CAN NFC SUPPORT VIRTUAL LEAN CONSTRUCTION?

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ABSTRACT

Near Field Communication (NFC) is a short-range (0-10 cm) wireless connectivity and identification technology that evolved from a combination of passive Radio Frequency Identification (RFID) and peer-to-peer technology. NFC is currently experiencing a major breakthrough in low-cost consumer electronic devices such as mobile phones and it has the possibility of becoming a technology that is simple and easy to introduce as a support within digitalisation of data collection in construction.

Therefore, it was decided to evaluate if NFC is capable of supporting Virtual Lean Construction by testing an early prototype of a quality and project progress management application for NFC enabled mobile phones. According to the author's observations, interviews, questionnaires and technology experiments the future users perceive benefits of enabling the technology during planning, quality management and follow-up. Use of traditional consumer equipment such as the NFC compatible mobile phones, was found to be a crucial aspect to lower the barrier of introducing automatic object identification in construction, but it is proposed to combine this technology with other identification technologies to improve reading distance and thereby potential uses.

KEY WORDS

NFC, RFID, Virtual lean construction, Ubiquitous technology

INTRODUCTION

Near Field Communication (NFC) is a short-range (0-10 cm) wireless identification and connectivity technology that evolves from a combination of passive Radio Frequency Identification (RFID) and peer-to-peer technology. NFC is currently experiencing a major breakthrough in low-cost consumer electronic devices such as mobile phones and digital cameras for identification, payment and information transfer. NFC is, within a short time expected to be a ubiquitous technology and so, no new communication infrastructure or hardware devices will be required to implement this technology in the construction industry.

Virtual Lean Construction, defined as lean construction enabled by virtual design and construction is one of the most promising developments to enable a leaner construction industry. It supports some of the important aspects of lean construction such as visualisation of design consequences to improve customer satisfaction, a structured work process reducing errors and waste, and efficient methods for planning and control of construction processes. To benefit from the Virtual Lean Construction it is important that the virtual models used as the primarily information carriers and

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planning tool in the construction process are consistent and continuously updated during the whole design and construction period. To enable this, automatic object identification by means of radio frequency identification (RFID) is in several research projects proposed as a key technology to enhance data capture and information management in construction (Jaselskis, 1995; Sacks et al., 2003; Chin et al., 2008). NFC is an example of such an RFID technology that can enable the easier data collection for process control, on-site and quick access to information stored in virtual models and improved logistics and inventory management

Therefore, it was decided to evaluate if NFC can support Virtual Lean Construction by testing an early prototype of a quality and project progress management application (in the following called Mobile Manager) for NFC enabled mobile phones. The evaluation was primarily qualitative and explored usefulness of the prototype in construction practice, barriers for implementation and usability of the user environment. This work was part of the author's research for obtaining the PhD degree and this paper briefly summaries the important findings from the practical evaluation.

EVALUATION METHODOLOGY

In this evaluation, the author has focused on qualitative evaluation methods since they are particularly helpful for evaluating complex systems involving several tasks embedded in other activities that include multiple users (Preece et al., 2002). The DECIDE (Determine-Explore-Choose-IDentify-Evaluate) framework (Preece et al., 2002) was used to structure and direct the prototype evaluations because it provides a useful checklist for planning an evaluation as described below:

Determine the overall goals addressed in the evaluation: The overall goal is to evaluate if NFC can support Virtual Lean Construction. This is done by evaluating the functionalities, usefulness and practical applicability of the Mobile Manager system. Lessons learned must be listed in a usable form for future development and new user needs must also be captured.

Explore the specific questions to be answered: The overall question "Can NFC support Virtual Lean Construction?" is evaluated through the following sub-questions: Does the technology work in practice and is it ready for implementation in construction? Do the methods, designed for quality management and project progress management for NFC enabled mobile phones, make sense for construction managers as well as labourers? The questions are further elaborated in the evaluation described below.

Choose the evaluation paradigm and techniques to answer the questions: The paradigms "Quick and dirty" where designers informally get feedback from users to confirm the ideas, and field studies are mainly used for the evaluation. The evaluation was done by observations in the field, practical experiments with the technology and as semi-structured interviews with future users after presentations of interactive prototypes. The future users involved in the evaluation included; manufacturers, construction managers, labourers, CAD technicians, and consulting engineers.

In order to reach a broader group of the respondents, the observations and interviews were supplemented with a web-based questionnaire where the prototype was explained in a web site, using storytelling, video clips and screen shots taken within the prototype. A group of approximately 10 lead users in Denmark responded to the questionnaire. The questions used in this evaluation were based on a combination of questionnaires developed by Lund (2001) and Davis (1989) for measuring usability and for evaluating perceived usefulness, and perceived ease of use of information technology.

Identify the practical issues that must be addressed: Running research project evaluations and construction projects in combination is a major challenge. It requires good timing, minimal disturbance of the construction team to avoid conflicts, and motivation of the future users to give feedback etc.

Decide how to deal with the ethical issues: The author was during the field studies and interviews as a participating observer (insider) with strong relations to the organisations involved. This can be seen as an opposition against the validity of the data, but on the other hand it is also an advantage because future users in construction are more likely to express their sincere opinions to people they can relate to personally. The authors' only interest is to elicit reliable knowledge in order to be successful with the future development, while the ethical issues of conducting the evaluation as an insider are assessed to have minor influence on the collected data. The involved users also felt free to comment on prototypes and questionnaires.

Evaluate, interpret and present the data: Results from the evaluation are presented in the following sections of the paper. The findings are condensed in a short summary explaining each objective and the most important lessons learned to respectively be reused and improved in future implementations.

EVALUATION OF MOBILE MANAGER

As described in Sørensen et al. (2009b), the prototype of Mobile Manager was developed in a Contextual Design process where the investigation was carried out in the construction management process in three different case studies. One of the case studies, concerning management of precast concrete element manufacturing and installation, was also used for the prototype and technology evaluation described in this paper. This case study used, is a traditional two-storey Danish office building of 3700 m^2 including a basement. The structure of the building is prefabricated of concrete elements - a very common construction method in Denmark.

Mobile Manager is a prototype of a system for project progress management and quality management. The key functionalities of the system is a simple interface as illustrated in Figure 5 providing the user with the possibility of entering text data, report task status and attach photo documentation on component level etc. The system is deployable to traditional mobile phones with an NFC/ISO 14443 compatible RFID reader embedded; see Sørensen et al. (2009a) for a discussion of RFID standards relevant to the construction industry. The mobile phone is connected to a Java web server application (M_Solution) through GPRS/EDGE or HSPA (3G) mobile broadband internet and used for automatic identification and data capture. By synchronising the database used by the web server for data capturing with the virtual model server (Tekla Structures), the mobile phone can be used to update the virtual model in real time. Tekla Structures is a 3D/4D modelling application for structures and M_Solution is a multi-purpose and configurable data capture server with possibilities for connecting different clients such as mobile phones and PCs. Popularly speaking, a digital link is created between the virtual model and the physical building shown in Figure 1. The scenario and system architecture evaluated is also shown in the figure, as well as how the construction manager uses mobile equipment to automatically identify and capture data when building components arrive at the construction site and during installation; see further description of user scenarios in Sørensen et al. (2009b).

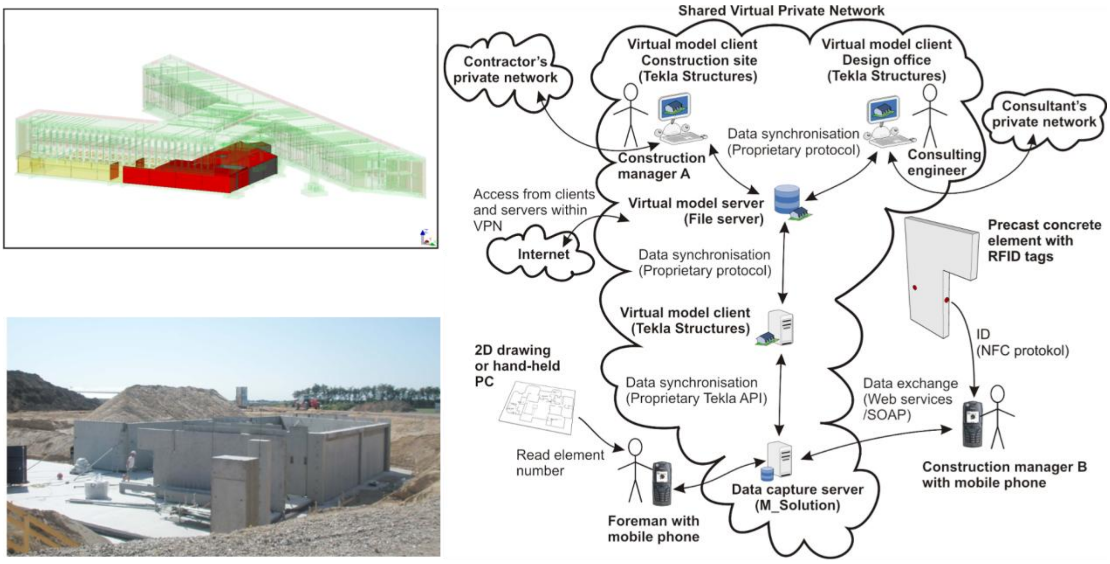

Figure 1: Left: Virtual 4D building model and physical building under construction. Right: IT architecture of the evaluated system. Communication protocols and application names are shown in brackets. The clouds illustrate different networks.

To realise this scenario a number of prerequisites are necessary: The virtual models of the building must be available and used both in design and construction. The users must have the competences to take advantage of the models, and the technology must be functional and have a proper user environment etc. It was decided to divide the evaluation into intermediate testable system domains covering central aspects of the whole system: 1) Implementation of daily virtual 3D model use at the construction site, 2) 4D model for planning, 3) Test of input of production status in 3D/4D virtual model, 4) Placement and readability of RFID tags embedded in concrete elements, 5) Usability of user interface of mobile equipment, 6) Use of RFID tags as a physical hyperlink to information in the virtual 3D model, 7) Real time project progress management based on RFID, virtual model and a mobile application, 8) Analysis of the actual work flow after the construction project is completed based on real life and accurate production data.

The synchronisation using the proprietary Tekla API between the virtual model server and the data capture server was not ready for use in production during the construction project, and it was therefore not possible to evaluate system domain 7 and 8. In the following sections, a summary of results from the evaluated system domains 1,4 and 5 is given by first briefly introducing the evaluated objective and then explaining the most important lessons learned to be reused and improved in future implementations. The evaluation of the remaining sub-domains can be found in Sørensen (2009c).

IMPLEMENTATION OF VIRTUAL 3D MODEL USE AT THE CONSTRUCTION SITE

3D models were created prior to construction and used for 2D drawing extraction. The structural models were created with Tekla Structures and MEP (Mechanical/Electrical/Plumbing) models were created with MagiCad. The architect used 2D drafting in AutoCAD. Aggregated models were created in Solibri Model Checker and Navisworks on basis of IFC and DWG file export/import, see Figure 2.

The construction site accommodation was equipped with computer equipment for accessing the design team's models on Ramboll's (consulting engineer) file server through a secure VPN Internet connection (Virtual Private Network). As illustrated in Figure 2 (middle) the site accommodation was also equipped with a projector and wireless internet connection for the handheld equipment.

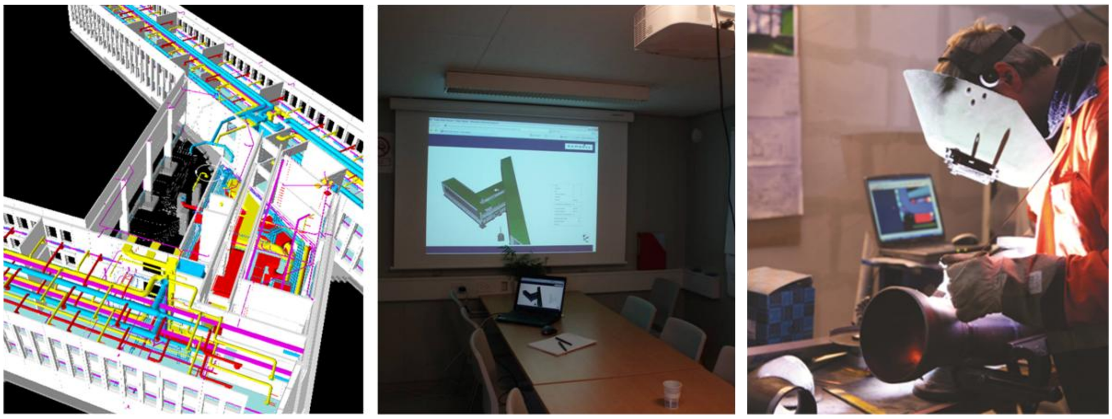

Figure 2 Left: Screen dump from aggregated model viewer. Middle: Virtual model viewer and projector in the construction site accommodation. Right: Welding of pipes directly from a virtual 3D model viewer. Image courtesy of Ramboll Denmark and Brondum.

Most Important Lessons Learned to be Reused in Future Implementations

Several people (typically engineers and construction managers) involved in workshops during the system development (supported by online questionnaires) have commented that it would be difficult for the skilled and the unskilled site worker to use the virtual models or the mobile equipment. A comment from a civil engineer in a workshop expressed it this way: *"Watch out not to lose "John the plumber", when introducing all this new technology"*.

However, based on observations and informal discussions on the construction site, the labourers were found to be very eager to use virtual models and mobile technology for quality assurance. They often need some assistance using the new equipment or show some reluctance using the mouse and keyboard, but they definitely don't act against the changes. They rather look forward to the further implementation and see great benefits in the improved overview the virtual model gives in their daily work.

This observation is contradictory to Davis (2004) where no difference in resistance to change was identified for different professions. However, it supports the observations of Gottlieb et al. (2009) that the workers are ready to use new technology in their working processes, but the middle management level (construction manager) is a *"crushing anti-program"* for use of virtual models. As argued by Gottlieb et al. (2009) this is because *"The manager also inserts a divide between knowledgeable and ignorant actors in order to uphold his own image of a social order in which the contractors retain their dominant position in the construction process, rather than having to conform to the requirements of the model…"*.

Most Important Lessons Learned for Improvement of Future Implementations

Several aspects of system functionality that could be improved were identified during the evaluation. Clash detections between virtual models were done sporadically and only visually during the design of the building while several design errors needed correction during construction, e.g. modifications of precast concrete elements and drilling of missing holes for pipes. Later examinations showed that a more formalised clash detection procedure could have eliminated these errors.

The system setup illustrated in Figure 1, where the contractors have direct access to the virtual models stored on the consultants file server through VPN caused some trouble. However, the technical solution was a minor problem. The hurdles were mostly organisational and interpersonal trust-oriented because of the security risks involved in sharing networks between two companies.

Simplifications of the user-environment to the virtual 3D model viewers and new features are needed to make them more directly useful in the construction process. The virtual 3D model viewers need e.g. automatic and dynamic dimension lines and a game-console like user-environment. Today even experienced users can have difficulties navigating a virtual 3D model viewer.

PLACEMENT AND READABILITY OF RFID TAGS IN CONCRETE ELEMENTS

Today, LF tags (see Sørensen et al., 2009a for an RFID technology introduction) are used in practice for identification of precast concrete elements at the Danish manufacturer Fårup Beton Industri and other research projects carried out successful experiments on the readability of UHF tags embedded in concrete. However, one of the important observations during the prototype design was the need for full compatibility with traditional consumer mobile phone technology. Therefore, it was decided to evaluate the placement and readability of ISO 14443 RFID tags compatible with the NFC (Near Field Communication) standard, which is already implemented by several mobile phone manufactures.

Another reason for using the ISO 14443 tags with short reading distance (0-10 cm) is to minimize the risk of unintended reading of the tags and violation of privacy – tags with long reading distance (>5 m) can e.g. be misused to overview employees, track competitors cost of goods sold etc. Today a requirement stated in a recommendation by the Commission of the European Communities (2009) states: *"Because of its potential to be both ubiquitous and practically invisible, particular attention to privacy and data protection issues is required in the deployment of RFID"*

Most Important Lessons Learned to be Reused in Future Implementations

The short reading distance leads to demands on the placement of the tags in the building components: They must be placed at the surface of the building component and if hidden be placed at the exact same location every time so it is easy for the user to find them.

In this evaluation precast concrete elements were used as an example and it was found useful to attach the RFID-tags with a "spacer" to the reinforcement in concrete beams, columns and slabs, see Figure 3 pictures D and E. The "spacers" are used in the concrete production to ensure the right coverage of concrete around the reinforcement bars and are therefore widely available. The tags used for this prototype evaluation was embedded in a traditional plastic smart cards and very rugged but there exist several different shapes and packaging's for RFID tags. For future implementation it would be useful to create "spacers" with tags embedded.

For precast concrete walls it was found sufficient to place the tags at the top of the wet concrete just before glazing since they are often produced horizontally with the inside surface upwards in the mould.

Several respondents to the questionnaires have expressed a desire for the applications to be implemented on traditional mobile phones rather than rugged PDAs. This feedback also supports the fact that despite traditional mobile phones are not being rugged and not having big screens they are already widely used in construction and must therefore be supported to ensure success with the system implementation.

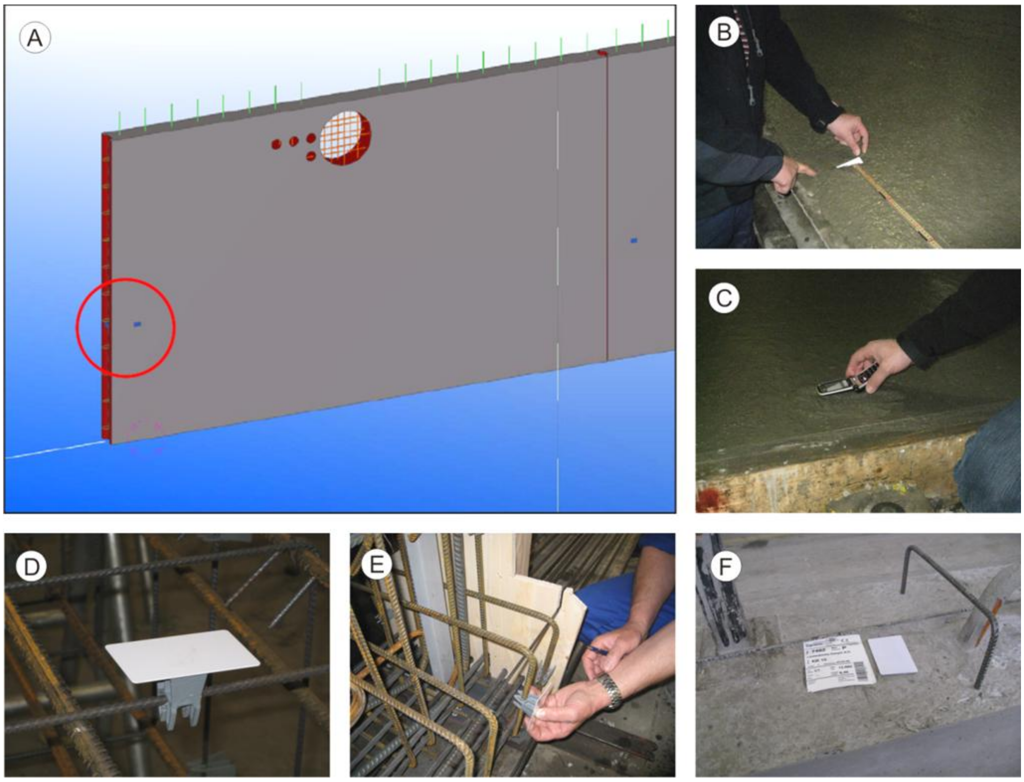

Figure 3: Screen dump and photos from experiments with embedding RFID tags in precast concrete elements.

To make sure the RFID tags were embedded correctly in the building components, it was found necessary to include them in the structural engineer's shop drawings and virtual models, as shown in Figure 4. This drawing is automatically generated on basis of the virtual precast element shown in Figure 3 picture A.

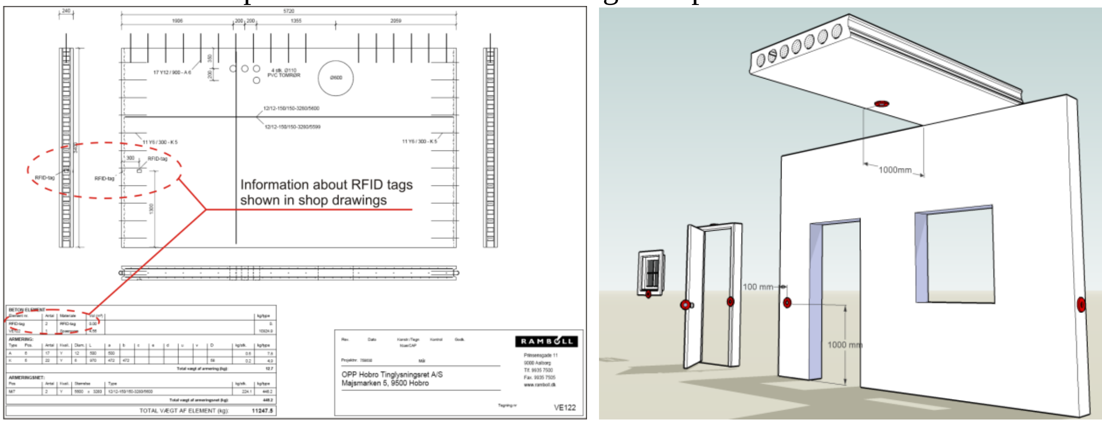

Figure 4: Left: Illustration of how the information about embedded RFID-tags was included in the shop drawings. Right: Proposal for a standardised method for RFID tagging of typical prefabricated building components.

To be able to find the hidden embedded RFID tags, it is necessary to standardise the placement of the tags. In Figure 4 it is shown how this can be done on some of the larger building components. In general, the tags were placed 1 m above finished floor or 1 m from the supporting structure. At least two RFID tags are needed when using passive tags on/in larger components such as the bearing structures, doors, windows etc. One tag should be placed at the end of the element next to the existing label and used during transportation and storage, and the other tags should be placed in a location readable after installation. Tags must therefore be placed on the underside of the slabs because levelling concrete and flooring is put on top. For doors and windows and their frames, it was found logical to place one tag near the handle and another at the top.

Most Important Lessons Learned for Improvement of Future Implementations

It was found that the cost of embedding the RFID tag in the concrete was higher than the tag itself. The price to embed any small part, such as a RFID tag, in a precast concrete element is approximately 1 EURO in Denmark. The cost of the smart card sized ISO 14443 PVC tags used in this evaluation was ~0.7 EURO when bought in small quantities. In future implementations, focus should therefore be on bringing down the embedment cost of the RFID tags. This can be done e.g. by refining the prototype of the RFID tag fixture shown in Figure 3, picture D or include it as an automatic operation handled by robots.

Approximately 85% of the 500 RFID tags embedded in precast concrete elements for this evaluation could be read after the components were installed in the building. All the tags were tested before the embedment, so the reasons for the 15 % none-readable RFID tags should be found in errors of embedment (wrong location or depth) and omission of the tags. All the tags attached to the surface of the elements could be read and only very few fell off during transportation and installation. To improve the reading distance and readability of the embedded tags, it is recommended to use a combination of HF and UHF tags in future systems. Thereby the support of mobile technology as well as fixed readers with long (several meters) reading distance can be achieved even with the passive RFID tags.

The main barriers for future implementation were found to be with the manufacturers. Even though it is well proven that the technology is useful in industrial production optimisation, they claimed to see very few benefits in the technology. It is the author's perception that this is due to unclear clarification of who and how the implementation cost should be paid and lack of competences to implement the technology. Therefore, it is suggested, that if the general contractor or building owner wants the benefits of using RFID technology in production and operation management, it must be specified and priced in the tendering or acquisition process.

USABILITY OF USER INTERFACE FOR MOBILE EQUIPMENT

A prototype of an application for mobile phones was developed to support the project progress management and quality assurance documentation. The usability (easy to learn and remember) of this prototype was evaluated on the construction site, during interviews and in questionnaires. Figure 5 shows some screen dumps of the application and use of it in practice at the construction site.

Figure 5 Left: Examples of user interface for Mobile Manager. Right: Photo from evaluation of Mobile Manager.

Most Important Lessons Learned to be Reused in Future Implementations

The idea of focussing on traditional mobile phone technology proved to be right also from a usability perspective. The practical usability experiments showed that it can easily be used for simple data collection needed to update production status in a virtual model and for quality inspection. Similar feedback was received in the questionnaires with comments from respondents like: *"It is cool to make use of a mobile phone, which everybody is carrying, at the construction site to collect data"* and "*The functionalities are limited, but it is clear and easy"*.

Most Important Lessons Learned for Improvement of Future Implementations

The first author's observations on site and during informal interviews of workers lead to contradictory conclusions when compared to the feedback received from engineers and managers in workshops and questionnaires. The engineers and managers see the major barriers as in motivating the workers to use the new technology and on questions about future barriers they gave comments like: *"Workmen must use it? – it's always a challenge"* and *"The major barrier is to educate foremen, gaffers etc. and change their attitude against the use of IT at the construction site"*.

However, during the informal interviews of the workmen, they claimed to find it easy to use the mobile application for data collection. It was also observed that the unskilled workers that stayed overnight in campers at the construction site had laptops and HSPA/3G Internet connection for private communication with their families. Future effort should therefore be focussed on changing the attitude about use of IT among construction managers rather than among the workmen. This observation also illustrates the importance of observing users in the real working environment rather than just relying on questionnaires, interviews and their immediate self-expressed needs as stated by e.g. Beyer and Holtzblatt (2000) and Kelley (2001).

CONCLUSIONS

In this paper evaluation of a prototype system supporting project progress management and quality management in construction by means of virtual design and constructio was described. The prototype was used to evaluate the usefulness of NFC/ISO 14443 compatible RFID tags and mobile phones for data capture in construction. The technology is available today in some traditional (low-cost) consumer mobile phones and is expected to soon become a ubiquitous technology.

The evaluations show that mobile technology and passive RFID technology is an efficient and practically implementable way to introduce digital links between virtual models and physical components in construction. It is useful for on-site inspection work and documentation, real-time project progress management, and quality assurance which are important aspects of implementing lean in construction. According to the author's observations, interviews, questionnaires and technology experiments the future users perceive benefits of the technology during planning, quality management and follow-up. They also find it beneficial to use the combination of automatic identification and virtual models to improve current practice of quality management by making this process digital and object oriented. Manufactures and mid-level managers/project managers were found to be the most reluctant to change. However, labourers were more willing to try the new technology and expected future benefits of using it.

Reuse of the virtual models and RFID tags from design and construction to operation of the building and use of traditional consumer equipment such as the NFC compatible mobile phones were found as crucial aspects to lower the barrier of the technology implementation and increase the chance of success in an appearing change process. However, because of the short reading distance of NFC compatible RFID tags, introduction of multi-band (HF+UHF) RFID tags are suggested for use in the construction industry to improve reading distance and thereby potential use-cases.

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