ACQUISITION AND DISSEMINATION OF BEST PRACTICES FOR SUSTAINABLE BUILDING PROJECTS

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ABSTRACT

Sustainable building projects are complex and intensively knowledge-based because each project generates different lessons due to the involvement of a large number of issues and diverse stakeholders. Sustainable building design and construction suffers from a lack of knowledge about past experiences, whereas knowledge management can store past experiences that can be considered in future projects, making traditionally embedded/hidden knowledge available to all parties involved in sustainability issues. The characteristics of sustainable building projects are discussed, knowledge management models currently used in the construction industry are reviewed, and a simple "knowledge management process" is proposed that encompasses acquisition, storage, update, and dissemination of knowledge. A prototype web-based best practices database system is developed and populated by information about buildings designed with sustainable principles. It is observed that problems are experienced in sustainable design and construction when (1) sustainability-related decisions are not made as early in the design phase as possible; (2) issues are encountered with respect to choices relative to indoor environmental quality and energy performance technologies, and the selection of sustainable materials; and (3) decision-makers do not make use of lessons learned in previous experiences. The best practices system is of relevance to researchers since it is an original initiative in this field, and can be of benefit to practitioners who have limited experience in sustainable design and construction.

Keywords: *Knowledge management, lessons learned system, best practices, sustainable building*

1 INTRODUCTION

Knowledge management is seen as a key factor of economic competitiveness and successful business performance in the building design and construction industry (Carrillo et al., 2000; Kamara et al., 2002a; Egbu and Robinson, 2005), but more so in sustainable building design and construction because sustainable building projects have different and more complex features than ordinary building projects. Efficient knowledge management in sustainable projects should provide designers and construction engineers the opportunity to adopt past experiences and apply them to future projects, making the traditionally embedded/hidden knowledge available to all parties in the design and construction process, hence disseminating the knowledge freely across the organization. Sustainable building projects should benefit a great deal from efficient knowledge management as the design and construction of sustainable building projects would improve significantly.

Because the use of sustainability principles is rather recent in building design and construction, the industry suffers from limited knowledge in sustainability issues, and lacks the ability to manage the little existing knowledge effectively. One of the greatest barriers that prevent the construction industry from implementing sustainable strategies is a lack of adequate knowledge (Egan, 2004; Fischer, 2010; EPA, 2012). According to Egan (2004), this lack of knowledge arises because: (1) experiences on sustainable practices are still at a nascent phase of development, as most projects have been implemented only over the last 20 years; (2) the design and construction community is unwilling to change the conventional way of design and construction processes, whereas sustainable building processes are more complex and require updated knowledge; and (3) the design and construction community does not have access to a source of knowledge about best practices in sustainable building design and construction. It is therefore clear that there is a need for a "lessons learned" approach that is capable of acquiring, storing and disseminating this kind of knowledge. However, a review of the existing literature indicates that such efficient lessons learned system does not exist.

The objective of this research is to develop a knowledge management model based on best practices for sustainable building projects. To that end, this research focuses firstly on the requirements in sustainable building projects and the challenges encountered in designing and constructing sustainable buildings. Second, the research examines knowledge management in the construction industry. In this regard, the techniques used for supporting the knowledge management process are examined, and the existing models are extracted from the literature and briefly discussed in terms of their strengths and weaknesses. Last but not least, a "best practices" system is designed that allows the acquisition, storage, dissemination and update of knowledge pertaining to sustainable project experiences.

2 SUSTAINABLE BUILDING PROJECTS

Sustainable construction involves building and managing a built environment with ecological principles and optimizing resource efficiency (Kibert, 1994; Pearce, 2006). According to Kibert (2005), resource efficiency covers highly efficient use of energy and water, use of land resources, use of environmentally friendly materials, and minimization of life-cycle effects of buildings on the environment. Sustainable buildings should have not only a balance among project objectives (cost, time, and quality), but also a balance among sustainability dimensions (environment, society, and economy) (Lopez and Sanchez, 2011).

Especially in the last decade, sustainable building activity has seen dramatic growth. In this process, the sustainable building industry has experienced successes and failures (Robichaud and Anantatmula, 2011). Because of the fact that these experiences are new and not universally known, the industry has a major challenge in tracking this information and in expanding knowledge. As a result, organizations are forced to apply sustainable principles with only limited knowledge. Given the slow and minute accumulation of knowledge in sustainable practices since the start of the sustainability movement, real opportunities exist to acquire, store, and disseminate relevant knowledge required for producing efficient solutions in sustainable building projects. Hence, this research claims that a "best practices" system can be of great help to the sustainable building design and construction industry.

The intensive use of knowledge is quite effective in enhancing the sustainability of buildings (Horvath and Matthews, 2004; Chong and et al., 2009). Knowledge about optimizing energy performance, enhancing indoor environmental quality, protecting and conserving water, reducing environmental impacts of materials, etc. require consideration at all stages of the process, as from pre-planning to design, construction, operation, maintenance, renovation, and demolition (Wu and Low, 2010). Hence, there is a significant need for practical knowledge-based approaches in order to cope with this complexity (Mateus and Bragança, 2011).

Government agencies and mainstream companies have tried to define the problems concerning the sustainable built environment, and develop strategies and technologies in order to plan, design, construct and operate sustainable buildings. The majority of sustainable building policies and programs are conducted according to building assessment systems such as LEED (U.S. Green Building Council's Green Design Rating System), BREEAM (a rating system in the U.K.), and GBTool (an international green metric and benchmark system) (Adler et al., 2006; Retzlaff, 2008). In general, these systems focus on energy efficiency, water conservation, site selection, building materials, waste management, indoor environmental quality, and education. However, challenges to sustainable building continue to exist, including the ability to pre-plan, design, construct, and operate/maintain a building within acceptable sustainable principles. At the same time, all of these efforts have pushed professionals to recognize the value of the experiences gained and have created the need for the systematic dissemination of knowledge in this field.

The U.S. Federal government and other partners including non-profit, non-government organizations, such as the U.S. Green Building Council (USGBC), the National Institute of Building Sciences (NIBS), etc., have commissioned analyses and reports for a sustainable built environment (USGBC, 2006; USGBC, 2012; NIBS, 2012). Especially with the Energy Policy Act of 2005, the U.S. Federal, state, and local governments have provided incentives for high performance sustainable buildings (U.S. DOE, 2012; U.S. GSA, 2012; NIBS, 2012; WBDG, 2012). These studies show that the experiences gained from sustainable building practices offer a significant opportunity for acquiring and disseminating knowledge.

3 KNOWLEDGE MANAGEMENT

The knowledge accumulated in a firm is viewed in the management literature as a powerful and sustainable competitive advantage (Davenport and Prusak, 1998; O'Dell and Grayson, 1998). Davenport and Prusak (1998) state, "the only sustainable advantage a firm has comes from what it collectively knows, how efficiently it uses what it knows, and how readily it acquires and uses new knowledge". If knowledge is not managed appropriately, mistakes can be repeated and opportunities can be lost, causing inevitable project delays, poor quality production, and overspending. Also, project success depends on persons moving between discrete construction projects having to update and develop their existing knowledge regularly.

Especially in the last decade, numerous researchers emphasized the importance of the acquisition and dissemination of knowledge for construction organizations, and presented models for managing knowledge. However, knowledge management is difficult to implement successfully in construction organizations due to ingrained culture and the dynamic nature of personnel movement in construction organizations. Developing a knowledge management system in sustainable building practices should be particularly challenging in an environment marked by a lack of established and widely used systems.

The most important challenge is seen as the reluctance of organizations to use knowledge management models (Carrillo et al., 2004; Anumba et al., 2005; Robinson et al., 2005; Lin et al., 2006). A study conducted by Carillo and Chinowsky (2006) on six engineering design and construction organizations revealed that project team members were unwilling to share their knowledge. This is one of the most important issues in these organizations. The most significant reasons for organizations' reluctance to using knowledge management models are a lack of trust among project team members and security of knowledge (Davenport and Prusak, 1998; Alavi and Leidner 1999; Barson et al. 2000; Egbu 2004; Ruikar et al. 2005; Tan et al. 2010). Barson et al. (2000) emphasized that organizations fear losing competitive force if they share their knowledge with individuals external to their organizations. Another important challenge is related to the nature of the construction activity, which is based on individuals' perceptions, which in turn increases the difficulty of capturing and reusing perceptions (An and Ahmad, 2010). Also, project team members are often under intense pressure because of the complex and dynamic nature, and time and budget constraints of construction projects. In addition to this intense pressure, there are several issues in managing knowledge efficiently, including an unsupportive organizational culture and time constraints (Carillo et al., 2004; Dainty et al., 2005; Serpell et al., 2010), inadequate communication (Alavi and Leidner, 1999; Dainty et al., 2005; Serpell et al., 2010), lack of ownership of knowledge (Egbu, 2004), and lack of standard processes in managing knowledge (Carillo et al., 2004; Serpell et al., 2010). Another important problem is that knowledge may remain tacit and may not disseminate if an appropriate system does not exist. The success of knowledge management depends significantly on its implementation. The literature reflects a wide range of perspectives and uses numerous terms in describing knowledge management processes. According to the works of Davenport and Prusak (1998), Robinson et al. (2001), Mertins et al. (2001), Kululanga and McCaffer (2001), Gold et al. (2001), Rollett (2003), Lin and Tserng (2003), Arditi et al. (2010), Tan et al. (2010), a successful knowledge management process depends on a good understanding of how knowledge is discovered, created, acquired, captured, discussed, converted, indexed, validated, organized, modified, adjusted, secured, updated, stored, protected, presented, maintained, shared, accessed, and applied to enhance learning and performance within an organization. The terminology used by different researchers is varied, inconsistent and duplicative. A consistent approach that reconciles these functions needs to be developed. The proposed knowledge management process is composed of four main stages that are necessary for complete knowledge management implementation as illustrated in Figure 1. These stages are explained in the following paragraphs.

3.1 Knowledge Acquisition

As illustrated in Figure 1, the essence of knowledge acquisition involves what is to be discovered and created, and how it can best be captured. Knowledge capture consists of discovering and creating knowledge (Tan et al., 2010). Knowledge discovery focuses on finding embedded knowledge residing inside people, projects, practices and organizations. It involves exploring sources that include lessons learned from experiences, benchmarking best projects, monitoring technological developments or innovations, collaborating with other organizations, establishing knowledge links with partners and collecting data from clients, contractors and project team members (Morse, 2000; Klulanga and McCaffer, 2001; Park, 2007). As for knowledge creation, it focuses not only on the past and current knowledge, but also on new knowledge (Bouthiller and Shearer, 2002). The proposed system aims to acquire knowledge by extracting it from practitioners with experience in sustainable projects and to serve all practitioners in the industry.

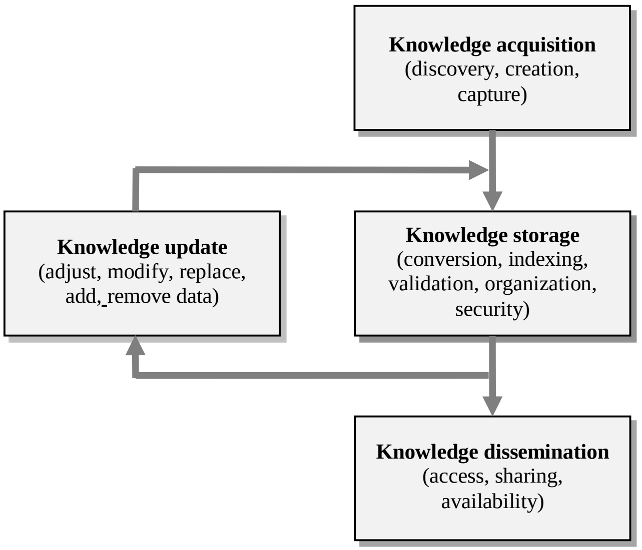


Figure 1. The Proposed Stages for Knowledge Management Process

3.2 Knowledge Storage

This component is the backbone of the knowledge management process because it allows the developer to save knowledge and it allows the user to retrieve knowledge. Knowledge storage requires a broad range of activities, including conversion, indexing, validation, organization, and security. Knowledge conversion involves converting the acquired knowledge into an accessible and usable format. Knowledge indexing refers to codifying knowledge with respect to its type and domain, hence facilitating recording, storing, and accessing the knowledge in the system in a short time and easily.

Knowledge validation involves reviewing, verifying for correctness and completeness, correcting, and clarifying the knowledge acquired (Kamara et al., 2003; Tan et al., 2010). Knowledge organization refers to systematizing validated knowledge by placing it properly into the system in order to make it easily accessible and searchable in a rational way. Security of knowledge refers to protecting the knowledge within an organization from illegal or inappropriate use or theft by closely monitoring who accesses the knowledge in the system (Gold et al., 2001). The proposed system described later in detail uses a simple database that requires negligible conversion, a simple indexing system, and an administrative mechanism to validate and secure the knowledge acquired.

3.3 Knowledge Dissemination

Knowledge dissemination consists of accessing and sharing the knowledge stored in the system. Egbu et al., (2005) point out that the main impediments in knowledge dissemination are lack of time, lack of communication skills, and rapid change in information technologies. Making the knowledge easily accessible and usable are therefore two important issues in dissemination. The proposed system is a simple database that is open to the design and construction community.

3.4 Knowledge Update

Knowledge should be continuously updated because knowledge is significantly affected by rapid changes (Rollett, 2003; Tan et al., 2010). The knowledge in the storage system should be revised periodically in order to keep it current. Updating involves adjusting, modifying, replacing, adding, and removing data. The proposed system that is described later in detail comes with an administrative mechanism that regulates the removal of out-of-date information, the inclusion of up-to-date information, and the revision of the existing information.

Some of the existing knowledge management models developed for construction projects and cited in the literature were examined in terms of their description, strengths, and weaknesses, namely CAPRIKON-Capri.Net (Udeaja et al., 2008; Tan et al., 2010; CAPRIKON, 2010), C-SanD (C-SanD, 2001; Shelbourn et al., 2006), B-Hive (B-Hive, 2001), CLEVER (CLEVER, 1999; Kamara et al., 2002b), IMPaKT (Carrillo et al., 2003; Robinson et al., 2004; KnowBiz, 2003), e-COGNOS (Whetherill et al., 2002; Lima et al., 2005), MBKM (Lin et al., 2006). The most important strength of these seven models is that they are quite good in identifying and acquiring knowledge. However, six weaknesses were identified as critical issues in effectively implementing knowledge management in practice. They are listed below in order of their frequency of appearance in the studied models.

1. The models require considerable effort and time for implementing them. Especially the time constraint has been the main deterrent for their adoption and implementation.
2. The use of the models is not simple and easy for users. The adoption of a system depends a great deal on how user-friendly it is.
3. The success of these models depends substantially on the experience of users. Thus, they are open to interpretation.
4. In most models, only few stages of the knowledge management process are considered. For example, most models focus on identifying, capturing and recording knowledge in a storage system, and the dissemination and update of knowledge are often left out.
5. The implementation of the models depends mostly on software applications that may be costly (e.g., annual licensing fees, and training fees).
6. A web-based infrastructure complicates ensuring security of knowledge, and protection against the use of the knowledge by undesired individuals.

A number of lessons learned systems have been developed in recent years with potential implementation in construction, namely DRChecks (East and Fu, 1996; Soibelman et al., 2003), KyTC Lessons Learned Database (Goodrum et al., 2003), IKIS (Kartam, 1996), COML2 (Vanegas and Nguyen, 1997), CLLD (Kartam, 1996), OKBANK (Nguyen et al., 1998), and CMAID (Arditi et al., 2010). They all make use of the principles put forward in the development of knowledge management models. The review of these seven lessons learned systems indicates that most of them focus on construction organizations. These lessons learned systems are not aimed at sustainable building design and construction. They suffer from similar weaknesses as the knowledge management models discussed earlier.

1. These systems do not cover all phases of the project life cycle. They focus on either the design or the construction phase of a project.
2. The success of the implementation of these systems depends to a great extent on the automation technologies that support the infrastructure of these systems.
3. These systems have complex operating systems, requiring significant time, cost, and expertise to implement them.

In essence, it can be said that a lessons learned system involves a systematic method that focuses on all phases of the knowledge management process and on all phases of the life cycle of a project. This means that a lessons learned system must have an efficient, easy to use, and economical mechanism to acquire and store best practices acquired in all phases of a project in order to use them whenever needed. A lessons learned system could be based on not only a database-supported software tool, but also on more sophisticated and advanced technologies that facilitate the use of the system and motivate users to use the system. In this way, it is possible that the flow of knowledge from project to project can be achieved.

4 PROPOSED BEST PRACTICES DATABASE SYSTEM

A web-based best practices database system is proposed as a method for acquiring, storing, updating, and disseminating knowledge about sustainable buildings. This system is to serve all designers and constructors involved in sustainable building projects. The system architecture of this database system is as follows:

4.1 Design Criteria

The design criteria used in developing the system are presented below in terms of accessibility, versatility, scalability, sustainability, and usability.

Accessibility: An important problem for many organizations is the inconsistent storage of data, whereby members of an organization who need a piece of information do not know where this information is stored. The proposed web-based best practices system makes the information widely available to all interested parties and allows it to be easily updated, since the knowledge resides in one central receptacle.

Versatility: The proposed system accepts multiple data formats and should help increase the system's longevity. All documents are stored in a virtual warehouse, and the text and drawings can be searched by unstructured processes. The system is fast and efficient.

Scalability: The system is scalable, i.e., a user can add additional categories and structure as long as the user is familiar with Google Sites, which is quite user-friendly. No website programming knowledge is necessary.

Sustainability: The proposed system does not require excessive input of manpower, time, effort and money to run. The process of inputting data into the system is efficient with minimal resource requirement. The benefits to be gained from the output are significant.

Usability: The proposed system is as simple and user-friendly as possible while still being effective. An independent administrator reviews the best practices and audits the system periodically. The administrator's responsibilities include deleting irrelevant/duplicate entries; add categories or subcategories; adjust site layout; and upgrade the site with user suggestions.

4.2 Site Construction

The selection of the database interface and of the systems' name are described here. Database interface: Two of the most popular database interfaces, Microsoft Access and MySQL where compared against the option Google sites. Google Sites are found to be more accessible, user friendly, maintainable, and cost effective than the other options. MS Access proved to be difficult to program and maintain for the average person. MySQL was an advanced free database software, but not widely accessible to everybody. Google sites are designed to be easily maintained and adjusted by someone with no background in website or database programming. It offers a flexible tool that provides the programmer with various options for functionality.

Database name: Informal surveys conducted with peers showed that "Best Practices" produced a connotation that was significantly more positive than any other naming suggestion, including "Lessons Learned." This is advantageous that it allows users to feel more comfortable utilizing the tool. "Best Practices" should be considered synonymous with "Lessons Learned."

4.3 Site layout

The layout of the site involves a home page, an entry form, an archived library, a discussion forum, and a help screen. These interface pages and the search criteria used in the system are described below. Home page: The home page gives a site breakdown and links to other pages (Figure 2).

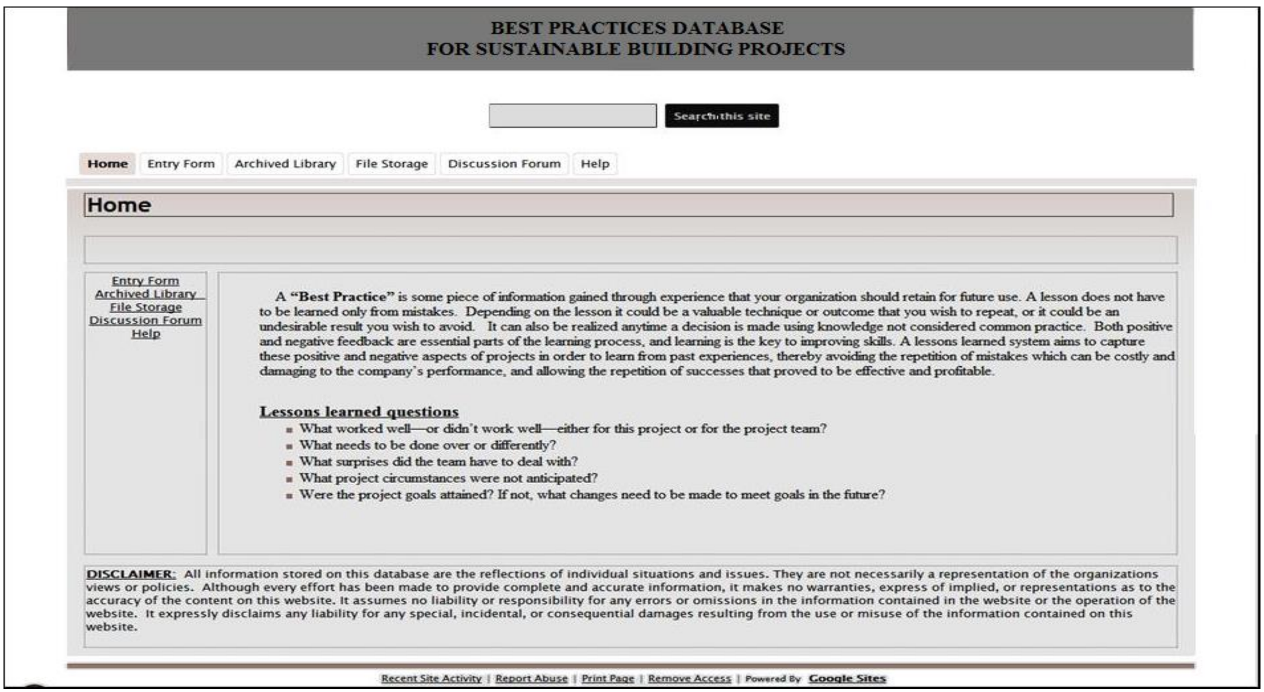


Figure 2. Home Page

It also introduces the definition and importance of best practices. "A "Best Practice" is some piece of information gained through experience that your organization should retain for future use. A lesson does not have to be learned only from mistakes. Depending on the lesson, it could be a valuable technique or outcome that you wish to repeat, or it could be an undesirable result you wish to avoid. It can also be realized anytime a decision is made using knowledge not considered common practice. Both positive and negative feedback are essential parts of the learning process, and learning is the key to improving skills. A "best practices" system aims to capture these positive and negative aspects of projects in order to learn from past experiences, thereby avoiding the repetition of mistakes which can be costly and damaging to your organization's performance, and allowing the repetition of successes that proved to be effective and profitable.

The entry form is simply a Google Docs Form that is embedded into the website. It creates a direct link to a shared Excel form and populates the cells via the form's entry fields. One of the fields asks for the solution to the issue by incorporating past experiences in the context of the problem at hand. Recommended actions are a key component to a well-defined best practice and act as a set of guidelines for the course of action chosen. The end goal is that the best practice provides the necessary context, background and recommendations that facilitate the decision-making process in the future. All data fields can be adjusted to be mandatory or optional entry. The default mandatory settings are for the main point of contact, knowledge category, and narrative fields. All are marked with an asterisk for the end-user.

Archived library: Once the entry form is submitted, the form populates the shared MS Excel file which is embedded into this site (Figure 3). This is advantageous because MS Excel files can be easily manipulated and transferred to other database systems in the future. Thus, if a different system is created, the best practices will not be lost.

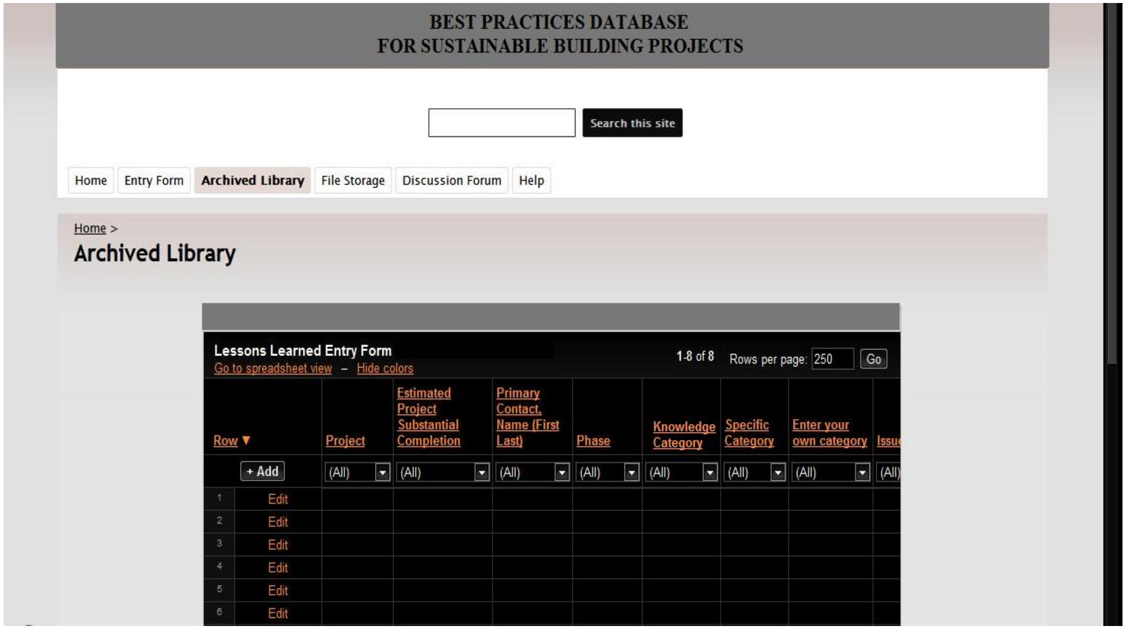


Figure 3. Archived Library

Categorization and search criteria: in order for the information to be easily accessible, keywords can be assigned to best categorize the practice for future search ability (Figure 4). The main categories and subcategories were created from the building project phases, the Project Management Body of Knowledge issued by the Project Management Institute (PMI, 2012); the Construction Management Body of Knowledge issued by the Construction Management Association of America (CMAA, 2012); and research into several organizational archives (U.S. DOE 2012; USGBC 2012; U.S. GSA 2012; NIBS 2012; WBDG 2012) concerning sustainability issues. The practices can be sorted by individual category or, the user can use the "Ctrl+F" command to "find" a particular word or phrase in the database.

File storage: The proposed best practices system accepts multiple data formats in order to help increase its longevity. The system allows users to upload files to the database that are not compatible with the entry form, such as pictures, drawings or links to other sites. A data storage site helps centralize the lessons and their accessibility.

Discussion forum: The Discussion Forum gives users an opportunity to interact through questions and answers in an open environment. Some users may use this facility to request clarifications and propose different solutions.

Help: The Help facility is used to present hints in site utilization as well as contact information to the system administrator.

Google sites, while a powerful tool, has limits to its functionality. The different options seen in this prototype display a large number of the system's capabilities. A minor limitation of the system is that the archived library is searchable only by keyword breakdowns and the "find" function (Ctrl+F).

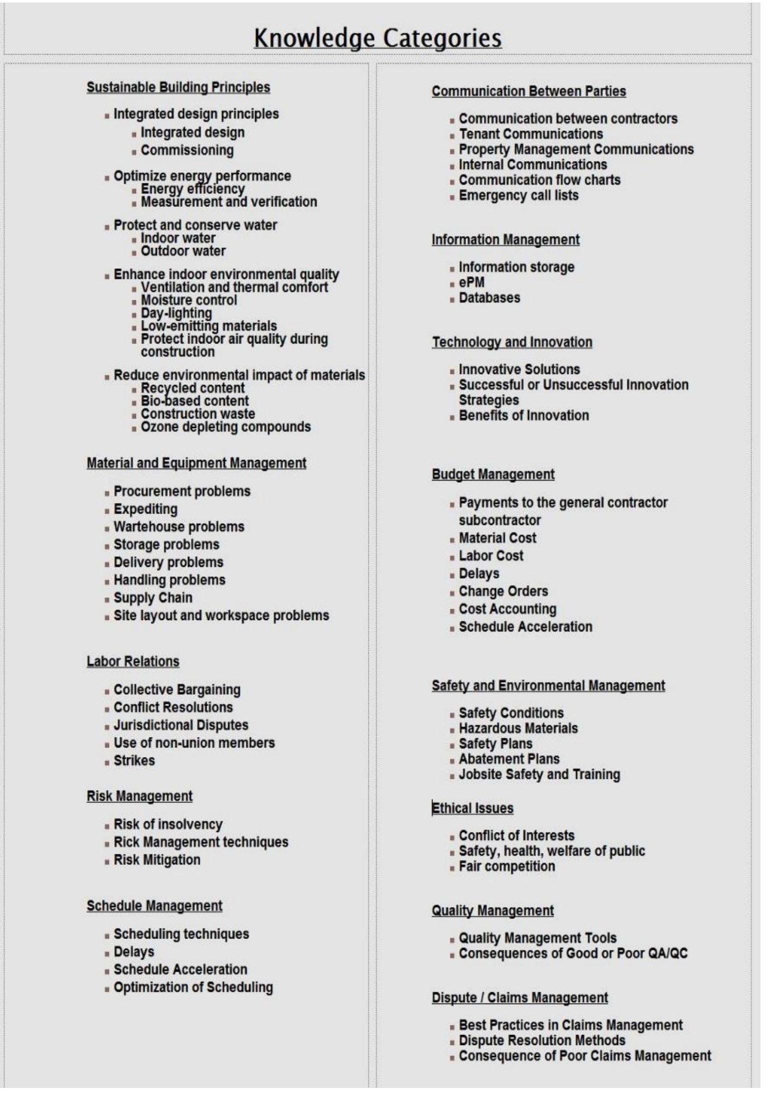
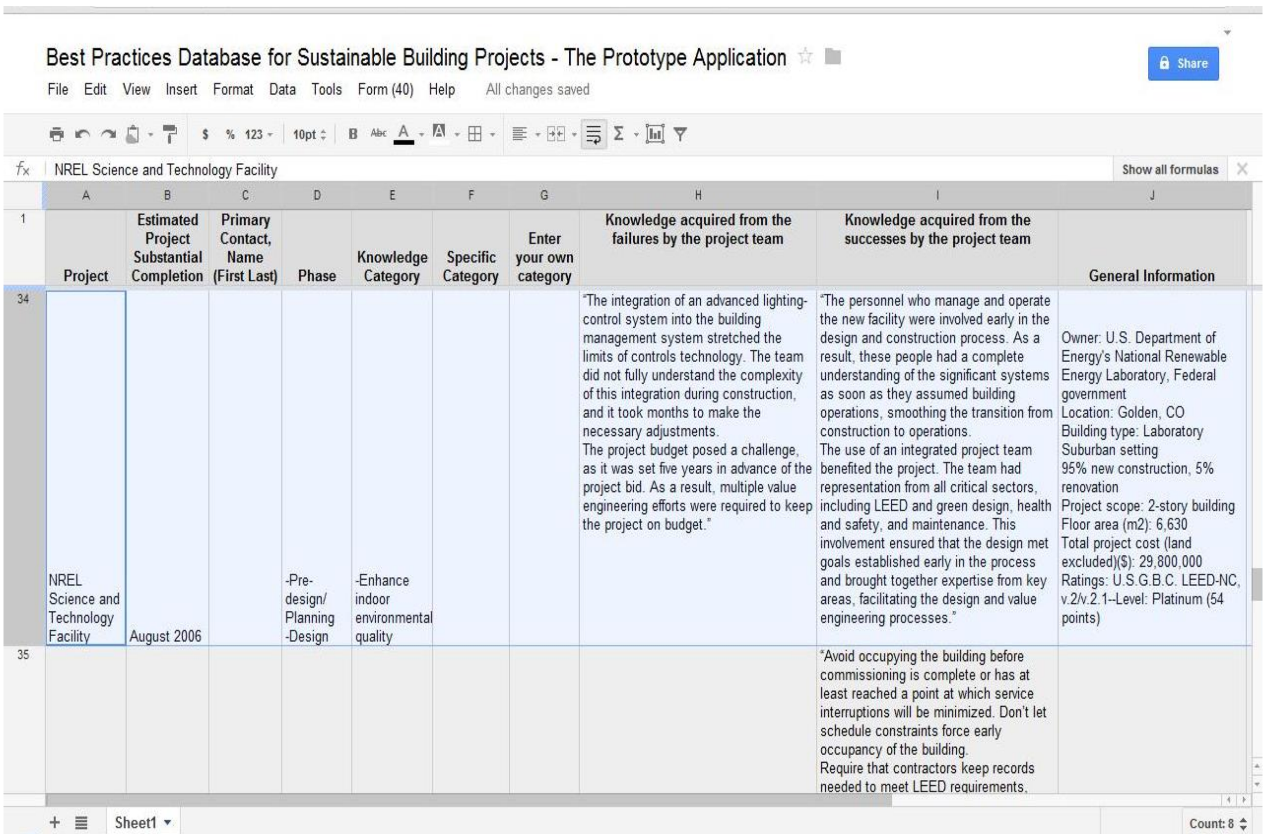


Figure 4. Knowledge Categories

5 FINDINGS AND DISCUSSION

The prototype “best practices” application was tested to check whether the system is functioning properly, including the user interfaces. The data set used to populate this prototype application was obtained from the U.S. High Performance Federal Buildings database provided by the U.S. Department of Energy's Building Technology Program (U.S. DOE, 2012). There are 61 buildings in this database, but lessons learned are reported for only 45. Hence, this study included these 45 buildings listed in Table 1. The data related to these 45 buildings were entered into the “best practices” database system using the knowledge categories presented in Figure 4. An example of the database is presented in Figure 5.


Best Practices Database for Sustainable Building Projects - The Prototype Application

File Edit View Insert Format Data Tools Form (40) Help All changes saved

fx NREL Science and Technology Facility

	Project	Estimated Project Substantial Completion	Primary Contact, Name (First Last)	Phase	Knowledge Category	Specific Category	Enter your own category	Knowledge acquired from the failures by the project team	Knowledge acquired from the successes by the project team	General Information
34	NREL Science and Technology Facility	August 2006		-Pre-design/ Planning -Design	-Enhance indoor environmental quality			“The integration of an advanced lighting-control system into the building management system stretched the limits of controls technology. The team did not fully understand the complexity of this integration during construction, and it took months to make the necessary adjustments. The project budget posed a challenge, as it was set five years in advance of the project bid. As a result, multiple value engineering efforts were required to keep the project on budget.”	“The personnel who manage and operate the new facility were involved early in the design and construction process. As a result, these people had a complete understanding of the significant systems as soon as they assumed building operations, smoothing the transition from construction to operations. The use of an integrated project team benefited the project. The team had representation from all critical sectors, including LEED and green design, health and safety, and maintenance. This involvement ensured that the design met goals established early in the process and brought together expertise from key areas, facilitating the design and value engineering processes.”	Owner: U.S. Department of Energy's National Renewable Energy Laboratory, Federal government Location: Golden, CO Building type: Laboratory Suburban setting 95% new construction, 5% renovation Project scope: 2-story building Floor area (m2): 6,630 Total project cost (land excluded)($): 29,800,000 Ratings: U.S.G.B.C. LEED-NC, v.2/v.2.1--Level: Platinum (54 points)
35									“Avoid occupying the building before commissioning is complete or has at least reached a point at which service interruptions will be minimized. Don't let schedule constraints force early occupancy of the building. Require that contractors keep records needed to meet LEED requirements,	

Sheet1 Count: 8

Figure 5. Best Practices in Sustainable Building Projects

Table 1. The U.S. High Performance Federal Buildings (U.S. DOE 2012)

Name of the building	Date	Owner	Location
NREL Solar Energy Research Facility	1993	U.S. Department of Energy	Golden, CO
Thoreau Center for Sustainability	1996	National Park Service and Thoreau Center Partners	San Francisco, CA
NREL Thermal Test Facility	1996	U.S. Department of Energy	Golden, CO
NAVFAC Building 33	1998	Naval District Washington	Washington, D.C.
U.S. EPA Region 7 Headquarters	1999	Rubicon-NGP, LLC	Kansas City, KS
Great Lakes Naval Training Center BEQ	1999	U.S. Department of Defense, Navy	Great Lakes, IL
Zion Visitor Center	2000	National Park Service/Dep. of the Interior	Springdale, UT
U.S. EPA Research Triangle Park Campus	2001	U.S. Environmental Protection Agency	Research Triangle Park, NC
Cusano Center at Tinicum	2001	U.S. Fish and Wildlife Service	Philadelphia, PA
The Louis Stokes Laboratories	2001	National Institutes of Health	Bethesda, MD
Navy Building 850	2001	U.S. Navy	Port Hueneme, CA
U.S. EPA New England Regional Lab.	2001	U.S. General Services Administration	Chelmsford, MA
U.S. EPA National Computer Center	2002	U.S. Environmental Protection Agency	Research Triangle Park, NC
Jones Federal Building and Courthouse	2002	General Services Administration,	Youngstown, OH
Caribou Weather Forecast Office (WFO)	2002	National Weather Service	Caribou, ME
Alfred A. Arraj U.S. Courthouse	2002	U.S. General Services Administration	Denver, CO
NREL Wind Site Entrance Building (SEB)	2002	U.S. Department of Energy	Golden, CO
U.S. EPA Region 7 Science and Tech. Cent.	2003	U.S. Environmental Protection Agency	Kansas City, KS
ORNL East Campus Private Development	2003	Keenan Development Associates	Oak Ridge, TN
STRI Research Station	2003	Smithsonian Tropical Research Inst.	Bocas del Toro, Panama
Scowcroft Building	2004	Cottonwood Realty Serv., LLC, Corp.	Ogden, UT
ORNL JICS Building 5100	2004	State of Tennessee, State government	Oak Ridge, TN
Personnel Support Facility (PSF)	2004	United States Navy	Virginia Beach VA
Carl T. Curtis - National Park Service	2004	Park Service Developers/ Noddle Comp.	Omaha, NE
William J. Clinton Presidential Center	2004	William J. Clinton Foundation, Corp.	Little Rock, AR
Bremerton BEQ Building 1044	2004	Naval Base Kitsap-Bremerton	Bremerton, WA
ORNL Research Support Center	2004	U.S. Department of Energy	Oak Ridge, TN
CDC Building 110	2005	Centers for Disease Control and Prevention, Division of Laboratory Sciences	Atlanta, GA
Byron G. Rogers Courthouse Renovation	2006	U.S. General Services Administration	Denver, CO
CDC Headquarters	2006	Centers for Disease Control and Preven.	Atlanta, GA
One and Two Potomac Yard	2006	Potomac Yard Holding Comp., LLC, Corp.	Arlington, VA
Annie Creek Restaurant and Gift Shop	2006	Xanterra Parks and Resorts, Corporation	Crater Lake, OR
NREL Science and Technology Facility	2006	U.S. Department of Energy's National Renewable Energy Laboratory	Golden, CO
ORNL Multiprogram Research Facility	2006	Keenan Development Associates, LLC,Corp.	Oak Ridge, TN
IRS Kansas City Campus	2006	U.S. General Services Administration	Kansas City, MO
Wayne L. Morse United States Courthouse	2006	U.S. General Services Administration	Eugene, OR
U.S. EPA Region 8 Headquarters	2007	Opus Northwest, LLC, Corporation,	Denver, CO
Craig Thomas Discovery & Visitor Center	2007	National Park Service	Moose,Wyoming
Atlantic Fleet Drill Hall No. 3	2007	U.S. Department of the Navy	Great Lakes, IL
EPA AWBERC Research Support Annex 2	2007	Environmental Protection Agency	Cincinnati, OH
Blue Ridge Parkway Destination Center	2007	Blue Ridge Parkway; National Park S.	Asheville, NC
EPA Gulf Ecology Division - CSL	2008	Environmental Protection Agency	Gulf Breeze, FL
Police and Security Operations Facility	2008	U.S. Navy	Norfolk, VA
ORNL Office Building 3156	2009	U.S. Department of Energy (DOE)	Oak Ridge, TN
John W. McCormack Building	2009	U.S. General Services Administration	Boston, MA

The following observations were made when the data were examined:

- Most sustainability-related problems were experienced in the planning and design phases. A project's sustainability goals can be attained if knowledge is acquired as early as possible. If one considers that the life cycle of a building includes planning, design, construction, operation, maintenance, renovation, and demolition, it is clear that sustainability-related decisions should be made as early in the planning/design phase as possible.
- The majority of lessons learned are on how to avoid failure and how to gain success in few knowledge areas, particularly in indoor environmental quality, energy performance, and environmental impact of materials (especially construction waste management). If one considers that the LEED certification system involves seven categories (i.e., sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design or operation, and regional priority), one can see that only the three named in the preceding sentence are the cause of most problems.
- The traditional project delivery system whereby the construction owner engages the services of a designer first, and the services of a contractor after design is substantially complete is likely to create problems in sustainable building projects. An integrated project delivery system that allows the collaboration and early involvement of stakeholders such as designers, consultants (structural, lighting, electrical, and mechanical), commissioning agents, and contractors is likely to enhance the likelihood of achieving sustainability goals in projects, because all participants in the process are actively engaged in achieving environmental performance goals. Integrated project delivery relies upon a collaborative process of a multidisciplinary team whose members make decisions based on their joint knowledge.
- Successes and failures are closely related to an organization's knowledge. Decision-makers who have access to a comprehensive and reliable best practices system are likely to avoid mistakes and promote efficient practices.

6 CONCLUSION

Sustainable building projects are of dynamic nature and involve multi-disciplinary teams. Knowledge management is difficult in sustainable building projects because of the novelty factor when compared to traditional building projects; the rapidly changing technology related to sustainable materials, methods, and practices; the complex process of coordinating the activities of many stakeholders involved in sustainability decisions; and the impact of sustainability decisions in different life cycle phases of a project. Thus, in these projects, best practices often occur as an embedded knowledge in all the stages of the project life cycle (Weber et al., 2001). Extracting this embedded knowledge from the actual practice and effectively disseminating it to professionals who will be involved in future projects requires a simple knowledge management process and a best practices database supported by a web-based approach.

Lessons learned play an important role in achieving sustainable building goals. Because lessons learned are extracted from real events, they represent proven knowledge and are likely to lead to advanced solutions in future sustainable building projects. When an organization encounters a challenge in a sustainable building project, the organization would probably know what to do and what to avoid if the organization is able to access and take advantage of lessons learned. Hence, lessons learned can be viewed as a set of best practices including a wide range of valuable knowledge that can eliminate failures, reworks and conflicts, and that can promote successes.

The most effective way of acquiring and disseminating knowledge from a broad range of stakeholders involves making use of a publicly accessible website. Therefore, in this research, a web-based best practices database is proposed. This means that the database provides not only information obtained from a broad range of stakeholders, but also allows the sharing of experiences about what needs to be done, and how to do it. Therefore, the aim of this research was to create a best practices system, a proof of concept that allows stakeholders to acquire, store, disseminate and also update best practices in sustainable building projects. This system was developed to serve all designers and constructors involved in sustainable building projects. The prototype application was populated by information about buildings designed with sustainable principles in order to benefit all parties involved in sustainable building design and construction.

In this research, knowledge management models and lessons learned systems were examined in detail, and a simple "knowledge management process" was proposed that encompasses acquisition, storage, update, and dissemination of relevant knowledge. The prototype application was populated by information about 45 Federal buildings designed with sustainable principles.

The "best practices" database system is versatile, user friendly, practical, understandable and expandable due to its very simple system architecture. In addition, it is inexpensive easy to maintain, simple, scalable, and transferable to other systems in the future. The "discussion forum" provides a communication platform for the users who want to benefit from accumulated knowledge concerning sustainable practices. Therefore, the proposed system is expected to hasten the dissemination of knowledge which can easily be acquired from sustainable practices posted by different organizations involved in sustainable projects.

An analysis of the limited data collected from 45 sustainable building projects indicated that problems are experienced when sustainability-related decisions are not made in the early phases of the project. The data also show that issues are encountered with respect to choices relative indoor environmental quality and energy performance technologies, and the selection of sustainable materials. Finally, it was found that an integrated project delivery system that allows the involvement of all stakeholders early in the project life cycle is encouraged.

Given these preliminary findings and the depth and breadth of the information in the database, it is concluded that a best practices system that is regularly updated to include experiences in new projects can be of great benefit to practitioners who have limited experience in sustainable design and construction.

Further research could investigate the improvement of the system's functions such as its "search capabilities" and "discussion forum" in order to provide a smoother operation. To maximize the benefits of this system and thereby the effective implementation of knowledge management during a sustainable project's life cycle, it would also be desirable to input more than the 45 cases currently in the prototype, as more cases become available in the future. Also, because sustainable buildings have been operational only in the recent past, not too many observations are available about the long-term performance of these buildings relative to maintenance and operation. As a result, the current system emphasizes mostly the design and construction processes. In future research, as data becomes available, the post-occupancy period should be covered too.

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