 4 explains the development and use of the database for experience transfer. For further depth, see Appendix A for the construction lessons learned concepts.

Ch. 2 Background of Construction Experience Transfer

2.1 Introduction

Transferring construction experience between projects can make significant contributions to achieving the project objectives of cost, schedule, quality and safety. The knowledge gained allows construction teams to repeat the successful techniques and avoid the problems of previous projects. Without transferring experience, the construction industry does not "learn" and improve as it can and should.

To transfer experience between similar projects, construction professionals have used techniques ranging from formal annual meetings to impromptu telephone calls to the home office. These forums can be effective but have inherent limitations related to timeliness (not available when needed) and broad scope in the former case and to the individual's capacity for recollection in the latter case. Recent efforts to transfer experience include "project closeout" or "lessons learned" reports to capture and retain information, in both text and graphic form. These reports address the issues of timeliness and recollection limitations but often fall into disuse under the severe pressures of operations on future projects.

This chapter reviews the relevant background of construction experience transfer using the topics of lessons learned programs by owners and contractors, project experience, and database applications.

2.2 Lessons Learned Programs by Owners and Construction Firms

Managers in several firms have recognized the importance and difficulty of transferring construction experience and taken steps to improve this process. We investigated programs for industrial projects in three firms (Bechtel, Chevron, and Fluor Daniel) and programs for building projects in three firms (Critchfield Mechanical, Korte, Pankow, and Turner).

Bechtel provided the following summary of its approach for transferring experience between projects (Williams, 1992). Bechtel Corporation has a corporate Constructability Lessons Learned

Program. The corporate program involves collecting information from individual projects and entering the lessons into a corporate database for storage and subsequent retrieval. The database exists in three different formats. These include text files that are searchable by key word, a PC based database that allows searching by project type, discipline and other key fields, and a new On Line Reference Library that will permit storage and retrieval of both text and graphical data.

Chevron Research and Technology Company also has a lessons learned program in place. This division of Chevron develops reports that describe successful approaches and ineffective techniques after each building project. Issues covered include contractor selection, design management, team-building, contracting approaches, safety and schedule/cost performance. One report focused on utilizing experience from an office building construction project to other similar buildings within the same Chevron complex. This report covered design concepts, materials, and details for several disciplines.

Critchfield Mechanical, Inc., a design-build mechanical contractor in Menlo Park, CA, has a lessons learned program involving a series of meetings to improve the design/construction interface. First, the "Engineering Review Meeting" focuses on design simplifications and improvements based on the input of construction experience to a partially completed design. Then, the "Construction Turnover Meeting" involves the design/procurement team to discuss with the field personnel subjects such as how much labor is included in the project, the type of equipment used, who the subcontractors will be, etc. (Critchfield, 1991). These mechanisms depend on the experience of the participants and the ability to recall the lessons learned. CMI also has procedure manuals that contain successful engineering and construction details.

Fluor Daniel, Inc. has a experience database called the Better Way Bank. It is based on an IBM application called "Ask Sam." Based primarily on experience from a large project, the database includes estimated cost avoidance for each entry. Examples of the entries include prefabricating reinforcing steel, using special formwork systems, bulk rail shipment of cement, vendor application of final coating for structural steel, and simplified instrument calibration.

Korte Construction Company, a design-build contractor based near St. Louis, Missouri, has numerous forums for transferring experience and is currently developing an advanced technology transfer system. Korte holds monthly company-wide superintendent meetings, formal in-house training classes, and pre-construction meetings with site personnel and subcontractors who are about to begin a project. In addition, quarterly company meetings include presentations of innovative techniques and tools developed within the company. Select ideas result in financial rewards and are included in a manual available in the home office.

Korte also has a R&D department, which is developing a prototype interactive computer environment for experience transfer. The multi-media format supports text concerning basic tools, techniques and key processes and a video of construction techniques taken on project sites. Korte plans to make this program available to the entire company after completing the necessary R&D.

Charles Pankow Builders, Ltd., a general building contractor headquartered in Altadena, CA, is developing a database application to transfer construction experience as a part of the firm's quality control program. Traditionally, the company has relied on technical reports on methods, materials and costs for each project. Annual meetings of the entire company are a forum for presenting positive and negative experiences on projects of the previous year. They also continually update their QC manual which contains multiple formats for implementing their QC program. The manual follows the CSI format in information organization (Morgan, 1992).

With the addition of a quality control staff in 1988, Pankow now also transfers its construction experience via a quality control engineer on every project. These QC engineers are responsible for recording lessons learned on portable computers loaded with a standard company DBase IV program. Pankow plans to integrate lessons learned from several projects and distribute the result to future projects for digital referencing. Common topics include curtain wall, roofing, and waterproofing difficulties due to workmanship and subcontractor management problems and design coordination. The activity reports from this system include the following elements:

- name of the installed feature that requires the QC activity
- QC phase of the project: planning, pre-construction, construction
- QC issue or problem related to the requirement
- QC requirement that applied to the issue
- action taken to resolve the issue
- reference to applicable industry standard, code requirement, or other technical information related to the issue

Turner Construction Company compiles and distributes in-house a group of manuals covering project administration, field practices, and technical topics. One of these manuals is a collection of papers called Building Digests. These digests contain checklists, points to consider, system requirements, desirable design characteristics, applications, and recommendations for use in the design and construction of a wide variety of building types. The technical information is structured by type of construction materials or services, following the 16 divisions used by the Construction Specifications Institute.

Two new manuals have recently been developed by Turner, based on their construction experience; these are the Material Expediting Manual, and An Introduction to Pharmaceutical

Facilities—the Contractor's Perspective. The Materials Expediting Manual describes a program that follows the same format as guidelines published by the Construction Industry Institute. It includes forms, schedules, and checklists. The purpose of the pharmaceutical manual is to familiarize the project personnel with the specialized systems and requirements of these facilities. It includes sections on processes and services, clean rooms, biotechnology, controlled environments, automatic controls, and validation (Prosek, 1992).

This range of programs by owners and contractors to transfer construction experience indicates a recognition of the need to provide new approaches. The programs differ in aspect of construction considered and level of detail. They highlight the need for increased understanding of the knowledge gained from construction experience and how to use it in other project phases.

2.3 Database Applications and Project Experience

An investigation of technological innovation in construction included development of a database application to capture the elements of construction technology and measure change resulting from innovation. This investigation defined construction technology as the combination of *resources, processes, and conditions* that produce a constructed product (Tatum 1988). Resources consist of permanent materials and equipment along with temporary additions by construction. Construction processes are the methods and tasks used to build. Project requirements and site characteristics are the major conditions.

Each of the major elements of construction technology offer the opportunity for construction experience transfer. Obtaining and effectively using all types of resources provides experience regarding problems, solutions, and means of avoidance. Innovative methods and operations that frequently cause problems provide subjects for experience concerning processes. Although conditions differ on each project, experience regarding actions to meet challenging project requirements or work under adverse site conditions is valuable for future projects.

The researchers discovered several applications of databases in the construction industry covering areas from international libraries of literature to reports of structural failures. The National Bureau of Standards sponsored a failures database after the 1982 skywalk collapse at the Hyatt Regency in Kansas City. This database contains thousands of detailed cases of structural failures. Its purpose is to identify the elements of design and construction that have led to the most–and most serious–failures over the past decade. This National Science Foundation project therefore collected lessons from the projects that experienced failures (ENR, 1987).

Another database application for construction contains information concerning building products. This system provides on-line access to summarized and detailed product data. The coding of entries is intended to provide a common language among the users of product information. The system has two accessible subsystems of summarized and detailed product information (Coker, 1985).

To facilitate access to a project controls data base, Logcher (1989) developed an expert system that allows access to the information without requiring structured queries or advanced programming. Users have ready access to over 7.5 million items of historical data from U.S. Army projects for use in estimating and planning.

A Washington, D.C.–based firm has developed a database that supplies information on building codes. It can provide project-specific, computer-generated reports to satisfy requirements of specific users. With approximately 44,000 jurisdictions that write or modify model codes, the complexity of the code system warrants a service that can quickly determine local building requirements. The engineer, architect or project manager using the system can access the information via modem or can have the search performed as a service (Post, 1988).

The first international construction database (ICONDA) was created by the International Council for Building Research, Studies and Documentation (CIB) in Stuttgart, Germany. The initial effort involved entering 130,000 publication titles on construction, engineering, architecture and technology. The CIB plans to add 35,000 titles annually, ultimately including titles and abstracts of newspaper and magazine articles, research reports, dissertations, et al. Users access the information via a modem call to data bank hosts in England, the United States and Japan (Hoffman, 1986).

The researchers also reviewed published descriptions of design and construction experience. The two example projects concerned transmission towers in Quebec and timber bridges in Ohio. The first project, by the electrical utility Hydro-Quebec, connected hydropower facilities at James Bay to Montreal and other cities in southern Quebec. The project report compares experience gained from the design and construction of two types of electrical transmission towers, including design approach and characteristics, construction productivity ratings, material costs, overall construction costs and environmental factors. The report included sketches, tables and photographs to fully describe this project (Ghannoum and Lamarre, 1985).

A second example project report reviewed by the researchers was written by the Ohio Department of Transportation to disseminate their experience in the design and construction of treated timber bridges. This report compared the design characteristics and service performance of reinforced concrete and wood bridges, reviewed the process of construction of timber bridges (including problems encountered), and evaluated the performance of bridges rebuilt with timber decking (Barnhart, 1987).

Chapter 3 Analysis of Construction Experience

3.1 Introduction

Many industry professionals have indicated a need for improved effectiveness in the transfer of construction experience. With their memory and retrieval capabilities, computers could provide extremely valuable support in this task. However, using computer tools to assist in transferring construction experience requires additional understanding of this knowledge. What are the elements of construction experience? Is it possible to capture and represent this knowledge electronically? Will computers really allow effective retrieval and use of construction experience? This chapter describes findings from this research regarding the types and characteristics of construction experience. The description uses two levels to classify this knowledge: data element and concept.

The *data elements* concerning construction experience are the information contained in the prototype database described in Chapter 4. They provide specific knowledge regarding actions to use better methods or avoid problems, based on experience from individual projects. Industrial projects, primarily cogeneration stations, provided most of the knowledge for the data elements.

The construction lessons learned *concepts* describe use of a management technique or the avoidance of a technical problem on individual projects. They include a greater scope than the data elements and often describe a process. Published descriptions of management techniques and experience in general contractor and engineer - constructor firms provided the basis for the concepts.

Building from the specific data elements to the more general concept, this chapter describes findings regarding the two levels of construction experience. For each, it includes an overview of the structure, sample items, and a description of characteristics for that level of knowledge. Appendix A gives the complete concepts.

3.2 Data Elements in the Construction Experience Database

The data entries in the construction experience database form the most specific level of knowledge regarding construction experience. The researchers developed the data elements by reviewing construction lessons learned reports and other documents from engineer - constructors and general contractors.

The following are examples of typical data elements (some are abbreviated from the form included in the database):

- Maximize offsite fabrication by: creating an engineering and construction team to identify prospects, reviewing the candidates to ensure that potential benefits are not offset by additional engineering and procurement support, involving equipment and materials vendors to implement specific programs.
- Drawings for equipment (such as boilers) should also provide a bill of materials so that these can be verified before construction.
- During contract negotiations, hazardous waste handling and disposal should be addressed. It is clear that during the construction phase, the contractor is responsible for his own waste. The question of responsibility for wastes arises during the startup and initial operation of the systems. If the owner supplies charging materials such as resins and oils, is should follow that the owner is responsible for the wastes from "cradle to grave." This responsibility should be explicitly assigned in the contract to minimize legal exposure and contract price.
- If welds in below-grade circulating water piping are vacuum tested as they are completed, the trench can be backfilled as the welds are finished. This yields overall schedule savings, reduces the schedule impact due to late pipe deliveries, and allows construction traffic to flow over the backfilled pipe location. The alternate testing procedure, hydrotesting on short lengths of pipe, requires expensive blind flanges and extra labor to seal and test the pipe.

The data elements identified during this research fall into the following categories by type of information contained:

- *Administrative* data elements identify needed support for construction operations.
- *People and management* topics in the data elements deal with motivation, organization, and managerial action.
- *Project control* topics in the data elements include the work breakdown structure, monitoring of operations, and analysis of status and problems.
- *Contractual* topics in the data elements identify scope elements, performance requirements, site conditions, or information needs imposed on the contractor or supplier.
- *Technical* topics in the data elements focus on changes in design requirements or construction methods to complete specific operations.

The data elements offer the following insights regarding the characteristics of knowledge gained from this level of construction experience:

- Many of the data elements describe actions to avoid problems during the construction phase of future projects, based on the steps needed to solve the problem on a prior project.
- The data element suggest three types of actions: input to other functional activities and project phases, action by others in response to this input (typically to provide resources for construction), and actions that are a part of field operations.
- Construction experience indicates that construction has a key role in design analysis and coordination between disciplines. The analysis includes completeness, fit with project and site conditions, compatibility with other disciplines and ability to use desired construction methods.
- Many data elements require a construction action to either provide input to another functional area or to a vendor, often acting during another phase of the project, or to revise standard approaches to managing, supporting, or performing construction operations. This may involve increased scope for others or transfer of activities that construction must perform by default to others who act earlier in the project and may be better qualified to perform the task.
- Some of the data elements suggest consideration of additional alternatives or influences in analysis prior to selection of design or construction approaches.
- Data elements may identify project conditions that prompt exceptions to general principles for selecting the design approach or the construction method for a portion of the project.

3.3 Construction Lessons Learned Concepts

Developing the data elements indicated a need for a more comprehensive level of knowledge regarding construction experience. Several examples of construction experience described the consequences of broader actions or decisions or of ongoing processes. The scope of this project did not allow developing each of the concepts suggested by the data, so the researchers developed several examples that appeared to illustrate the different types of construction lessons learned concepts. See Appendix A for the description related to the following concepts identified in this research:

- design-build contracting
- team building
- materials management
- schedule performance
- temporary facilities
- waterproofing
- HVAC systems.

Analysis of the construction lessons learned concepts lead to the following insights regarding the characteristics of knowledge related to this level of construction experience:

- The concepts often describe a process that can be improved on future projects by considering construction experience.
- Many of the concepts describe a series of actions that focus on meeting a critical project objective, such as cost, schedule, quality, or safety.
- Other concepts describe ways to improve administrative systems that support construction operations, such as materials management.
- Another type of concept describes experience regarding effective construction procedures for complex and problematic operations, such as waterproofing.
- The concepts also include experience related to the site and facilities to support efficient construction, such as development of the construction plant.

Chapter 4 describes the development and use of a prototype database application to evaluate the feasibility of using computer tools to capture and disseminate knowledge based on construction experience. This is necessary to make the knowledge readily available for application on future projects.

Ch. 4 Construction Experience Database

Evaluating the possible use of computer tools to capture information regarding construction experience and make it available for use on future projects was an objective of this research. This chapter describes the attributes matrix used to classify this information and the database application developed to capture construction experience and make it available for use on other projects.

4.1 Introduction

To formalize the capture and retrieval of multi-disciplinary construction experience, the researchers developed a prototype computerized database for lessons learned. The system used an Apple Macintosh™ computer and a Claris software program named Filemaker Pro™. The categories and subcategories used as descriptors for the data and the lessons that became the data elements were gleaned from knowledge sources for construction experience, such as project reports and procedures manuals from various companies. Developed to provide comprehensive construction information categories, the descriptors form an attributes matrix of categories and subcategories. The main categories in the attributes matrix were programmed as fields in the database. The subcategories were predefined as the values that can be selected for each of these fields.

4.2 Attributes Matrix for Construction Experience

The purpose of the attributes matrix is twofold: (1) to provide a comprehensive group of descriptors (categories and subcategories) for classification of construction lessons learned and (2) to display the descriptors to the new system user who needs to classify information for a data search or entry. A secondary benefit of the matrix is that it can act as a guide to the types of information included in the database such that construction professionals have a point of departure for data generation or an overview for access to the information.

The categories of the attributes matrix describe the major dimensions of construction information. The researchers adapted the categories for construction management, construction engineering and resources, and project team organization from a previous classification of construction technology (Tatum, 1988). The physical environment represents tangible external factors that potentially influence a construction project. Categories such as project type, discipline, specification number and facility are standard dimensions used to classify information in the construction industry. Finally, project phase and project party indicate the applicable point in the project life cycle and the responsible person.

The attributes matrix is closely related to the construction experience database. The main categories in the attributes matrix were programmed as fields in the database. The values programmed for each of the database fields correspond to the subcategories in the attributes matrix. Selecting one or more subcategories and attaching those descriptors to an entry indicates potential application of the information in the lesson learned. The attributes matrix also serves as a tool that facilitates the expansion of the construction experience database.

4.3 Elements of the Attributes Matrix

This section describes each element of the attributes matrix and give the possible values (indicated in italic). See Figure 4.1 for the matrix.

4.3.1 Type of facility

This designation limits the search to a specific type of facility. The prototype system developed in this research included data for power plants. Power plant type is a high-level category that limits the data to a certain type of power project. The power plants selected reflect the most common in the construction industry. The types of power plants used are *coal, gas, geothermal, nuclear, oil* and *solar*. This category could be extended to other segments of the construction industry for a firm with more than one line of business. Conversely, it could be made more specialized for a company focused on one sector. For example, a buildings contractor may substitute offices, courts, prisons, apartments/condominiums, government facilities, warehouses, etc.

4.3.1 Construction management—impact

This designation focuses a search of the database on the aspect of the project for which the construction experience has the greatest impact. The construction management category covers the basic project objectives of *cost, schedule, quality, safety* and related issues such as *productivity, permits, documentation, security* and *expediting*. All these subcategories represent points that are controlled by the managers of a construction project.

4.3.2 Construction engineering and resources—prerequisites

The construction engineering and resources category contains several sub-categories from the classification of construction technology (Tatum, 1988). The possible values are: *labor, materials,*

POWER PLANT TYPE	CONSTRUCTION MANAGEMENT	CONSTRUCTION ENGINEERING & RESOURCES	PROJECT TEAM ORGANIZATION	PHYSICAL ENVIRONMENT	PROJECT PARTICIPANT	PROJECT PHASE	DIVISN	DISCIPLINE OR SPECIFICATION NAME	FACILITY	REFERENCE	DATA
COAL	BONDS	LABOR	ADMINISTRATION	ACCESS	ACCOUNTANT	PLANNING	1000	GENERAL REQUIRMNTS	ASH HANDLG	ACI	PROBLEMS
GAS	CONTRACT	MATERIALS	AUTHORITY/RESP.	BENCHMARKS	CONSTR. MGR.	PRE-CONSTRCT	2000	SITEWORK	AUX. BOILER	AISC	RECOMNDTS
GEOTHERMAL	COST	METHODS	COORDINATION	CLIMATE	CONSULTANT	PROCUREMENT	3000	CONCRETE	BAG HOUSE	ANSI	CHECKLIST
NUCLEAR	DOCUMENTATION	OFFICE EQPMT.	INCENTIVES	EXTG STRCTRS	COST ENGINEER	MOBILIZATION	4000	MASONRY	BOILER	ASTM	SEQUENCING
OIL	EXPEDITING	PERM. EQUIPMT	INTEGRATION	HAZ. WASTE	CRAFTS	PREFABRCTN.	5000	METALS	CIRCUL. WATER	BIA	ALERTS ON
SOLAR	INSPECTION	SITE EQUIPMENT	STRUCTURE	LAYDOWN YARD	DESIGNER	CRITICAL PATH	6000	WOODS/PLASTICS	COAL HANDLG	NAP-H-C	PRODUCTS/
	INSURANCE	SITE LAYOUT	(SUB)K'OR SLCTN.	LIGHTING	DEVELOPER	GENERAL OPNS	7000	THMAL/MOISTR PROT.	COOLING TOWER	NFPA	SYSTEMS
	LIABILITY	TRANSPORT	TEAM BUILDING	REMOTE	ESTIMATOR	TESTING	8000	DOORS AND WINDOWS	INTAKE	NRCA	
	PERMITS	TOOLS		SOIL CONDITS	FIELD ENGINEER	PUNCHLIST	9000	FINISHES	TEMP. FACILS.	OSHA	
	PRODUCTIVITY			TOPOGRAPHY	FIRE MARSHAL	CLOSEOUT	10000	SPECIALTIES	TURBINE	PCA	
	QUALITY			URBAN	HOME OFFICE	START-UP	11000	EQUIPMENT	WATER TMT.	SMACNA	
	RISK MANAGEMT			WEATHER	LENDER	MAINTENANCE	12000	FURNISHINGS		U.S. GYP.	
	SAFETY				MEDIA/PRESS		13000	SPECIAL CONSTRCTION			
	SCHEDULE				NEIGHBOR		14000	CONVEYING SYSTEMS			
	SECURITY				OFFICE MGR.		15000	MECHANICAL			
	SEQUENCING				OWNER		16000	ELECTRICAL			
	STAFFING				PARTNER		17000	CONTROL SYSTEMS			
					PURCHASING			LAND & RIGHTS			
					QA/QC			BOILER PLANT			
					REGUL. AGENCY			TURBINE PLANT			
					SAFETY ENGNR			ACSSORY ELEC.			
					SCHED. ENGNR.			SUBSTN EQPMT.			
					SUBCONTRCTR.			PIPING			
					SUPERINTENDT			INSTRUMNTN.			
					SURVEYORS			INSULATION			
					USER						
					VENDOR						

Figure 4.1 Construction Experience Attributes Matrix

methods, permits, permanent equipment, site equipment, site layout, and *transport.* These sub-categories pertain to the means and methods that support building the constructed product.

4.3.3 Project team organization—structure and relationships

This category covers the human dimension of the construction process, specifically the form and mechanics of the group of participants to the construction process. The form of the organization is defined by the *structure, authority/responsibility, integration* and *(sub)contractor selection* subcategories. The sub-categories of *administration, coordination, incentives* and *team building* add dynamics to the organizational framework.

4.3.4 Physical environment—constraints

The physical environment is one of the categories of exogenous factors (external influences) identified by Fischer (1991). Fischer identified *weather*, *climate* and *topography* as such factors which are external to the locus of control of the project. Other factors were added to accommodate conditions that require special attention to avert problems: *existing structures, hazardous waste, lighting (for night work), soil conditions, urban (setting),* and *(inclement) weather.*

4.3.5 Project participant—party involved

The project participant category contains all the parties to a construction project in a engineer-constructor company, i.e., the *designer, purchasing agent, field engineer, cost engineer*, etc. It also contains entities with which the construction team interfaces: *regulatory agencies, partners, owners, subcontractors, vendors*, et al.

4.3.6 Construction phase—activity

The construction project phase is a category that ties the lesson to a particular stage in the construction process. The phases used as subcategories are standard to the industry with the exception of general operations, which is used for lessons that are not related to a particular phase of the project. They include: *planning, preconstruction, procurement, mobilization, prefabrication, critical path, general operations, testing, punchlist, closeout, startup,* and *maintenance.* Placing concrete, erecting steel, hanging pipe and pulling cables are all examples of tasks that would fit in the general operations subcategory.

4.3.7 Discipline or specification name—design responsibility

The discipline or specification name category mirrors and expands upon the classification system that is widely used in the industry. The sixteen "*divisions*" of the Uniform Construction Index published by the Construction Specifications Institute are the foundation subcategories. The other subcategories are generic to most projects *(land & rights),* common in industrial projects *(accessory electrical, piping, instrumentation, insulation);* or basic to power plants *(boiler plant, turbine plant, substation equipment).* The subcategories that supplement the UCI category should also be tailored by companies to suit their project needs.

4.3.8 Facility—physical location

Zones or physical areas are important divisions for many types of industrial plants. The facility category currently includes examples of area or function for power plants, such as *ash handling, boiler, coal handling, turbine, and water treatment.* The facilities consist of both major permanent equipment (boiler) and systems that serve a specific function (circulating water system) in the constructed product. Facilities are the focus of attention during the start-up phase of a project, a departure from the previous disciplinary focus. The facilities cross the disciplines or systems listed in the previous category. For example, electrical and mechanical systems service the coal handling unit, which is supported by a concrete structure.

4.4 Process of Selecting the Data

4.4.1 analyzing the data and selecting information to include in the database

The researchers reviewed several project reports to identify information suitable for entry in the data base. The subjects in the reports were evaluated using several criteria:

- must have potential utility on other projects, or value in helping to achieve project objectives (this filter removes interesting but not valuable data)
- must be applicable on another project with some but not necessarily all of the same conditions (eliminates project-specific knowledge)
- must be a lesson upon which a member(s) of the site construction team can act (removes feedback to design function) because the database focuses on transfer between construction projects
- must not be obvious or trivial knowledge
- must not name specific persons or companies.

Information that met these criteria was earmarked for inclusion in the database. The researchers condensed the information, deleted project-specific terminology, added background details as necessary to define the context of the experience, and worded the data element in the form of a suggestion, rather than a directive.

4.4.2 means of selecting the appropriate values in the matrix for specific data

The next step in entering the selected lesson in the database was to categorize the information. Since the purpose of categorization was to allow searching a large number of entries, several descriptors were used for each data element. For example, the transportation of a gas turbine in a manner that eliminates fire hazards is a *safety* issue (construction management category) with potential *cost* implications. It also pertains to the *transport* of *permanent equipment* (construction engineering and resources category). The specification title is the *turbine plant* and the facility is the *turbine*. The project phases are *planning* and *procurement*. Attaching a large number of applicable descriptors to each data element assures that a general search with just one of these key words would result in a "hit."

Different sources of the need for information ranging from a need to improve a project safety record to an assignment of responsibility for the turbine necessitate different avenues to reach the same data element. Further, multiple subcategories assigned to a data element provide the detailed description that is required to allow a user with a well-defined need to limit his or her found set to just the relevant entries. This powerful searching capability, particularly important with a large database, justifies the additional effort to categorize the lessons learned information.

4.4.3 construction lessons learned concepts and framework

As the lessons learned were selected and recorded, it became apparent that some lessons could be grouped into a broader concept at a more general level. Repeated entries on the same topic are an indication of a "problem area" that has a higher relevance than the isolated incidents recorded in the lessons. Further, extensive treatment of the same topic by more than one company, as in the example of waterproofing, is strong evidence that the difficulties are prevalent in the industry. As described in Chapter 3, the researchers prepared summaries of lessons learned concepts to capture this broader types of construction experience.

4.5. Description of the Construction Experience Database

This research project included developing a prototype database application to capture and transfer construction experience. The database uses the attributes matrix to code new entries and facilitate access to the specific information needed. The prototype includes data elements concerning construction experience from cogeneration projects.

There are over 70 records in the lessons learned bank that were extracted primarily from Lessons Learned reports produced by the Bechtel Construction Company. Bechtel's power plant construction group has been especially diligent in compiling these reports and made several of them available for this research project. The reports contain information items that describe a situation, the decisions that were made, the outcome, and why it was (un)successful. Some items were more complete in their supporting descriptions than others, but all made some sort of recommendation for improved performance on future projects.

Subjects covered in the recommendations included successful construction materials/methods, coordination problem areas, preventative measures to avoid repeating the same mistake and consequently avoiding an undesirable outcome, and contract or purchase order issues to address. The prevalence of contract-related topics reflects the industry's heightened liability consciousness and reliance on contracts to define relationships with external entities.

The Apple-based software program used for this project is *Filemaker Pro*® by Claris Corporation® in Santa Clara, California. A Macintosh Plus or higher model, with at least 1 megabyte of RAM is required. System 6.0 or later operating system is needed, and a hard drive and 800k disk drive is recommended, although two 800k disk drives suffice (Filemaker Pro *Getting Started,* Claris Corp.).

The database program, Filemaker Pro, has an export command that includes conversion to Dbase III documents. However, the data has to subsequently be formatted in the Dbase program (IBM environment). Another problem is that the export does not support repeating fields, resulting in the export of only the first value for each field (i.e., the first selected subcategory in each category).

4.6 Using the Construction Experience Database

The major operations in using the construction experience database are adding new items that include both the appropriate items from the attributes matrix (descriptor) and the data elements (subject matter) and searching for applicable data elements. This section describes both. Because the database application is so simple, this is all the documentation required to use it.

4.6.1 adding new items to the database

Adding a new item to the data base consists of the following general steps:

1. Open the data base file by double-clicking on the icon that represents it. The user is automatically placed into the "browse" mode.
2. Create a new record by:
   - holding the Apple key and typing **n**, or
   - selecting the New Record function in the Edit Menu
3. The program will generate a new blank record. Click on the empty data field and type the lesson learned text.
4. Proceed to the descriptor fields by clicking on the empty boxes next to categories that apply to the specific lesson learned. A pop-up menu with a scroll bar will appear below the box just clicked. To select one of the subcategories, scroll as necessary and double-click on the desired entry. The program will automatically advance to the next field, or the user can select a different field for the next entry.
5. To add a picture to the illustration field, use either the program's drawing capabilities or import the picture from another Macintosh program such as MacDraw or MacPaint. (A description of the procedure for drawing and

importing pictures from other applications is available in the Filemaker Pro® *User's Guide.*)

4.6.2 searching for applicable data items

To search for a lesson on a particular subject, the user should first determine how the desired information can be described with the subcategories available as preset search strings in the database. For example, the user might wish to find all information related to schedule on a nuclear project that pertain to steel. "Schedule" (Construction Management category), "Nuclear" (Project Type category), and "steel" (data field) would be the key words for the search. Having established the subcategories that describe the data, the user should then proceed as follows:

- Initiate the find by:
  - holding the Apple key and typing **f** or
  - selecting the Find function in the edit command menu.
- Enter the key words for the desired search in the appropriate fields.
- Click on the "Find" button on the left of the screen. The program will search the files for any that match all the criteria given by the user.
- To merge the results of two searches if they identified too few items, open a new record after specifying the first search, and enter the second search criteria (key words) as above.
- If a search identifies too many items, add more descriptors to the first search record and repeat the search.

4.7 Experience with trial application on the Scrubgrass Project

4.7.1 scope and activities of the test

The objectives of the field test were to obtain input from practicing construction professionals on the experience transfer system developed by the researchers and to gain further insights into the nature of construction experience deemed important to transfer. To accomplish these objectives, the researchers obtained permission to visit Bechtel's Scrubgrass project site (a cogeneration project in Pennsylvania) with the hardware and software needed to provide "hands-on" contact with the experience transfer system. An introductory session was held to explain the concepts and tools to the engineers, superintendents and managers. The project team recorded lessons learned that were then entered into the Filemaker Pro™ database first by the researcher and later by a clerk.

4.7.2 lessons recorded

Participation in the program during and after the researcher's site visit was good. In six months, 18 members of the field staff recorded a total of 53 lessons, covering most of the disciplines and functional groups. Some lessons were a page long and could be classified as "concepts," as introduced in Section 3.3. Most appear applicable to other similar projects with little editing.

Of the three functional groups in an engineering, procurement, and construction project, the most lessons (41%) were directed at construction, e.g., construction methods, materials selection, subcontracting strategy, building sequences, and project administration. Feedback to the design staff was second at 32%, with entries pertaining to constructibility of details, interdisciplinary coordination, operability of configurations and materials specification. Procurement lessons made up the remaining 27%, with most concerning vendor purchase order requirements, field assembly versus vendor prefabrication, materials management, and automation.

The different formats of important construction experience were again highlighted by this experiment. Most lessons were short "data elements," while the major topics warranted one-page "concepts."

The categorization used to classify construction experience was not used consistently by the different participants in the Lessons Learned program. For example, some participants listed their own discipline rather than the discipline of the lesson; some confused subject with discipline and event.

4.7.3 automation

The project team did not demonstrate the same commitment to automation as to capturing the lessons learned. The project ultimately switched to a basic spreadsheet to enter their information on the computer after the researcher left the site, apparently for two reasons. First, the project team members were more familiar with this IBM-based application that the Apple-based database provided. Second, the data are used in written form in the company, eliminating the perceived need to enter the data in a database with searching and sorting capabilities. Those project members with limited computer experience avoided the learning curve by using paper forms provided by the field engineer. This suggests that field use of computers is still limited by a dearth of training; in fact, this was one of the suggestions recorded in the lessons learned.

4.7.4 implementation insights

Significant momentum has already been gained in capturing lessons learned. Participation in this program was broad and extensive, with important knowledge being captured by most of the field team. Other projects have also participated, creating the potential for a large multi-project database for application on future projects. To achieve this, significant challenges remain in automation (hardware and training), database maintenance, and incorporation into corporate standards.

The dearth of computer experience in construction staffs and the training required by the new systems make it difficult to achieve an automated lessons learned program that facilitates the data retrieval, entry, searching and transmission capabilities that are critical to its effectiveness. Computer literacy is often in IBM-based applications that do not have all the capabilities of software utilized in this research and are more difficult to learn. Top management leadership and vision is needed in selecting a system that will be durable, powerful and user-friendly.

The different interpretations of the categorization system and the variety of approaches to recording the lessons demonstrated the need to filter the entries for appropriate classification, generalization, intonation, and importance. This could help support accurate and complete searches and guide usage of the lessons.

To actually "learn" the lessons, a transfer to other functional departments and a memorialization are needed. Communication to engineering and procurement and group reviews would support incorporation into standard specifications, details, and contracts used on future projects. The payback on the investment made to record the lessons depends on this critical step.

Ch. 5 Conclusions and Applications

5.1 Introduction

This chapter reports conclusions related to each of the objectives of this research: understanding construction experience, investigating means to capture and represent this information, and developing a prototype computer application to enable construction experience transfer. Building on these conclusions, the chapter also includes sections concerning application on engineering and construction projects, an implementation plan, and vision and needs for future research.

Why collect and transfer construction experience? The elements of construction experience indicate major potential benefits from transfer and effective use during each phase of succeeding projects. These benefits include:

- improved cost, schedule, quality, and safety
- problem avoidance and more rapid dissemination of successful innovation
- increased integration of the project team, including improved understanding of design intent and construction operations
- improved training and professional development.

The major conclusion from this research is that it is feasible to capture and disseminate knowledge based on construction experience using computer tools. The research identified three levels of construction experience, described characteristic of the knowledge, and developed a set of attributes to facilitate easy access. Development and testing of a prototype application demonstrated the system's ability to capture and disseminate construction experience on a cogeneration project.

5.2 Content of Construction Experience

Analyzing construction experience at two levels in this research resulted in the characteristics described in Chapter 3 and in the following conclusions concerning the content of construction experience.

- The appropriate level of detail for the knowledge, ranging from broad concepts to detailed checklists, depends directly on the level of experience of the user. The concepts require greater user experience and reasoning than the checklists, but they increase the potential to benefit from the experience despite differences in the project situation. The checklists allow use by less experienced persons, but narrow thinking and increase risk of missing opportunities for major benefits.
- A major portion of construction experience relates to *problem avoidance.* Knowledge from this experience often requires actions and may add cost effective scope to other functional activities performed earlier in the project to avoid repeating problems during construction.
- To realize potential benefits, construction experience should *influence all phases* of a project. Experience-based knowledge assists in *forecasting the consequences* of early project decisions on downstream phases.
- Construction experience indicates ways to *improve processes;* this indicates an important potential to form a vital portion of programs for Total Quality Management.
- *Design criteria,* focused on the construction phase of a project, result from application of construction experience.

The knowledge contained in the *data elements* fits into categories of actions. These actions highlight essential support by others for effective construction. The elements range from broad activities applicable to most types of construction to very specific actions that apply only to particular types of construction activities. The construction experience *concepts* generally contain procedural or process knowledge that is applied in many steps. They illustrate the difficulty in classification of experience and using computer tools for access.

5.3 Capturing and Gaining Access to Construction Experience

Current efforts to capture and disseminate construction experience generally use lessons learned reports and manuals. Managers in some firms make this a project responsibility while others assign this responsibility to staff persons. A few firms are experimenting with computer tools to capture and transfer experience. However, current approaches offer substantial potential for improvement by incorporating information capture as a part of operations and increasing ease of access to relevant knowledge.

The attributes matrix developed in this research provides a basis for capture and classification of construction experience. Based on the pilot test conducted on the site of an active construction project, it appears that the matrix and database provide a workable method to capture construction experience and make it available for future projects.

5.4 Prototype Application and Feasibility of Using Computer Tools

The attributes matrix includes the major characteristics necessary to allow user access to needed experience: type of project and portion of the facility, project phase, responsible party, and impact. The database application proved adequate to capture and provide access to the knowledge, along with the extremely desirable feature of ease of use.

The prototype included two major limitations. First, use of the Apple hardware limits application in firms that use only IBM compatible computers. Database products with similar or even greater functionality are available for these platforms, but they appear less flexible and more difficult to use for the type application developed in this research. Fortunately, Claris recently introduced a PC version of the software used in this research.

The second limitation of the prototype results from the lack of reasoning capability in database applications. The prototype system and extensions can capture knowledge related to construction experience and make it available in compliance with a number of sort codes, but cannot reason about the presence of appropriate conditions for its application. This presents an important topic for future research concerning the possible use of artificial intelligence techniques.

5.5 Implementation Plan

Construction experience does not present difficult concepts but implementation presents major challenges. Implementation of the results from this research to develop an approach for transferring construction experience between projects within a firm would require the following steps:

1. Identify the *kinds* of construction experience that are available and would be beneficial to transfer within the firm, based on completed and active projects, expected types of future projects, and expected contractual arrangements and project conditions. The data elements and concepts developed in this research provide a starting point to assist in defining appropriate types of information. Existing approaches for experience transfer within the firm, such as lessons learned reports or portions of quality control programs, can provide the initial knowledge.
2. Using the attributes matrix developed in this research as a starting point, develop a set of sort *characteristics* for the planned experience, based on the expected type of information, the sources and uses of the information, and the work breakdown structure planned for future projects. This custom classification should fit the needs of potential users of the experience.
3. Evaluate the potential to use the *hardware and software* environment in place within the firm to implement a pilot system for capture and dissemination of construction experience. If existing platforms are capable of handling the information and providing easy capture and access, they are preferred for the obvious advantage of easier implementation.

4. Select hardware and software, and scope the information needed for a *pilot project*. If sufficient knowledge regarding relevant experience exists, implement the system as early as possible in the project to evaluate use and allow collection of additional knowledge.

5. Develop and test the application on the *pilot project*. This should include entering available knowledge that is applicable to the project, assigning responsibility and training regarding entry and use of the information, and monitoring use.

6. If the pilot project is successful, commit resources to develop and implement a *company-wide system* for capture and transfer of construction experience. Based on the findings from this research, the most effective method of capture is by making an easy-to-use computer application available to the engineers and superintendents who are directly involved in the construction operations that result in the knowledge about experience to transfer.

7. Test different *incentives* for expansion and use of the system, including making it a part of normal processes by each functional element involved in a project, requiring checking at approval of technical or contractual documents, and recognizing or rewarding beneficial use of additions to the system. Consistent and appropriate use is needed to disseminate the knowledge. This requires both incentives and convincing demonstration of benefits from use.

8. Periodically evaluate *extensions* of the system to take advantage of increased knowledge about construction experience, new potential applications, or advances in information technology.

5.6 Needs for Further Research

This research identified several topics for additional investigation of transferring construction experience and increasing project integration:

- What are the best methods to represent construction experience in knowledge bases?
- What information flow on projects best supports the use of construction experience?
- What new forms of contracts are needed to avoid barriers to experience transfer?
- What hardware and software capability is required to best support the capture, classification, and dissemination of knowledge from construction experience?

Appendix A Construction Lessons Learned Concepts

Design-build Contracting

The term design/build refers to a method of project delivery in which a single entity provides to the client all of the services necessary to both design and construct all or a portion of the project. This single point of responsibility fundamentally distinguishes design/build from other forms of project delivery (Twomey, 1989). This entity can be a developer, designer or a contractor, any of which may perform all functions in-house, use subcontracting, or form a joint venture.

Contractors' advantages in design/build arrangements are: greater control over the project, increased level of job satisfaction, minimized risk and project uncertainty, improved communication with the designer, and greater profitability. Disadvantages include responsibility for the acts and omissions of the designer, difficulty in obtaining adequate insurance coverage, or gaps in existing coverage (Twomey, 1989).

Design/build contracting is more cost effective than conventional delivery processes insofar as the fees are less for design/build. In conventional contracting, the architect's fee is 5 to 6% and the contractor's fee is 5 to 10% of the construction cost, usually totaling 12 to 15%. Under design/build, the maximum combined fee probably will be about 10%. Firms are often able to reduce liability insurance costs by consolidating their design and construction-related coverages (Design/Build 1987).

In all design-build fixed price contracts, estimation of construction costs is critical. Sizing the project budget may require the use of independent consultants to verify the architect's and contractor's anticipated costs (Limber, 1990).

The integrated nature of design/build contracting allows the selection of materials and methods that are best suited to the capabilities of the construction team, supporting constructibility, adherence to budget and timeliness. However, difficulties have been experienced in meeting quality standards and functional requirements (Rowlinson, 1986). A quality control engineer may be appropriate to ensure that all requirements are met.

When evaluating whether to use the design-build approach on specific systems in a building project, there are several factors to consider. First, the level of coordination with the architect; if the system is closely dependent on architectural design details, it is better to place the design of that system within the purview of the architect, who can then subcontract and retain ultimate design coordination responsibility for that system. In a studied project, plumbing was removed from consideration from design-build because of the extensive coordination required with the architectural aspects of the building. Second, the design-build experience of the potential contractors organization and of the individuals who would manage the process should be evaluated. In the same project, a security contractor interpreted the scope of his design-build contract differently than the contracting organization and as a result did not provide sufficient coordination with the architect. Third, the maximum benefits are achieved when the services of the systems design-build contractors are retained early in the project, i.e. during the schematic or conceptual design phase. Obtaining the early constructibility feedback which these contractors can provide will require a short-term design investment for long-term benefits during the design, construction and O&M phases of the project. Fourth, consider hiring a consultant to develop the design criteria to be used in the Request for Proposals sent to the D/B contractors. This assures greater quality and coordination if more design criteria are added to the systems specifications than in typical D/B contracting. The context is important here; experienced in-house and contracting personnel may negate the need to incur additional expenses for an outside consultant (Chevron, nd).

Sources:

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4. Rowlinson, Steven and Langford, David (1986), "The Constructor as Designer," International Association for Bridge and Structural Engineering Workshop Proceedings, April 1986, pp. 169-175.

5. Chevron Research and Technology Company, Oxnard Building Project Lessons Learned Report, pp. 24-25.

Team Building

PERFORM:

Develop a sense of *Purpose*, a common vision shared by team members. The team should support the mutually agreed goals that clearly relate to the vision. Each member understands his or her role in realizing the vision.

Achieve a sense of *Empowerment*. Team members are confident about their ability to overcome obstacles and realize the vision. Members share responsibilities, help each other and take initiative to meet challenges out of a sense of mutual respect and reciprocity. Team processes are developed and used to facilitate work. Members have opportunities to grow and learn new skills. There is a sense of personal as well as collective power.

Foster strong ***Relationships*** and open communication. A commitment to open communication allows the team members to comfortably state their opinions and feelings. Listening is considered as important or more important than speaking. Differences of opinion and perspective are valued. Methods of managing conflict are agreed upon and understood. Through honest and caring feedback, members are aware of their strengths and weaknesses as team members. There is an atmosphere of trust and acceptance and a sense of community. Group cohesion is high. The concept of strength through difference is supported.

Encourage ***Flexibility***. Group members are able to perform task and maintenance functions as needed. Team development and leadership responsibilities are shared. The team is open to both opinions and feelings, hard work and fun. Members recognize the inevitability and desirability of change and can help each other adapt.

Work towards *Optimal Productivity*. The team is committed to high standards and quality results. Effective decision-making and problem-solving methods are developed to achieve optimum results and encourage participation and creativity. In addition to valuing task accomplishment, the team members are encouraged to strengthen group process skills.

Provide ***Recognition*** and Appreciation. Milestones, accomplishments and events are frequently celebrated by the leader as well as by team members. Team accomplishments are recognized by the larger organization.

Boost *Morale*. Members are generally enthusiastic about the work of the team. Each person feels a sense of pride in being a member of the team and of optimism about the future. There is a sense of excitement about accomplishments and the way team members work together (Chevron, Richmond, nd).

Construction management practices and adversarial relationships have been cited as the cause of rework value of 25% of installed cost (Measuring, 1989). Management practices (such as team building) that work towards improved relationships between the parties to a construction project can hence save rework and the associated costs.

To implement a team building plan, one project studied developed two programs: training and monetary incentives. In the training program, the firm sponsored a consultant-led meeting of owner representatives, the architect and the design consultants to develop a purpose statement and discuss the elements of team building such as trust, communication, involvement and commitment. A second meeting was held early in the construction phase, again facilitated by a consultant, to develop a purpose statement, establish communication norms of openness and honesty, develop vocabulary which promotes harmony by not offending the receiver of the communication, discuss and finalize the administration of the Team Building Incentive Program and discuss team approaches to solving problems. The second meeting added the general contractor and major subcontractors. A third session was held in the eighth month of construction to reinforce the team commitment by the original team members and to involve new subcontractors in the team building effort. Presentations were given to review the topics of the previous meeting on team building and team building exercises were led by the consultant. In addition, team building/quality sessions were held by the owner, general contractor and architect. These sessions were two to three hours in length and were based on two team-building texts (Chevron Oxnard, nd; Yound, nd; Scholtes, 1988). The monetary incentive program consisted of an intra-team evaluation based on a set of teaming skills criteria and monetary awards given according to resulting ratings.

Sources:

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4. Yound, Don and Francis, David, Improving Your Work Groups; A Practical Manual for Team Building. Don Yound and Dave Francis, University Associate, Inc., San Diego, California.
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Materials Management

Materials management can best be defined as the planning and controlling of all necessary efforts to insure that the correct quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed (Business Roundtable, 1982). The materials management process combines and integrates the individual functions of project planning, material takeoff, vendor inquiry and evaluation, purchasing, expediting and transportation, field material control, and warehousing. To coordinate these functions, some type of computer-aided system is usually required (CII, 1986).

The first step in materials management is the materials takeoff. A bill of materials is developed within the framework of materials specifications and materials coding systems. The transfer of computer-aided design information from the designer to the contractor can automate this process. The purpose of the bill of materials is to define in an accessible format the materials requirements for any combination of code number, material category, drawing number, subcontractor responsibility, work area, or need date (CII, 1986).

Vendor inquiry and evaluation can be facilitated by a computer program that supports analysis of vendor performance on past and present projects. Points to include are the dollar value of materials committed, the dollar value received, the number of partial deliveries per purchase order, the number of late deliveries, and the number of nonconforming materials deliveries (CII, 1986).

Purchasing procedures define the vehicle for obtaining materials for use on the project. Whereas the bills of materials define the project materials requirements, the resulting purchase orders define the actions that were taken to meet those requirements. It is useful to be able to print reports by vendor, type of material, status and material need date (CII, 1986).

Expediting is done to provide timely information regarding anticipated materials deliveries to all concerned project personnel. Expediters receive prioritized information pertaining to projected or actual material information and then ascertain via inspections an estimate of delivery dates based on projections of work loads, labor climates, etc. Shipping plans should be established early and cover primary and alternate transportation methods and route inspections (CII, 1986).

Warehousing guidelines should be established by the owner and the contractor together and should cover the location and organization of materials, security issues and environmental protection. Receiving and material distribution functions revolve about the use of the computer system to support generation of formal materials receiving reports covering the quality and quantity received and issued. A terminal in the warehouse facilitates rapid dissemination of materials receipt information. Computer generated bills of materials reports can be used by the crafts to assist requisitions (CII, 1986).

Material control (acquisition and distribution) is one of the primary justifications for computerizing materials management. Identifying potential materials shortages and averting materials surpluses will avoid costly labor delays, improve project cash flow, and avoid costly surplus. The system should produce a history of an unavailable material from material takeoff through purchasing, expediting and shipping. It also should provide field controls to material issues such that instances where the crafts request materials that have already been issued are flagged. Finally, the control function compares actual inventories with those shown in the system to reconcile quantities (CII, 1986).

Computer systems used for materials management have typically been home office mainframes or large mini computers. On-site minicomputers could significantly cut costs (CII, 1986).

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3. Construction Industry Institute, "Costs and Benefits of Materials Management Systems," Publication 7-1, November 1986, pp. 3-8.

4. Montana One Project Lessons Learned Report, Bechtel Construction Company, January 1991, p. 14.

Schedule Performance

Measures can be taken throughout the course of the project to maintain and improve schedule performance. A control-level schedule developed during the constructibility phase with the owner and designer as required could support comprehensive sequencing and time-framing of construction plans based on available resources and various other constraints (Constructability, 1987a). The original schedule should include design freeze dates, design issue dates, and a method to schedule design changes. To ensure support of the construction schedule, the design schedule of engineering and vendors should incorporate construction input. Items critical to startup needs should be indicated as critical on the schedule. This can be accomplished via startup input to early schedule development (Intermountain, nd).

Identifying cost-effective construction techniques as an ongoing part of the constructibility review process can benefit schedule performance. This should involve designers, vendors and sub-contractors as required to implement specific techniques. For example, permanent work can often be used for temporary purposes and preassembly can have wide labor-saving applications (Montana One, nd).

Off-site fabrication can shorten project schedules by utilizing off-site resources for prefabrication while other activities continue (with less obstruction) on the site. Off-site fabrication can be maximized by:

1. creating an engineering and construction team to identify prospects for off-site fabrication
2. reviewing the candidates to ensure potential benefits are not offset by the additional engineering/procurement support which will be required
3. involving equipment/material vendors to implement specific programs (Intermountain, nd).

In the area of labor relations, a pre-construction labor stabilization agreement can allow open competitive bidding by qualified union and non-union contractors, establish uniform working conditions for all craft employees, and define specific procedures to avoid interruption of work. The agreement can also ensure an adequate supply of skilled labor to support the project schedule (Intermountain, nd).

During the project, field management should hold regular, informal working meetings with designers, vendors and sub-contractors to review critical schedule items in a positive, problem-solving environment. Over the course of repeated projects, managers can "institutionalize" the scheduling approach used instead of using a different process, system or level of detail on every project (Intermountain, nd).

Numerous on-site approaches are most conducive to schedule performance. Completing underground yard work before materials deliveries and peak staffing at the site supports free lay down of and access to materials. This eliminates crafts delays and consequent schedule impact. Providing staff to the tool room to avoid crafts delays in finding and checking out tools. To ensure timely repairs/replacements during plant startup, warranty requirements for equipment should state that warranty work during startup of the plant should support the startup schedule. To avoid parts–related delays during startup, order spare parts for major equipment(Montana One, nd).

References:

1. Intermountain Power Project, Lessons Learned Report, Bechtel Construction Corporation.
2. Montana One Power Project, Lessons Learned Report, Bechtel Construction Corporation.

Temporary Facilities

Temporary facilities including power, bulk material storage areas, and dining halls should be located on site for convenient access, to avoid double-handling of materials, to provide *prefabrication* areas adjacent to the work site (Constructability, 1989a), to maximize efficiency of the flow and traffic patterns and to avoid unnecessary relocation (Constructability, 1989b).

Centralized networks for utilities such as welding, compressed air, and electricity, should be considered when demands are high, or where access for conventional systems is difficult (O'Connor, 1988).

Temporary roads should facilitate access for construction equipment, materials and personnel (Constructability, 1989b). These roads can be constructed of locally available materials such as shell, culm or recycled pavement. Extension of this paving to the remainder of the site mitigates the effects of mud on work conditions (O'Connor, 1988). Temporary construction such as site roads and gantry cranes should be used for the permanent facility wherever possible (Constructability, 1989c).

In laying out the site, potential needs for emergency access and evacuations should be considered. Site layout should also consider construction safety, security and theft prevention (Constructability, 1989c). Construction warehouses, parking facilities and supervision facilities should be located close to the worksite (Constructability, 1989c). In establishing clearances, give particular attention to heavy lift operations, modularization needs, and potentially congested areas. Minimize interferences among different types of traffic and locate heavy traffic paths on stable ground (Constructability, 1989c).

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1. "Constructibility: A Primer," Constructability Task Force, Construction Industry Institute, Publication 3-3, Austin, Texas, August, 1987.
2. "Constructability Concepts File," Constructability Task Force, Construction Industry Institute, Publication 3-3, Austin, Texas, August 1987.
3. O'Connor, J. T. and Davis, V. S., "Constructability Improvement during Field Operations," Construction Industry Institute, Source Document No. 34, Austin, Texas, May 1988.

Waterproofing *

Elastomeric sealants should be selected and applied carefully to ensure building integrity with respect to moisture protection. Application surfaces should be very clean to ensure good adhesion. The manufacturer's technical department should be consulted in every installation. Precautions must be taken against exposure to fire and the toxic effects created by volatile solvents, especially in enclosed areas.

When using caulking and sealing products, the manufacturer should provide batch code number and date and product name on each container. Other required documentation incudes performance characteristics, test information on the specific use of the material on the application surfaces of the subject building, laboratory certification of the properties and contents of the material, experience records of product use, certification that the sealant meets the specifications, a written definition of the manufacturer's technical assistance, and a guarantee for materials and workmanship.

Workmanship is critical to waterproofing integrity. Coverage should be complete and to the recommended/specified thickness.

When installing insulation with aluminum foil vapor retarders in a wet wall made of concrete masonry units, apply an alkali resistant acrylic coating or bituminous paint to prevent corrosion of the vapor retarder by galvanic reaction (applies to cold regions.)

Fluid applied waterproofing should not be applied to a non-ventilated metal deck roof system nor to a roof system with lightweight aggregate concrete. The trapping of moisture in such roof systems has led to membrane failures.

Reference: Turner Building Digests

* Selected comments taken from a more comprehensive document.

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