COLLABORATIVE MOBILE VISUALISATION IN CONSTRUCTION (MOBVISCON) FRAMEWORK DEVELOPMENT AND VALIDATION

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ABSTRACT: Mobile technologies and wireless communication experienced a rapid development over the last decade, with many industrial sectors realising the benefits of mobile collaboration. The advantages of using mobile computing are in the ability to share data remotely in real time, reduce rework and paperwork, being able to solve problems on site, construct accurate databases by the timely and continuous collection of data, improve the quality of information, and decrease operational costs. Mobile technologies are now widely available offering good opportunities to the construction industry to work collaboratively. Due to the limitation in computational resources of mobile devices, the use of visualisation of design documents through mobiles has not been investigated in detail. However, mobile devices for the visual representation of design documents and specifications may offer new opportunities for accessing and monitoring the construction remotely. The latest developments in mobile hardware and software enable unconditional access to 2D and 3D design information and corresponding documents. Mobile visualisation and visual communication may completely change collaboration between the project stakeholders during the execution of the construction activities.

The main aim of this research is to investigate the use of mobile communication and visualisation technologies during the exchange of information between design teams based in the office and construction sites with a focus of achieving real-time collaboration. This paper presents the development of a "Collaborative Mobile Visualisation in Construction (MobVisCon)" framework based on knowledge from the literature, results of a detailed industry survey, and construction scenarios. Results from the application of the MobVisCon framework on a live construction project case study are also presented.

KEYWORDS: mobile and wireless technologies, visualisation, collaboration, construction, MobVisCon.

1 INTRODUCTION

Communication is an important part of relationship and co-ordination between project participants in construction (Murray & Langford, 2004). Good communication between the construction manager, consultants, sub-contractors, designers, architects leads to complete construction projects being completed on time and within budget (Emmitt & Gorse, 2003; Cohen, 2000). Decision making is important for both the design and construction stages of construction projects. However, in construction projects, 90% of the time in meetings is spent on the description of the problem and only 10% is spent on the real-decision making such as discussions on what-if scenarios (Lee and Pena-Mora 2006). From a designer's point of view, decisions are made using information and knowledge to create new ideas and from a contractor's point of view decisions are focused on problem solving throughout the process (Emitt and Gorse 2003). Traditional 2D paper-based drawings are not fully adequate in conveying design information to contractors on site, as they neither give a sense of the dynamic process of construction nor explain the order of assembly (Ferguson 1989).

Better collaboration between design and construction site teams is needed in order to enable the construction industry to deliver projects on time and within budget. In the existing working practices team members organise site meetings to enable face-to-face communication, monitor progress on developments and changes, review progress against programs, identify problems, and check costs against budgets. These meeting are generally informal and the collaboration tools are mostly paper based drawings and textual documents (Spence et al. 2001, CIOB 1996, Griffith and Sidwell 1995). During the construction stage construction teams generate most of the design changes. Therefore, design teams should collaborate with the construction site in order to control construction, design changes, quality and program (Lafford et al. 2000).

Collaboration practices are improving on construction sites with many contractors using project collaboration technologies. Some of them still use e-mails to exchange drawings. Without a central repository where project members follow design changes and documents, collaboration is limited (Rakow 2002). Moreover, collaborative

technologies are not just limited to collaboration software (project extranet) and document management platforms. Visualisation tools are playing an important role for design collaboration through various technologies such as 3D and 4D modeling. Many architectural and design firms realized that using 3D models in the design phase will provide numerous benefits (Rakow 2002). The benefits of 3D modeling can be felt through the project lifecycle but had limited use so far (Sarshar 2004). In a 3D model project members can visualize images of construction, share project information and review constructability issues (Kamat and Martinez 2003). However, 3D does not enable supply chain members to monitor progress of construction projects (Wang et al. 2004). 4D CAD models enable project teams to explore various `what-if` scenarios and identify conflicts. Moreover, communicating scheduling details and 3D models to the whole supply chain is one of the important aspects of 4D modeling (Best and Valence 2002, McKinney and Fischer 1998). By using 4D models in real-time, there will be two way communications between construction site engineers and other project members. This enables the design office, head office, etc. to monitor how work is progressing, what problems have occurred, what information is needed, which materials and equipment are required etc. (Forster 1989).

Construction professionals are becoming aware of the benefits of the implementation of mobile technologies within their work activities. However, most of them lack the experience in doing so (CPN 2006). There is a need to improve communication between designers and builders using mobile technologies (Mobile Enterprise Analyst 2005). Integrating mobile devices into visualisation environments may offer new opportunities for accessing and manipulating data remotely (Brodlie et al. 2004). Some construction collaboration technology providers and end-users have already tested the use of mobile devices on site. However, most trials focused on asynchronous use where data are not been exchanged in real time (Wilkinson 2005). Moreover, there has not been much material in the literature which provides information for possible mobile visualisation applications in construction industry.

This paper presents development of a "Collaborative Mobile Visualisation in Construction (MobVisCon)" framework based on knowledge from extensive literature review, results of a detailed industry survey, and construction scenarios. Results from the application of the MobVisCon framework on a live construction project case study are also presented.

2 MOBVISCON FRAMEWORK

The Collaborative Mobile Visualisation in Construction (MobVisCon) framework aims at facilitating the implementation of mobile visualisation and communication technologies to communicate design information and support decision making and collaboration between design and construction teams during the construction stage of a project.

Scenarios, validated within various construction organizations, named as Mobile 2D/3D, 4D Collaboration, and 3G

Communication have been used as an input for design process of the framework. Mobile 2D/3D scenario presents the case of a site engineer who communicates and collaborates with the project team in real-time, access project drawings, documents and specifications, requests information for design queries or buildability problems. The 4D Collaboration scenario presents the case of a site engineer who checks and monitors construction against planned schedules, resources and specifications. He accesses a collaborative 4D modeling platform and communicates with the project team using a 3D model which enables him to manage resources, schedule, tasks and cost, and explore various "what if" scenarios at the construction jobsite. The 3G communication scenario presents the case of a site engineer who makes decisions and shares information and knowledge using 3G visual communications to solve problems on a construction site due to buildability, and other unexpected situations. (see Figure 2-1)
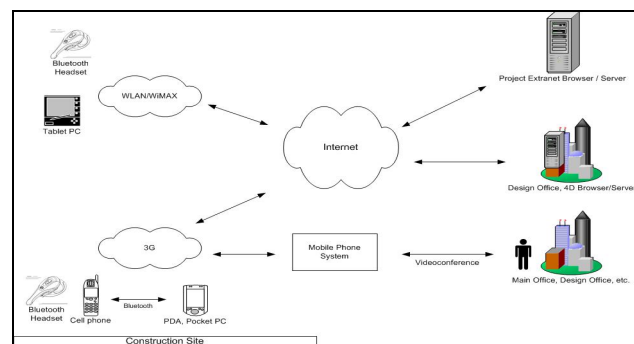

Figure 2-1. Mobile communication architecture for data, audio and visual information transfer through wireless technologies and general technology layout of MobVisCon framework.

The scenarios were validated with experts from contractors and design/engineering consultancy organizations. As a result of these evaluations, organizations accepted to support the implementation and testing of these scenarios on live construction projects. Requirements for the implementation stage were summarized and e-mailed to the experts to make every detail clear for the implementation and testing.

The development of MobVisCon highlights the need to use various mobile technologies and wireless communications, collaboration software, and visualisation applications to create a better collaboration environment.

The objectives of MobVisCon are:
- To provide a real-time wireless communication based virtual platform capable of using collaboration software, visualisation technologies and communication tools to support communication and collaboration between engineers on site and other project members (Mobile 2D/3D and 4D Collaboration scenarios).
- To provide a real-time and mobile telecommunication based platform capable of sharing visual information to support communication and knowledge sharing between engineers on site and other project members (3G Communication scenario).
- To demonstrate how mobile visualisation can enhance the existing design problem resolution and decision making processes during the construction stage of a project.

- To test the framework within various organizations and identify technical and non-technical issues which occur during the implementation of MobVisCon framework to real construction projects.

2.1 *Framework components*

The testing and implementation of the MobVisCon framework require the consideration of three components: hardware (mobile devices), wireless networks, and software. All components of the framework were identified and selected after detailed reviews of existing mobile technologies, wireless communication networks, and visualisation technologies in the market. Details of framework components are presented in the following section.

Hardware

Hardware selection is an important factor in the success of implementing mobile collaboration in construction. Screen size, battery power, processor, device size, wireless network capability, operating environment and robustness are critical considerations in the selection of appropriate hardware for the testing of scenarios presented within the research context. The hardware planned to be used for the implementation of MobVisCon framework and scenarios are described in the following sections.

Tablet PC

A Toshiba Portege M400 was selected as a touch screen tablet computer for use on site engineer within Mobile 2D/3D and 4D Collaboration scenarios. This Tablet PC enables engineers on site to gain access to wireless networks Wireless LAN 802.11a/b/g and Bluetooth 2.0. The new 12.1" SXGA+TFT screen display and digital ink capability enables users to take notes, annotate documents and sketch drawings in a similar manner to working with a paper notebook (see Figure 2-2).

Figure 2-2. Toshiba Portege M400.

3G pocket PC

A Qtek 9000 3G Pocket PC was selected for use in the 3G communication scenario. The Pocket PC uses the latest Windows Mobile 5.0 Pocket PC Phone Edition Operating System, and is an ideal mobile device for email, Internet browsing and gaining access to project members using video telephony (see Figure 2-3).

Figure 2-3. Qtek 9000 Pocket PC (adapted from Expansys).

3G mobile phone

A Samsung Z500 will be used in the 3G communication scenario of the MobVisCon framework for testing video-conferencing between project members. Samsung Z500 is one of the most lightweight 3G handset with video streaming, video messaging and video telephony functionalities (see Figure 2-4).

Figure 2-4. Samsung Z500.

Bluetooth headset

A Plantronics Voyager 510 Bluetooth headset was chosen to be used in all of the scenarios. The Bluetooth headset enables site engineers to make hands free voice calls using VoIP either through the Tablet PC or Pocket PC. Voyager 510 has a noise cancelling microphone which allows engineers on site to be heard clearly wherever they are working and lets them use voice dialing capabilities more effectively. The multipoint capability of the Voyager 510 allows engineers to remain paired to their mobile phones and still have the ability to accept incoming calls from any of the other Bluetooth devices such as the Tablet PC or Pocket PC (see Figure 2-5).

Figure 2-5. Plantronics Voyager 510 Headset.

Wireless networks

As this research aim is the development of a mobile collaboration platform, wireless communication is the underlying infrastructure for such a platform. Various wireless networks will be used in the scenarios developed within the MobVisCon framework. Most of the latest wireless communications such as Bluetooth, Wireless Local Area Networks (WLAN, 802.11) and Third Generation (3G) will be tested within the context of this research. All of the mobile devices have the Bluetooth capability. Therefore, there is no need for any add-on network hardware to enable the devices to connect with each other via Bluetooth. The 3G access of the Pocket PC and the mobile phone were activated by using 3G SIM cards. The WLAN will be tested to access real-time design information sharing and collaborative visualisation platform in the Mobile 2D/3D and 4D Collaboration scenarios. A wireless broadband router (WRT54GS produced by Linksys) was used to establish WLAN access for testing purposes.

Software

The Mobile 2D/3D and 4D collaboration scenarios have specific software needs for a real-time collaborative platform, i.e. collaboration software, the Acrobat Professional 7.0 and 4D modeling software. The Collaboration extranets 4Projects and Autodesk Buzzsaw 7 were provided by the construction organizations involved in development of case studies and testing stage of MobVisCon. Both products facilitate the testing of the Mobile 2D/3D scenario and enable project teams to store, view and download 2D and 3D CAD model files, published drawings, documents, specifications, and photos; to mark up documents in real-time; and to share project information in a virtual collaborative platform.

Acrobat Professional 7.0 was selected to assist data exchange and mark-up of documents and drawings within the extranet system. The MobVisCon collaboration platform will be open to different data formats, the Mobile 2D/3D scenario intends to test the exchange of 2D/3D drawings in PDF format. Acrobat Professional 7.0 converts and combines AutoDesk AutoCAD; Bentley MicroStation; Microsoft Visio, MS Outlook and MS Project; Microsoft Office; Microsoft Internet explorer; and other sources of files into a single PDF file.

The Synchro 4D modeling software license was granted for research purposes in order to test and implement the 4D collaboration scenario. Synchro is a new software solution that provides real-time web based 4D collaboration between project members. It provides 3D object creation/manipulation, rapid 4D project visualisation using project schedules and advanced filtering of a 3D model of the project. Synchro users can display 3D model of the project and project schedule together on computer screen and they can make changes to the schedule in real-time.

3 CASE STUDY IMPLEMENTATION - BUILDING SCHOOLS FOR FUTURE

Building Schools for the Future (BSF) is the biggest single government investment for the improvement of school buildings for over 50 years. The aim is to rebuild or re-

new every secondary school in England over a 10-15 year period (BSF 2007). BSF brings together significant investment in buildings and in ICT (Information and Communications Technology) over the following years to support the Government's educational reform agenda (BSF 2007).

Paradigm, a consortium led by Taylor Woodrow Construction (TWC) has been selected as the preferred bidder for the £320 million Building Schools for the Future (BSF) programme in Sheffield. TWC's partners in the Paradigm consortium are Civica, Building Design Partnership (BDP) and HLM Architects, Faber Maunsell Structural, Faber Maunsell Building Services and HSBC. The first stage of the BSF programme in Sheffield, which is due to be completed by 2009, involves the construction of 3 new secondary schools across the city. The consortium is working toward financial close on the initial three projects: Newfield and Talbot School; Silverdale School , and Yewlands School.

The Yewlands school project was selected as a case study due to it being unique within the UK construction industry in that the project team are using the Avanti Collaborative Working Procedures (http://www.avanti-construction.org/construction.shtml) whilst developing the design in 3D CAD model files and publishing both extracted drawings and the co-ordinated 3D model within the project extranet. All project stakeholders, including the clients, have access to the 4Projects extranet, and can comment on the development of the design. HLM Architects share 3D model files in the agreed DWG (AutoCAD format) format within the extranet. Faber Maunsell Structural can download the HLM Architect's 3D model files and create their co-ordinated 3D structural model files. Within the project there are two sets of 3D files developed by the architectural and the structural engineering organizations (see Figure 3-1). Taylor Woodrow check the co-ordination in Navisworks Jetstream, a software that combines architectural and engineering designs in a single virtual model stored within the project extranet. As a result, both the clients and the Taylor Woodrow Construction project team can download the Navisworks NWD file for review (see Figure 3-2).
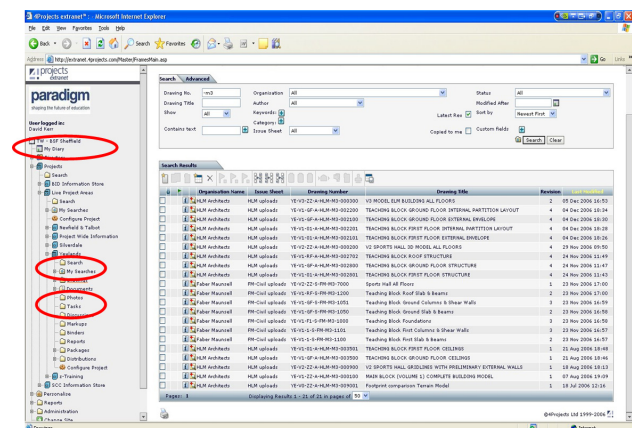

Figure 3-1. 3D Model files (-m3) within the Paradigm-Building Schools for Future (Sheffield) project extranet.
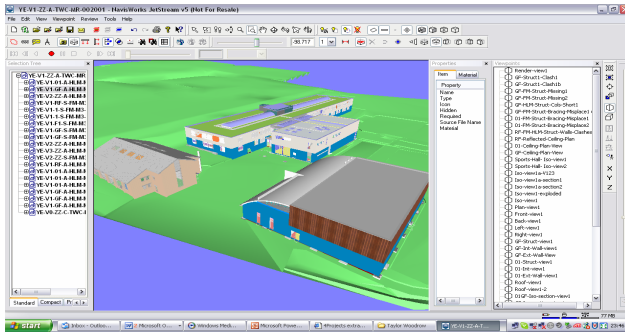
Figure 3-2. BSF Sheffield Yewlands Project 3D model in Navisworks .

While project stakeholders can share, download and view co-ordinated 3D model files during design development, the majority of engineers on site still use paper-based drawings with limited access to 3D models whilst monitoring construction progress. The MobVisCon framework addresses the collaboration gap between the design and construction site teams and proposes a combined mobile digital collaboration model for the improvement of existing working environments.

The MobVisCon-TWC case study focused on Mobile 2D/3D and 4D Collaboration scenarios of the MobVisCon framework. The objectives of this case study are:
- To develop a 4D model for the Yewlands (BSF) project using the design team's 3D model files
- To identify technical and non-technical problems that occur during the development of the 4D models.
- To demonstrate how mobile visualisation applications can be applied to real construction projects for design-construction collaboration.

3.1 *4D model development*

To commence the development and implementation of the 4D model the source data had to be made available in the following formats:
- 2D CAD model file in DWF
- 3D CAD model file in DWF
- The project program data from MS Project or Asta Power Project in XML (Extensible Markup Language) format

These requirements were specified by Synchro which is a 4D modeling software and real-time collaboration platform used in MobVisCon.

Synchro is a new software solution that supports the construction process in a way that will drive efficiency through better project management and enables the project team to monitor progress in real-time on a web-based platform. Therefore, Synchro Professional version 3.1 was used during the development of the 4D model and the related server was used for the real-time web based collaboration so that changes made by one client are broadcast immediately to all other connected participants.

The process of developing the 4D model for the BSF-Yewlands project and the problems that were experienced during the 4D model development phase are presented as follows:

- Taylor Woodrow Construction- BSF Sheffield project team agreed to give access to the project extranet hosted by 4Projects.
- 3D and 2D CAD model files (DWG format) produced by HLM Architects and Faber Maunsell were downloaded from the 4Projects extranet.
- The Coordinated 3D model of Yewlands project produced by Taylor Woodrow Technology Centre in NWD format (Navisworks) was obtained in order to find out which files were used to develop the 3D model and how they are related to each other.
- As another 3D and 4D modeling platform, Navisworks does not allow project team members to access the 4D model in real-time on a web based collaboration platform. Therefore, it was only used for displaying and examining the existing 3D model of the project.
- The BSF-Sheffield Yewlands project schedule exported from Primavera as a PRX (project reporter export format) file was provided by Taylor Woodrow Construction- BSF Sheffield project team. The Synchro project modeling team converted this into a XML (extensible markup language) format and imported it into Synchro Professional v 3.1.
- The first attempt to integrate the 3D model with the project schedule was to export the Navisworks 3D model as a DWF file and directly import it into Synchro. However, the software operation became too slow due to the large number of references resulting in the 3D model being too slow to load and update. In the upcoming version of Synchro, there will be new improvement which provides full access to the DWF format information allowing an optimized data storage. Moreover, problems occurred related with the 3D model in Navisworks due to being outputted in a manner that seems to be separate parts and containing a great deal of 2D plans.
- The solution developed through the collaboration with the Synchro 4D modeling team used the original model files (those produced by Faber Maunsell and HLM Archtitects in dwg format) in order to create a new 3D model of the project suitable for the Synchro software by switching off the 2D CAD grid layers.

As a result of all these efforts the 3D model and project schedule of the Yewlands project were completely imported into Synchro Professional v3.1 and users can display the project named as MobVisCon-TWC through the workgroup product of Synchro which allows end-users to log into the project model located on the web server (see Figure 3-3, 3-4).
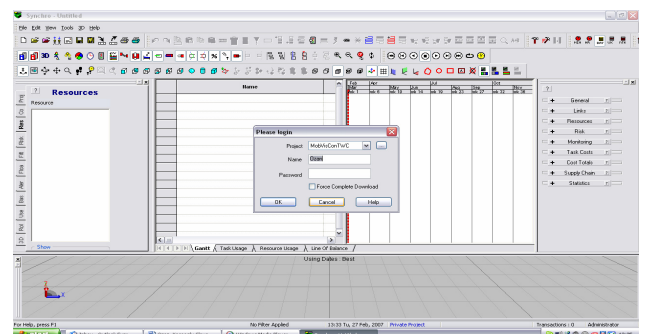

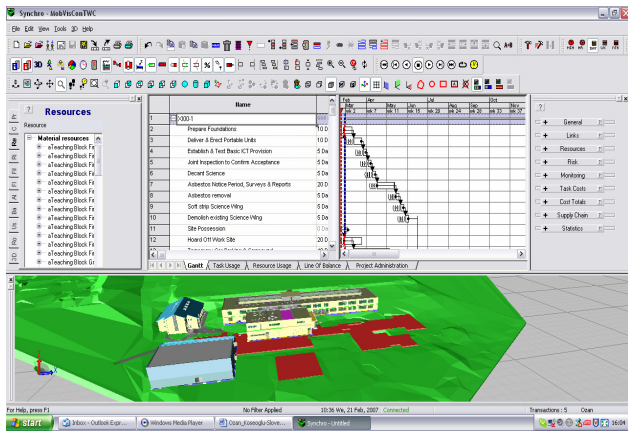Figure 3-3. Log into Yewlands project model on Synchro Web server.

Figure 3-4. MobVisCon-TWC Case Study (BSF-Yewlands project) 4D model.

- The Synchro application is made up of different views which display different information views that constitute the project information including companies involved in the project, the 3D model, material resources, human resources, risks, Gantt chart, tasks, task properties (general, costs, assigned resources and resource utillization, etc.) (Figure 3-4).
- One of the main objectives in this case study was to develop a fully integrated (3D+Tasks) 4D model for the BSF-Yewlands project. A fully integrated 4D model means assigning every object (material resources) in the resources list to the related task. Assigning resources (3D CAD objects) to tasks enable users to monitor resource utilization and display the 3D model from the start of the project to the end in a sequence using the project schedule information. However in this case study there was no direct linkages between the detailed BSF-Yewlands programme and the objects in the 3D model. In order to achieve this would require extensive work from the project team.

3.2 *Findings*

During the development of this case study some interested findings were captured:
- Construction projects are considering the use of mobile and visualisation technologies for a better design–construction collaboration environment. It was revealed that a project extranet, visualisation technologies and collaborative working procedures are used by the BSF-Sheffield Yewlands project team. However, the missing component from the design-construction collaboration in this project is the fully integrated 4D model and the real-time mobile collaboration on site.
- 4D modeling can be a lengthy process if the project plan is not fully developed and identified according to the resources included in the 3D model. In general, 2D drawings and 3D models are produced in the design environment while schedules are developed by contractors not aware of the 3D modeling process.
- Meetings conducted during the BSF-Yewlands case study revealed some key issues about the implementation of the MobVisCon framework on live construction projects including potential barriers and benefits, solutions to overcome barriers, and specific use in

Off-site construction. These key results are presented as follows:

Barriers:
- People do not want to change the way they work from the traditional methods.
- Construction organizations involved in some projects do not always fully embrace the use of information and communication technologies (ICTs) because of the fear that ICT systems have a risk of not working properly and cost them huge amount of investment.
- Poor wireless networking and mobile telecommunication performance at remote construction sites.
- Construction project teams do not always follow standard procedures for sharing, developing and accessing project design information and documents.

Solutions to barriers:
- To convince users in projects that using MobVisCon can facilitate collaboration. .
- To demonstrate to the project team how they can reduce project costs and manage the risk of unexpected project costs through the use of MobVisCon framework.
- Collaborate with wireless and mobile network technology providers to provide construction sites with 3G (Third Generation) and WiMAX (Worldwide Interoperability for Microwave Access) technologies.
- Procedures of implementing MobVisCon framework needs to be clearly identified so that the problems that occurred due to use of different data formats for design information, modeling platforms, and collaboration technologies can be eliminated for a better design-construction collaboration during the project lifecycle.

Benefits of using MobVisCon:
- MobVisCon enables all stakeholders to view the development of the co-ordinated model (CM) at any point in time with the project programme and to identify any problems (possibly expensive problems) well in advance of them happening on site.
- Using MobVisCon improves communication and collaboration on site as the user can view the CM; access published drawings, videos, animations; and upload videos from the site.
- Designers generally produce designs for a project and move onto other projects before construction starts. The MobVisCon framework proposes a virtual collaborative working platform where designers can produce their co-ordinated design information faster and more accurately reducing the amount of time spent on rework.
- The MobVisCon framework reduces the risk of buildability problems occurring, unforeseen additional costs and time delays to projects by enabling project team to work in a real-time collaboration platform.

Off-site construction:
- A specific construction method which can benefit from the MobVisCon framework is Off-site production.. In this construction method, fabricators supply 3D models in different data formats which is not always compatible with those used in the construction industry. The MobVisCon framework can benefit the installation of the offsite fabricated components on

site if the 3D model files are made available to be used for the development of a 4D model.

4 CONCLUSION

The MobVisCon framework developed within this research into the Planning of Effective Design & Construction Collaboration through Mobile and Visualisation Technologies proposes a solution for a better implementation of mobile and visualisation technologies within construction projects. This paper presented the development of the Collaborative Mobile Visualisation in Construction (MobVisCon) framework which was based on knowledge from literature, results of a detailed industry survey, construction scenarios; and a case study carried out with Taylor Woodrow Technology Centre on the Building Schools for Future-Sheffield (Yewlands) project. MobVisCon raised awareness for the use of mobile and visualisation technologies for design-construction collaboration on site. Future research will focus on increasing the number of real project case studies and evaluating the implementation of the framework for cost vs benefits of use within construction projects.

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