Design Review Checking System with Corporate Lessons Learned

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Abstract: Design reviews are critical to the success of a construction project. They eliminate costly rework and conflicts, and promote creative and innovative design and construction. This paper discusses a unique way to improve design reviews by gathering and including direct corporate experience that can be used company- and industry-wide. The Design Review Checking System (DrChecks) and the system called Corporate Lessons Learned (CLL) were developed by the U.S. Army Construction Engineering Research Laboratory to collect personal experiences and lessons learned on projects and incorporate these data into corporate knowledge, expressly for the design review process. DrChecks provides a framework for a standardized review process. Typically, exchanges of personal experience and knowledge have occurred informally by word of mouth. With DrChecks and CLL, direct personal experience can be collected into a database while the design review process is on-going. Lessons learned, success stories, and good work practices, which can be identified easily by experienced staff members, can then be shared throughout the organization. DrChecks and CLL both take advantage of the Internet and facilitate the management of design review process and the collection and reuse of corporate lessons learned asynchronously and remotely.

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Introduction

Several research studies illustrate the importance of design management (Koskela et al. 1997; Ballard 2000). A report by the Building and Economic Development Committee showed that more than 50% of the problems encountered on building sites were related to poor design information (NEDC 1987). A survey conducted by Baldwin et al. (1999) highlighted some information-related problems during construction design processes. Survey participants noted the following:

- Inaccurate design assumptions cause errors in task planning,
- Team members withhold information from each other,
- Incomplete or missing information is common,
- Poor quality of exchanged information leads to poor judgments and assumptions,
- Various changes are expected during design, and
- Multiple organizations and individuals are involved at different phases; therefore, no one can claim to have all the most up-to-date information all the time.

Baldwin et al. argue that by understanding the process and eliminating such difficulties, the management of the design process can be significantly improved, thus leading to better design and construction.

Techniques and tools have been developed to support design management, such as the Dependency Structure Matrix (Steward 1981), the Analytical Design Planning Technique (Austin et al. 1999), and Deplan (Hammond et al. 2000). Although these methods provide support for planning, scheduling, and controlling the design process, the design review process has not been brought up to date with the latest advances in information technology.

The process of reviewing construction documents for accuracy, completeness, and correctness is widely recognized as an integral part of the proper execution of professional design services. The characteristics of many projects suggest that design reviews are necessary for ensuring a balance among the various conflicting requirements of many projects (O'Connor et al. 1986).

According to a study conducted by the Federal Facilities Council (FFC) (Spilinger 2000), total project cost may be significantly reduced by conducting an effective design review process. This study found that effective design review practices result in

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less rework on the part of the construction contractor, fewer change orders to correct design errors and omissions, and a reduction in the cost of additional project upgrades not included in the original design. The FFC reported that 30 to 50% of all construction change orders result from errors in the design document that are directly related to improper interfaces between design disciplines. Briefly, the FFC study presents the following five key findings on design review processes:

- Effective design review processes add value by saving time and money over the entire design and construction process,
- The team responsible for design review should include representatives of all project stakeholders: owner, user, architect/engineer, construction contractor, operation and maintenance staff, and major equipment vendors,
- There is a lack of established standard in measuring the design review process,
- To provide effective oversight of design review processes, the owner's interests are better served when the in-house staff can fulfill the functions of a smart buyer, and
- The ongoing evolution in information technology and communications offers opportunities to improve design review processes.

This paper describes how the Design Review Checking System (DrChecks) and Corporate Lessons Learned (CLL) address these design review issues and provides a framework for the development and continuous improvement of design review processes. The first section presents an overview of the design review process, followed by an analysis of the available tools that can be used to support this process. The next section discusses the limitations of the existing systems and the need to develop an improved design review framework. DrChecks and CLL are presented as systems that can help fulfill this need. A detailed description is given of the systems' characteristics and their benefits, as well as case studies and evaluation surveys of several construction projects. Conclusions and current research initiatives are also presented.

Design Reviews in the Construction Acquisition Process

The process of acquiring a facility usually includes five phases: conceptual planning, design, procurement, construction, and start-up. The contracting method used will determine whether the five phases occur in sequence or if some phases occur concurrently. The contracting method can also affect who is involved at each phase. The design review process plays an important role in each of these phases.

Decisions made during the conceptual planning phase establish the initial constraints that limit future design flexibility. These early decisions thus have a disproportionately greater influence on a facility's ultimate quality, cost, and schedule than decisions made later in the process. Therefore, the conceptual planning phase should be the time when the review of design is most intense, with the primary focus upon ensuring the appropriateness, accuracy, and thoroughness of the owner's expectations regarding facilities performance. During the design phase, formal reviews may be scheduled periodically (e.g., at the 35, 60, 90, and 100% design completion milestones). Such structured formality helps ensure the widest possible participation of interested parties during the review, including specialists and consultants who bring expertise from different knowledge domains. During the procurement phase, the review of designs can continue to contribute to overall project success by monitoring progress made in acquiring the required resources. In the construction phase, changes by the owner, errors and omissions in the plans, unknown or changed site conditions, and creative initiatives on the part of the construction staff will result in recommended changes to the facility design. In this phase, design reviews should focus on assessing the impact and advisability of changes on facility performance. During the start-up phase, design reviews are conducted as a postoccupancy evaluation, whose purpose is to record lessons learned for future reference.

Table 1. Topics Addressed in an Effective Design Review Process (Spilinger 2000)

Topic	Key questions to be addressed
Owner satisfaction	Does the constructed facility meet the owner's expectations as originally defined by the project scope definition or statement of work (i.e., performance characteristics, architectural statement, level of quality, cost, schedule, and any relevant owner-published standards and/or policies)?
Sound professional practice	Is the approach taken in each of the specialty areas (architectural, civil, mechanical, and electrical) commensurate with professional standards?
Code compliance	Does the design comply with all applicable codes, such as fire protection, life safety, and access?
Architectural statement	Is the overall presentation representative of established architectural standards?
Value engineering	Are there any less expensive methods or materials that could be used in the design without impacting project quality or performance (or life-cycle costs)?
Biddability	Are the construction documents sufficiently clear and comprehensive so construction contractors will have no difficulty developing an accurate bid with minimal allowance for contingency?
Constructability	Does the design impose any unnecessarily difficult or impossible demands on the construction contractor?
Operability	Does design of the facility operating systems ensure ease and efficiency of operation during the facility's useful lifetime?
Maintainability	Does the facility design allow for easy and cost-effective maintenance and repair over the useful life of the facility?
Life-cycle engineering	Does the design represent the most effective balance of cost to construct, cost to start up, cost to operate and maintain, and (perhaps most important) the user's cost to perform the intended function for which the facility is being acquired over the useful life of the facility?
Postoccupancy evaluation	Based on a review of the construction, start-up, and ongoing functioning of the facility, could any unexpected difficulty have been avoided by a different design approach?

According to Spilinger (2000) plus Table 1, we can conclude that design reviews can address several project aspects and can add value by saving time and money over the entire project life cycle. In general, design reviews can help to

- Detect problems related to errors, omissions, and inconsistencies caused by the design process,
- Identify inappropriate construction methods and materials that would increase construction costs,
- Certify compliance to standards, specifications, codes, and regulations,

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- Identify components and building systems that would result in facilities difficult to maintain and operate,
- Increase project quality, integration, biddability, constructability, and maintainability,
- Reduce construction change orders with the consequent decline in construction delays associated with them,
- Decrease the number of requests for information (RFIs). Design conflicts usually require resolution by RFIs, clarifications, and conflict resolution techniques. Catching these conflicts before construction greatly reduces the time needed to resolve them,
- Acquire knowledge that can be applied in other phases of the project life cycle, improving their returns, and
- Improve client satisfaction and usefulness of the facility.

According to Spilinger (2000), an effective design review process should be structured to address the topics shown in Table 1.

In recent years, industry research has been conducted to establish a set of criteria that can be used to quantify the efficiency and the effectiveness of each phase of the facility acquisition process and compare results with established benchmarks. However, in the design review process, the use of metrics to measure the value added by such reviews is not well established. A survey conducted by the Federal Facilities Council (FFC) (Spilinger 2000) in nine federal agencies indicated that they measured the value added of design review processes primarily from a broad context. Their questions were subjective (Is the user reasonably happy with the completed facility?) and objective (How close did the completed facility come to the original cost and schedule objectives?). The FFC study also identified 18 best practices and technologies that could be used to provide adequate management and oversight of design reviews. These best practices, which are presented in Table 2, are organized into five categories related to the role of the owner, teamwork and collaboration, advance planning, process, and establishing benchmarks.

Even though they were generic in nature, these practices highlighted some issues that should be addressed during the development of appropriate design review tools.

Table 2. 18 Best Practices for the Review of Designs (Spilinger 2000)

Categories	Best practices
Role of the owner	• Be a smart buyer.
	• Develop a scope of work that clearly and accurately defines the owner's expectations regarding cost, schedule, performance, and quality.
	• Avoid the temptation to micromanage the design review process.
Teamwork and collaboration	• Use teambuilding and partnering techniques.
	• Ensure that all interested parties participate in design review processes.
	• Use the same architect/engineer throughout the process.
	• Use senior, experienced staff to evaluate the evolving design and guide the review process.
	• Commit for the duration of the activity.
	• Participate in a design awards program.
Advance planning	• Focus attention at the front end during the conceptual planning and design phases, where the ability to influence the ultimate cost of the project is greatest.
	• Do not start the final stage of design until the preliminary engineering is complete.
Process	• Taylor the review approach to project specifics.
	• Keep up the pace of the process to maintain momentum.
	• Pay special attention to civil, structural, electrical, and mechanical interfaces.
	• Exploit technology.
	• Conduct a postoccupancy evaluation to develop a lessons-learned document.
Benchmarking	• Measure results achieved by the design process.
	• Document both unusually good and bad performance.

Design Review Tools

Specific design review tools provide the framework that assist in the design review process. Traditionally, the most common means for design reviews is to print reports and re-enter data manually. Although inefficient and subject to error, this approach is still commonly used today. Only in the early 1980s, with the widespread use of personal computers, did software to automate the design reviews begin to be developed. Two groups of design review tools can be identified: mature systems and new technologies.

Among the mature technologies, Redicheck was one of the first specific design review approaches (Redicheck 1981). It is a construction document review service specifically designed to locate design coordination errors and omissions. A team of design reviewers, from different expertise areas, uses a systematic method of construction document quality control and a review system that specifically addresses points of interface between building systems in order to check for coordination between these different disciplines. The reviewers use a checklist and an overlay checking process to discover common errors and omissions. The Automated Review Management System was developed in the late 1980s to foster increased communication and interaction among all design review participants, providing a mechanism for data collection, collation, distribution, and incorporation into contract documents (Kirby et al. 1988). The Project Definition Rating Index (PDRI), developed by the Construction Industry Institute, provides tools for measuring the degree of scope development in either industrial projects or building projects (Gibson and Dumont 1996). This analysis can provide direct benefits to the design review process. Specifically, the PDRI is a checklist of scope definition elements weighted according to their relative importance and presented in a score sheet format. It provides a means for an individual or team to evaluate the status of a project during preproject planning with a score corresponding to its level of definition. According to Cho and Gibson (2000), the PDRI for industrial projects was the first publicly available tool of its kind that allowed a project planning team to quantify, rate, and assess the level of scope definition on industrial construction projects prior to authorization for detailed design or construction. Limitations with the use of mature design review tools include: The lack of integration and interoperability with other companies' systems, scalability limitations that constrain the participation of all stakeholders organizations, and the absence of mechanisms to capture and reuse lessons learned from past projects.

New technologies have been employed to try to make an impact in the design review process. For instance, some project management software, such as *Primavera Expedition* and *Prolog Manager*, has added some design review capabilities. Design reviews are also being incorporated as a workflow in project extra-

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nets. These communications and information systems are enabling practitioners in construction to perform web-based project management over the Internet. A number of construction companies are adopting this technology either because they realized its competitive advantages or they are being forced to use it by their clients. When a construction company decides to adopt a web-based project management system, there are two possible alternatives that the company can choose in developing the system: in-house development or outsourcing this activity to a project extranet service provider. Examples of applications are extensively described in literature (Fu and East 1999; O'Brien 2000; Zarli and Rezgui 2000). Rojas and Songer (1999) described web-centric systems as a new paradigm for collaborative engineering. They argue that the World Wide Web now provides new opportunities for development of distributed systems. These systems can traverse organizational boundaries and provide a unique opportunity for teamwork automation among otherwise isolated organizations. Each of these corporations has a specific role in the development of the project. They work together to achieve a common project goal, while maintaining their individual objectives, acting as virtual organizations. These networked information systems can create new efficiencies and new relationships between organizations, redefining their organizational boundaries, but there are still some barriers to be crossed. Rojas and Songer (1999) argue that the World Wide Web is still an infant technology that is redefining itself every day. Integrating the different technologies that make up the web is not an easy task. A close working relationship with several companies is also necessary to successfully incorporate their technologies into the system. O'Brien (2000) claims that project web sites need to be better integrated into the job activities of project team members, and that the current one-size-fits-all team members' model that most web sites ascribe to does not maximize the value of this technology. He suggests the definition of specific uses for project web sites, and the enforcement of the web site for these specified uses. Some limitations in the use of these generic project management systems for design reviews are the lack of specific support for design review processes, difficulty in finding problem issues, and the absence of corporate knowledge capture and management.

Issues in the Implementation of Design Review Systems

The complexity and multiparty nature of the design review process require the development of more efficient collaborative systems to support this process. Four important issues that need to be considered during the implementation of improved design review tools are discussed below (O'Connor et al. 1986; Kirby et al. 1988; Fu and East 1999; Spilinger 2000).

Specific Support for the Design Review Process

The definition of a standard review process can improve the overall process time, cost, and quality by creating an environment that facilitates the capture, analysis, and dissemination of design review comments and their resolutions. Problem issues can be more easily detected, and new design alternatives can be explored.

Participation of all Stakeholders

The traditional design review process is time consuming, requiring a series of interactions among various participants. The success of this process depends on the participation of all parties involved. Design review systems must offer the capability to foster collaboration, coordination, and information exchange among the stakeholders. This will be particularly important in projects where the stakeholders are located in different cities.

Process Control and Establishing Benchmarks

Because design review processes will occur often among project organizations, design review systems must provide the means to monitor and control the review processes, making it possible to establish benchmarks for future design developments.

Capture and Management of Corporate Knowledge

Given the high turnover rate of experienced personnel throughout the architect/engineer/contractor community, exchange of individual lessons learned and other important organizational experience typically occurs only informally by word-of-mouth among colleagues. Very often, experienced people do not have the time or tools to transfer their hard-earned knowledge to others. Translating an individual's unique project learning into corporate knowledge is essential and critical to providing a quality product. Past experience has shown that proprietary, stand-alone systems to capture and use lessons learned are too expensive to maintain over time.

The intersection of the process of conducting design reviews (addressing of topics shown in Table 1, with the participation of all stakeholders) with the process whereby organizational knowledge can be captured and evaluated provides one of the best points at which to develop an integrated design review system.

To tackle these issues and after considering the limitations of the existing systems, the U.S. Army Construction Engineering Research Laboratory (CERL) has developed a prototype computer system that supports the capture and use of organizational experience in the context of the design review process. The World Wide Web provides the communications backbone of the DrChecks and CLL systems. Users access DrChecks/CLL using commercially developed web-browser software. The hardware and software to operate a local DrChecks/CLL server are inexpensive commercial products. The use of such simple, robust, and inexpensive commercial software means that a large number of personnel with limited computer knowledge can quickly learn to operate the system. Current experience has shown this facilitates its widespread adoption by many construction project members.

Design Review Checking System (DrChecks)

As previously mentioned, existing tools do not provide specific support for the design review process. Thus project managers have difficulty using those systems to focus easily on problem issues. Also, the absence of corporate knowledge capture and management makes the use of project resources inefficient. DrChecks, as a design review tool, is an on-line system that can improve the traditional design review process and overcome the existing deficiencies. It is clearly designed as a system to support design review tasks and, by modeling the process on-line, produces electronic processes that facilitate interactive communications among all participants. While a complete trail of all activities is kept in DrChecks database, the management levels are able to detect problem issues. Reuse of the prior design review efforts as well as lessons learned is also achievable and helps in future design developments.

Promoting a Design Review Environment

DrChecks provides specific support to the design review process. It enables users to view, retrieve, and store digitized information

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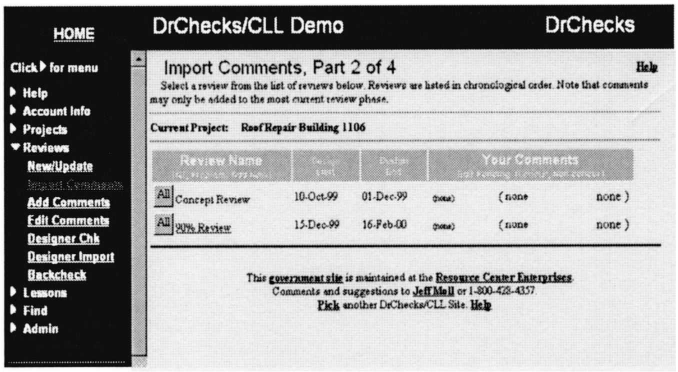


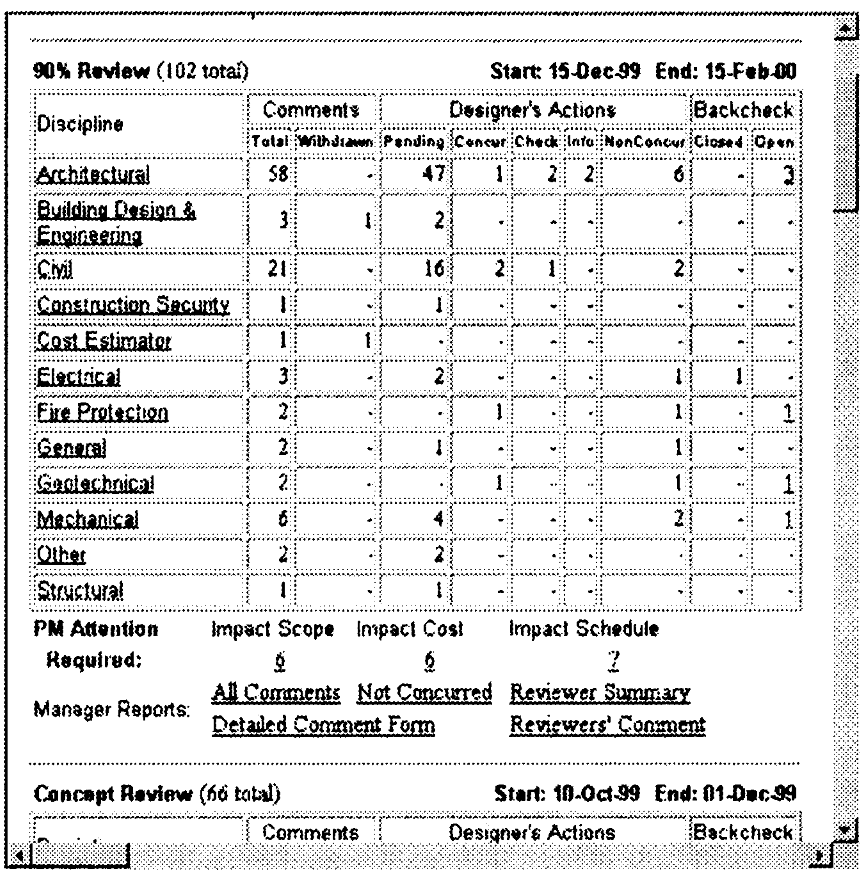
Fig. 1. Main web page for reviewer's importing review comments

from or into its on-line system. Fig. 1 shows the main web page for a reviewer to perform tasks such as importing review comments. Comments can be written or imported from users' local files, or existing comments from DrChecks can be picked and modified. Because DrChecks allows easy reuse of prior knowledge, the quality of review comments is expected to be more comprehensive and insightful. In DrChecks, review comments clearly display the comment trail of the involved parties (reviewers and designers) and certain E-mail links and telephone numbers. Therefore, it can easily promote a dialogue between designers and reviewers. Additionally, DrChecks supports a range of documents and browser-compatible files (e.g., *Word, Excel, JPEG*), which can be attached to the review comments to further clarify issues. Newly written comments can be based on comments from prior projects or lessons learned, and this feature can and does improve the overall quality of comments.

To shorten the design review time and improve the information flow between reviewers and designers, the use of project web sites, centralized database, and process automation have been adopted. In DrChecks, the traditional design review process is modeled on-line by producing a similar electronic process. During project initiation, descriptive information is entered that enhances the future ability to retrieve comments. Next, system permissions are assigned to other participants and the desired design review phases are added. Project managers can control when design review phases are open to both reviewers and designers. When review comments are entered and the review is open to designers, designers evaluate the review comments. Once a designer has completed a response to a comment, the response is highlighted in the comment creator's work area as available for back check. If the reviewer is not satisfied with designers' responses, the cycle can be repeated. Actual design reviews using DrChecks have shown that this web approach significantly speeds up the design review process. It has also been found that traditional face-to-face design review discussions can be either eliminated or significantly reduced, since most problem issues have been resolved electronically.

Fostering the Participation of all Stakeholders in the Design Review Process

The design review process is essentially distributed. Geographically, many organizations have offices in different locations that usually participate in this process. Systematically, the design re-


90% Review (102 total) Start: 15-Dec-99 End: 15-Feb-00

Discipline	Comments		Designer's Actions					Backcheck	
	Total	Withdrawn	Pending	Concur	Check	Info	NonConcur	Closed	Open
Architectural	58	-	47	1	2	2	6	-	3
Building Design & Engineering	3	1	2	-	-	-	-	-	-
Civil	21	-	16	2	1	-	2	-	-
Construction Security	1	-	1	-	-	-	-	-	-
Cost Estimator	1	1	-	-	-	-	-	-	-
Electrical	3	-	2	-	-	-	1	1	-
Fire Protection	2	-	-	1	-	-	1	-	1
General	2	-	1	-	-	-	1	-	-
Geotechnical	2	-	-	1	-	-	1	-	1
Mechanical	6	-	4	-	-	-	2	-	1
Other	2	-	2	-	-	-	-	-	-
Structural	1	-	1	-	-	-	-	-	-

PM Attention Required: Impact Scope 6 Impact Cost 6 Impact Schedule 7

Manager Reports: All Comments Not Concurred Reviewer Summary Detailed Comment Form Reviewers' Comment

Concept Review (66 total) Start: 10-Oct-99 End: 01-Dec-99

Comments Designer's Actions Backcheck

Fig. 2. Snap shot report for project managers

view process should include all stakeholders, including the client, the designers, the contractors, and the suppliers. Most of the current design review tools exclude client involvement, often because of the difficulties in collecting client feedback during design development. By providing the system on the World Wide Web, DrChecks offers opportunities for all stakeholders to participate in the project. It allows all reviewers to have equal ability to enter comments during an equal time period, and receive an equal evaluation. Remoteness of stakeholders will no longer impact the review process, and automated responses ensure comprehensive communication.

Facilitating Design Review Process Control and Establishing Benchmarks

During the design review process, review comments and communication between reviewers and designers naturally occur. The traditional design review process has no specific management mechanisms to control the information, activities, and participants. As a result, extensive efforts are needed to track and update all related documents, changes, and progress.

One strategy to tackle the issue is to keep a complete history trail along the design review process. DrChecks stores all comments and communications, summarizing all of the important records into snapshot reports. The snapshot report is one of the most useful tools in DrChecks as it displays the current status of all comments, highlights problem issues, and provides detailed management reports. Fig. 2 shows the snapshot report for a 90% review phase. Comments are listed according to their disciplines. Distribution of the comments, in terms of the number submitted, the status of the designer actions, and the comments' back check status are shown in the snapshot report. The snapshot report draws an outline of design review process so that project managers can see the overall picture. Since designers' actions are divided into five categories, a project manager can observe how the designers move items from the "pending" category to the "concur" category or other categories as shown in Fig. 2. For the nonconcurred issues, a special manager report is available, since these conflict issues may become future problems. Review comments that may impact the project scope, cost, or schedule are also grouped for special attention.

Besides designer's actions, reviewer's actions are also recorded and outputted in a Reviewer's Summary Report. The Reviewer Summary Report shows every reviewer assigned to the review and whether or not they have submitted any comments. This report helps project managers identify the delinquent participants who should have contributed but have not done so. Project managers may either use built-in E-mail links or the telephone numbers provided in the Reviewer's Summary Report to contact reluctant reviewers, with the objective of ensuring all stakeholders participation.

In DrChecks, metrics are used to focus corporate resources where they are needed in the process. For example, through an improved automated standardized review process, reviewers and designers can have instant feedback on review comments and can also expedite the conflict resolution. Later on in the review conference, project managers will be able to pay more attention on the nonconcurred comments or the ones that would have great impacts on project scope, cost, or schedule issues. Additionally, past comments can be reused to avoid duplicate comment entry or to revise technical regulations. If data mining techniques are applied, the trend of possible problems can be further recognized so as to generate preventive strategies.

Corporate Lessons Learned (CLL)

Review comments for a specific project form the knowledge repository for that single project. Some comments may occur more frequently or be of great significance. These comments, if applicable to other projects, can be refined into lessons learned or even corporate lessons learned if this concept is appropriate for the entire organization. Corporate lessons learned are very important for three reasons. First, they are very valuable for clarifying client lessons, since some project clients have very specific requirements and those requirements are embedded in a great number of documents. Second, these lessons can be the educational materials within organizations to improve the performance of newly employed engineers. Third, this information can be adopted to revise design guides and manuals so that lessons learned today will not be the lessons learned again tomorrow.

Managing Corporate Knowledge

Despite the recognized importance of corporate lessons learned, most companies still face the following three challenges:

1. Loss of information: Problems with previous approaches include lessons lost in hand-off between phases and the difficulties of sharing lessons outside the group. Because of the high turnover rate of reviewers, designers, and managers within an organization, it is very difficult to retain individual's lessons learned as corporate lessons learned. Another problem area is that lessons learned typically reside only with the experienced individuals. In large-scale organizations, with a large number of professionals, difficulties exist in capturing this diverse expertise.
   To achieve the goal of sharing knowledge-intensive lessons learned, some basic problems of the design review need to be overcome. For example, any system that captures knowledge must support diverse business processes, such as line and staff operations, and extract similar elements to maintain a standardized knowledge-sharing platform. The indexing of items is widely used to identify specific items and is the most important and common method to retrieve lessons learned. A good indexing system that includes project characteristics allows easy cross-referencing at each phase of the design and construction process;
2. Knowledge management: There is a need to eliminate knowledge-management bottlenecks so as speed up the capture and validation of good working practices and successful experiences. The more focused a piece of information is, the more difficult it is to convey the generalized component of the knowledge to others. Thus, one feasible solution is to provide design review participants the opportunity to upgrade their review comments into possible lessons learned within the review process. If a spontaneous capturing mechanism is utilized, it will not impact the design review process. After the capture of potential new lessons learned, the validation can be accomplished by designated experts; and
3. Sharing lessons learned: In the past, knowledge has been viewed not only as a tool but also as an in-house proprietary information. In fact, this impression exists between personnel in other business areas as well, especially when there is keen competition and when the competition is a zero-sum game, meaning that the benefits are not dividable and only one party can reap all the benefits. However, this is not the case in the design review process where the main team purpose is to improve the design quality so as to deliver good documents for clients' use during the construction phase. The

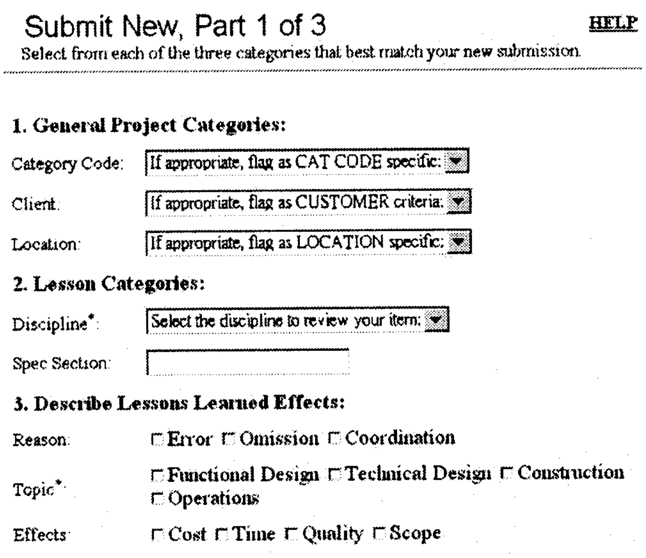


Fig. 3. Submission of new lesson learned in DrChecks

design review process should be a very cooperative process among all participants; there is no need to conceal good working experiences. The concept of sharing corporate lessons learned with customers and clients can be a critical key to business success.

In addition to the above challenges, tracking the use and benefits of lessons learned is also important. The feedback from the actual applications of the lessons learned will support the need to improve the quality of the lessons learned knowledge base.

Capturing Corporate Lessons Learned

Though DrChecks improves the communication quality and expedites the design review process, it does not nor cannot support the corporate lessons learned concept as a stand-alone system. A separate system CLL has been designed to support the capturing and managing of lessons learned. The first application linked to CLL was DrChecks. CLL can help users distill high-quality comments for future benefits. CLL was designed to allow the establishment of links with other software systems. Increased benefits are to be expected when many applications that deal with the facility delivery process are linked with CLL. This is the long-term goal of the Corps of Engineers. For example, lessons learned entered by postoccupancy inspections or the construction bidding process would be very useful during design review.

CLL is composed of four main activities: capturing, validating, sharing, and updating potential lessons learned. Lessons learned can be defined as knowledge or understanding gained by past experiences, good work practices, or innovative approaches. Under the tenet that similar problems have similar solutions and that problems will recur, lessons learned become very significant because they may be applicable to other projects. Most participants who take part in the four activities are designers, reviewers, program managers, clients/owners, and facility operators. Reviewers in DrChecks are the key participants in CLL, as they can submit potential lessons learned when adding new review comments.

Fig. 3 shows the first web page used by design reviewers to submit potential lessons learned in DrChecks. Alternatively, participants can submit lessons learned directly in CLL, outside DrChecks. In DrChecks, reviewers and clients can flag comments as potential lessons learned and they are given the opportunities to offer recommended solutions. This approach allows a spontaneous lessons learned capturing mechanism while people are doing their routine works (in this case: design review). Clearly, this approach eliminates the knowledge-acquisition bottlenecks. In addition, the problem of capturing dispersed expertise is also eliminated because potential lessons learned can be captured from all participants in the design review process.

When a new lesson is part of a design review, context information, such as project type, client, location, and discipline, is used as indexing items. Describing the effects of the new lesson forms another indexing item, which represents an important characteristic of potential lessons learned. In CLL, three description fields are identified to describe the lesson effects. The first description is the reason to submit a new lesson, which is predefined as an error, an omission, or a coordination issue. The second description is the topic of the submitted lesson, such as functional design, technical design, construction, or operation. In the third description, the writer of a lesson learned needs to define which effects are expected (e.g., cost, time, quality, or scope). Therefore, when review comments or good work stories are stored into CLL, metadata, these indexing items, can be used to classify data and retrieve information.

When a potential lesson learned is submitted, all designated participants are notified by an automatic E-mail system. Automatic E-mail keeps CLL users informed of the status of the review and approval process without having to log in and out of a separate system to check the status. Participants in the validation process include a list of experts in domain topics responsible for reviewing the submitted potential lessons learned. They may approve, deny, reassign the submission, or request backup from the writer for a given submission. Within 30 days, the validation from the experts will be completed and an automatic E-mail notification of the decision is sent to the writer. If a potential lesson learned is approved, it will be available for retrieval in both CLL and DrChecks.

Sharing lessons learned among the participants is fostered by CLL. The indexing items, such as keywords, writers, disciplines, customers, locations, and other criteria, are used to quickly and precisely identify and retrieve approved lessons learned. Reviewers can automatically create new comments by selecting and editing previous related lessons from CLL. In this way, not only traditional project-based learning models can be upgraded to corporate learning mode, but it will allow small businesses to expand knowledge capacity by partnering and sharing lessons learned from others.

Case Studies

DrChecks and CLL are provided as a service by the Engineering Research and Development Center's Construction Engineering Research Laboratory (CERL). It is now used throughout the Corps of Engineers, Department of State's Office of Foreign Building Operations and U.S. Navy on a variety of project types such as hospitals, administration building, barracks, training facilities, as well as on some civil works like flood control structures. DrChecks/CLL can be applied to other commercial types of projects and it can also be adopted by other industry entities as long as the responsibility of review task can be clearly and adequately assigned.

As of February 9, 2001, there were 1,918 users in nine Corps districts in the United States using DrChecks on 270 projects,

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which had produced 42,605 design review comments. As of then, 139 potential lessons learned were submitted to CLL, and 88 of the 139 were approved as lessons learned. All the potential lessons learned are saved in a central Access Database repository for DrChecks/CLL as maintained on the DrChecks website, and each of them is recorded based on a number of attributes. For example, one potential lesson learned for the mechanical discipline is "independent building commissioning requirement" (which emphasizes the omission in the guide specification for Commissioning of the HVAC) systems. In the database, the solution field is recorded with the suggestion of extending current guide specifications to include an independent and qualified agency to commission the HVAC system. Automatic routing of potential lessons for vetting by a preidentified subject matter expert utilizes the succeeding lesson approval process. If this expert agrees that the submission does constitute a lesson learned that has reuse capability, he (or she) can approve it and make it available for reuse. This review process effectively limits the creation to only those items that are appropriately lessons learned. After being approved by the assigned expert, the potential lesson learned is labeled "yes" under the attribute field "approved" in the database.

For economic evaluation, several analyses were conducted by the Pertan Group (2001, 2002) on the effect of DrChecks and CLL systems. For example, by using DrChecks it was found that for the Alaska district, both the number of people that had to be involved in a design review meeting and the meeting length were reduced, resulting in a significant savings of $1,706,400 per year with the expected savings to investment ratio greater than 600. Besides, using DrChecks for design review could save the entire Corps of Engineers $30.7 million a year as an extended savings. It was also found that the potential savings from the reuse of 29 lessons in DrChecks/CLL for the developing Corps of Engineers district was $3 million. Enterprise wide, these lessons learned are expected to product a cost savings of $53 million over the same five-year period. Experience has shown that only a very small portion of design comments are ultimately approved as lessons that can be reused, but the payoffs from these lessons are quite high. Regarding the time issue, a independent review of the impact of DrChecks on the Department of State design review process indicated that the historical four weeks period to conduct a design review could be reduced by one week for each review. DrChecks also allowed in-house design commentors to delete 20% of design comments before submission to the designer for action. All these findings triangulate well with the findings from the study of Alaska district evaluation.

Meanwhile, in order to get user feedback and explore desired future directions of the DrChecks/CLL system, an on-line survey was collected from 58 users where most respondents are project managers, designers, or reviewers. The 1-to-5 ratings were used as ordinal levels of measurement for system improvement evaluation, where "1" represents no improvement and "5" the greatest improvement. The survey covered the overall opinion of the systems, the scale of "communication" improvement after using DrChecks in the design review process, and the "usefulness" improvement of using DrChecks compared with other communication approaches. Some characteristics of the system, such as the usefulness of its managerial reports, the swiftness of resolving problematic comments, and the applicability of past review comments, were also included in the evaluation. Other characteristics, such as the improved function of the design review process after using DrChecks/CLL and add-on features of the systems for future development, could be selected by the user for evaluation.

In general, positive results were collected from the survey, and the overall improvement evaluation for DrChecks/CLL systems located between Levels 3 and 4 (the average is 3.75), which indicated a desirable level of improvement assessment. Through the survey, DrChecks is identified to be the most useful tool for design review process if compared with other approaches. One user said, "The DrChecks review comment function has been great. We can easily access and respond to comments. It reduces our time in responding and allows for more accurate tracking." The most improved part in the design review process, according to the survey, is the quick response from other parties on review comments. This quick response can allow other improvements to be made more quickly, thus allowing other benefits that a design review process can deliver to also improve, such as owner satisfaction, sound professional practice, and code compliance. However, the life-cycle engineering and postoccupancy evaluation have no distinct advancements, and these may be included in the add-on features in the system to strengthen their functions. Two add-on features, the integration with other systems and the expanded capabilities to retrieve lessons learned, were selected by most users and should be given fair consideration in future developments. The complete results as well as the outlines of on-line survey are summarized in Table 3.

Conclusions

Conceptual planning and design are the initial phases in the implementation of a new construction project. The multidisciplinary characteristic of construction projects makes it necessary to include in these earliest stages representatives of varied domain-specific backgrounds. They work in a coordinated and collaborative way, sharing data, information, experiences, and knowledge to produce the final design for a specific project. Decisions made during these initial phases will have a greater influence on a project's ultimate quality, cost, and schedule than decisions made later in the project life cycle. The conceptual planning and design phases should therefore be the stages when the review of design is most intense, with the primary focus upon ensuring the appropriateness, accuracy, and thoroughness of the owner's expectations regarding facilities performance. As the complexity of construction projects increases, making design decisions becomes more interdependent, and design reviews become crucial to the success of construction projects.

DrChecks provides a framework for the development of an improved standardized design review process. The system promotes the participation of all project stakeholders during this process, enabling managers to quickly find design problem issues and resolve them. Metrics on the design process can be established, which will allow corporations to place resources where needed. The CLL system facilitates the incorporation of individual's unique project learning into corporate knowledge. In this corporate learning approach, personal experience is extracted directly during design activities. Lessons learned, success stories, and good work practices, which can easily be identified by experienced staff members, can then be shared throughout the organization for current and future projects.

The increased adoption by U.S. Army Corps of Engineers districts and the positive results of the evaluation survey demonstrate the success of the implementation of both systems. The use of DrChecks and CLL by other federal agencies and by private firms is growing. To improve the function and expand their capabilities of DrChecks and CLL, the Construction Engineering Research Laboratory is developing new features and supporting new research.

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Table 3. DrChecks/CLL Improvement Survey Results from 58 Users

	Please rate the following questions from a scale 1–5 (1: no improvement, 5: the greatest improvement)	Average	Standard deviation	90% CI
Question 1	Overall Evaluation for DrChecks/CLL system	3.75	0.90	3.32–4.17
Question 2	Communication Improvement	3.66	0.86	3.25–4.07
Question 3	Usefulness for design review process	—	—	—
Question 3a	DrChecks	3.86	1.01	3.39–4.34
Question 3b	E-mail	3.71	0.85	3.31–4.12
Question 3c	Telephone/fax	3.32	0.97	2.86–3.78
Question 3d	Paper documents	2.90	0.92	2.46–3.34
Question 3e	Face-to-face talk	4.12	1.12	3.59–4.65
Question 4	Scale of improvement after using DrChecks/CLL	—	—	—
Question 4a	Save travel time. No need for face-to-face meeting	3.42	1.21	2.85–4.00
Question 4b	Save oral communication time	3.56	0.88	3.14–3.98
Question 4c	Quick response from other parties on review comment issues	3.75	1.09	3.23–4.26
Question 4d	Design quality is improved if compared with traditional design review process	3.39	0.91	2.96–3.82
Question 5	Usefulness of managerial reports provided in DrChecks	3.42	1.18	2.86–3.98
Question 6	Swiftness of resolving problematic design review comments	3.42	0.97	2.96–3.88
Question 7	Applicability of past review comments to your projects	3.44	0.91	3.01–3.88
Question 8	Level of ease to use DrChecks/CLL system	3.69	1.16	3.14–4.25
Question 9	Please rate the functions of the design review process that were improved by using DrChecks/CLL	—	—	—
Question 9a	Owner satisfaction	3.32	0.95	2.87–3.78
Question 9b	Sound professional practice	3.49	0.94	3.05–3.94
Question 9c	Code compliance	3.39	0.89	2.97–3.81
Question 9d	Architectural statement	3.07	0.85	2.67–3.47
Question 9e	Value engineering	3.02	0.90	2.59–3.44
Question 9f	Value engineering	3.22	0.89	2.80–3.64
Question 9g	Constructability	3.31	0.93	2.86–3.75
Question 9h	Operability	3.24	0.84	2.84–3.63
Question 9i	Maintainability	3.19	0.88	2.77–3.60
Question 9j	Life-cycle engineering	2.97	0.87	2.55–3.38
Question 9k	Postoccupancy evaluation	2.78	0.89	2.36–3.20

Future Directions

The DrChecks/CLL effort is continuously evolving. The U.S. Army Corps of Engineers plans to extend the web-based work environment for DrChecks/CLL to include other aspects of the facility delivery process:

- National Criteria Management System (NCMS): Criteria management is being added to the U.S. Army Corps of Engineers delivery process. Whenever a corporate lesson learned is submitted, a copy of the comment is sent to a criteria point of contact. If it appears to have an impact on criteria, it can be forwarded to a national criteria expert for that specific topic for action,
- Requests for Information (RFIs): During the bidding process, contractors often request additional information. The U.S. Army Corps of Engineers must manage these requests in a timely manner and if appropriate pass information to all bidders so no competitive advantage is developed. A web-based RFI submission, response, and management system is being developed, and
- Postoccupancy inspection: Identification and resolution of these issues will also be addressed by a web-based system.

Our long-term plans are to capture and effectively reuse the information generated throughout the facility delivery process with a suite of design quality products. DrChecks will address the design review process, the RFIs during the construction bidding process, and the NCMS criteria management. CLL will provide the method for users of each of these systems to obtain appropriate lessons generated by other suite users. For example, RFIs lessons dealing with clarifications of design intent should be used by designers to change details or specifications. These lessons would then be used to eliminate future RFIs issues.

New research initiatives focus on the identification of metrics to assess the design review process, the creation of on-line project databases to store and retrieve construction documents, the development of expanded capabilities to retrieve lessons learned, the analysis of workflow to improve information access and distribution during design reviews, and the integration with design coordination tools.

We envision the possibility of linking DrChecks/CLL with existing design coordination tools based on three-dimensional/four-dimensional (3D/4D) computer-aided design (3D/4D CAD). 3D/4D CAD tools would focus on physical interfaces and issues. Lessons learned could be retrieved using more advanced techniques, like case-based reasoning, data mining, and knowledge discovery in databases would be used to generate knowledge from the lessons stored in the databases. Knowledge generated would be distributed to all stakeholders, facilitating its reuse in future processes and projects.

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