Coordinating Loosely-Coupled Work in Construction Inspection Activities

Sergio F. Ochoa · Gabriel Bravo · José A. Pino · Juan Rodríguez-Covili

Abstract   Inspections represent key activities in construction projects. They allow coordinating the work of the main contractor and the subcontracted companies participating in the project. Today the inspection activities and the coordination process are done using information recorded into paper-based blueprints. As a consequence of it, coordinating the activities derived from inspection processes become expensive, slow and error-prone. This paper presents a mobile shared workspace, named COIN (Construction Inspector), which helps the participants in a construction project to overcome these limitations. COIN was particularly designed to be used on tablet PCs, but it is able to run on several computing devices. This workspace has been tested in a controlled work scenario. The preliminary results are highly positive, indicating this proposal could have an important impact on the construction management process.

Keywords   Coordination process · Mobile shared workspaces · Loosely-coupled work · Mobile collaboration · Construction management

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1 Introduction

Construction projects typically involve a main contractor, which in turn outsources several parts of the project, e.g. electrical facilities, gas/water/communication networks, painting and architecture. The companies in charge of these activities usually work concurrently and they need to be coordinated because the work they are doing is highly interrelated. In fact, the project progress rate and the product quality increase when these actors work in a highly coordinated way. Typically, the main contractor is responsible for managing the coordination process.

The inspection activities play a key role in this process. The goal of these inspections is to diagnose the status of a construction project's component and to determine the need to approve, reject or modify such component based on that diagnosis. Each inspection is carried out by one or more inspectors, who work alone (doing independent tasks) or by forming an inspection team (when their inspections are interrelated). The inspection activities require these persons to be on the move and record the contingency issues (i.e. problems identified by an inspector) related to particular project concern, e.g. the electrical facilities.

Periodically, the main contractor informs the subcontracted companies about the list of contingency issues they have to address. The process to deal with these issues could involve the work of more than one subcontracted company, and at least one additional inspection.

Currently, inspection activities are done using paper-based blueprints (Fig. 1a). The contingency issues (e.g. annotations done by the inspectors on a blueprint) are identified and integrated using a manual process; therefore, the process is expensive, slow and error prone. In addition, the delivery of information to the involved subcontractors is done using paper-based blueprints and hard-copied reports. Depending on the project and the number of contingency issues, the time period between the information gathering (during the inspection) and delivery (when the information is given to the subcontractor) can take from 2 to 3 days to 1 month, and even more.

This bureaucratic and error-prone coordination process causes several problems to both main contractor and subcontractors. For example, the delays in transmitting the information affect the project schedule and force the involved companies to make decisions with little and perhaps outdated information. Furthermore, it also increases the cost of the project and usually it reduces the earnings of the subcontracted companies. If the contingencies delivery process is not fast enough, the subcontractor's resources (personnel, time and equipment) become underused, and consequently they turn out to be more expensive than expected. Unfortunately, underutilization of these resources is sometimes cheaper than transporting them to another construction site; therefore the subcontracted companies must just assume these cost increments.

This paper presents a mobile shared workspace, named COIN (Construction Inspector), which helps to address these coordination challenges. This groupware system provides mobile users with a virtual space in which information can be shared, exchanged and managed in digital format. Figure 1b shows the inspection work scenario when COIN is used. Based on the utilization of this technological solution, the coordination effort may be considerably reduced, the quality of the inspection process should improve and the process of managing contingency issues should be fast and
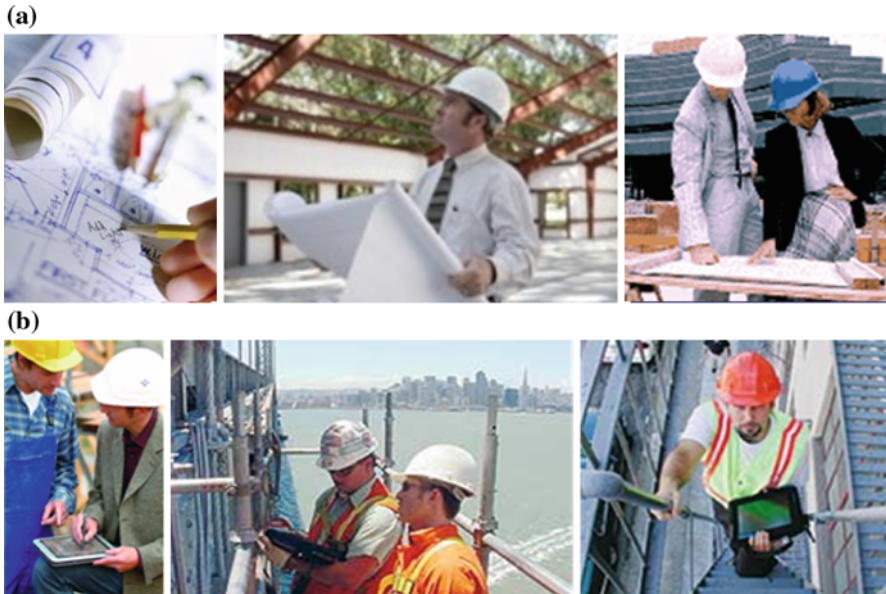
(a)

(b)

Fig. 1 **a** Current situation in construction inspections, **b** future situation based on COIN usage

accurate. COIN also provides useful online information to support the main contractor and subcontractors into the decision making process.

Next section introduces the mobile shared workspaces as tools that support mobile collaborative work, particularly loosely-coupled activities. Section 3 describes COIN and its main components. Section 4 shows the results obtained in the evaluation process. Section 5 presents related work. Finally, Sect. 6 presents the main conclusions and further work.

2 Mobile Shared Workspaces

During the last two decades, shared workspaces for wired networks have been proposed to increase the users' joint productivity. A number of studies and projects have shown that workspaces are also valuable for distributed collaboration (Gutwin and Greenberg 2002; Whittaker et al. 1993). Typically, these groupware applications consider distributed users communicated by a wired network. However, advances in mobile computing devices and wireless communication have allowed transporting the shared workspace metaphor to mobile work scenarios. In those scenarios, a group of mobile workers are on the move to carry out the assigned activities. Workers in these groups are weakly dependent on each other; they can function autonomously and collaborate on-demand. This type of collaborative work is known as loosely-coupled work (Neyem et al. 2007; Pinelle and Gutwin 2005). If mobile workers collaborate on demand, then they have to be aware of the others' locations and availabilities in order to communicate and coordinate their work (Pinelle et al. 2003).

Fig. 2 MSW supporting loosely-coupled work

These mobile shared workspaces (MSW) seem to be an interesting tool to support mobile workers doing loosely-coupled activities. These systems are strongly being studied because of the impact they could have in productive scenarios; not only in terms of the mobile workers' productivity (Andriessen and Vartiainen 2006; Ochoa et al. 2007; Schaffers et al. 2006; Wang et al. 2005), but also in quality of the mobile work (Andriessen and Vartiainen 2006; Brugnoli et al. 2005; Neyem et al. 2007; Schaffers et al. 2006). Each mobile shared workspace represents a portion of the office (i.e. information and services) being available at a mobile worker's computing device. These systems allow mobile workers to collaborate with other people or systems in an ad-hoc way (like a plug & play mechanism), adapting themselves depending on the context information (Tarasewich 2003).

Mobile workers who could benefit from the use of MSW in different scenarios include several types of engineers, physicians, salesman, police officers, firefighters and persons doing nomadic work (Fig. 2) (Favela et al. 2007; Neyem et al. 2008; Schaffers et al. 2006; Spinelli and Brodie 2003; Tarasewich 2003). All of them carry out activities included in the category of loosely-coupled work. Therefore, they require MSW embedding functionalities to support discretionary collaboration (e.g., data sharing, data synchronization, user/session management and automatic communication mechanisms) and awareness mechanisms (e.g., users' connection, users' proximity and users' availability) which help them to decide when it is a good time to start an on-demand collaboration process.

The COIN (Construction Inspector) workspace was designed to support inspection activities in construction scenarios, and it simplifies the information synchronization and delivery processes. This tool allows discretionary collaboration and it embeds awareness mechanisms to support loosely-coupled work. COIN provides information sharing in the sense of cooperative authoring, commenting and annotating shared documents as a group activity. It runs on TabletPCs and it is able to manage several construction projects. Each project contains various digital blueprints, annotations (i.e. project's contingency issues) and tasks assigned to them. Mobile users utilizing COIN are able to collaborate and coordinate their work on-demand doing simple actions on the user interface. Next section describes the main components of this workspace.

3 The Construction Inspector Workspace

The Construction Inspector workspace was designed to help reduce the inspection and coordination effort, the number of errors due to information transportation and
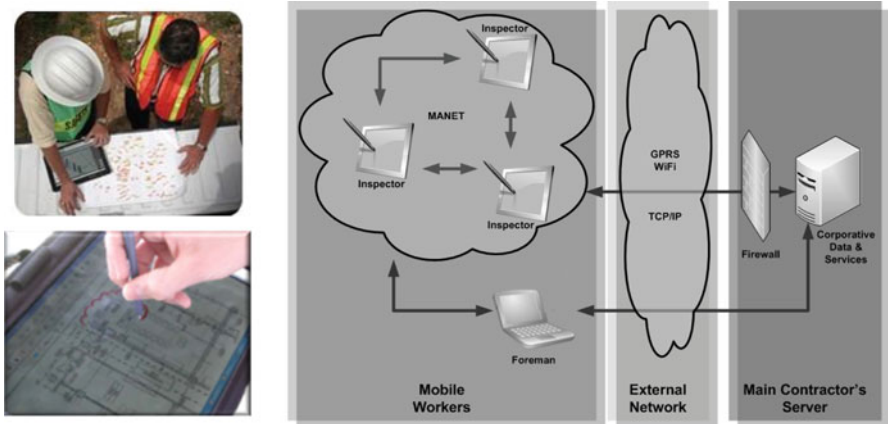
Fig. 3 Information retrieving/reporting process using COIN

the time involved in the contingencies communication process. As a consequence of COIN usage, the project's time and cost should be reduced.

COIN also supports the main contractor in the decision making process, because it is able to store and process meta-information related to inspections and generate some indicators of subcontractors' and inspectors' performance. The tool also allows managing the annotations and the status of the inspected facilities, which help subcontractors to make sound decisions to optimize their resources allocation to each project.

Several construction projects can be managed simultaneously using COIN. Each of them can include various digital blueprints that can store one or more annotations (contingency issues recorded by the inspectors). In turn, each annotation will generate one or more tasks that will be assigned and communicated to a subcontracted company or a particular worker.

Figure 3 summarizes the dynamics of the information exchange process when COIN is used to support an inspection activity. Typically, the digital blueprints composing a construction project are stored in the server of the main contractor. Inspectors can consume these blueprints or report the inspection results through Web Services exposed by that server. This communication process can be done on-demand using a wired/wireless/cellular networks; therefore the inspectors do not need to go to the company headquarters to retrieve the blueprints or report the contingency issues.

When the inspectors arrive to the construction site, their mobile computing devices automatically form a Mobile Ad hoc Network (MANET) (Aldunate et al. 2006; Tschudin et al. 2003). Although the inspectors carry out their own work in an autonomous way, depending on their physical locations they could know when their partners are near and available to collaborate. Once the inspection is concluded, and before leaving the construction site, the inspectors typically perform three activities: (1) synchronize annotations among them, (2) solve ambiguities (if needed), and (3) report the results of the reviewing process. This last task can include not only sending the information to the main contractor's office, but also to the foreman located in the

construction site. This reporting process allows subcontractors to retrieve the informal list of contingency issues from the foreman's cabin. It helps them to optimize the use of the company resources and provide a better service to the main contractor. This strategy to integrate, share and communicate information not only is faster than the paper-based process, but it also avoids annotations transcription process errors.

3.1 COIN User Interface

The COIN user interface exposes the functionality allowing mobile users manage the information of the inspection process (Fig. 4). This user interface separates the functionality in multiple panels: (1) Main Menu, (2) Navigation/Visualization, (3) Blueprints Manager, (4) Annotations Manager, and (5) Shared Panel. Next, a brief explanation of the panels is presented.

3.1.1 Main Menu

COIN main menu provides the functionality to manage projects, annotations and support collaboration (e.g. users' detection and on-demand data synchronization). The tool allows users to work on several projects. Each project is represented by an XML file storing all related information (e.g. digital blueprints, annotations and tasks). The associated application's menu provides the services for creating, opening, saving, renaming, importing/exporting and synchronizing projects. Creation of a new project triggers the creation of the corresponding XML file. Then, the various blueprints intended for inspections (e.g., the electrical one) can be added to that project.

Typically, more than one blueprint is used for any floor of the construction to be inspected. Inspectors are able to open a project and make as many annotations as they need. Afterwards, they can save or rename it, which produces an update of the XML
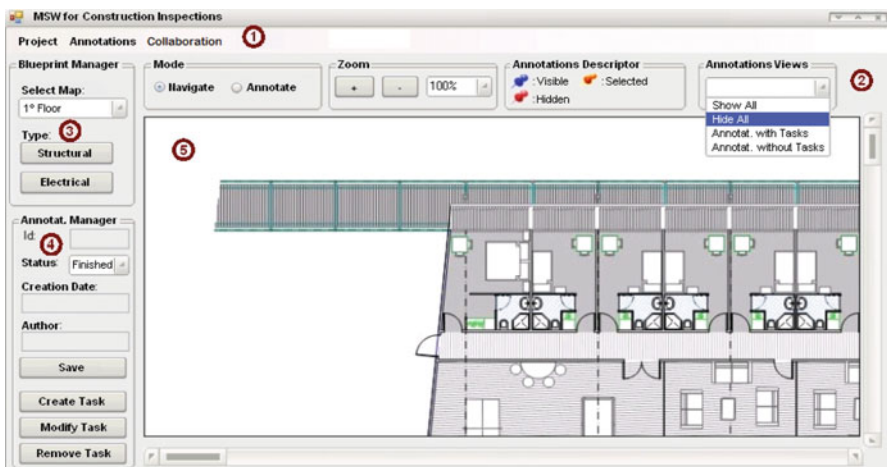

Fig. 4 COIN main user interface

file associated to the inspected project. The functionality related to importing/exporting projects is based on file transfer operations performed through Web services. Some validations are performed during these operations; in particular, the project files' format is validated to determine whether or not it adheres to a project format.

Since a complete project is represented with an XML file, the contents of these projects can be synchronized through a functionality provided by the Service-Oriented Mobile Unit (SOMU) platform (Neyem et al. 2008). This operation is available under the "Annotations" option in the main menu. The synchronization process can spend from some seconds to a few minutes depending on the information to be synchronized and the bandwidth of the communication channel between sender and receiver. However, the quality and performance of that process is highly superior to the manual one.

The "Annotations" option in the main menu also allows users with the corresponding grants to automatically generate the contingencies report (in PDF format) classifying such information under several criteria, e.g., by responsible subcontracted company or by inspector. These reports can be printed or delivered by email to the involved companies as a media to communicate the main contractor assignments.

Finally the "Collaboration" option allows the mobile workers that are reachable (i.e. physically close) and available to collaborate, interacting among them in order to reach a common goal. This common goal could be to validate the annotations before informing them to the main contractor. In that case, the inspectors meet after the reviewing process to integrate their annotations, analyze the contingency issues and identify contradictory diagnoses. This collaboration process involves the use of the synchronous/asynchronous messaging system, the annotations synchronization mechanism and the on-demand data sharing system.

3.1.2 Navigation/Visualization Menu

This panel implements the functionality required to navigate the information shown on the shared panel (panel 5) and also to do annotations on that information. The navigation *mode* indicates the functionalities the inspector will have available in the user interface. A "Navigate" mode means the mobile workers will be able to scroll and zoom-in/zoom-out the blueprints shown on the shared panel. Besides, they will be able to manage the visualization of annotations (e.g., show, hide or filter), but they cannot add or remove them. Adding or removing annotations can be done just if the mode is set to "Annotate" and the user has the grant to do such operation.

Typically, each annotation has a specific location on a digital blueprint, and it can have cero or one associated task (i.e. the task assigned to a subcontractor for dealing with that annotation). The text of an annotation cannot be modified, in order to avoid inconsistencies between the one the inspector writes and the annotation read by the subcontractor in charge of handling it. If the annotation needs to be changed, it should be removed and then re-created indicating whatever the inspector wants. Figure 5 shows two annotations on the blueprint; each one is related to the place where the pin is located. Provided the *Annotations View* is set to "*Annotations with Tasks*", just the annotations having tasks related to them are shown on the map.

Fig. 5 Visualization of annotations

3.1.3 Blueprints Manager

This panel is available once the inspector has selected a project to work on. A particular floor of the building can be selected to be inspected using the blueprints manager, and then a particular blueprint (i.e. the electrical network facilities) can be loaded on the shared panel. It allows the inspectors to start the inspection process.

The main contractor is able to add blueprints to the project through a specific COIN module. The inspectors could add blueprints to the project by synchronizing the project content with the main contractor. The inspector must have the corresponding grants on that project in order to successfully perform this operation.

3.1.4 Annotations Manager

This panel allows handling all information related to an annotation (i.e. contingency issues). It shows all the data related to the annotation being selected on the shared panel, e.g., author of the annotation, current state and date it was done. The panel also allows changing the state of an annotation, and therefore the state of the task related to it. The task related to an annotation can be added, modified or removed using the services available through this panel. Each task has a single assignment and a resource in charge of handling it; typically, a subcontracted company or a specific worker (Fig. 6). The assignment (task) has an ID, name, starting date, duration, status, company destination and previous tasks. The initial values of each assignment are set by the main contractor. The subcontracted company in charge of performing these assignments can receive this information through two ways: printed or in digital format. The assignments report in PDF format can be obtained through the "Annotations" option available in the main menu. Therefore, this report can be printed or delivered by email to the corresponding subcontractor.

Each annotation in the project not only generates a task, but also a work item that is reported and stored within the XML file. These work items record meta-information related to the reviewer who identified the contingency issue, the company responsible to address it, the reporting and completion time, and the number of re-inspections of that issue. That information will be processed by COIN to determine the inspectors'

Fig. 6 Tasks related to a
subcontractor

and subcontractors' performance in each particular project. Some of the indicators which can be easily obtained from this meta-information are the following ones: (1) number of reviews per inspector per inspection instance, (2) time period between the contingency identification and its solution, (3) number of identified contingencies related to a subcontractor's work, and (4) deadline accomplishment levels for each subcontractor.

These indicators can support the main contractor during the decision making process. Thus, the project manager can see what is happening with the contingency solution process, while the project advances. Such information allows him to replace a subcontractor in case its work is not good enough (e.g. if it requires several reviews) or slower than required (e.g. it involves long time periods between the contingency detection and its solution). This information also helps subcontracted companies to evaluate its performance and establish an appropriate resource allocation strategy to deal with the assignments.

3.1.5 Shared panel

This panel represents the main part of the COIN user interface. There, the shared information is deployed, input, reviewed and modified by the inspectors. Typically, the blueprints visualization and annotations review are the main functions used by mobile workers on this panel.

3.2 Interaction with MS Project

According to the feedback received from civil engineers who evaluated COIN, one important feature of the tool is its association with the MS Project 2007 product. The tool links annotations with the MS Project tasks related to them. All tasks are stored inside the COIN project file, but in MS Project format. Therefore, a task can be exported to be viewed and modified using that product, which is widely used in construction management. It allows the main contractor to separate the project concerns in two different plans (Gantt charts): one to manage the main advances and another to manage the contingency issues. Diagnosing the current project state can be done by using these plans together.

The annotations review and the process of task creation and follow-up in MS Project are associated to the users hierarchy implemented in the tool. Various types of users are recognized by COIN; each user type has been assigned different grants to access the annotations and the associated tasks. The users' grants are assigned by project; therefore a same user could have different access rights for different projects. The implemented user types are the following ones:

- *Full Access:* The user may create, modify and delete annotations and tasks.
- *Admin:* These users may create and modify annotations and tasks, but they cannot delete those items.
- *Normal:* These users may only read existing annotations and tasks involving them as a resource. In other words, they may read just the items assigned to them.
- *No access:* These users are not allowed to access any annotation or task related to a construction project.

A new task in the Gantt chart associated to the project is created by selecting the annotation, and then, clicking on the "Create Task" button (panel 4), which will display the dialog window presented in Fig. 6. The result will be a new task with those parameters set by the user. Such task is now part of the Gantt chart embedded in the XML file representing the project. Figure 7 shows the Gantt chart based on the tasks related to the project annotations.

Modification of a task is done as follows. The user must select an annotation associated to the task. Then, the user must click on the "Modify Task" button (panel 4). The system will display the dialog window (Fig. 6). The information related to task duration, state and responsible person can be updated. Of course, it is also possible to directly update the MS Project file using that software product, but the information will not be updated in the COIN workspace. This situation produces a data inconsistency because the MS Project file embedded in COIN is dynamically generated, as an export of the information stored in the workspace. In case more than one user create/update tasks (annotations) concurrently, synchronizing those annotations must be done before generating the MS Project file in order to get a file with all the tasks included in it.

On the other hand, the process to delete a task requires to select the annotation associated to such task, and then to click on the "Remove Task" button (panel 4). In that case, the user should enter an explanation indicating the reason for deleting the
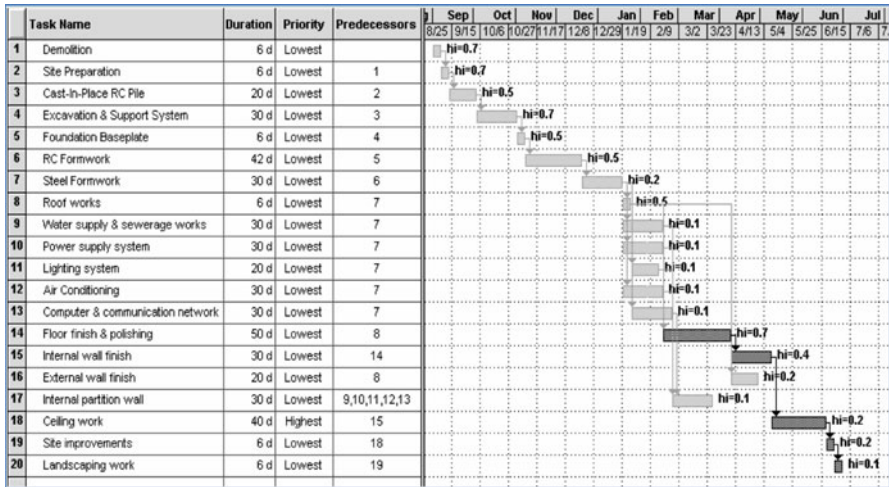
	Task Name	Duration	Priority	Predecessors	Sep / Oct / Nov / Dec / Jan / Feb / Mar / Apr / May / Jun / Jul (Gantt)
1	Demolition	6 d	Lowest		hi=0.7
2	Site Preparation	6 d	Lowest	1	hi=0.7
3	Cast-In-Place RC Pile	20 d	Lowest	2	hi=0.5
4	Excavation & Support System	30 d	Lowest	3	hi=0.7
5	Foundation Baseplate	6 d	Lowest	4	hi=0.5
6	RC Formwork	42 d	Lowest	5	hi=0.5
7	Steel Formwork	30 d	Lowest	6	hi=0.2
8	Roof works	6 d	Lowest	7	hi=0.5
9	Water supply & sewerage works	30 d	Lowest	7	hi=0.1
10	Power supply system	30 d	Lowest	7	hi=0.1
11	Lighting system	20 d	Lowest	7	hi=0.1
12	Air Conditioning	30 d	Lowest	7	hi=0.1
13	Computer & communication network	30 d	Lowest	7	hi=0.1
14	Floor finish & polishing	50 d	Lowest	8	hi=0.7
15	Internal wall finish	30 d	Lowest	14	hi=0.4
16	External wall finish	20 d	Lowest	8	hi=0.2
17	Internal partition wall	30 d	Lowest	9,10,11,12,13	hi=0.1
18	Ceiling work	40 d	Highest	15	hi=0.2
19	Site improvements	6 d	Lowest	18	hi=0.2
20	Landscaping work	6 d	Lowest	19	hi=0.1

Fig. 7 MS Project file related to the contingency issues

task. The project data will now include date and time of deletion, the user's name and the explanation.

These task maintenance activities are made easy if the user selects a convenient way to display annotations. The user is allowed to see only those annotations without associated tasks, only those having associated tasks, or another criterion (there are a few other filters available). The user can choose the filtering option in the upper part of the user interface window (panel 2).

3.3 Communication/Coordination Support

The communication and coordination support is based on the capabilities provided by the SOMU platform (Neyem et al. 2008). When a user start-ups a mobile computing device, it automatically detects physically close peers and it tries to form a Mobile Ad hoc NETwork (MANET) (Aldunate et al. 2006; Tschudin et al. 2003). These networks are formed on-demand and do not require any pre-existing communication infrastructure (e.g. access points), because each mobile computing device act as a network node and a repeater. The IP addresses of the devices forming the MANET are randomly assigned considering a predefined IP range. Duplicate addresses are automatically detected by the network protocol, producing the address migration of one node with identical IP.

The SOMU platform also provides peers' detection, users' connection awareness, file transfer and data synchronization. All these services are useful to support the inspectors' work; therefore such functionalities were embedded as part of COIN.

In order to ease the coordination process among the companies involved in a project, COIN provides two ways of reporting the contingency issues. The first strategy is to use the contingencies report mentioned in Sect. 3.1. This report is a PDF file containing the annotations to be addressed by a particular subcontractor, and the Gantt chart

related to those contingencies. Then, such information is given to the corresponding subcontracted company as a printed report or by email. Due to privacy reasons, a particular subcontractor is not able to see the contingencies to be addressed by others subcontractors.

The second reporting strategy involves the use of COIN as a contingencies management tool. In this case each subcontractor should have a computer running COIN and embedding the annotations assigned to it. The main contractor office could expose Web services allowing a valid subcontracted company to retrieve its digital blueprints (with the contingencies) and the Gantt chart assigned to it, and also to inform when these issues were solved. Thus, the coordination process considerably improves in terms of accuracy, agility and flexibility. Of course, the main contractor could also use both reporting strategies if it is not sure if the contingency issues will be addressed on time. In addition, this second strategy allows subcontractors to retrieve the interim annotations assigned to them from the foreman cabin, as a way to reduce the time for treating each contingency and to optimize the allocation of the company resources.

3.4 Implementation Issues

COIN was mainly implemented in C# using the .Net Framework. The tool is able to run on tablet PCs and notebooks. However, there is a slim version of COIN which was implemented using the .Net Compact Framework and able to run on PDAs. For usability reasons this second option was discontinued.

This workspace follows a traditional groupware system architecture with three layers dealing with the three major groupware concerns: communication, coordination and collaboration (Neyem et al. 2008). The functionality of the two lower layers (communication and coordination) is provided by the SOMU platform, on which this application runs. The communication among collaborators is supported mainly by Mobile Ad-hoc Networks (MANETs) (Aldunate et al. 2006).

The implementation of this Mobile Shared Workspace (MSW) involved just standard technologies in order to ease the interoperability among MSWs belonging to different companies participating in the construction process. The project data is stored in XML, the interactions among collaborators are supported by Web Services and the communication support is mainly provided through MANETs adhering to the IEEE 802.11b/g norm. The MSW also includes communication support via cellular networks, such as GSM and 3.xG.

4 Obtained Results

The design and development of this tool was supported mainly by two civil engineers who currently perform construction inspections activities for the industry. In order to determine the pertinence of the COIN functionality, the *cooperation scenarios* evaluation method (Stiemerling and Cremers 1999) was periodically used during the development process. This method allowed the authors to identify interaction scenarios, cooperative behaviors, users involved in them, their roles and the relevant

work contexts. This information was gathered based on semi-structured interviews and workplace visits.

For each role involved in the cooperative activity, the authors analyzed how to take advantage of the technology to support its work. Once a prototype was obtained, it was shown to the users in order to receive feedback allowing us to evolve the product. Finally, when COIN was stable, the workspace was tested in a controlled work scenario. Next sections explain the experimentation process and the obtained results.

4.1 Experimentation Process

The main experience was carried out in the Computer Science Department of the University of Chile. It involved an area of $2,000\,\text{m}^2$ approximately, deployed in two floors. These areas included mainly offices, meeting rooms, laboratories and public spaces. Forty labels indicating contingency issues were adhered to the physical infrastructure and the electrical facilities.

Two civil engineers with an important experience in construction inspections conducted the reviewing process. In turn they first used COIN running on a Tablet PC to carry out the inspection, and then they repeated the process using physical blueprints. After the first inspection, the labels simulating contingency issues were changed and relocated trying to reproduce the experimental conditions of the first experience. An observer followed the activities of each inspector in order to verify the coherence between the inspectors' opinions and the empirical observation. These observers were in charge of recording the time spent in each studied tasks.

Previous to begin the activities, the inspectors agreed a common strategy to conduct both inspections processes. Afterwards they performed two activities: (1) to conduct the inspection process and (2) to determine the coherence of the annotations. During the first activity the inspectors identified the contingency issues and created the corresponding annotations. Subsequently, they met to review each annotation. They decided the reviews were consistent.

After performing these activities the inspectors were interviewed in order to determine their feeling about the use of the tool to support inspection processes. Besides, authors asked inspectors to estimate the duration of activities which were additional to the inspection itself (e.g. integration of annotations done on blueprints), which were not conducted in this experimentation process. The idea was to establish a sound parameter to compare the whole process of inspection with/without COIN usage.

4.2 Experimental Results

Table 1 shows the results obtained during the first two activities of the experimentation process. These results indicate an improvement of the elapsed times when COIN is used. During the interview to the inspectors both indicated they preferred to use COIN because: (1) digital maps are easier to use than paper-based blueprints, (2) writing annotations on the screen of a tablet PC is more comfortable than writing them on a blueprint placed on a wall, (3) the user mobility improves when COIN is used, and (4) reviewing annotations is faster when using COIN because both tablet PCs can be put

Table 1 Results of the inspection process

Experience	Labels found	Inspection—elapsed time (min)	Annotations review—elapsed time (min)	Total elapsed time (min)
With COIN	37	23	6	29
Without COIN	38	35	9	44

Table 2 Results of coordination activities

Experience	Time for retrieving blueprints	Time to integrate annotations	Time for reporting annotations	Tasks creation—elapsed time	Contingencies report—creation time
With COIN	<2 min	<1 min	<2 min	35 min	<2 min
Without COIN	Go to the main contractor's office	1 h*	Go to the main contractor's office	40 min*	1–2 h*

* Estimations done by the inspectors

together, and thus the distance between annotations to be compared is small (it easies the process).

Although the use of COIN shows positive results, they do not represent a great improvement to the current inspection process. The key reason behind the COIN design was the improvement of the coordination process, in terms of time and accuracy, among the companies involved in the construction project. Therefore, some additional tests were done with the inspectors once the inspection process was concluded.

Table 2 shows interesting improvements in the coordination activities. For example, digital blueprints can be retrieved from the main contractor's server through a Web service which is accessed via Ethernet or a cellular network when COIN is used. This operation involved less than 2 min and avoided the trip to the main contractor's office. During the experimentation process, the blueprints where retrieved from a server located at the basement of the building where the inspection was performed. The communication support was a Wi–Fi network.

The process to integrate the annotations done by the inspectors involved less than a minute when COIN was utilized. By contrast, the integration could have taken about one hour for paper-based inspection.

The time to report the annotations to the main contractor is also considerably reduced because COIN is able to report them through two different communication networks. Thus, the inspectors do not have to go to the main contractor's office after each inspection to report the results.

The time spent to create the tasks related to the annotations is similar in both cases. Nevertheless, this activity can be done by several users working in parallel when COIN is used. It avoids the main contractor's employees becoming a bottleneck. A similar situation happens with the creation and delivery of contingencies reports. However, the use of COIN has an additional benefit in this case: the brief time required for the creation and delivery of such report.

The use of COIN also reports a benefit in the quality of the activities coordination process, because it avoids the errors by manual transcription and integration of annotations. In the inspectors' opinion, it makes the process fair and trustful for all the involved companies.

Finally, the inspectors were asked about the COIN usability and the limitations of using a Tablet PC to conduct the inspection process. With respect to the first issue, they found the application usable and helpful for the inspection process. They acknowledged the value of the tool to support the coordination activities and data exchange. This information matches with the observers' opinions, whom followed the inspection process.

Concerning the use of Tablet PCs, the authors asked the inspectors about the limitations caused by the battery life, the screen light and the weight of the computing device. Although they did not identify limitations during the experimentation process, they mentioned the battery life is a challenge to deal with if COIN is used in real scenarios. Extra batteries and power-plugs for cars where suggested as first alternatives. Anyway, it represents a temporal limitation, because recent research in this area is showing this problem will be easy to overcome (Chan et al. 2008). Next section presents the corresponding related work.

5 Related Work

Several researchers in construction management have identified the importance to count on mobile computing solutions to replace the paper-based work (Bowden et al. 2004; Chen and Kamara 2008; Kimoto et al. 2005; Rebolj and Menzel 2004). However, few proposals have been done in such direction. As evidence of it, Turk has recently presented an ontology of solutions based on Information and Communication Technologies (ICT) to support construction projects (Turk 2006). The ontology is based on the analysis of the last seven editions of the two most important conferences in Construction Informatics. Such ontology shows most of the current relevant works involve stationary computing solutions. The article also emphasizes the importance of supporting collaboration among mobile workers during construction projects, but it does not identify a clear proposal to address this need.

Similarly, Kimoto et al. (2005), Löfgren (2006) and Chen and Kamara (2008) have also identified this need and they have proposed guidelines to use mobile technology to support the construction inspection process. However, none of these proposals present a technological solution to get the envisioned benefits.

The closest works in this area were proposed by Saidi et al. (2002) and the COMIT Project COMIT (2008). These proposals present software applications that run on PDAs (Personal Digital Assistants) and they allow mobile users to do basic annotations. Although using these applications is better than using paper-based information, they do not support instances for collaboration among the actors involved in the inspection process. In addition, these solutions are based on PDAs, therefore they have several usability problems to do hand-written annotations (Guerrero et al. 2006; Ochoa et al. 2007). In fact, COIN also runs on PDAs, but our usability tests indicated that plat-

form is not appropriate to support construction inspection processes: PDAs are not comfortable enough to input unstructured and intensive data (Guerrero et al. 2006).

On the other hand, there are collaborative solutions proposed to support mobile workers in specific settings (André and Antunes 2004; Guerrero et al. 2006; Menchaca-Mendez et al. 2004; Muñoz et al. 2003; Zurita et al. 2005), different to construction management. These proposals have shown to be useful to support particular collaborative processes; however, they were not designed as general solutions, therefore it is not easy to reuse or adapt them. Moreover, most of these solutions are not applicable to the construction inspection scenario because they are not able to deal with loosely-coupled work.

Initiatives in the middleware area, such as YCab (Buszko et al. 2001), JXTA (JXTA Project 2008), LaCOLLA (Marques and Navarro 2006) and iClouds (Heinemann et al. 2003), are also related to this proposal from a technical point of view. These products allow the software applications to support collaboration in peer-to-peer networks. However, they do not provide support to exchange shared objects, synchronize files or work without connecting to a server. The SOMU platform (Neyem et al. 2008) which is the basis of COIN, is a middleware able to deal with these requirements. Therefore, COIN inherits such capabilities. Based on the analysis of related work in this area, it seems that COIN matches a current need in construction management.

6 Conclusions and Future Work

Several technological trends are affecting the future of mobile work (Brugnoli et al. 2005). Low cost communication services, such as WiMax and WiMax Mobility, are becoming increasingly common every day. Periodically, mobile computing devices reduce their cost and increase their computing power. These advances promote the inclusion of mobile applications in many scenarios, such as education, health, productive processes, security and business (Schaffers et al. 2006). Particularly, advances in MANET and the development of collaboration frameworks like SOMU (Neyem et al. 2008), enable now stakeholders to do inspection-related tasks in a faster and less error-prone way than a few years ago.

This paper presents a mobile shared workspace (MSW), named COIN (Construction Inspector), designed to support construction inspection processes. Although, mobile shared workspaces are not currently used in the construction industry, they could play an important role while coordinating the efforts carried out by companies involved in a construction project.

Among the main functions that COIN exposes to mobile workers are the following ones: manage the inspections in several construction projects, retrieve digital blueprints from a remote server, do annotations on digital blueprints, create tasks linked to the annotations, report an inspector's results to a remote server, synchronize information of a project, exchange information among collaborators, create and deliver contingencies reports and retrieve metrics to evaluate the inspectors and subcontractors performance. These functionalities help reduce the coordination time and cost, reduce the number of human errors in annotations integration and transcription, and

keep an updated overview of the project. It is expected COIN could also support the decision making process carried out by the main contractor and subcontractors.

The tool was evaluated by two civil engineers experienced in construction inspections. The evaluation process involved two inspection activities: the first one using COIN and the second one using paper-based blueprints. Although the use of COIN showed a positive impact in terms of effort required to conduct the inspection process, the main contribution of the tool was clear when the authors compared the effort spent in coordination activities. In such category, the use of COIN is at least one order of magnitude better than the paper-based process. Typically, it has a positive impact on the project's cost and duration. In addition, the use of COIN reduces the number of human errors and makes the inspection process fair and trustful. Therefore, this tool could represent an interesting contribution for the construction industry.

The indicators provided by the tool to evaluate the performance of inspectors and subcontractors were not considered during the experimental process. The main reason was no main contractor participated in the process. However, the inspectors were able to see and briefly analyze these indicators. In their opinion, these metrics look useful to support decision making processes usually carried out by the main contractor. The evaluation of these metrics is part of an experiment currently being designed, which involves a real inspection scenario: a main contractor, inspectors, subcontractors and a building under construction. Moreover, additional features are being added to the MSW, particularly the capabilities to do audio-annotations on the digital blueprints. It is expected this feature helps to considerably reduce the time spent in an inspection process.

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