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A lessons-learned system for construction project management: a preliminary application

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Abstract

Construction companies are project-based organizations, since much of their knowledge is generated on site, from projects they carry out. In fact, projects are an important source of expert know-how and organizational knowledge, but lessons-learned from them are not systematically incorporated into subsequent projects, evidencing a lack of knowledge management and learning culture in local construction companies. This article describes a research effort that addressed this situation and developed a lessons-learned system to help construction companies to overcome these limitations. A multiple case-study methodology was applied to understand the knowledge and learning realities and needs of three Chilean construction companies. Based on these results, a mobile cloud-shared workspace to support knowledge management was developed. Results show that major concerns of users are associated with how the system acknowledges the particularities of construction projects and how it will be incorporated into daily activities. Main conclusions indicate that (1) companies acknowledge the need to develop a culture of innovation within the organization, (2) users consider the system as a tool that could really contribute to improve the construction project management process, and (3) the system needs improvements regarding database search and the Internet support before being fully implemented in the company as a project management tool.

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Keywords: construction industry; group decision support; mobile shared workspaces; cloud workspaces; loosely-coupled mobile work; design guidelines

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1. Introduction

The construction industry is a knowledge-based industry: It relies heavily on knowledge input by the different participants in a project team (Forcada, Fuertes, Gangolells, Casals, & MacArulla, 2013). In fact, as construction is a project-based industry, most of its knowledge is generated in projects (Tan, Carrillo, & Anumba, 2011). Then, capturing, sharing, and utilizing the combined knowledge of the current workforce is essential to avoid losing vital corporate knowledge assets (Caldas, Gibson, Weerasooriya, & Yohe, 2009). This means construction companies need to capitalize what it is learned in each project to continuously improve organizational performance (Almeida & Soares, 2014). But, despite the efforts made, progress in improving the learning from projects appears to be slight (Hartmann & Dorée, 2014), as organizations consistently repeat mistakes, fail to learn from projects and fail to transfer lessons from one project to another (Swan, Scarbrough, & Newell, 2010).

In this regard, construction companies need to develop techniques and use tools in their projects that facilitate the capture and sharing of lessons learned throughout the project's lifecycle (Paranagamage, Carrillo, Ruikar, & Fuller, 2012). In fact, every construction organization should have a proper lessons learned database, because using it, project team individuals can acquire and assimilate more knowledge through organizations and, further, organizations should also not rely heavily on individuals (Senaratne & Malewana, 2011). Also, many organizations in the construction industry have recognized the importance of a lesson learned program as a vital asset for knowledge management (Caldas et al., 2009). Based on this need, we envision that shared workspaces emerge as a possible solution to knowledge management within construction companies. This paper proposes a Mobile Cloud Shared Workspace (MCSW) which allows recording, representing and distributing organizational knowledge during the construction project management process. The platform intends to improve the decision-making and coordination processes among project managers, project supervisors, quality chief, operations manager and other construction professionals. This article presents the results of an evaluation of a prototype of the mobile cloud shared workspace. The next sections include a literature review on the main topics related to the study, the research methodology, and the prototype system and their evaluation by users, followed by the main conclusions of the study.

2. Lessons-learned

Lessons –learned (LL) are elements of both organizational learning and knowledge management (Carrillo, 2005). A lesson learned is defined as knowledge gained from experience, successful or otherwise, for the purpose of improving future performance (Construction Industry Institute, 2007). In this regard, having LL programs have become critical for construction companies, given the globalization of project execution, and the fact that a considerable number of employees are approaching retirement (Caldas et al., 2009). In this regard, what has motivated construction companies to conduct LLs is (Paranagamage et al., 2012): (1) to learn from similar past projects to avoid repeating mistakes, (2) to ensure that past successes are replicated in future projects, (3) to gain competitive edge over companies, (4) to avoid corporate "brain drain", and (5) to encourage innovation. About lessons recorded by construction professionals, there are three important phenomena to considered (Fong & Yip, 2006): (1) professionals sometimes record good/bad practices during the running of projects and upon their completion; (2) the frequency of recording bad practices or failures is much lower than that of recording good ones; and (3) most of the recorded good/bad practices are for individual use, but not for the team or organizational use. The leading reasons for this behavior are lack of employees' time, lack of management support, and lack of incentives, resources or guidelines (Williams, 2008).

Most Construction Industry Institute organizations that already have a LL program use a searchable, web based database with some degree of security (Construction Industry Institute, 2007). A problem with lessons-learned databases is that they are not widely used because the documents that existed tended to focus very much on what had been achieved by a project team (product knowledge) rather than how this had been achieved and/or why it either worked or did not work (process knowledge) (Newell, Bresnen, Edelman, Scarbrough, & Swan, 2006). The same authors indicated that what might be more useful is knowledge about the process since this has potentially much wider relevance across different projects (Newell et al., 2006). Even though construction companies have taking positive steps regarding lessons learned capture, the benefits of learning are not realized (Paranagamage et al., 2012).

It has been proposed that more needs to be done to not only ensure that the lessons are accessible to those who need them; but also to ensure that their validity and integrity are continually monitored (Paranagamage et al., 2012).

3. ICT in construction companies

Construction industry has been slow in adopting ICT (Information and Communication Technologies) and often technology that is available and easily accessible is not been utilized to the full extent (Ahuja, Yang, & Shankar, 2009). This happens because most construction firms are small-to-medium enterprises (SME) and, therefore, lack the budget for IT (Information Technologies) investments (Cheng & Kumar, 2012).

In contrast, currently, more construction workers use their own mobile devices while working on the job (Sage, 2012). An ICT survey indicated that 81% of construction workers use smartphone devices at the job site, 69% use laptop computers, and 26% use tablet PCs (Alliance Solutions Group, 2013). The use of mobile computing devices, such as personal digital assistants (PDAs), smartphones, and other mobile-enabled technologies, enables construction managers to input, store, process, and access project information at any location and to communicate that information to any location (Son, Park, Kim, & Chou, 2012). In fact, mobile technologies components allows for a flexible management of working process, adapted to each person (Suman, Ursic, Psunder, & Veselinovic, 2009). Also, these technologies could provide the link to workers at their point of activity so that lessons learnt as the project progress are capture immediately, then the real-time knowledge can also be incorporated in future phases of the current project (Bowden, Dorr, Thorpe, & Anumba, 2006). Several authors have proposed different mobile systems to be used in specific tasks of construction management, but most of these studies emphasize on the access to project information for very specific tasks or construction areas, such as safety or construction management on site.

Besides mobile devices, other trending information technology in construction industry is Cloud Computing (CC). Cloud computing enables businesses, particularly SMEs, to access resources from a resource pool on-demand; allowing greater flexibility and lower costs related to managing computer resources (Lin & Chen, 2012). Its services are divided into three classes (Sultan, 2014): Software as a Service (SaaS) for business-related computer programs, Infrastructure as a Service (IaaS) for almost unlimited fast processing capabilities and large storage facilities, and Platform as a service (PaaS) for tool development and hosting options for clients who prefer to create and manage their own applications. The tradeoff between these three comes down to customizability and control versus speed of deployment and ease of maintenance, being SaaS the most easily to maintain and deploy from the end user's perspective.

CC is also beneficial in enhancing information safety and security because storing data in smartphones' local storage is a hazardous practice due to their susceptibility to theft, loss, and physical damage (Sanaei, Abolfazli, Gani, & Buyya, 2014). Finally, cloud computing addresses many of the efficiencies contractors seek, including mobile accessibility, scalability, and more expansive Information Technology capabilities without massive outlays and larger long-term fixed costs (Thomas, 2012). Also, cloud computing technology provides a promising means for the adoption of IT and multi-organizational collaboration in the construction industry (Cheng & Kumar, 2012).

4. Methodology

As discussed in the previous section, several ICT systems have been proposed for the daily work of the construction companies. Nevertheless, very few of them were designed to fulfill the knowledge management need in this industry. Besides, the reason the construction industry has been slow to adopt new technologies is that they have not yet been developed to suit the needs of the industry, hence there is a strong demand pull which is yet to be satisfied (Bowden et al., 2006). This means that if a system is going to be designed and then successfully adopted to satisfy this need, it has incorporated a market pull perspective. Nevertheless, it is important to remember that innovation is never a simple matter of pull or push but rather their interaction (Bessant & Tidd, 2011). For this research, the interaction between market pull and technology push means that it is necessary to design not a generic LL system, but one that fits the specific needs and dynamics of the construction industry (pull), and do so by incorporating state of the art technologies (push).

In order to achieve this, the first step was to understand how construction companies work on-site. For that matter, we used a multiple case study approach in the first stage of the research. This included understanding how they currently manage their knowledge, and how a lessons- learned system should be to support the improvement of the management of construction projects. We chose this research strategy because we want to answer "how" questions, so they are more explanatory and likely to lead to the use of case studies (Yin, 2003). At this stage we worked with three Chilean construction companies with more than 20 years of construction experience (see Table 1). All the participating companies were medium size construction companies in geographical expansion. In each company, semi-structured interviews, direct observations, and review of documentation were conducted.

Table 1. Information about the case studies

Company	Type	Position in the company
A	Construction company	3 Project Manager, 1 Project Supervisor, 1 Quality Chief, 1 Operations Manager
B	Construction company	3 Project Manager, 1 Project Supervisor, 1 Quality Chief
C	Real estate and construction company	2 Project Manager, 3 Project Supervisor

A brief summary of the case studies results is shown next:

- None of the three companies formally document lessons. Because of this, most knowledge is on people's minds and not in the organization.
- Interviewees indicated that the lack of time during projects execution, and the lack of organizational procedures to manage knowledge are the main constraints to acquire and store knowledge.
- People expect a LL system of easy access that allow a quick data entry, and also a quick search of the required information from any location and at any time.
- Face to face contact among professionals of the same company is considered a relevant activity to share knowledge, even though just one of the companies have regular meetings among professionals.
- Finally, most respondents (81%) trust that the use of mobile technology on the field would facilitate the use of a LL system.

As a result of these case studies, we proposed the design of a Mobile Cloud Shared Workspace (MCSW) as the best approach to address the challenge of implementing a LL system in construction companies.

5. The Mobile Cloud Shared Workspace (MCSW) system

The proposed system consists of three main components. Each one of them copes with a different challenge within the implementation of a usable and useful LL system for the construction industry. First of all, as LL management is a cooperative process, we propose the system to be a Shared Workspace. These kind of tool is focused on information sharing regarding cooperative authoring, commenting, and annotating shared documents as a group activity (Chen & Kamara, 2011), even when participants are not physically in the same location. Shared workspaces aim at supporting cooperative tasks, providing users with a virtual space in which information can be shared and exchanged (Neyem, Ochoa, & Pino, 2007). In this regard, mobile shared workspaces provide the user with a partial view of the office through his/her mobile computing device giving support to mobile collaborative work (Rodríguez-Covili et al., 2011).

But geographical distribution of the people who owns the knowledge and who needs it goes further in construction companies, as construction professionals are not only in different offices, but they are mostly at construction site instead of at an office. Because of this, we propose that the shared workspace should incorporate mobile technologies, to avoid the need to rely on a stable internet connection or the presence of a laptop for knowledge sharing, using a smartphone or tablet instead. Moreover, apart from providing ubiquity, mobile devices are capable of easily capture multimedia, which enriches the process of knowledge sharing. Mobile devices offer a wide range of advantages for a LL system, but also an important limitation: Their storage and processing capabilities are small. As the amount of information will constantly grow in a LL system and it would not be possible to store all of it within the smartphone or tablet, it becomes necessary to add a third component to the system as a whole.

This third component emerges when we consider a computing model called Mobile Cloud Computing (MCC), where both the data storage and data processing may happen outside of the mobile device if necessary, specifically in the cloud (Dinh, Lee, Niyato, & Wang, 2013). Instead of Cloud Computing, other option was to use typical web architecture, but we found that the Cloud Computing approach is more attractive to the construction industries because it is seen by them as an investment that fit their long term needs. For example, CC offers some advantages by allowing users to use different kind of modalities provided by cloud providers at low cost (IaaS, PaaS and SaaS, as previously discussed). This allows construction companies to outsource the servers' installation, security and management to reliable providers, so construction companies can focus solely on their core business. Besides, the cloud offers superior storage and processing capabilities, as well as flexibility to use it or not, which would allow to take the LL management to the next level. For example, the cloud offers the possibility of easily raising the processing capabilities on-demand, making feasible in the near future to not only store large volumes of information, but also processing it and analyze it within a reasonable amount of time. All of this could be done with a traditional server architecture, but it would mean larger and slower efforts in installation, configuration and maintenance of the servers. Besides, these efforts would have to be done by the company itself. Using CC instead, the increasing of the storage and processing capabilities is transparent for the company, because they would access the application as Software as a Service (SaaS), similarly as they could access services like Google Apps or Microsoft Office 365.

6. System validation

The pilot implementation was conducted within Construction Company A. This company selected one of its running projects and used the system to manage the knowledge generated on site. By its particular characteristics, this project was considered as an excellent source of lessons-learned. This project involved the work of finishing the common spaces (2,400 m^2) of a mayor office building and ended on September 30, 2014. The team that participated on the system validation included a Supervising Manager, a Project Manager, a Site Manager, a Technical Office Professional, a Technical Office Assistant, and the Management and Innovation Chief of the company. This pilot study allowed these professionals to interact with the system, according to the role they should play in it, evaluating all of its functionalities.

At the end of the pilot implementation a test was conducted to obtain the opinion of the professionals regarding the system and evaluate its capacity as a tool for improvement. The evaluation was structured in three parts: (1) an overall assessment of the system, where some elements defined in ISO/IEC 25010: 2011 quality software standard were incorporated, as well as other elements considered relevant to the project, (2) an assessment of usability, according to the System Usability Scale (SUS), which defines 10 questions which are evaluated on a Likert scale of 1 to 5; and (3) open questions to identify in greater detail the perceptions and opinions of users.

For the first part of the test, interviewees answered 11 questions using a Likert scale from 1 to 5. For each question, Table 2 shows the percentage of the answers that falls on each category. The items that presented the lowest scores were associated with the response speed time of the system and the speed to access to the information and knowledge provided by the system, followed by the adaptation of the system to the use in everyday work. Here we can identify two main concerns. Firstly, how the technical features of the system could cope with the lack of time in construction projects, especially regarding the quick access to knowledge through the database search, using an unstable internet connection on site. If this connection fails, the system will not work properly. Secondly, how the particularities of the construction industry, such as its traditionalism, lack of IT implementation, lack of training of the workforce, geographical location, work on site and not at the main office, among others, could affect the use of the system in everyday work.

The objective of the second section of the test was to measure the usability of the system. The SUS test consists of 10 standard sentences and every participant must assign them a score within a scale from 1 (totally disagree) to 5 (totally agree) regarding their opinion of the system they are evaluating. Sentences have both positive and negative connotations, then the final score is calculated as follows (Brooke, 1996): (1) For items 1, 3, 5, 7, and 9 the score contribution is the scale position minus 1, (2) for items 2, 4, 6, 8 and 10, the contribution is 5 minus the scale position, and (3) Multiply the sum of the scores by 2.5 to obtain the overall value of system usability. Based on research, a SUS score among 70-80 is considered good, among 80 and 90 is considered excellent, and over 90 is considered the best imaginable (Brooke, 2013).

Table 2. Results from questions with Likert scale

Question	**Totally disagree 1 (%)**	**2 (%)**	**3 (%)**	**4 (%)**	**Totally agree 5 (%)**
The system responds to my requests in a timely manner	0	0	50	33,3	16,7
The system can be used in different environments, for example, at central office and the field	0	0	16,7	33,3	50
The system prevents access by persons outside the company or without associated permissions	0	0	0	16,7	83,3
The system offers a structured way of storing knowledge in the company	0	0	0	33,3	66,7
The system provides a useful way of storing knowledge in the company	0	0	16,7	33,3	50
The system allows quick access to the information and knowledge stored in the company	0	16,7	33,3	50	0
The system will increase the amount of stored knowledge in the company	0	0	0	33,3	66,7
The system will increase the amount of knowledge available to professionals in the company	0	0	16,7	16,7	66,7
The system will allow the active participation of company's professionals in the lessons learned process	0	0	16,7	33,3	50
The knowledge stored in the system will improve the process of decision making in the company's projects	0	0	16,7	50	33,3
The system is suitable for use in everyday work	0	0	50	16,7	33,3

The SUS results for the prototype system are presented in Table 3. As the average score of the six users is higher than 80 points, it is considered that the system meets appropriate levels of usability, being in an "excellent" category. However, it is important to assess the reasons for the low scores of users N°4 and N°5. In the case of user N°4, he forgot to answer one of the questions; therefore it was evaluated with a zero point, which affected the calculation of the SUS score. User 5 meanwhile, was much more critical regarding the integration of the different elements of the system and the need to learn many things to be able to use the system.

Table 3. SUS Scores

User (N°)	**SUS score**
1	92,5
2	90
3	85
4	65
5	62,5
6	87,5
Average score	80,42

The final part of the test consisted of three open questions. The first one asked if the system can be considered as a tool that contributes to the improvement of the construction management process on site and why. All respondents give a positive answer, indicating as main reasons the following: (1) it allow to formalize the transfer of knowledge, (2) allows to have a knowledge repository to avoid making the same mistakes and to learn from good ideas, (3) the system is friendly, flexible and simple and can be used on site, and (4) allows feedback for problem resolution in a simple, practical and orderly manner, allowing the interaction among different levels of the organization. Regarding the limitations that could hinder the proper use of the system inside the company, respondents mentioned: (1) the user age and the little knowledge that some older professionals have regarding the use of information technologies, (2) characteristics of the mobile devices that the company provides to workers, as some of them are obsolete to be able to use this system, (3) the internet speed on site and the internet browsers versions that the company's computers have, (4) that the system could be filled with information that is not useful to work, and (5) the current search engine of the system and the use of keywords included in the prototype. Most concerns related to technical aspects of the system, such as the quick access to knowledge through the database search, and the use of an unstable internet connection on site, reinforcing the findings of part 1 of the test. About the first concern regarding the use of IT by older people, a training session must be incorporated in future implementations of the system to avoid problems using it by lack of knowledge.

About modifications that can be done to the system to improve its usability for every day work, the interviewees pointed that it could be good to (1) improve graphical environment of the page and add auto save every 1 minute, (2) add a profile picture for the project, (3) get e-mail notifications for approvals, rejections or other messages, (4) have a more joyful and innovative webpage design, with more colors and graphics, (5) improve labels and search, and (6) foster the culture and openness to innovation. Regarding this last statement, culture repeatedly appears as a concern not only among the professionals participating in the pilot study, but also among the management of the company. In fact, the studied company is trying to incorporate innovation as part of the company's culture, so they recognize that is a complex subject that requires changing how people used to work.

7. Conclusions

Main conclusions indicate that (1) companies acknowledge the need to develop a culture of innovation within the organization, (2) users consider the system as a tool that could really contribute to improve the construction project management process, and (3) the system needs improvements regarding database search and the Internet support before being fully implemented in the company as a project management tool.

The test results shows that the users are satisfied with the prototype system. There is consensus that it can be considered as a tool for improvement of the management process in construction projects, as it allows to use the corporate knowledge. On the same matter, people value the access to what their colleagues have learned on different projects of the company, standing out that the system allows them to get a greater access to knowledge, with an active participation in the learning process. To have a successful learning process, the interviewed professionals acknowledge the need to develop a culture of innovation within the organization, as this is the first step to change the status quo and incorporate new technologies and processes inside the company. The biggest worries of the interviewees are associated with the database search and the internet support of the system, as this have a direct impact in the response time and fast access to information, especially when professionals are in the field. Regarding the improvements that can be done to the system, they pointed out the enhancement of the notifications of new requirements or messages in the system, the information search system and the overall look of the system. All of these suggestions will increase the system usability. About future developments of the system, it is considered that the design of a recommendation system can be a very useful tool for construction professionals and that it will answer some of the observations about improving the search system. Besides, next to the worry about internet access quality, the implementation of the auto save function of lessons learned forms, especially for people that are in the construction field, is a very useful improvement to the system, that will avoid information reentry in case of an internet connection failure during the process of writing a lesson. All of these modifications will be included in the system as part of a Master Thesis that is currently under development.

Finally, the results of the research show that IT could be a useful element for construction project management, if it recognizes the needs and requirements of construction companies. When this is achieve, the use of a system like the one presented could give support to project management as it: (1) allows the storage of the organizational knowledge, giving an easy access to all the people who require the information; (2) reduce the time spend in decision making, as the knowledge and information stored in the system could be use as part of the decision process; and (3) reduce the asymmetry of information among projects and professionals of the same company.

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