CONSTRUCTABILITY KNOWLEDGE-INTENSIVE DATABASE SYSTEM

Constructability knowledge-intensive database system

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Abstract

Generally, lessons learned in the construction, operation, and maintenance of a facility are not effectively fed back as input to the design and construction phases of new projects. Traditional methods of collecting and disseminating lessons-learned in the construction of projects have enjoyed limited success due to: (1) the unreliable communication channels between construction experts and practitioners, (2) the lack of a meaningful classification system, (3) the unmanageable format that made it difficult to access, retrieve and update the potentially enormous volume of lessons, (4) the difficulty of integrating new systems into existing operations and procedures, and (5) the focus on failures or incidents, rather than on both positive and negative experiences with constructed facilities. If the experience and lessons learned at the construction site could be captured and incorporated into a dynamic, interactive, knowledge based information system, then great benefits could be realized as this information is utilized in the design and construction of future facilities. Constructability and maintainability can be enhanced, more efficient construction methods can be utilized, facility quality and safety can be maximized and total life cycle costs can be minimized.

This paper presents a knowledge-intensive database system for constructability improvement. Construction lessons were collected; a framework for classifying, storing and disseminating lessons was designed; and a prototype system was developed, tested and validated. This system can be used: (1) as an assistant and decision-making tool by engineers and foremen of contractors, and (2) as an educational and training tool by undergraduate and graduate students of civil engineering at Kuwait University.

Keywords: Constructability, value engineering, lesson learned, feedback system, database

1 Introduction

Each failure or nonperformance of a material, system, etc. can contribute to the advancement of engineering and construction management; just as every medical *post mortem* can contribute to the advancement of medicine. The problem in the past has been the establishment of a system to perform *post mortem* analyses and diffuse the knowledge gained. Medical doctors use a system called *Medlars*, and lawyers use a system called *WestLaw*. Unfortunately, no such system is available to construction companies, though construction is the largest industry in most countries.

Valuable information on the design, construction, operation, and maintenance of facilities is gained each working day. The problem has been the lack of a format for capturing and retrieving that information for use at some future date. The standard practice has been to depend on personnel who, through years of experience, know what happened and what was learned as a result. This information abruptly comes to an end when the experienced personnel are no longer available. In addition, failures and service interruption need quick and efficient solutions, both in time and money. The quick and easy access to a "lessons learned" feedback system will allow this in an interactive, proactive, and efficient manner.

While past efforts have focused on the design phase, opportunities for collection and dissemination exist in all phases of the facility life-cycle. Without making use of construction lessons learned, mistakes will be repeated; resulting in an increase in the overall construction cost due to repair, rework, construction failures, claims, poor reputations, etc. One study of industrial-type projects showed direct costs for construction rework at greater than 12% of the total project costs (Ledbetter 1989).

The Constructability Task Force of the Construction Industry Institute (CII) describes constructability as:

> "the optimum use of construction knowledge and experience in planning, engineering, procurement, and field operation to achieve overall project objectives." (CII 1987)

Similar to improving constructability during planning and design stages, the key to improving constructability during the construction phase is a formalized feedback system for construction knowledge (Kartam 1997). 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, and coordination. This type of input will influence the construction phase of the project with respect to duration, efficiency, and contractor profit.

2 Feedback in the 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 their genesis in any phase of a project's life cycle. Similarly, these lessons may be applicable in one or more phases of the project life cycle.

The various sources and uses of engineering-construction knowledge are depicted in Figure 1. Three feedback loops exist in a project life cycle; these include: value engineering, constructability, and post occupancy evaluation.

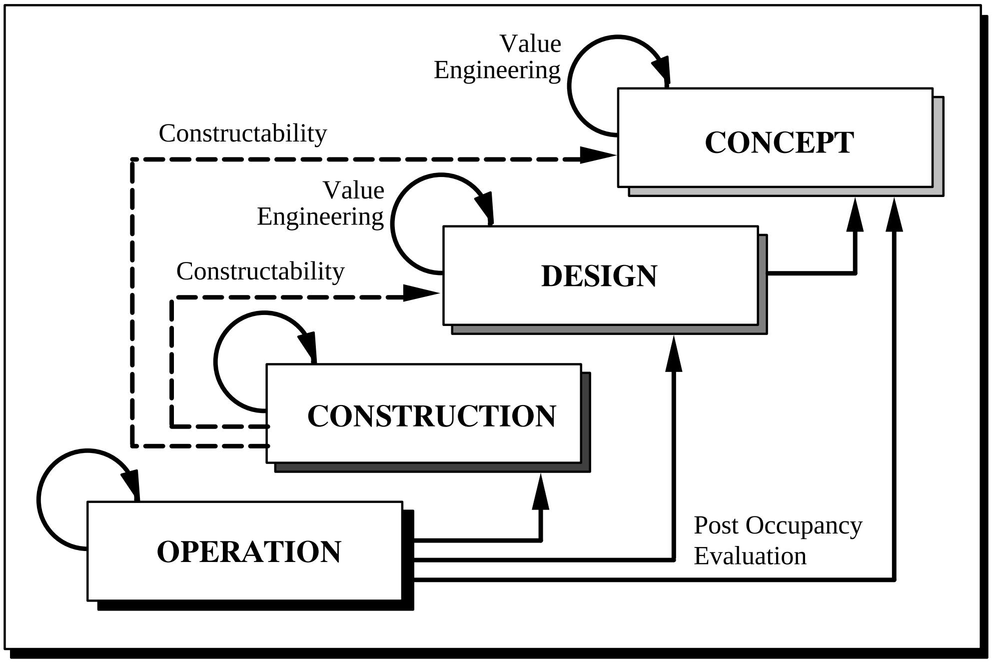

Fig. 1: Feedback channels in the project life cycle

3 Research objectives

The overall objective of this project is to design and develop a constructability management information system for construction lessons learned. The specific objectives are: (1) collect expert knowledge and lessons learned to perform concrete construction operations, (2) design a framework for storing and disseminating construction lessons learned, and (3) implement a knowledge-intensive database system for applying these lessons in the construction of future facilities.

Below, two important issues in the development of the Constructability System are discussed: (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.

4 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 Figure 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 effectively retrieve because of the inability to sufficiently narrow the scope of a search query. If the classification system is too specific with excessive categories, selecting between available categories becomes onerous.

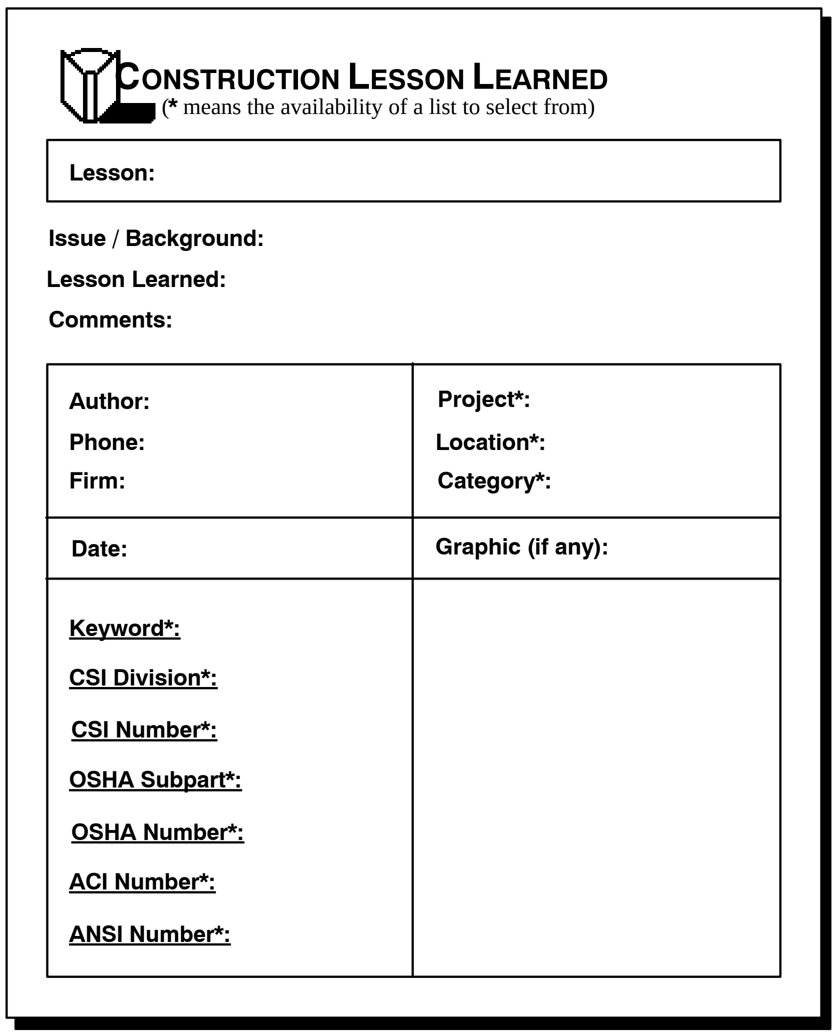

Fig. 2: The format of a constructability lesson learned

In the Constructability System, the lessons were analyzed and classified into the 16 divisions of the MASTERFORMAT system (CSI 1995), a widely used coding system in building construction in North America. The use of a common coding system improves consistency and information flow between the Constructability System and other computer-based construction systems allowing for better integration of organizational efforts. This is based on Construction Specifications Institute's (CSI) 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 which was adopted in the Constructability System, alternative means of information access and multiple views of the database are available, e.g., key words, structural component, construction activity, American Concrete Institute (ACI), American National Standards Institute (ANSI) and Occupational Safety and Heath Administration (OSHA) codes (see Figure 3).

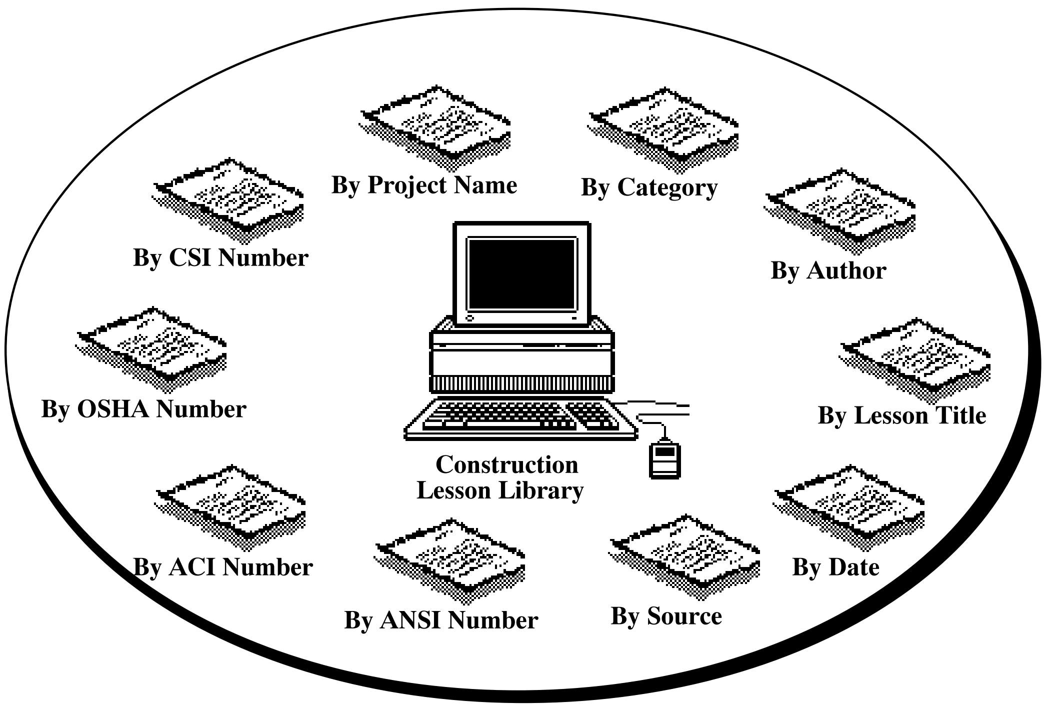

Fig. 3: Multi-classification approach for the constructability system

This system accommodates classification of many construction lessons, including those which 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 keyword "space conflict". Keyword 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 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 CSI classification is not widely used.

5 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 1990). In the construction arena, solid lessons are very difficult to extract (Fischer 1991). Consequently, 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 gaining an understanding of how successful project superintendents approach their business. It allows insight as to how they categorize, organize and utilize 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 fifty construction experts, including project executives, project managers, estimators, superintendents, field engineers, and foremen. Due to their hectic, unpredictable schedules, initial interviews were conducted by simply spending the day following superintendents around job sites. 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 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 upon, 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.

6 System implementation and operation

The system was developed using a relational database management system MS-Access™ 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 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 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 was considered as a potential implementation environment, but was 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, insures credibility and provides a reference for further investigation when necessary. An explanation facility has also proven 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 a number of major contractors in Kuwait have found the system user friendly and realized the 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 since 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 a Total Quality Management Committee (TQM) that was established specifically for the purpose of reviewing and approving new lessons. The system is described as being flexible in retrieving information through the multi-classification option, and as 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 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 the 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. 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. Figure 4 illustrates the operation of the system.

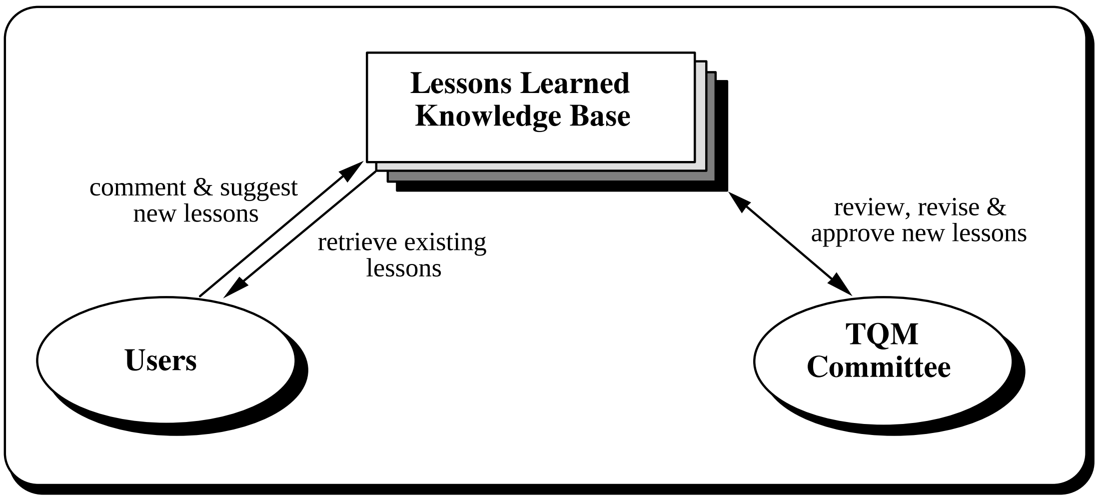

Fig. 4: The lessons learned system in operation

Since the knowledge base is quite limited in the development stage of a construction project, a major goal of the successful prototype is to generate enthusiastic support and a willingness to contribute personal experiences to system developers. As a recognition for contributors, the TQM Committee select the most fruitful lesson captured and identify it as “The Idea of the Week”. The prototype is expanding with about six new lessons every month, mostly from superintendents. Such new lessons are now being submitted electronically. 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.

7 Conclusions

Historically, the collection and dissemination of engineering/construction knowledge has proven 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 effectively utilizing 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 Constructability System using a database management system and hypermedia techniques. Such database environment combined with the use of a common classification format (i.e., 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 the Constructability System 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 planning and executing future construction work.

8 Acknowledgments

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