Context Aware Information Delivery for On-Site Construction Operations

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ABSTRACT: The information intensive nature of construction projects requires the site personnel to have an on-demand access to project information. Current information delivery methods are primarily static and do not take into account the site personnel's changing context. Delivering information to site staff, based on their context (such as location, time and profile) has the tremendous potential to improve construction productivity. In this paper a prototype application for context-aware information delivery is discussed. The implementation is based on a Pocket-PC platform and makes use of wireless local area networking (WLAN) to capture context parameters. A semantics-based Resource Description Framework Schema (RDFS) is used for both context interpretation and to define construction documents and project task structure. Conclusions are drawn about the possible future impact of context-aware applications for the construction industry.

1 INTRODUCTION

The construction industry is experiencing unprecedented change and dynamic conditions resulting from clients demanding better value-for-money, higher quality, shorter cycle times and access to the latest information, produced at any point in the project life cycle and supply chain. This demand reflects the increasingly competitive pressure to deliver faster and cheaper solutions. Current thinking within the industry is that major benefits can be obtained through improved collaboration and enhanced enterprise efficiency. A fundamental underpinning to achieve these goals is construction field force enablement, by ensuring optimal support for onsite staff.

The information-intensive nature of construction projects requires the site staff to have on-demand access to construction project plans, drawings, schedules, budgets, etc. The unstructured and dynamic nature of the construction site, and the hazards and difficulties presented by the on-site work, also necessitate the use of intelligent ways to support on-site construction staff.

In recent years, the emergence of powerful wireless web technologies coupled with the availability of improved bandwidth, has enabled mobile workers to access in real time different corporate back-end systems and multiple inter-enterprise data resources to enhance construction collaboration. Context-aware information delivery adds an additional layer on top of such real time wireless connectivity, by providing the ability to intelligently interpret the user context, and delivering data and services to the mobile worker based on the user's context. This way, it is possible to eliminate distractions for mobile workers, related to the volume and level of information. Also, user interaction with the system can be reduced by using context as a filtering mechanism to deliver only context-relevant information to users. This has the potential to increase usability, by decreasing the level of interaction required between the mobile devices and the end-users. The emergence of complementary technologies such as user profiling, ubiquitous computing and sensor networking enables the capture of many other context parameters.

This paper presents a scalable architecture and a prototype implementation for a context-based information delivery system for supporting construction site staff. The paper is organised as follows. The next section reviews the concept of context-aware computing and related work. Section 3 discusses the system architecture for context-aware data delivery, and is followed by presentation of the prototype system. Section 5 presents the future outlook and summary.

2 CONTEXT-AWARE COMPUTING

Context-aware computing is defined by Burrell et al (2001) as the use of environmental characteristics such as the user's location, time, identity, profile and activity to inform the computing device so that it may provide information to the user that is relevant to the current context. Context-aware computing enables a mobile application to leverage knowledge about various context parameters such as who the user is, what the user is doing, where the user is and what terminal the user is using. The application adapts services to the interpreted context, thereby ensuring that the busy user gets highly specific data and services (Schilit et al., 1994). Pashtan (2005) described four key partitions of context parameters, including user static context, user dynamic context, network connectivity and environmental context (Figure 1).

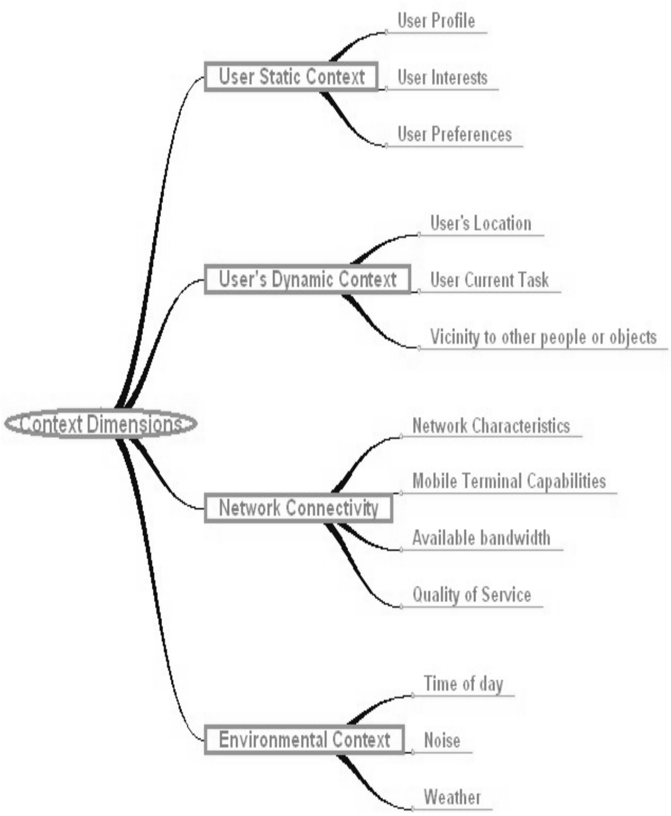

Figure 1. Context Dimensions

2.1 *Related Work*

The application of context-awareness for mobile users has been demonstrated in a large number of applications, including fieldwork (Kortuem et al., 1999; Pascoe et al., 1998), museums (Fleck et al., 02; Lassila et al., 2003), route planning (Marmasse et al., 2002), libraries (Aittola et al., 03) and tourism (Long et al., 1996; Laukkanen et al., 2002). Other projects that have specifically focused on location-based data delivery include the GUIDE project (Davies et al., 99) and the Mobile Shadow Project (MSP) (Fischmeister et al. 2002). The MSP approach is based on the use of agents, to map the physical context to the virtual context. Ambience project (Ambience, 2004) has adopted a different approach by focusing on creating a digital environment that is aware of persons' presence, context, and sensitivity and responds accordingly. Context-aware applications are also being investigated by other fields of research in computer science, including mobile computing, wearable computing, augmented reality, ubiquitous computing and human-computer interaction.

There is also a great deal of interest in the application of Semantic Web technologies in context aware applications. The Semantic Web technologies provide a framework for shared definition of context, resources and their relationships. It also provides an application and platform independent way to interpret context, thereby enabling both humans and software agents to infer new context knowledge and consequently take intelligent actions. In the Konti Project, an ontology is developed for expressing the properties required for constructing contextual profiles (Toivonen et al., 2003). Chen et al (2003) also applied the Semantic Web technologies for modeling context and for supporting context reasoning.

3 CONTEXT AWARE SERVICE DELIVERY ARCHITECTURE

The concept of "context-aware information delivery" as discussed in this paper centres on the need to provide mobile construction workers highly specific information and services on an as-needed basis. This concept goes beyond merely capturing user context. It encompasses the creation of a pervasive, user centred mobile work environment, which has the ability to deliver relevant information to the workers by intelligent interpretation of their context so that they can take more informed decisions. Figure 2 presents a system architecture for context aware information delivery. It is based on multiple tiers which are explained below:

3.1 *The Client Tier*

The Client tier provides users with access to the system. It also facilitates context capture. It includes WLAN-enabled devices and WLAN tags, which contain information about the objects they are attached to.

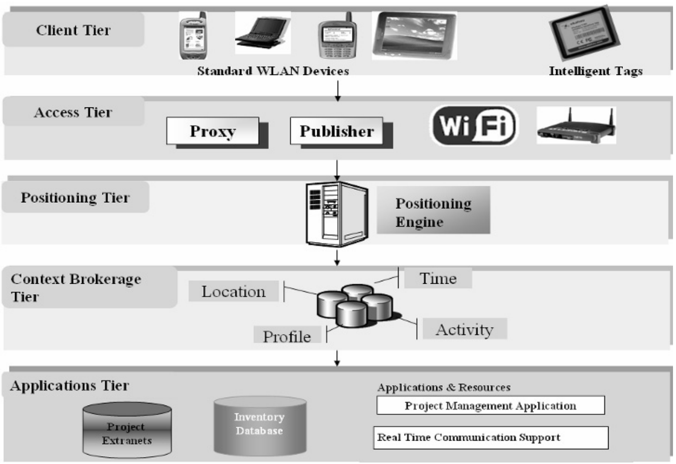

Figure 2. Context Aware Services Delivery Architecture

3.2 The Access Tier

This provides the vital communication link between the wired back-end and the wireless front-end, using a WLAN-based infrastructure. The proposed architecture relies entirely on standard Internet technologies (e.g. IP addressing, HTTP). This ensures that any IP-based wireless technology can possibly be used. Key components in the access tier include a proxy and a publisher. The proxy server keeps a cache of active user sessions and the most accessed services. This eliminates unnecessary traffic over the wireless network. The publisher handles device detection and content update based on the changing user context. The access tier supports both push and pull modes of interaction (i.e. information can be pushed to the user while the user can also proactively access the relevant information.

3.3 The Positioning Tier

The positioning tier tracks all mobile devices and tags in a wireless domain and determines their current location, by displaying coordinates corresponding to device/tag current location on a map. Tags contain important information about the object they are attached to.

3.4 The Context Broker

The context broker acquires context information, applies semantics-based reasoning to the captured contextual information and determines information relevant to users based on their existing context.

3.5 The Application Tier

It contains construction applications and services, to support mobile workers. As logic and data processing resides on the wired network, the mobile client is charged with minimal memory and processor-consuming tasks.

4 CONTEXT BROKERAGE AND MAPPING

Five context dimensions are addressed in this research, including Location, Time, User Device, User Profile and User Activity (Figure 3).

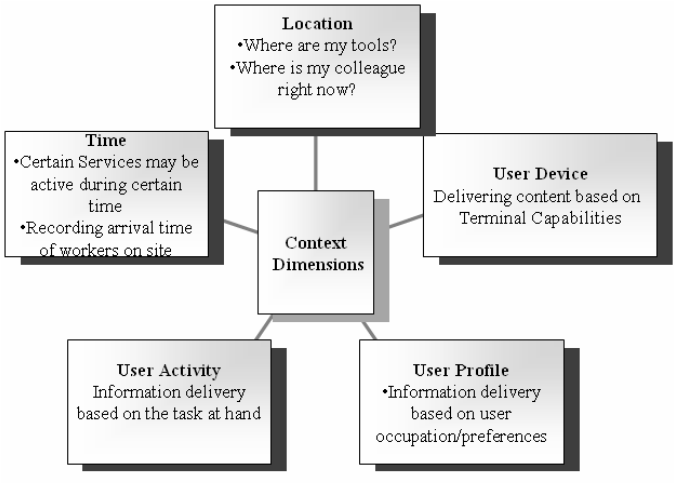

Figure 3. Context Dimensions

Context is drawn from the following sources:

- Current location, via a wireless local area network-based positioning system. A client application running on a user's mobile device or a WLAN tag sends constant position updates to the position engine over a wireless link. This allows real time position determination of users and equipment;
- User Device, through a Microsoft.NET framework application;
- User profile, associated with mobile device's unique IP address;
- User's Activity via integration with MS Pocket Outlook;
- Time via computer clock.

Changes in the context prompt the context broker to trigger the pre-programmed events. Events may include delivery of push-based messages to the users (e.g. H&S warnings) or an exchange of information with other applications, to make them aware of the events on the site. As the user context changes (e.g. change of location, tasks), the context broker recalculates the available services to users in real time. In the prototype implementation, RDF schema (RDF, 2004) was used to provide vocabulary and structure to express the gathered contextual information. Previously, many researchers have also used RDF schema for representing and delivering the context information (Ferscha et al., 2002; Chen et al., 2004; Toivonen et al., 2003). Being XML-based, RDF also ensures provision of context information in an application and platform-independent way.

Using RDF schema, the context broker maps captured contextual information to available data and services.

Mapping includes:

- *User Profile to Project Data:* Mapping of information, based on the role of user on site;
- *Location to Project Data:* Mapping user location to project data (e.g. if electrician is on floor 3, he probably requires floor 3 drawings and services);
- *User Task to Project Data:* Mapping information delivery to the task at hand.

This mapping is then *used* as a filtering mechanism to find relevant documents for a given context. Figure 4 shows a higher level ontology used in the mapping process, describing the link between user profiles and associated resources.

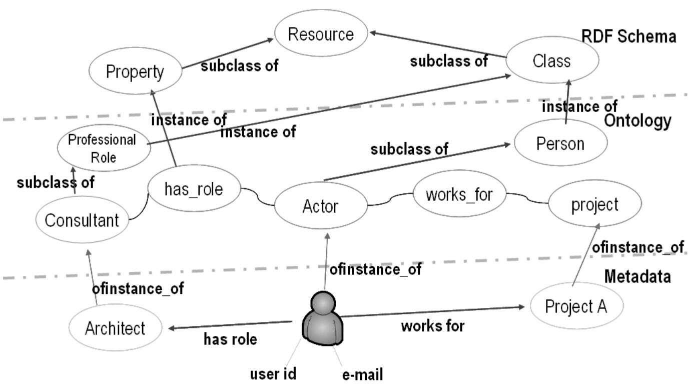

Figure 4.Team Profile Ontology

The Resource Description Framework Schema (RDFS) was selected as the ontology language of the system. With regard to ontologies, RDFS provides two important contributions: a standardized syntax for writing ontologies and a standard set of modelling primitives such as ‘instance-of’ and ‘subclass-of’ relationships (W3C, 2004). Ontology is developed using a modular approach with high flexibility so that it can be extended to accommodate an unlimited amount of new ontologies in the future.

RDF was also used as a meta-language for annotating construction project resources, drawing, images etc. with machine readable information. For instance, the RDF description of a CAD drawing of the main entrance slab with unique identification FF-A23 is illustrated in Listing 1.

Such a semantic description provides a deeper understanding of the semantics of construction documents and an ability to flexibly discover required resources. The RDF schema can also become more detailed by adding related documents and tasks. A semantic view of construction project resources logically interconnects project resources, resulting in the better application of context information. At the same time, semantic description enables users to have different views of data, based on different criteria such as location and profile (e.g. all the electric drawings for floor 3). This allows mapping of the captured context (e.g. Joe is an electrician working on floor 3) to available data (e.g. drawings of floor 3).

```
<rdf:description
about="http://www.lboroCivilExtension.co.uk/dra
wings/Floor1/MainEnteranceSlab.CAD"
ref:ID="FF-A23">
        <res:creator>
        <rdf:Description>
            <architect:name> Joe Blog     </architect:name>
            <architect:email> joe.blog@lboro.com
</architect:email>
        </rdf:Description>
        </res:creator>
    <res:description> Drawing OF Main Enternance Slab for
Floor 1 </res:description>
    <res:title> Floor 1 Main Enterance Slab Drawing
</res:title>
    <res:date> Feb 10, 2005 </res:date>
    <res:type> CAD Drawing </res:type>
</rdf:description>
```

Listing 1. RDF description

5 PROTOTYPE IMPLEMENTATION:

5.1 *Overview*

The prototype implementation involves a proof-of-concept demonstrator and provides an initial working model of a large, more complex entity. It demonstrates some of the concepts presented in this research in realistic construction scenarios. The implementation is based on a Pocket-PC platform. It makes use of a wireless local area network (WLAN)-based positioning engine to map a user’s physical location to a virtual environment. Figure 6 shows the implementation architecture.

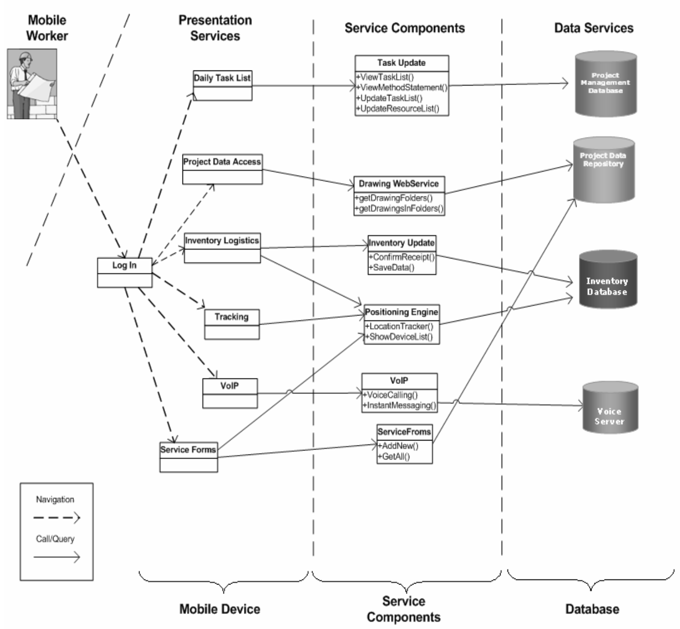

Figure 6. The application architecture

After a successful Log-In, the site worker can see a set of services. These services could be accessed on an as-needed basis. Three of these services are discussed in more detail below:

5.2 *Profile Based Task Allocation*

This implementation describes the process by which tasks are allocated to site workers based on their profile. Task list specifies the activities a site-worker must perform and it also includes the associated method statement, describing how tasks need to be performed. As the site worker arrives for work, the site server detects the unique IP address of their mobile device and prompts the worker to log-in. On a successful log-in, the worker can see his/her task list and associated method statement (Figure 7).

Using an administration application, the site manager assigns tasks and method statements to site worker. The client application running on the site worker mobile device detects that data on the server has been changed. The changed files are then synchronized using WLAN-based synchronization. Synchronization is a two ways process (i.e. synchronizing files between the mobile device and the server application). This way, the completion of tasks can be monitored in real-time and an audit trail maintained. A Similar concept can be used to update changes in project management plans.

5.3 *Inventory Logistics Support*

WLAN tags were used to store important information about a bulk delivery item. XML schema was used to describe the tag information structure. As the delivery arrives at the construction site, an on-site wireless network scans the tag attached to the bulk delivery and sends an instant message to site manager's mobile device, prompting him/her to confirm the delivery receipt.

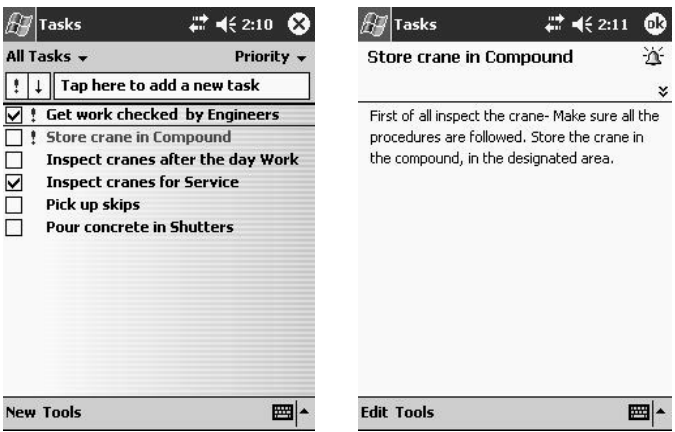

Figure7. Profile based task allocation

The site-supervisor browses through the delivery contents and records any discrepancies. Once the delivery receipt is confirmed (Figure 8), data is stored locally on the site manager's mobile device. Local information stored on the mobile device is subsequently synchronized with the site server, resulting in an update of the inventory database.

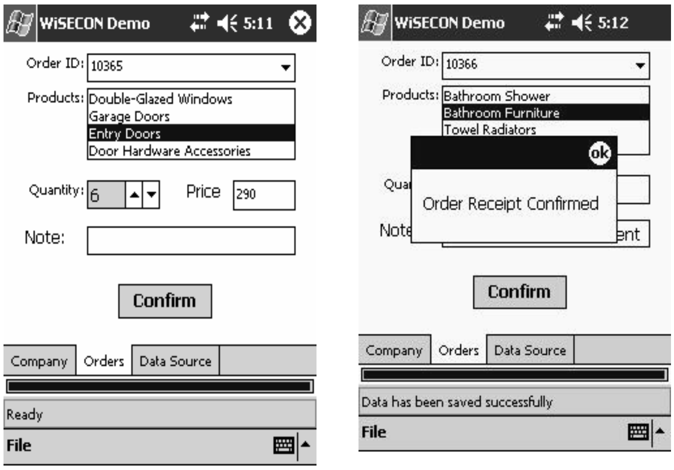

Figure 8: Inventory Logistics Support

5.4 *Real Time Tracking Support*

For real time tracking support, a WLAN-based positioning engine from Ekahau (Ekahau, 2004) was used. The Positioning Engine tracks the real time position of a WLAN-enabled mobile device/tag. It discovers all the WLAN-enabled devices using their IP addresses, and makes use of the signal strength measurements as detected by the access points to determine the actual position. A key advantage of using a WLAN-based positioning engine is that it has considerably less infrastructure requirements, compared to other location determination techniques such as Global Positioning System (GPS) and other real time location tracking systems. This makes it affordable for deployment in a site environment. Also, it is appropriate for use within the indoor environment.

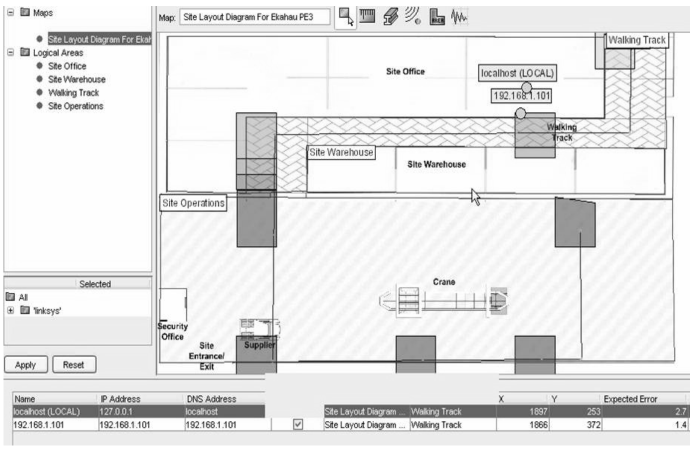

Figure 9: Tracking a notebook device and a W-LAN tag

As the user moves across the construction site, his location details are updated on the corresponding site map using a positioning engine. Real time positioning of site workers can be recorded for Health and Safety objectives. Four logical areas were defined within a simulated construction site, including a site office, site warehouse, a walking track and site operations area (Figure 9). As a site worker enters a restricted area, appropriate warning messages are generated.

Similarly, tracking information was used to assist site-operatives to query the system using various search strings (e.g. Device type and area, etc). Using a positioning engine, a mobile worker can obtain a map-based navigation from his/her current location to the target object. Also, knowledge of the user's location was used to deliver data relevant to the location context (Figure 10). To implement this functionality, an XML Web Service was written to query the semantically annotated data on the server, using the location context as a filtering mechanism.

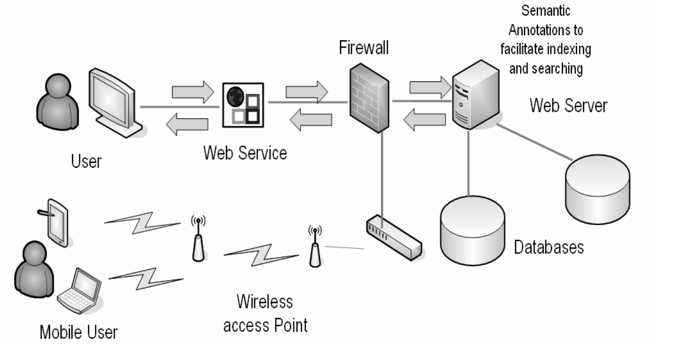

Figure 10. Location-based data delivery

6 SUMMARY AND OUTLOOK:

In this paper, the architecture and implementation of a context-aware information delivery system for mobile construction workers was discussed. The application of Semantic Web technologies, both in context interpretation and at the application and services layer allows for better understanding of contextual meaning and relationship. Better context-awareness has the potential to cause a paradigm shift in construction management practices, by allowing mobile workers access to context-specific information and services on an as-needed basis. The proposed architecture can be adapted to different implementations. For instance, integration with a project management application will allow a project manager to monitor:

– What tasks have been assigned to worker A?
– How much time has it taken for worker A to complete the tasks?
– Which task is worker X involved in right now?
– What is the on the task queue (tasks which can be allocated to workers in real time)? Based on worker location and real time progress, how can this task queue be allocated to workers?

The knowledge of such contextual information allows for better monitoring of the current status of the project (the tasks completed) and the velocity with which the project is moving ahead (against the project plan). In future, using different enabling technologies such as wireless communications, smart materials, sensors and actuators, it is possible to capture a wide range of context variables. This enables the design of better user-interfaces, by shifting the focus from explicit to implicit human-computer interaction (Schmidt et al., 1999). It also prevents users from information overload, thereby allowing the site workers to do their tasks efficiently and safely. Also, new application scenarios are becoming viable by the ongoing miniaturisation, developments in sensor networking, the increase in computational power and the fact that broadband is becoming technically and financially feasible. However, realisation of the real potential of context-aware services for mobile computing in the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. At the same time, at the level of an individual construction firm, it often takes more than technology to determine whether or not returns on innovation investments are always positive. Also there is a need for successful industrial case studies. The next step in this research is to undertake field trials to test the prototype system in a real life construction project.

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