MAKING EFFECTIVE USE OF CONSTRUCTION LESSONS LEARNED IN PROJECT LIFE CYCLE

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ABSTRACT: Expert knowledge and lessons learned in the construction phase of a project are not systematically incorporated into the design and construction phases of subsequent projects. The advancement of construction since ancient times has been predicated on the communication of lessons learned. Although past efforts have focused on the design phase, opportunities for the collection and utilization of lessons learned exist in all phases of a project life cycle. Constructability, the early integration of construction knowledge into all phases of a project, can be improved by effective use of lessons learned. This paper identifies feedback channels in a project life cycle and describes previous and current efforts to develop lessons-learned systems. Next, the paper describes the design and implementation of a constructability feedback prototype called interactive knowledge-intensive system (IKIS) for constructability improvement (IKIS-Constructability). Finally, the paper highlights the operation of this system and its potential benefits.

INTRODUCTION

During the construction of any facility, knowledge is gained and lessons are learned. Over time, those involved in construction processes have the opportunity to accumulate a plethora of knowledge, some of which is learned at great human or financial cost. Yet, how much of this hard-earned experience is passed on from project to project and from person to person? Benefits in cost, schedule, quality, and safety could be realized on future projects, if this wealth of constructability knowledge could be effectively harnessed in planning and executing future work.

The Constructability Task Force of the Construction Industry Institute (CII) sponsored a series of studies, which advocate construction expert input to the conceptual planning (Tatum 1987), and engineering and procurement phases (O'Connor et al. 1987), as well as field operations (O'Connor and Davis 1988), as the key to more efficient construction and achievement of overall project objectives. While admitting that cost savings are difficult to quantify, the Business Roundtable estimates that constructability improvements saved at least 10–20 times the cost of the constructability effort (*More* 1983). Constructability programs also contribute intangible benefits including: team building, improved coordination, greater construction planning, and adoption of a project viewpoint by all team members (Tatum 1987).

Generally, lessons learned during the construction phase of a project are not effectively incorporated into the design and construction phases of other projects. O'Connor and Davis (1988) conclude that constructors need to improve documentation of lessons learned related to field constructability, and to communicate them more effectively. The CII advocates a corporate lessons-learned database as a key element in any constructability program (''Guidelines'' 1987).

Traditional (existing) methods of gathering and using lessons learned have enjoyed limited success due to:

1. Unreliable communication channels between construction experts and less experienced individuals.
2. An unmanageable format that limits access, retrieval, and updating of the potentially enormous volume of lessons.
3. The lack of a meaningful classification system.
4. Difficulty in integrating new systems into existing operations and procedures.
5. A primary focus on failures or incidents, rather than a balance of positive and negative experiences with constructed facilities.

Most discussions on comprehensive constructability programs focus on the benefits and necessity of establishing a feedback system for channeling construction knowledge and experiences back into the design stages. The most effective form of feedback system is to bring experienced construction personnel on board in the earliest stages of projects so that constructability is integrated in the planning and design development process.

While incorporation of construction input into the design phase is optimal, many constructability improvement opportunities exist entirely within the construction phase. This area has not been sufficiently explored nor effectively utilized, perhaps because the short-term cost savings during this project phase would be realized by the contractor (in traditional design, bid, construct projects).

In a manner similar to improving constructability during the planning and design stages, the key to improving constructability during the construction phase is a formalized feedback system for construction knowledge. When a project has moved into construction, the feedback needed relevant to the tasks at hand primarily includes specific construction knowledge, e.g., methods, materials, equipment, coordination, etc. This type of input will influence the construction phase of the project with respect to duration, efficiency, and contractor profit.

This paper begins by exploring feedback opportunities in the project life cycle. Then, it provides a review and analysis of related efforts to classify and use lessons learned in engineering and construction. Based on the analysis of existing systems, and on consultation with construction industry experts and professionals, this paper describes the modeling, implementation, and operation of a prototype system called interactive knowledge-intensive system (IKIS) for constructability improvement (IKIS-Constructability), which has been developed for The George Hyman Construction Company. Finally, the paper demonstrates the main features of the system and its potential benefits to end users.

FEEDBACK IN PROJECT LIFE CYCLE

The traditional life cycle of a project typically includes the following phases: conceptual planning and feasibility studies, design and engineering, construction, and operation and maintenance. Lessons learned from constructed facilities may have

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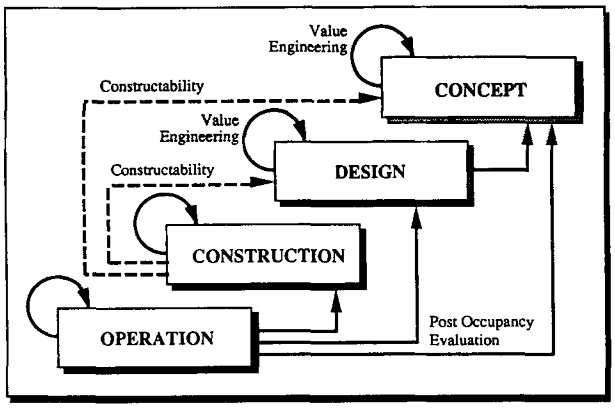

FIG. 1. Feedback Channels in Project Life Cycle

their genesis in any phase of a project's life cycle. Similarly, these lessons may be applicable to one or more phases of the project life cycle. The various sources and uses of engineering-construction knowledge are depicted in Fig. 1. Three feedback loops from the construction project life cycle will be examined in detail.

Value Engineering

Some feedback loops, value engineering for example, have become formalized in the construction industry. Value engineering is traditionally viewed as an intentional reexamination of existing designs by the construction contractor or some other designers, usually on an incentive basis (Kavanagh et al. 1978). Value engineering is a feedback loop generally confined to the design phase.

Project performance is improved by effective communication between design and construction professionals during the design process. Obviously, the earlier a value engineering study is conducted, the greater the potential to influence total project cost (Paulson 1976). Value engineering studies that occur late in the design phase, or after the design is complete, are limited. For example, the suggestion of an alternative structural system after the design is complete would most likely be rejected, because it would entail substantial redesign and considerable loss of time. Feedback occurring, or knowledge being available, as early in the process as possible allows alternative decisions to be implemented at minimal costs (Tatum 1987).

Regretfully, design professionals often lack the practical construction knowledge required to make prudent construction-driven decisions; they are unable to visualize the flow of labor, materials, and equipment required during the construction process (''Can'' 1986). The effects on a given project include diminished project quality, increased rework costs attributed to design errors, increased change orders and claims, and missed opportunities to reduce costs through design optimization. One study of industrial-type projects showed direct costs for construction rework at more than 12% of the total project costs (Ledbetter et al. 1989). Recent studies have also indicated a sharp increase in claims (Kagan 1985). A study of 22 federally funded projects indicated a large proportion of change orders originating with the project owner or owner agent (Nelson and Diekmann 1985). This trend can be attributed in part to the lack of construction knowledge among design professionals.

Constructability

CII shuns the notion that constructability is merely a review of a completed design by construction experts. Rather, it espouses the basic constructability premise that integration of construction knowledge and expertise into all phases of a project is beneficial. It also recognizes the need to bridge the traditional gap between engineering and construction early in the project if full benefit is to be achieved (''Guidelines'' 1987). CII has also commissioned various studies on ways to improve constructability (Tatum 1987; O'Connor et al. 1987; O'Connor and Davis 1988). CII further recognizes that constructability is not a natural process, instead, it demands a conscious, continued effort.

Constructability encompasses feedback loops emanating from the construction phase as depicted in Fig. 1. CII has shown that integration of construction knowledge into all project phases has resulted in paybacks of up to 15 to 1 (''Constructability'' 1986).

Postoccupancy Evaluations

Postoccupancy evaluations represent another formal feedback loop in the project life cycle. Evaluations occur during the operational and maintenance phase of the life cycle, but can be applied to virtually any phase. Many owners of a large number of facilities use postoccupancy evaluations to assess the effectiveness of their design and construction programs. The Army, Navy, and the General Services Administration all have active postoccupancy evaluations systems (Plockmeyer 1988).

By definition, postoccupancy evaluations occur after completion of a facility or structure. Therefore, lessons gleaned from the operation and maintenance of completed facilities may be too late to benefit the facility from which the lessons were learned, but are potentially useful when applied to the planning, design, and construction of new facilities.

ANALYSIS AND CRITIQUE OF EXISTING FEEDBACK SYSTEMS

To investigate the state of the art in engineering-construction feedback systems, about 100 letters were sent, and follow-up phone calls were made to various universities, organizations, and construction firms who have historically conducted research or performed work in this area. The response rate of more than 60% was encouraging. Finally, personal interviews were conducted.

Many professional organizations have initiated efforts to collect and disseminate failure and performance information in specific disciplines and specialized fields: soil and foundation engineers (ASFE), fire protection engineers (NFPA), National Bureau of Standards (NBS), the Committee on Large Dams (COLD) of ASCE, and the National Transportation Safety Board (NTSB) for the Federal Aviation Administration (FAA). On an interdisciplinary level, the Architecture and Engineering Performance Information Center (AEPIC) in Maryland (Vannoy 1983), the *Journal of Performance of Constructed Facilities* of ASCE (Carper 1987), and the Center for Excellence in Construction Safety at West Virginia University (Eck 1987) have attempted to integrate lessons learned from the performance of constructed facilities (spanning all trades and disciplines) into industry practice.

Although many organizations have formal or informal methods of obtaining and using feedback in the design phase, relatively few attempts to collect, classify, or disseminate lessons learned from the construction phase have been documented. Perhaps this is because the contractor is responsible for means and methods. Improvements in construction operations increase contractor profits and are withheld for competitive advantage over others in the industry. Although most of the following systems are not construction-oriented, the various approaches and classification systems developed provide insight into essential elements of a successful feedback system. A description and critique of various existing systems follows.

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Architecture and Engineering Performance Information Center (AEPIC)

In the early 1980s, Neal Fitzsimons and Donald Vannoy initiated AEPIC with a mission as summarized in *Architecture and Engineering Performance Notes*:

> The initial objective of AEPIC . . . is the improved design, construction and performance of buildings, civil structures and other constructed facilities. That objective is based on the premise that collection, analysis and dissemination of information on performance . . . will assist in the improvement of the built environment. (*AEPIC* 1988)

In 1986 AEPIC began to collect information from two major sources for incorporation into the first computerized depository for failure data of this type. The first source was case files from a major architecture/engineering (A/E) liability insurance company. The second source was Federal and State Appellate Court case summaries involving building and civil structure failures. The AEPIC system contains more than 4,000 coded cases. This scheme has 67 different data fields and covers numerous topics.

The volume of encoded information facilitates the analysis of trends over time. The results have been published in a series of newsletters. Performance failure trends were identified and analyzed. For example, siting and excavation problems make up 18% of all performance incidents in terms of property damage and management problems. Roofing problems account for 10% of the reported failures. Of the roofing failures, 61% involve water penetration and 35% involve structural failure (*AEPIC* 1988).

This system catalogs performance incidents from the perspective of a forensic engineer. Given the sensitive nature of information dealing with actual or alleged failures and litigation, it is very difficult to acquire factual data. Claims cases, purged of incriminating information to protect privacy, are perhaps the only realistic source of large-scale data of this sort.

The AEPIC system was initiated almost 10 years ago, employing basic database technology. At its inception, there was tremendous enthusiasm, excitement, and support in the trade journals, but in recent years the AEPIC system has not enjoyed widespread use. The objectives are clear and worthwhile, but the system seems to lack focus, and integration into actual practice has not occurred.

The AEPIC target audience is vast and includes architects, engineers, contractors, developers, manufacturers, lawyers, building owners and users, federal and state agencies, insurance underwriters, university and private research organizations, and others (Loss 1987). There are a myriad of potential uses, but no specific customer. The sources and volume of encoded information make the database effective for research and analysis of trends, but is perhaps too broad and lacking in focus for individual clients.

The disadvantage of using third-party information as a knowledge source is that it may have been filtered of specifics that could adversely affect the reputation of the party from which the information originated. In addition, the original litigants or claimants may not be available or willing to clarify the information further if questions arise at a later date. Therefore, the only information available to a user is what has been included in the system.

American Society of Civil Engineers (ASCE)

Published since 1987, the ASCE *Journal of Performance of Constructed Facilities* "Seeks to coordinate and expand failure information dissemination strategies" (Carper 1987). Its objective is the development of professional practices to improve quality and promote public confidence in the engineering design professions.

Various committees of the ASCE have collected and categorized information on failures, accidents, and the performance of dams and hydraulic structures for many years (Committee 1975; Hydraulic 1986). Each publication contains case studies collected through questionnaires and generally includes a narrative description of the structure and the incident. Although substantial work has gone into collecting and disseminating performance information related to hydraulic structures, no attempt at a comprehensive classification system has been made.

Currently, there is no industry standard for classifying performance information. The Committee on Dissemination of Failure Information of the ASCE Technical Council on Forensic Engineering is currently studying the matter to adopt a uniform system for classifying failures (David Nicastro, personal communication, 1992), similar to the well known biology taxonomy (kingdom, phylum, species). Such a common classification system would be a major step toward industry standardization and would be an enormous benefit for communication and research.

Construction Industry Institute (CII)

CII was officially established in 1983 at the University of Texas at Austin. In part, the mission of CII—which is an association of owners, contractors, academic institutions, and other construction professionals—is to improve construction industry cost-effectiveness and disseminate state-of-the-art knowledge to the construction industry. One area of research funded by CII is the interface between design and construction practices, for which it has designated a Constructability Task Force. Two primary objectives of the Constructability Task Force are to promote the benefits of constructability improvement to industry professionals, and to provide a package of concepts for improving constructability.

CII has sponsored research, distributed CII task force publications and source documents providing suggestions for constructability improvement, sponsored seminars and workshops, and given lectures on constructability (ASCE 1991). CII maintains and updates a "Constructability Concepts File," which provides guidance to design and construction organizations for implementing constructability programs ("Constructability" 1987). The work performed to date by CII is highly useful as it has promoted the concept of constructability improvement, provided general suggestions for implementing constructability programs, and included specific examples for improving project constructability.

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL) has developed two systems to improve constructability through design review. The first, automated review management system (ARMS), was developed to help managers track constructability and design reviews of construction projects with the major participants being geographically dispersed. ARMS manages review dead lines at all user levels, provides database management for comment manipulation and analysis, provides for electronic forwarding of comments, and permits on-line or off-line batch comment generation from standard word processors (Kirby et al. 1991). This system is designed as a PC-based management tool, and aids in the constructability process, but does not actually contain performance information.

The follow-on system, currently under development, is called BCO advisor: expert system for bidability, constructability and operability review. It is a PC-based hypertext pro-

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totype designed to help CERL personnel perform constructability reviews on construction design documents. The prototype uses the KnowledgePro expert system shell. The user interactively compiles a tailored checklist based on the design stage (35 or 95% design) and discipline or the compliance sampling inspection (CSI) division of interest. This customized checklist is then used to review the design of a particular project. The prototype contains more than 2,500 individual comments (checklist items) from various sources, over half of which deal with "routine design construction evaluation" (Kirby et al. 1991). CERL hopes to merge the benefits of ARMS and BCO advisor to provide a complete design review package.

Naval Facilities Engineering Command (NAVFAC)

The Design Division of the NAVFAC has initiated numerous attempts to gather and classify lessons learned in the design and engineering of facilities for the Navy. One of the attempts was by Yachnis (1985), former chief engineer, who assembled a manual with more than 100 lessons learned from problems encountered on actual NAVFAC construction projects. It is organized by discipline (structural, architectural, mechanical), but also includes some problematic areas of concern to the Navy (corrosion, cranes, welding and nondestructive testing, and physical security). Each lesson includes the problem, symptoms, collection of facts, and solution as well as sketches where applicable.

Another attempt was by Nigro (1984) who developed *Redicheck*, a manual checklist designed to assist the design reviewer in locating and eliminating coordination problems among the various design disciplines and between the various contract documents at the final design review stage. *Redicheck* is a good source of relevant information; more than half of the errors and omissions in construction drawings and specifications are a result of inadequate coordination between the disciplines. Examples of such coordination problems include: specification sections referring to other, nonexistent sections, or interference between mechanical and electrical fixtures. Users have reported a savings of 1–3% of total construction costs on projects utilizing *Redicheck* (Nigro 1984).

Drawing on the lessons from earlier attempts at the Design Division of the NAVFAC, Tom Hurley developed an extensive value engineering database that has gained widespread use in the Navy in the 1990s. It is written in "C," uses Clipper database software, and stores information on compact disks. Value engineering comments from various Department of Defense field activities around the world are submitted on floppy disks and batch-loaded into the Navy's corporate database. Designers of new facilities review from more than 16,000 accumulated value engineering suggestions by a five-digit category code for the type of facility under consideration. While the system scores high marks for integration into the existing method of doing business, its weakness lies in the collection and verification of data. Many valid value engineering comments are not accepted for a particular project because of the advanced stage of design. Acceptance may essentially require redesigning the facility, or some accepted comments may be appropriate for a facility in one location, but inappropriate in a different location. Further, the system has no way of sorting or classifying except by category code and discipline.

Another recent effort in the Navy has focused on streamlining the review of computer-aided design (CAD) generated projects through the automated editing of comprehensive checklists to provide customized checklists tailored to a specific project (Antelman 1991). This is accomplished through the use of a rule-based diagnostic expert system [C Language Integrated Production System (CLIPS)] capable of reading CAD drawing database files (CADplus total architectural/engineering software). CADplus, which runs in conjunction with AutoCAD, implements the CAD drawing layering schemes, which are developed by NAVFAC and the American Institute of Architects (AIA). Layering schemes place individual disciplines and subdisciplines onto separate layers, which can then be overlaid in any combination for interference-checking or plotting. For a given project, an ASCII file listing all the applicable drawing layers is generated within the CAD system. The contents of the file are loaded as "facts" into CLIPS using a load-facts function. The CLIPS inference engine uses the loaded "facts" to identify which layers exist, then applies the knowledge-base rules developed from NAVFAC interdisciplinary checklists and *Redicheck* to determine the applicable review comments for the combination of layers given. A customized checklist containing only the applicable comments will be output for use by the designer/reviewer (Antelman 1991).

Construction Feedback Systems

Many construction companies use some type of formalized construction feedback system and/or conduct some type of lessons-learned review. Construction knowledge feedback may occur through distribution of a memorandum regarding an interesting problem, but more likely through discussions in various meetings. A major disadvantage of the feedback systems currently in use is that information is primarily transferred verbally along a limited group of people. Lessons learned are, therefore, not readily available in an easily retrievable format for all potential users.

The most common formalized feedback system presently in use is what has been termed "close-out" or "postconstruction" conferences at the conclusion of projects. The participants in these conferences are usually key personnel from the project (superintendent, project manager, project executive) and home office, such as vice presidents and estimators. The main function of these conferences is to recap lessons learned on the project so that mistakes are not repeated and innovations are promoted.

Close-out conferences, while beneficial to some participants, have many shortcomings, including the following:

1. Only a selected group of people participate in the conferences, though many others might benefit from the conclusions reached.
2. By the conclusion of the project, many issues and lessons will be forgotten by the participants. Even when a particular issue is recalled, contributory circumstances often go untold and undocumented.
3. After a project is completed most people are busy thinking about the future rather than the past. With personnel often transferred to other projects, and others soliciting new work, people may not want to dedicate time to reviewing past issues. Therefore, close-out conferences are sometimes treated as a burden to be rushed through so that attention can move on to more pressing matters.
4. Perhaps the most serious shortcoming of close-out conferences is a failure to uniformly document lessons learned in a manner useful to others in the future. Even when detailed minutes of the conference are prepared and distributed to the participants, the availability of this information to others is very low, and retrieval for use in future work is difficult. This shortcoming is even more pronounced in large companies with many offices.

DESIGN OF IKIS-CONSTRUCTABILITY

This section presents the design of IKIS-Constructability, an interactive knowledge-intensive system for making effective

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use of construction lessons learned in a medium to large-size construction firm. The primary focus of IKIS-Constructability is lessons that have their genesis and application in the construction phase. While considerable effort has been exerted in developing classification and dissemination strategies to benefit the planning and design phases, almost no work has been dedicated to the construction phase.

The system was developed by the writer for The George Hyman Construction Company. Two important issues in the design of IKIS-Constructability are discussed in the following sections: (1) A manageable format for organizing, storing, retrieving, and updating information, i.e., modeling; and (2) an effective mechanism for collecting, verifying, categorizing, and storing information, i.e., knowledge acquisition and knowledge engineering.

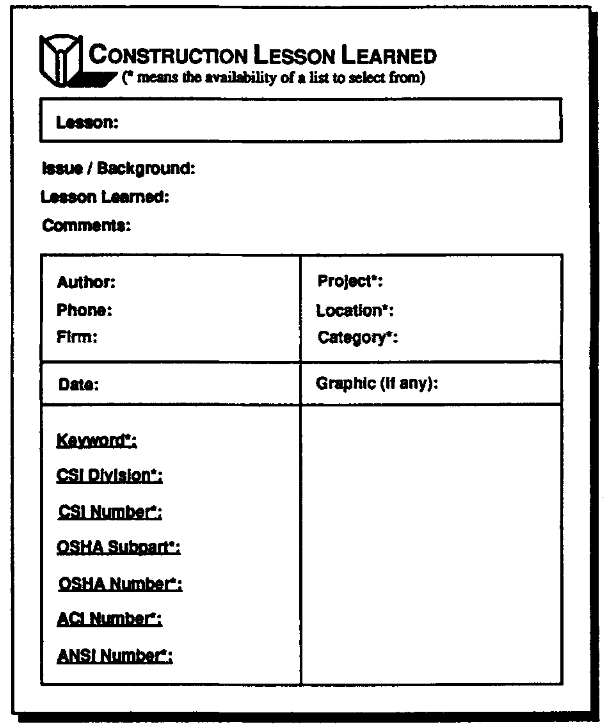

FIG. 2. Format of Constructability Lesson Learned

Modeling Constructability Knowledge

Because the type of information needed to properly document a construction lesson learned can take any shape, a simple, comprehensive, and flexible framework is needed. After reviewing previously attempted feedback systems, three major components of a lesson learned emerge (see Fig. 2). First, a set of attributes necessary to sufficiently describe and explain the lesson itself. A lesson title, a description of the problem or situation, a description of the solution or method, additional comments, and perhaps a relevant sketch or reference to other documented information may be sufficient to describe a construction lesson. Second, information regarding the source and context from which the lesson is collected is necessary. The final component of a lesson learned involves the means for classifying the lesson in a manner that allows fast, clear retrieval by multiple parameters. A classification system is needed that will enable a user (expending minimal effort and from various perspectives) to quickly review selected, relevant lessons from the knowledge base. If the classification system is too general with categories that are too broad, lessons will be easily classified but relatively impossible to retrieve effectively because of the inability to sufficiently narrow the scope of a search query. If the classification system is too specific with excessive categories, selection between available categories becomes onerous.

In IKIS-Constructability, the lessons were analyzed and classified into the 16 divisions of the MASTERFORMAT system (CSI 1983), the most widely used coding system in building construction. The use of a common coding system improves consistency and information flow between IKIS-Constructability and other computer-based construction systems, allowing for better integration of organizational efforts. This is based on the Construction Specification Institute's (CSI's) broad, medium, and narrow scope approach to classifying construction activities. Code extensions can be added to the basic CSI codes to indicate more specific information such as location of work or responsible organization.

Although the CSI system is the main coding and classification system that was adopted in IKIS-Constructability, alternative means to information access and multiple views of the database are available, e.g., key words, structural component, construction activity, and Occupational Safety and Health Administration (OSHA) codes (see Fig. 3).

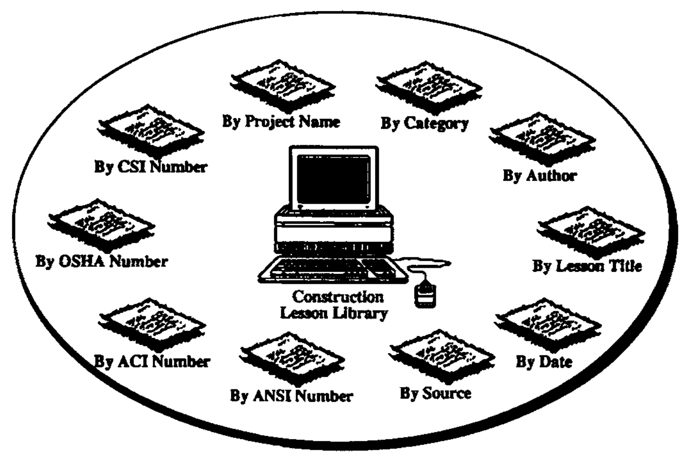

FIG. 3. Multiclassification Approach for Constructability Feedback System

This system accommodates classification of many construction lessons, including those that involve the interface of two or more CSI categories. For example, a lesson involving space conflicts between electrical conduit and reinforcing steel within a concrete column could be classified under a CSI electrical category (16050), under a CSI concrete category (03200), under the component entitled "column," and perhaps under the key word "space conflict." Key word and component libraries were developed so that terms can be applied consistently.

Additional information that can be linked to the source project (e.g., concrete frame building, location, etc.) or source person (e.g., assistant superintendent) can be used as additional parameters in information retrieval. Lessons could also be categorized by an individual contractor's chart of cost accounts, a method that may have more appeal with certain groups within organizations as well as with contractors who work in sectors of the industry where the CSI classification is not widely used.

Constructability Knowledge Acquisition

Extracting expert knowledge from subject matter, or domain experts is perhaps the most difficult step in the development of any knowledge base. "Knowledge acquisition has been reported as the major bottleneck in the development of expert systems" (Bowen and Erwin 1990). In the construction arena, solid lessons are very difficult to extract (Fischer 1991). Con-

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sequently, few construction lessons learned have been documented. Successful project managers and superintendents have developed individual methods and procedures, proven effective by their longevity in this highly competitive market. Achieving a consensus when attempting to compile information on the best methods or procedures is difficult, further complicating the knowledge-acquisition and validation process.

Experience in knowledge engineering has shown that personal interviews, rather than pure questionnaires, is the most effective method of knowledge acquisition. The interview process itself is critical to understanding how successful project superintendents approach their business. It allows insight into how project superintendents categorize, organize, and use their rich experience. Heuristics, or rules of thumb, are plentiful in construction but difficult to articulate.

Interviews, with the main focus on concrete and site works in building construction, were conducted with more than 50 construction experts, including project executives, project managers, estimators, superintendents (Jimmy Forsythe, personal communication, 1993), field engineers, and foremen. Due to their hectic, unpredictable schedules, initial interviews were conducted by simply spending the day following superintendents around jobsites. As areas of personal expertise became apparent, further questioning in those areas was pursued. Daily project dilemmas provided other opportunities to gain insight into frequently applied heuristics and problem-solving techniques. It was immediately apparent that the extraction of valuable lessons requires much patience and persistence.

Decisions about information or lessons to be included in the system are not clear-cut. Any lesson learned regarding the construction of a project is a viable candidate provided the lesson is based on acquired construction knowledge and is not merely common sense. Once the appropriate level of knowledge is decided on, the process of collecting, classifying, and disseminating the information becomes essential. Because unique, universally accepted solutions to any construction predicament are not common, alternative solutions, wherever they exist, have been included.

The process of knowledge acquisition follows a three-step format:

1. Preinterview planning: Top-level management provide a list of construction experts, which includes their position, area of expertise, jobsite location, and phone numbers. Contacts are made over the phone to provide a brief overview of the feedback constructability system, a detailed description of what is requested from the employee, and a date and time for the interview. Sample lessons are faxed to the expert to illustrate the level of detail required during the interview.
2. Conducting the interview: Two students have conducted interviews, in which one interviewer directs the conversation while the other transcribes notes. Each interview takes about an hour. As the meeting progresses, they switch on and off to keep the discussion flowing. This two-interviewers approach has proven to be very fruitful in minimizing misunderstandings and focusing the discussion on related constructability knowledge issues.
3. Postinterview activities: The information obtained is quickly formulated into lessons learned and a copy of each is sent to the original expert for verification and validation. During its monthly meeting, the total quality management (TQM) committee at The George Hyman Construction Company (Hyman's) reviews and refines the constructability lessons that have been collected, and approves those lessons to be included into the knowledge base. This committee consists of eight individuals including a vice president, project managers, superintendents, field engineers, and foremen. Currently, the knowledge base contains more than 60 lessons, most of them in the area of concrete building construction.

SYSTEM IMPLEMENTATION AND OPERATION

The system was developed using a relational database management system (SuperBase) and hypermedia techniques running on IBM-PC class of computers. Combining the capabilities of database with hypermedia techniques allows alternative means of accessing information as well as potential integration with other computer-based construction systems. Hypermedia techniques permit the dynamic linkage of separate text or graphic files or other forms of computer data. These techniques reduce the scope of interest to a manageable size, allowing the user to concentrate on a reasonable amount of information at a time. As a result, the IKIS-Constructability system allows the developer to encode knowledge efficiently and users to navigate through the sea of expertise interactively.

At the initial stages of this research, expert system software were considered as a potential implementation environment but were not selected. First, expert system technology is new to construction companies, making its integration with other pieces of existing software more difficult and limiting its acceptability among potential users. Second, expert systems do not provide convenient access to external information and they experience significant performance degradation as the size of the accessible information becomes large.

Construction practitioners will not accept an assertion that a certain method is superior to another, without a sound rationale. An explanation facility, including the source and context from which the lesson was obtained, ensures credibility and provides a reference for further investigation when necessary. An explanation facility has also proved indispensable when debugging or validating the system as it evolves from a prototype to a mature system.

After a rapid prototype was developed and demonstrated, users at Hyman's main office in Bethesda, Maryland have found the system user-friendly and realized its potential benefits. First, the system retrieval facility has been used by project managers, field engineers, superintendents, and foremen engaged in field operation and in search of the most effective construction methods based on company experience. According to these users, the amount of rework has been minimized because mistakes can be avoided. The constructability feedback system earned credibility since the knowledge has been thoroughly refined and validated with the original experts and with Hyman's TQM committee. The system is described as being flexible in retrieving information, through the multiclassification option, and fast in retrieval time. The system is used during the planning stage to alert engineers of potential problematic areas and the most effective ways of dealing with them. In this respect, the constructability feedback system is explored as a proactive planning tool in conjunction with a project critical path method (CPM) scheduling network. Also, the system is used as a reference library whenever an engineer, superintendent, or foreman is faced with a constructability problem.

The second important benefit reported by users is the availability of a mechanism (i.e., add/delete/modify a lesson option) to update the knowledge base and capture new and innovative construction methods as they become available. So, the process of expanding the knowledge base is partially automated, pending final review and approval by the TQM committee. Lessons learned must be documented in a standardized format when they are fresh in mind. The task of submitting new lessons or commenting on existing lessons should not be arduous and time-consuming, but needs to fit into everyday activities.

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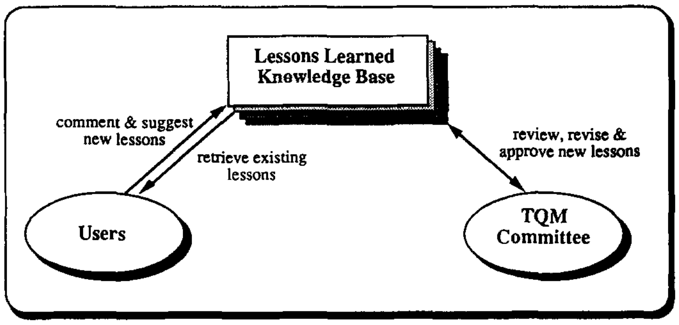

FIG. 4. Lessons-Learned System in Operation

An interactive capability via the use of menus is available within the system to submit new lessons. Once a lesson is proposed for inclusion into the system, technical review and classification of the lesson are conducted by the TQM committee before release for widespread use. Many organizations have committees that address quality issues and would be a natural choice for this task. Fig. 4 illustrates the operation of the system.

Since the knowledge base is quite limited in the development stage, a major goal of the successful prototype is to generate enthusiastic support and a willingness to contribute personal experiences to system developers. As a form of recognition for contributors, the TQM committee select the most fruitful lesson captured and identify it as "The Idea of the Week" in their weekly newsletter. The prototype is expanding with about six new lessons every month, mostly from superintendents. Copies of the system are in the process of being distributed to different sites where PC computers are available. Currently, the system is running only at the main office. As the knowledge base grows and the number of participants increases, the TQM committee must find the time and resources to review and approve lessons effectively.

CONCLUSIONS

Historically, the collection and dissemination of engineering/construction knowledge has proved to be difficult but invaluable when accomplished. This paper demonstrated the feasibility and potential benefits of making effective use of construction lessons learned. Key challenges to the effective use of feedback channels in the project life cycle were identified along with methods to meet these challenges.

The CII has called for improved documentation of lessons learned from the field. Although construction of a facility is typically viewed as a one-of-a-kind operation, there is a considerable amount of repetition. Facades, bays, and often entire floors are repeated. Lessons acquired in one project by a particular crew must be communicated to other crews on the same project as well as to other projects. As the CII advocates, a corporate lessons-learned database is a key element in any constructability program.

This paper described the design, implementation, and operation of a prototype system called IKIS-Constructability, using a database management system and hypermedia techniques. Such database environment combined with the use of a common classification format (CSI) permits integration with other computer-based construction systems, and allows a more direct representation and modeling of real-world construction projects.

An interactive menu-driven capability has been incorporated in IKIS-Constructability to ensure its continuous expansion and use by construction individuals within a contractor company. Such a dynamic, interactive system provides significant improvements in construction cost, schedule, quality, and safety in the planning and execution of future construction work.

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