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A lessons-learned mobile system for construction companies: motivation and design

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Abstract

Construction projects are an important source of organizational knowledge. Though, it is common to find that most lessons learned in construction projects are lost because most companies never take care of collecting them. To change this situation, a mobile lesson-learned system application with interface for smartphones and web in a cloud environment is proposed. This article focuses on the design of a prototype of the system and the main characteristics of its architecture. It is concluded that the application of mobile technology on the field would facilitate the use of the system, been an appropriate tool for knowledge management.

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Keywords: cloud computing; knowledge management; lessons; lessons-learned; mobile applications

1. Introduction

As the global economy is ever-changing, it is crucial for construction organizations to adapt with it [1]. This is a challenging situation for construction companies, who need to improve project performance to survive in the present economic and financial environment [2]. Project performance can be improved when people communicate and share best practices, lessons learned, experiences, insights, as well as common and uncommon sense [3]. Therefore, it is

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imperative that the construction industry start to pay more attention to knowledge and knowledge management strategies [4]. Carrillo et al [5] indicate that a common means of identifying improvements and innovations in project-based environments is through lessons learned (LL) activities. Many organizations in the construction industry have come to recognize the importance of a LL program as a vital asset that plays an essential role in knowledge management [6]. These lessons are the knowledge gained from people's successful or failed experience [7]. To manage these lessons, construction companies need a lesson learned system that fit their specific needs and that use the new technological advances to obtain a system really applicable on-site. Currently, mobile technologies present new and interesting opportunities to improve the access to knowledge and information. The use of mobile computing devices can play a vital role to improve data collection and process efficiency in construction processes [8, 9], enabling construction managers to input, store, process, and access project information at any location and to communicate that information to any location [9]. Then, mobile technologies can be a very useful tool for a LL system. Through them, people can have access to the information and knowledge very easily. Then, this research considers the development of a lessons-learned system mobile application with interface for smartphone and web, in a cloud environment. It is expected that this system could contributes to improve on-site management in a construction project. This article focuses on the design of this system, presenting a literature review on the main topics related to the study, the proposed LL system and the main characteristics of its architecture.

2. Lessons-learned

The Construction Industry Institute (CII) defines a lesson learned as knowledge gained from experience, successful or otherwise, for the purpose of improving future performance [10]. Lessons learned can be seen as elements of experiential or tacit knowledge that have been rationalized and saved for future use, where the main idea is to encourage good practice to repeat successes and avoid past mistakes [11]. Kartam [12] identify three major components of a lesson learned (1) a set of attributes to sufficiently describe and explain the lesson itself, (2) information regarding the source and context from which the lesson is collected, (3) the means for classifying the lesson in a manner that allows fast, clear retrieval by multiple parameters. Fong and Yip [13] define LL systems as the activities, people, and products that support the collection, verification, storage, sharing, dissemination and reuse of verified lessons in organizations. Their goal is to capture and provide lessons that can benefit employees who encounter situations that closely resemble a previous experience in a similar situation [14]. A main problem in the construction industry is that recording good or bad practices at different stages of projects is not common [13]. Generally, lessons learned during the construction phase of a project are not effectively incorporated into the design and construction phases of other projects [12]. Despite this, LL can be a very useful tool for knowledge management in construction companies, because the work they performed is highly intensive in knowledge and experience; therefore, there are many lessons to keep from each project that can be useful for similar future projects. Then, it is clear that construction companies needs to develop better ways to keep and use the knowledge they gain on each project. To accomplish this, information technologies are a very useful tool because of all the capabilities they currently have.

3. Mobile technologies in the construction industry

Construction engineers are interested in improving site information exchange for increasing productivity of the construction project [15]. The advances in affordable mobile devices, the increase in wireless network transfer speeds and the enhancement in mobile application performance, mean that mobile computing has a great potential to improve on-site construction information management [15-16]. Also, the use of mobile computing devices can reduce the unnecessary cost currently inherent in construction projects by improving opportunities for data collection and thereby the process efficiency [9]. In the last ten years construction companies and academia start to show interest in mobile computing through an increasing number of research related to mobile applications in construction projects, such as Kimoto [17], Bowden et al [18], Chen and Kamara [19], Chen and Kamara [16], Lee et al [20], Irizarry and Gill [21], Kim et al [15], Ochoa et al [22], Son et al [9], Nourbakhsh et al [23], and Kim et al [24]. Even though construction companies have been slow to adapt to new technologies, this situation is starting to change. In fact, the industry needs to open up to new technologies and make the best use of them for performance improvement. Currently, a new challenge includes the use of cloud computing in construction companies.

4. Cloud computing

A new paradigm related to mobile technologies has appears in the past few years: cloud computing. It can be understood as a new computing model in which resources (e.g., CPU and storage) are provided as general utilities that can be leased and released by users through the Internet in an on-demand fashion [25]. Cloud computing services are divided into three classes: 1) Infrastructure as a Service: Refer to the tangible physical devices like virtual computers, servers, storage devices, network transfer, which are physically located in one place but they can be accessed and use over the internet using login authentication systems and passwords from any dumb terminal or device [26]; 2) Platform as a Service: A cloud platform offers an environment on which developers create and deploy applications and do not necessarily need to know how many processors or how much memory that applications will be using [27]; and 3) Software as a Service: Services provided by this layer can be accessed by end users through Web portals [27] .

Security and privacy concerns are the primary obstacles to wide adoption of cloud computing [28]. This problem arose because enterprises have total control of their data when they own their physical server, but in the cloud, they must trust in the provider [29]. Gartner's seven security issues which cloud clients should advert include: privileged user access, regulatory compliance, data location, data segregation, recovery, investigative support, long-term viability [30]. Ryan [31] indicated that many of these aspects are not unique to the cloud setting, for example, data is vulnerable to attack irrespective of where it is stored. We need to consider that an in-house IT department is not necessarily more secure than a cloud-based offering as it is still connected to the internet and thus susceptible to hacking attacks [32]. Reiterating this affirmation, there are some analysts and cloud users who think that cloud computing can still provide better security and greater reliability than those provided in-house [33]. Among the security benefits imposed by cloud computing we could find centralization of security, data and process segmentation, redundancy and high availability [34]. It is expected that the emergence of powerful players behind this technology in a massive way could help to mitigate this worries [33]. In fact, providers like Amazon and Microsoft, for example, have the capabilities to deflect and survive cyber-attacks that not all providers have [32]. Based on this, it is considered that in smaller organizations with limited resources, data may be safer with a cloud provider [29]. Gupta et al [26], in a study about the usage and adoption of cloud computing by small and medium business, indicated that the ease of use and convenience is the biggest factor cited by these companies to adopt cloud, follow by the improved security and privacy. Then, there is not definitive opinion about the security of the cloud. If a company wants to innovate and include this new framework on their daily work, it must evaluate the cloud features, the provider behavior, the company characteristics and the risk associated with it. Based on this, each company must take his decision.

5. Lessons-learned system proposal

We worked with three Chilean construction companies with more than 20 years of construction experience, using a multiple case study research approach. Then, semi-structured interviews, direct observations, and review of documentation were conducted. The main information of these companies and the number of professionals interviewed is show in Table 1. All the participating companies were medium size construction companies in geographical expansion. The main results obtain on this activities are present next.

About knowledge management, interviewees recognize the relevance of knowledge to perform the on-site management process, but they also emphasized knowledge is generally on people's minds and not documented in the organization. Because of this, face to face contact among professionals of the same company is considered a critical activity. The main problem is that communication and cooperation between professionals of the same company is complicated and slow, because the projects are scattered through all the country. Also, people recognized the need for lessons learned about the design and execution of the project, in order to reduce and prevent the occurrence of mistakes. According to respondents, the main constraint to acquire and store knowledge is the lack of time during projects execution. Also, professionals indicated as an important constraint the lack of organizational procedures to manage knowledge. They indicate that they do not store knowledge because it is not clearly defined what information or knowledge they need to save, which is the format or where it must be stored.

Table 1: Information about the case studies

Company	Type	Quality Certifications	Number of Professionals interviewed	Position in the company
A	Construction company	ISO 9000	6	3 Project Manager, 1 Project Supervisor, 1 Quality Chief, 1 Operations Manager
B	Construction company	ISO 9000	5	3 Project Manager, 1 Project Supervisor, 1 Quality Chief
C	Real estate and construction company	None	5	2 Project Manager, 3 Project Supervisor

About lessons learned, none of the three companies formally documented lessons learned, but all the professionals indicated that a LL system would help them on-site. According to interviewees, among the main characteristics that a LL system must have, we could find: (1) the lessons must be collected during project team meetings or through interviews. The Project Manager should be responsible for the approval of the lessons of their project; (2) the system should be simple, allowing a quick search of the required information. Also, most of the respondents believe that the use of mobile technology on the field would facilitate the use of a LL system, especially to search and retrieve information; (3) to replace or complement face to face interaction among professionals, interviewees indicated that it could be useful to have a place to leave short recommendations on certain issues to be read by colleagues.

It is possible to conclude that construction companies need to focus in the following problems to organize their knowledge and get benefits from it: (1) To document lessons learned, (2) to foster face to face contact among construction professionals, and (3) to define a procedure to manage their information and knowledge. We proposed to face these problems through the development of a lessons learned system with two main components: (1) an organizational database of lessons-learned, and (2) an organizational microblog. The lessons-learned database must allow the storage, reuse and transfer of the knowledge created in the design and construction phases of a project, to avoid the occurrence of mistakes. The organizational microblog will allow a more fluid contact among professionals, being considered as a complementary tool to transfer knowledge inside the company. To benefit from the new technologies, this system considers the development of a mobile application with interface for smartphone and web, in a cloud environment. It is expected that a system like the proposed one would help construction companies to manage their knowledge, fostering the transfer and reuse of knowledge. Also, the use of mobile technologies, specifically cloud computing, would allow a faster and easy access to the relevant knowledge from any location, and the possibility to keep in touch with company colleagues to share experiences through a private social network. Finally, the use of cloud computing will also diminish the investment associated to the IT infrastructure required to host and manage the system, especially for medium sized construction companies, that normally do not have a big IT infrastructure. The next section presents the main characteristics of the design of the prototype system.

6. Prototype System Design

The first phase in the development of a domain-specific application is getting insight into the problem domain or business logic [35]. This phase involves understanding the work and activity contexts involved in construction companies. We have identified and developed seventeen use cases and a set of complementary mockups. Together, they represent the proposed functionalities of the system and its requirements. Figure 1 presents an example of a mockup of the mobile application, including some comments made by the researchers to explain the expected functionalities to the programmer.

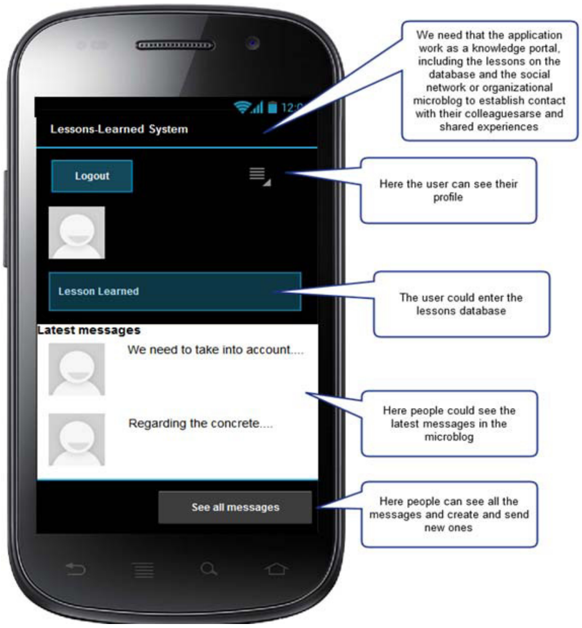

Fig. 1. Example of mockups of the mobile application

As indicated before, the system includes two main components: (1) an organizational database of lessons-learned, and (2) an organizational microblog.

Regarding the database of lessons, the system includes three entities: users, projects, and lessons. Concerning the users, the system recognizes four types of users: System Manager, Lessons Creator, Approver, and Consultant. Each user has a clear role inside the system, as indicated in Table 2. In each project, the System Manager must define who the Lessons Creator and the Approver will be, according to the indications of the Operation Manager. Each user could perform searches to get information about other users, companies' projects, and the store lessons. The information about projects include the project name, address, Project Manager name, project start date, project due date, volume to build (m2), contract cost, project type (residential, commercial, institutional, among others), type of contract (fixed price, unit price, percentage of construction fee, among others), type of client (private, government, own project). Each lesson must be related to one or more projects of the company. Finally, each lesson must include the information included in Table 3.

Once a new lesson is created, its information will be held in the organizational database, which is a relational database. Its schema was built using the "code first" paradigm, meaning that the main system entities and the relationships between them were first modeled as classes in the application code and, then, mapped to a relational schema, using the ASP.NET Entity Framework version 6. The lessons learned search will be performed in two ways, (1) through a quick search feature, which allows searching by keywords; and (2) through an advanced search, which allows searching using filters such as project name, user, description of the case, description of what was learned, and the lessons' tags. Once the user find a useful lesson learned, the system will display all the information indicated before, allowing the use of the knowledge acquired by the company. After using the lesson, each user will have the opportunity to include a comment about the usefulness of the lesson or any other relevant observation that they could want to include. These comments will be visible for every user that read the lesson.

Table 2: System users and their roles

Action / Role	System Manager	Consultant	Lessons Creator	Approver
View Lesson	Yes	Yes	Yes	Yes
View Microblog	Yes	Yes	Yes	Yes
Comment Lesson	-	Yes	Yes	Yes
Post on Microblog	-	Yes	Yes	Yes
Create Lesson	-	-	Yes	Yes
Approve Lesson	-	-	-	Yes
Review Lesson	-	-	-	Yes
Deactivate Lesson	Yes	-	-	-
Moderate Microblog	Yes	-	-	-
Create Project	Yes	-	-	-
Deactivate Project	Yes	-	-	-
Create User	Yes	-	-	-
Deactivate User	Yes	-	-	-

Regarding the organizational microblog, people will communicate with their colleagues through short messages, posting useful comments about their work. Each user will have the opportunity of sending messages to all the organization, a specific group of people inside the company or just to a specific person.

As indicated in section 5, the prototype includes a mobile application as well as a web application. Then, considering that there will be more than one system interacting with the LL database, it is required an API (Application Programming Interface). An API defines how different software components should interact, particularly, how the mobile and web applications interact with the database.

Table 3: Lesson content

Lesson-Learned Content		
1.Title of the lesson	2.Brief summary of the lesson	3.Creation date
4.Information regarding the project (s) related to the lesson	5.Name of the lesson's creator	6.Name of the lesson's approvers
7.Involved disciplines	8.What triggers the lesson: error, omission, best practices, improvement	9.Collaborators in the creation of the lesson
10.Description of the case or situation that motivated the lesson	11.Description of what was learned on the case	12. Lessons' tag: keywords or term assigned to a lesson
13.Classification of the lesson: estimation, project design, techniques and construction methods, quality management, new technologies and products, regulations, suppliers and subcontractors, administrative processes, security and risk prevention, project planning and strategy.		14.Attached documents

Regarding the mobile application, the next step in the design process was to decide if we are going to do a cross-platform or a native mobile application. Despite the advantages of a cross-platform, such as its lower cost and lower fragmentation, we chose a native development because the resulting applications are faster, have better user interfaces and their security features are stronger [36]. Also, considering that the LL system needs to be adopted by many users within the company, we decided to work with Android because it has a superior market share and price variety. Finally, as cloud services provider we decided to use the Microsoft's Windows Azure platform because (1) their uptime is 99.9%, (2) they have technical support in Chile and, (3) they offer an academic pass for research. Two natural implications of this decision were to build the web interface and the cloud service using ASP.NET MVC Framework 5.0 and to store the data in a relational database that works on Windows Azure SQL database, being both Microsoft technologies as well. Regarding the class of cloud computing services used, we worked with the concept of Platform as a Service, because it provides the required infrastructure to develop the LL application, being a flexible and adaptable solution. From the user point of view, the system work as Software as a Service, were they can access the application through internet.

The mobile application will allow creating, approving, evaluating, and searching lessons inside the database, and use the organizational microblog. We include these functions in the mobile application because they are mostly executed on-site, in different locations. As shown in the conceptual design of the proposed lessons-learned system (Figure 2), the database is not directly modified by the mobile application, but the mobile application sends the information and instruction to the cloud services, which is the only component that has control over the database. Thus, we take advantage of the computing capacity of the cloud with just one agent that manages the database, facilitating information integrity in this way. This means that the mobile application will only be responsible for the graphic interface and to provide the information as input for the cloud, who will be responsible for most of the operations, reducing as much as possible the computing made on the mobile device itself. As this schema relays on connectivity, the mobile application shall have a queue system for pending requests, and it will try to send them again when recovering the internet connection, so the user will not lose his work when using the system with limited connectivity.

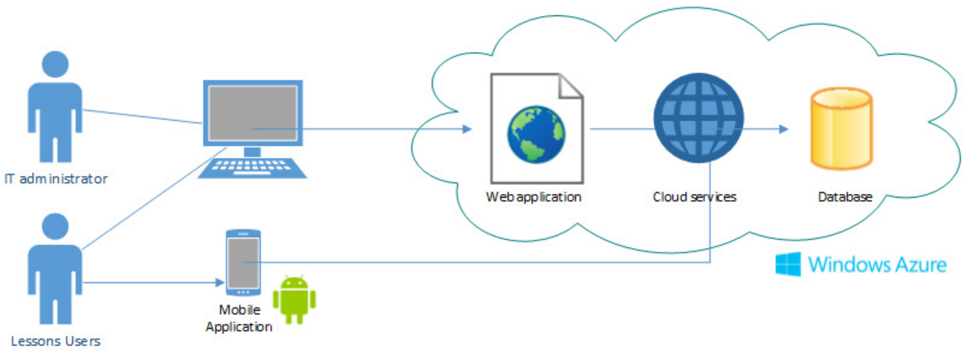

Fig. 2. Conceptual design of the lessons-learned system

The web application also interacts with the database through the API. This web application includes all the functions available in the mobile application, but also contains all the administrative tasks required by the system, such as creating users and projects in the database, and managing the microblog. The architecture of each one of the system's components was developed using the software architecture pattern Model-View-Controller (MVC), which separates application data, user interface and business logic into three distinct components. Also, we used design patterns (standard solutions to recurring problems in software development). For example, we used the Memento Pattern to implement a version control system for the lessons' creation, review, and approval process. This is a relevant process for the lessons-learned system that starts when a professional writes the initial draft for a lesson and saves it, which creates a lesson entity on the system. Then, a supervisor reviews it, being able to directly approve it or to add comments and ask to the professional to improve the content of the lesson. When the professional (main author or collaborator) receives these comments and modifies the initial draft, the system modifies the lesson entity and also creates a memento entity with the relevant information of the previous version and the current modification, considering information traceability and accountability for the changes made.

As discussed previously, a main concern when working on the cloud is security. We faced this problem from two perspectives: security on the cloud and security on the application. To accomplish the first challenge, we decided to use Microsoft Azure as our cloud services' provider taking into account that its solutions can easily face cyber-attacks. However, the security on the cloud is not enough; the application built upon it must secure itself. To do this, we took advantage of Azure's natural integration with ASP.NET MVC framework, which have built-in functions the programmer can use to robustly solve security and authentication issues. This allowed us to rapidly develop an application that uses ASP.NET's security best practices, based on membership providers, which are the software components responsible for authorizing (or not) every access or request made to the application, through the web application or cloud services.

7. Conclusions

Despite the fact that knowledge management is not a new issue, most construction companies still have problems with this process. The interviewed professionals recognize the relevance of a good organizational knowledge management for the success of their projects, and also acknowledge that the use of mobile technologies on the field would facilitate the use of a knowledge management system. We concluded the studied companies have three major needs associated to knowledge management: (1) to document lessons learned, (2) to foster face to face contact among construction professionals, and (3) to define a procedure to manage their information and knowledge. The proposed lesson-learned system was developed based on this requirements and needs, so it is expected that it could help to improve their knowledge management practices once implemented. Given the new trends in mobile technology, the opinion of the construction professionals, and the characteristics of the most probable users of the system (medium size construction companies) we decided that our system must include a mobile application in a cloud environment. For construction companies, the availability of information and knowledge on short notice is an important issue to improve project decisions. Then, mobile cloud computing can be a very useful tool that allow construction professionals an easy access to knowledge and information everywhere and anytime. The main concerns about the design of the system were shown on this article, including how we treat the security on the cloud, a very sensitive issue in this type of development.

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