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A cloud-based mobile system to manage lessons-learned in construction projects

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Abstract

Knowledge and experience are vital assets within the construction industry. Nevertheless, small and medium construction companies still have problems to transfer the knowledge acquired in their projects to the rest of the organization. Lessons-learned are elements of knowledge management that could help companies to improve this process, and therefore, their global performance. This research presents a cloud-based mobile shared workspace to support knowledge management in construction. The article presents the original system and the modifications made to it based on an initial evaluation by construction professionals. The main upgrades were to include a notification system, letting users know when an action is required from them, and to improve the synchronization process for a better offline experience on site. The evaluators considered these were essentials features to be able to use the system on site. The 2.0 version of the system was validated with construction experts. The article concludes that one of the most relevant features of the system is its capacity to save information on site without an internet connection for later synchronization. Also, the proposed cloud-based shared workspace is a feasible option to improve knowledge management in small and medium Chilean construction companies, mainly because of mobility, usability and investment-related factors.
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1. Introduction

Construction companies are project based organizations characterized by uniqueness, uncertainty and complexity, which makes them different from other business organizations [1]. Thus, it is difficult to manage the knowledge they generate during the progress to deliver a custom-built facility [2]. In fact, many project based organizations constantly fail to learn from their own experience, as shown by their tendency to 'reinvent the wheel', repeating mistakes and failing to transfer lessons from one project to another [3]. These difficulties arise due to the unique and discontinuous

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nature of project-based work, which creates intra-firm boundaries that hinder the transfer and use of valuable knowledge gained within particular projects to subsequent projects and/or the organization as a whole [4].

In this regard, efficient Knowledge Management (KM) would allow construction companies to transfer knowledge across their various projects, to create synergies inside the organization, to learn from the mistakes and successes of others, and to receive benefits in terms of productivity and performance [5]. Despite this, construction organizations have historically failed at effectively transferring project information and have not yet developed a learning culture that takes into account both technology and people [6]. This is a complex situation, as transferring learning to future projects allows staff to use existing knowledge to solve problems, instead of having to generate new knowledge which generally requires more time [5]. This also could hinder a companies' performance, as effective KM is believed to be one of the performance enhancers for organizations wanting to remain successful in the construction industry [7].

There are different approaches to conduct KM, such as self-service, communities of practice, transfer of best practices and lessons learned [8]. Lessons learned (LL) are elements of both organizational learning and KM [9] as they capture knowledge from projects, events, or other work to apply in similar situations [8]. Typically, LL from different construction projects are not systematically integrated into a construction firm's memory [5]. In fact, the benefits of learning are still not realized, despite the efforts of some construction companies [10]. There is also the need to maximize opportunities for people to meet and make an efficient use of information technologies (IT) to find information and knowledge [11]. Because of that, this research explores how to use some trending IT, such as mobile cloud computing to the collaborative KM process in medium-sized Chilean construction companies. Specifically, this article presents the first version of a cloud-based mobile system to manage LL in construction companies, developed under the Lean Startup methodology. It also shows the improvements made to the first version, following the feedback received from construction professionals and experts.

2. Review of literature

Companies have come to understand knowledge as a resource and a vital asset to carry out their activities. They have implemented various ways of capturing, storing, transferring and reusing it [5]. For example, large companies as Fluor have KM programs including communities of practice, expertise locator system, mentoring, people developments programs, online collaboration, document management spaces, and process improvements methodologies to capture and transfer critical knowledge [8]. Despite these successful experiences, several construction companies still have problems regarding their KM, especially about extracting, distributing and applying knowledge across both cultural and structural boundaries, given its condition of project based industry [12].

An interesting approach to KM is the use of LL. LL are knowledge gained from experience, successful or otherwise, for the purpose of improving future performance [13]. A LL process include mainly three steps: identification (capture), dissemination (transferring) and application (implementation). The last one appears to be the most difficult to operationalize [14]. A survey made to major construction contractors in the UK [10] helps to understand current practices of LL. Its findings include: (1) The most commonly used practices for LL activities include both explicit and tacit methods such as post project reviews (68%), company intranet/extranet (64%), and face-to-face meetings (62%); (2) the most informative practices include communities of practice (56%), brainstorming sessions (54%), and knowledge repositories (53%), followed by post project reviews (52%) and face-to-face meetings (52%) and to a lesser extent technical forums (42%); and (3) face-to-face meeting and post project reviews were commonly used and most informative. Regarding the adoption of corporate LL processes by site teams, Carrillo et al [15] identified some challenges that need to be addressed, such as (1) lack of communication and transparency between site teams and head office teams; (2) strong emphasis on people-to-people dissemination even though they have received tools from the corporate office which they consider useful; (3) a culture of encouraging the collection and dissemination of lessons needs to be addressed; and (4) site teams do not properly recognize the value in collating lessons and therefore excuse themselves by saying they do not have enough time.

It is important to consider that most studies regarding LL in the construction industry have been conducted in developed countries. Thus, these studies have focused on large and/or international construction companies or have assumed that LL are an issue that a large number of companies already have implemented. Therefore, the implementation and adoption of LL systems in small and medium size construction companies, especially in developing countries, have not been adequately studied in the past. This occurs even though construction industry

comprises primarily small and medium enterprises (SMEs) [16], with less opportunities to implement new technologies.

Previous research [17,18] has shown that, within small and medium size companies, knowledge is generally kept in people's minds and not documented for the benefit of the organization, despite the fact that they acknowledge the need for LL in the design and execution of future projects in order to reduce or prevent errors. Regarding this, some problems faced by SMEs in the construction industry include [18] the following:

- The lack of organizational procedures to manage knowledge. Construction professionals have indicated that they do not store knowledge because it is not clearly defined what information or knowledge they need to store, what format to store it in, or where to store it.
- Communication and cooperation between professionals of the same company is difficult and slow, given the geographical dispersion of projects.
- A major limitation to capture and store knowledge is the lack of time during the execution of projects. This has an impact in the communication process project teams, experts, and the central office.

3. Methodology

This research was conducted using the Lean Startup [20] methodology because (1) it was necessary to understand the uniqueness of the construction SMEs' requirements and (2) the main goal of this research is to develop a functional product. Lean Startup is an approach that seeks to eliminate the waste of time and resources spent on the effort of trying to understand what customers really want [19]. The core of the Lean Startup model is the Build-Measure-Learn feedback loop. During the Building phase of this loop, a hypothesis guides the development of an artifact (e.g. mockups or prototypes) that would allegedly satisfy users' needs. The Measure step consists on evaluating the performance of the artifact, validating or discarding the proposed hypothesis. Finally, in the Learn phase, researchers further analyze the results of the Measure step, gaining more insight about the problem they are trying to solve and deciding if they start the cycle again with an improved version of their original hypothesis or with a completely new one. This process allows to turn ideas into products, measure how customers respond, and learn whether to pivot or persevere [20]. This research has completed the Build-Measure-Learn cycle three times so far.

The goal of the first cycle was to create a valuable system proposal. During the initial Learning phase, we identified deficiencies in the KM and LL processes, through a literature review and semi-structured interviews with 16 construction professionals from 3 different construction companies. During the Building phase, initial mockups were made. Later, the Measurement phase consisted in new semi-structured interviews with 5 construction experts within the companies.

The second cycle focused on building a first version of the system, to test the proposal with on-site professionals. In order to do so, during the Building phase the main functionalities were implemented in a cloud service. During the Measurement phase we worked in detail with one company from the previous cycle. A team of on-site professionals used the prototype to register and access LL from an on-going project and then participated in a focus group. Also, periodic interviews with the Chief Operating Officer (COO) and Innovation Chief continued, in order to consider both the operational and managerial vision. Finally, during the Learning phase, the results and comments from the focus group and the interviews with the managers were analyzed.

The goal of the third cycle was to improve the first prototype, after it proved to be useful on measurement phase of the second cycle. The Building phase focused on the development of the version 2.0 of the system, based on previous cycle's feedback, including a cross-platform mobile application and the improvement of the existing cloud service. During the Measurement phase, expert construction professionals were consulted and interviewed to receive feedback regarding the system's performance.

4. System development and improvement

4.1. General description

The proposed LL system is a cloud-based mobile shared workspace. Its main features are grouped in two modules fostering both explicit and tacit knowledge management: (1) an organizational database of LL, and (2) an organizational microblog. The LL database allows the storing, reusing and transferring of knowledge created in the design and construction phases of a project, avoiding the re-occurrence of mistakes. Regarding the organizational microblog, it is design to allow a more fluid contact among professionals, fostering tacit knowledge transfer, as interactive IT tools are often preferred over face-to face interaction, between both co-located and distributed workers since they are non-intrusive and commonly support multitasking [21].

The cloud-based mobile shared workspace's architecture considers three main components, as shown in Fig.1: (1) a LL cloud-based service platform, (2) a web-based software solution, (3) a mobile software solution. Both web and mobile applications allow access to system's functionalities, by consuming the services exposed by the cloud-based API. Fig. 1 also show the expected use of the platform in a construction company work scenario.

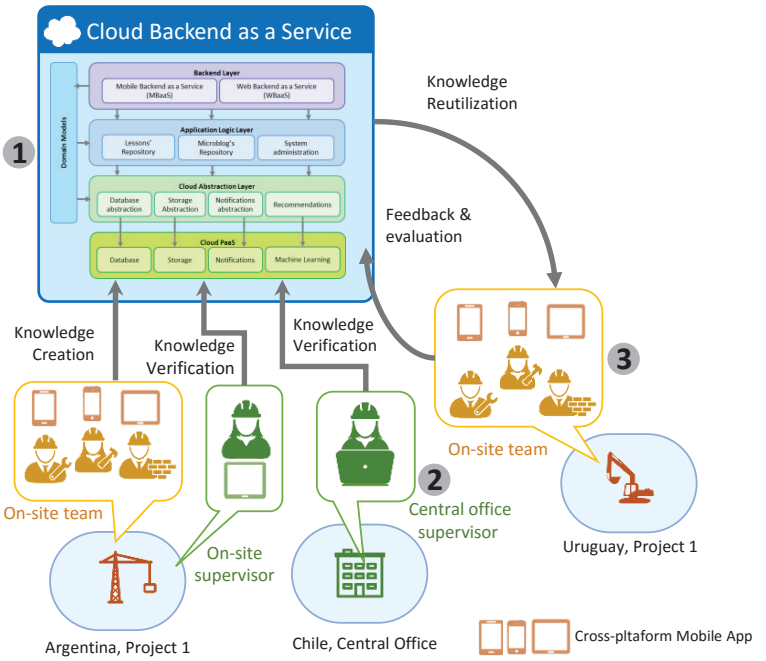

Fig. 1. General Architecture of the Proposed Cloud-based Mobile System

The web application's main goal is to allow access to all shared workspace's functionalities, including usage of the microblog, creation, consultation and evaluation of LL, besides system management options. On the other hand, the mobile application was developed for Android, iOS and Windows Phone devices (Fig. 2), using Xamarin.Forms, a C# multiplatform framework which allows to easily communicate with the C# built core. Main goals for the mobile application are to allow quick and comfortable field data collection and to allow timely access to LL already published in the system, supporting decision making. This application considers the same functionalities as the web application, except for system management options, and consumes a specialized cloud service for mobile devices. Finally, the worker role in the cloud provides the common ground for all client applications and it is responsible for handling business logic. It is implemented using Entity Framework 6 and centralizes access to the LL system's database and storage.

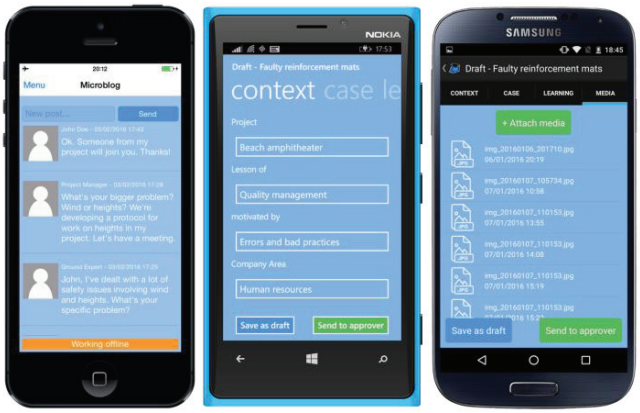

Fig. 2. Mobile application on three different mobile devices

This system recognizes four types of users: System Manager, Lessons Creator, Approver, and Consultant. These users perform four main tasks regarding the LL stored in the system:

- Creation: The system (web or mobile) displays a LL form to be completed with relevant content. The content of the LL was defined with the construction companies that work on the case study [18], and then refined with the company that decided to implement the system.
- Approval: To ensure accountability and credibility to the lessons included in the database, each new lesson has to be approved by one or more Approvers. They can ask the authors to make improvements to their LL before these are published.
- Search: It is possible to search lessons through a quick search feature, which allows searching by keywords; and through an advanced search, which allows searching using several filters, such as lessons title, author, approvers and project's name, disciplines, source of the lessons, and lessons' tags.
- Evaluation: Users give explicit or implicit feedback about LL's content and relevance, regarding their experience using them. This information is input for the future development of a recommendation system.

4.2. Initial evaluation of the system

The pilot implementation was conducted in project involving the work of finishing the common spaces (2,400 m2) of a mayor office building. The company that owned the project has more than 20 years of experience in the area. The team that participated on the system validation included 7 construction professionals. The evaluation conducted at the end of the pilot implementation had three parts: (1) an overall assessment of the system, using elements defined in ISO/IEC 25010: 2011 quality software standard [22], (2) an assessment of usability, according to the System Usability Scale (SUS) [23], and (3) open questions to identify perceptions and opinions of users.

The results of the evaluation (scores and comments) shows a positive reception of the system's proposal, as all users agreed that system can be considered as a tool that contributes to the improvement of the construction management process on site, as currently de company does not have any knowledge management system and company's knowledge is kept on people minds. In this regard, evaluators indicated that the system allowed to use the knowledge created by other professionals and learn from their mistakes and best practices. Not only were the system's features well evaluated, but also its usability. The average SUS score was 80.42, as indicated in Table 1, and a SUS score among 80 and 90 is considered excellent [24]. Nevertheless, the system could still be improved. Regarding the limitations that could hinder the proper use of the system inside the company, most concerns related to technical aspects of the system, such as quick access to knowledge through the database search, and the use of an unstable internet connection on site. 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.

Table 1: Initial evaluation SUS Scores

User	SUS score
A	92,5
B	90
C	85
D	65
E	62,5
F	87,5
Average score	80,42

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. 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. About modifications that could be done at this point to the system to improve its usability for every day work, the interviewees pointed, among other things that it could be good to (1) have graphical environment improvements (2) get e-mail notifications for approvals, rejections or other messages, (3) improve search feature, (4) foster the culture and openness to innovation and (5) improve offline functionalities. Company managers and interviewees agreed on these points.

4.3. Improvements made to the system

Following the evaluation's results and the periodic interviews with both the company's COO and company's Innovation Chief, authors decided to make lessons' approval and evaluation more flexible and less intrusive, in order to encourage more users to enter information to the LL system more often. Another decision made after the evaluation was to implement push notifications. This feature will draw more attention to the system while facilitating and guiding access to relevant information.

To encourage users to participate, the lessons will now require only one supervisor's approval before it is published. This way, the results of an author's work will be visible more quickly. The second approval will be optional, as it was designed for higher level experts, whom may not have enough time to review all the LL they will receive. Thus, there will be balance between ensuring the quality and achieve a smaller amount of bureaucracy before a lesson is published. Also, regarding the LL evaluation and feedback process, after the system's evaluation the problem of discouraging bad-evaluated lesson's authors became notorious. To avoid this, the five star ranking option was replaced with implicit feedback. The option to comment remained, as it is an opportunity to have constructive feedback to help improve authors' future interventions. Table 2 summarizes the main differences between the first and second versions.

Table 2. Main improvements from version 1.0 to version 2.0

Feature	Version 1.0	Version 2.0
Approval	Requires two users to approve the lesson before it is published.	Requires only the first user to approve before it is published. The second approval it is optional, but desirable.
Evaluation	Allows users to post comments and to rate lessons with 1 to 5 "stars" (the more stars, the better).	Allows users to post comments. The system measures how much people reads the lesson.
Notifications	Non-existent.	The system sends push notifications to mobile devices when an action is required from the user at some stage of the approval process and when the lesson created by the user is finally published.
Offline use	Work in progress can be saved locally. Synchronization with remote server is manual.	Work in progress can be saved locally if there is no internet connection (mobile application). Synchronization is automatic.

This new version was evaluated by 7 construction experts, following the same three-part questionnaire used to evaluate the first version. Improvements were well received. Experts said the changes made to the system were consistent with work in the industry. This time, the average SUS score for the system was 84, as indicated in Table 3. Work under unstable internet connection is still a major concern. The most frequent comment in both evaluations was the importance of being able to work without Internet connection. In this case, the experts noted that the system could not be used at all without this feature. Also, experts indicated the relevance of an improve search feature.

Based on the results of the second and third development cycles of the methodology, a new cycle is currently under development to address the improvement needed by the search feature and to make easier the access to collected information in general. Its objective is to enhance the system through the incorporation of Machine Learning and Content-based Recommendation, allowing the generation of suggestions based on the feedback and evaluations of users.

Table 3: Second evaluation SUS Scores

User	SUS score
G	92.5
H	87.5
I	82.5
J	87.5
K	90
L	70
M	75
Average score	84

5. Conclusions

The results of this ongoing research show that the issues of how to manage knowledge in construction companies are not totally resolved, especially in SME from developing countries. To offer a solution to these problems we developed a cloud-based mobile shared workspace.

Construction companies has been slow in the adoption of IT. One of the many reasons for this situation is the fact that many of the systems currently offered in the market were developed without addressing the real needs of construction companies regarding their project's work conditions and culture. Therefore, one way to improve the use of IT in these companies, especially in SME, is through the use of more collaborative methodologies such as lean startup. A work methodology like this one allows for a direct involvement of the final user in the system development, allowing the creation of systems that are really useful in everyday work. For instance, the system not only allows classic sharing of LL, but also considers tacit knowledge through the microblogging platform; it acknowledges the nomad nature of the construction professionals, allowing access to virtually any user from any location, through the cross-platform mobile application and synchronization process; it is user-friendly and inexpensive; it allows SMEs to stay in real control over their information and communication technologies resources even when they are maintained by cloud services' vendors, and recognize the concerns of construction professionals regarding the capacity of the system to save information on site without internet connection. Requirements like this one are not the main focus of previous academic researches, and are often overlooked. Therefore, this collaborative and practical approach to resolve the KM problems face by many companies in the construction industry, especially SME, is one of the major contributions of this work.

The version 2.0 of the system includes new features according to construction professionals' feedback. These improvements were well received by construction experts that evaluated them later, leading us to believe that the application of methodologies of collaborative work could increase the chance of success of IT implementations on site in construction projects. Finally, the cloud-based mobile shared workspace was considered a very useful tool to manage LL in project.

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