Integration Of Tablets And Smartphones In Construction Projects: Challenges And Solutions

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Abstract

The construction sector has a high degree of decentralisation of information, a high degree of mobility and a high rate of mobile content access in comparison with other big industries. Consequently, there are trending investigations for implementing mobile devices such as smartphones and tablets in the industry. This paper is aimed at reviewing the main technologies related to mobile devices as well as suggesting solutions to some of the main challenges of the construction sector by adopting smartphones, tablets and their latest technologies. A literature review was performed highlighting the main technologies that currently can be used to develop solutions to construction projects such as Augmented Reality (AR), Building Information Modelling (BIM), Geographic Information Systems (GIS), Cloud Computing (CC) and Mobile Cloud Computing (MCC). It was found that these technologies have been merged to provide solutions for complex challenges in construction projects. In addition, a case study was analysed where BIM, GIS, and MCC were implemented to successfully address the project's requirements. The review of the literature provided enough information for this paper to suggest solutions to some of the main challenges in the construction sector, namely: materials, finance, design, knowledge and management.

Keywords:

mobile cloud computing; AEC sector; augmented reality; Building Information Modelling; Geographic Information Systems.

1. Introduction

The construction industry has the highest degree of decentralisation of information among five different industries, namely: Manufacturing; construction; financial services; media and entertainment and software (Box, 2014). This indicates how information is distributed within construction organisations. Another important variable measured by Box (2014) is mobility, according to this study the construction industry has the highest rate of mobile content access, this resulting in stakeholders interacting and accessing content via mobile devices more than any other sector analysed by this study. The last variable where the construction sector has the first place is external collaboration; this results in a high rate of subcontracting and interaction between workers.

This defragmented nature in the construction industry incentives researchers and software developers to create solutions based on mobile content access to increase productivity and cross-functional communication in most of the fields within the industry. Some investigations focus on integrating mobile applications on the job site (Sattineni and Schmidt, 2015), others focus on Augmented Reality (AR) solutions for further application in the industry (Chen *et al.*, 2015). Ultimately, the main goal is solving some of the main challenges in the sector related to sustainability and productivity.

This area of research relies on current technology embedded in devices like smartphones, tablets and wearables. Since this is a relatively recent technology which evolves very quickly, it is necessary to provide scalable and generic solutions which can be implemented after sudden changes in technology. On the other hand, it is required from developers to do the opposite, which is creating very specific solutions, utilising the best of current mobile technologies.

This paper will contribute to a broader research about the implementation of mobile devices in the construction sector, by reviewing and summarising the main technologies utilised in the AEC industry which are related to smartphones and tablets and can provide solutions to some of the main challenges in the industry. It is the interest of this paper to discuss the solutions offered by Mobile Cloud Computing (MCC), Building Information Modelling (BIM), Geographic Information Systems (GIS) and AR.

The main idea behind MCC is enabling mobile devices to augment constrained resources such as processing, storage, and battery autonomy by using the cloud infrastructure. Subsequently, users can perform more intensive operations on mobile devices such as accessing BIM or GIS data.

Both, MCC and BIM are currently being implemented worldwide, and although their state of implementation changes from country to country; Currently, their application in the construction industry is more advanced than AR related technologies. The main idea of AR is allowing the observer to visualise useful information which is overlaid upon the real world, usually providing information about the current task being performed by the user. According to Milgram and Colquhoun (1999) the term AR refers to the class of display systems comprising some head-mounted display in which the viewer observers a direct visualisation of the real world, upon which computer generated graphics are overlaid. However, with the uprising of smartphones and other mobile devices, AR technologies currently, do not necessarily require to be head-mounted. More recent research can be useful to understand the main concept of AR better. According to Wang (2007) and Wang (2009), AR technology creates an environment where the supplementary information produced by a computer is implanted into the user's view of a real world scene.

2. Research methodology

This paper is aimed at exploring key drivers and barriers in the implementation of smartphones, tablets and wearables in the construction sector. Initially, the main enabling technologies existing in mobile devices are discussed. Subsequently, this paper proposes potential solutions to some of the main barriers in the industry via the implementation of mobile devices.

This article follows a systematic approach for reviewing compendium of literature to explore current and previous research in this field. The search for peer-reviewed journal articles has been done via databases, initially in chronological order. Subsequently, this allowed performing a literature review. A literature review is a systematic and reproducible approach for synthesising the existing body of recorded work generated by researchers or scholars (Fink, 1998). Due to the ever increasing number of academic papers (Conferences, journals, books, etc.), literature reviews have become a usual and indispensable method for synthesising a specific research field (Teuteberg and Wittstruck, 2010).

Section 3.A presents the chronologic implementation of AR-related technologies in the AEC sector. Section 3.B continues with the implementation of BIM technologies in the construction industry, also addressing the utilisation of MCC in combination with this technology. The implementation of GIS in its combination with other technologies is addressed in section 3.C. Section 3.D presents a case study of the High Speed 2 (HS2) in the UK, addressing the main technologic challenges and how MCC, BIM and GIS were integrated and implemented to address these challenges. Section 3.E mentions the current challenges in the construction sector and plausible solutions via the implementation of mobile devices and their latest technologies. In the conclusions, findings from the literature are revisited and analysed.

3. Results

3.1AR implementation in the construction sector

AR represents a viable and efficient approach for combining virtual reality with the real world (Kamat *et al.*, 2010). AR augments user's perception of a real-world entity by inserting relevant digital information into the real environment. Similarly, Chi et al. (2013) explain AR creates an environment where computer generated information is superimposed onto the user's view of a real world scene.

One of the first attempts to develop an AR system solution was Sketchand+. It is an experimental tool which made a first attempt to use AR in the early architectural design stages. This AR prototype utilised a scribbling interface through the metaphor of a digitizer tablet and provides a 3D sketch as a virtual response. The next generation of sketchand+ is BenchWorks, developed as an AR prototype for analysing representational design in an urban design scale, which focused on techniques and devices necessary to create 3D models for urban design. The system was designed as a workbench, which combined optical tracking with magnetic tracking. Another AR system derived from ARToolKit was developed by Dias et al (2002), which provides a Mixed Reality system for implementing tasks in architectural design, which developed tangible interfaces using ARToolkit patterns on a paddle and gestures.

There are several noted efforts towards collaborative AR systems in design and planning. For instance, Wang *et al.* (2003) developed an intuitive mixed environment called Mixed Reality-based collaborative virtual environment (MRCVE) to support the collaboration, design and spatial comprehension in collaborative design review sessions. The environment could be for mechanical contracting, face-to-face manner or distributed over network. Some investigations are focused on to the utilisation of AR technologies to address problems in the fields of AEC.

shows various research projects oriented to provide cyber-information to field personnel through mobile devices and/or AR systems. Some of these investigations have primarily focused on using Wireless Local Area Networks (WLAN), Global Positioning Systems (GPS), or Indoor GPS for accurately positioning the user within congested construction environments. Meanwhile, others have attempted to implement AR to help with heavy equipment operations. A common conclusion of these investigations is the positive effect obtained by the integration of AR in one or several processes of the AEC sector.

3.2BIM implementation in the construction sector

BIM integrates a 3D model for display and a data set of properties to maintain. The implementation of BIM in construction projects can increase collaboration within project teams, improved profitability, reduced costs, better time management and improved customer/client relationships (Chong *et al.*, 2014).

Challenges and drivers for BIM implementation have been evolving with time. Currently, Chen *et al*. (2016) highlights a current issue with the BIM industry: Although a common BIM file format has been proposed, which is the industry foundation classes (IFC); the logic and definitions of BIMs among commercial software vary endlessly. Therefore, it results very complicatedly to maintain consistency on the exported information format and content for the IFC exported by different commercial BIM software. They may even lead to loss of important data from the BIM project, even with the same commercial BIM software. With a specific software, different versions are likely to experience compatibility issues for transferring BIM projects. Consequently, managing BIMs in many projects remains a challenge, despite the fact some BIM software vendors have developed viewers for accessing different versions of BIMs.

Some studies suggest that BIM should be incorporated with new technologies, such as cloud computing (Chong *et al*., 2014), but instead of thinking of cloud computing as a new technology to be incorporated with BIM, it should be thought of as a requirement for a fully functional BIM implementation. To obtain collaboration between project parties, it is necessary to share a BIM project and related information through the Cloud. Additionally, by implementing MCC, users can perform more intensive operations related to BIM, such as access, consult or modify properties from the project's dataset.

Table 1: Compilation of some of the main AR research projects for the AEC sector

Year	Contribution	Author
2006	Presentation of various case studies to illustrate the concept of context-aware service delivery within the AEC sector	Anumba and Aziz
2007	Utilisation of AR to assist in the training of operators of heavy equipment	Wang and Dunston
2007	Utilisation of AR to develop a cooperative reinforcing bar arrangement support system	Yabuki and Li
2008	Discussion of the importance of location in context-awareness. Location aware apps can utilise the knowledge of the user location to provide relevant information.	Behzadan *et al*.
2008	Investigation of constraints related to construction sites for the implementation of accurate calibration methods for multi-range AR systems.	Shin *et al.*
2009	Utilisation of AR to display 4D models used for managing construction activities	Golparvar-Fardet *et al*
2009	Utilisation of AR to display the positioning and layout of underground infrastructure and to mitigate undesired damages.	Schall *et al.*
2009	Investigation of effectiveness of three wireless technologies for dynamic indoor user position tracking	Khoury and Kamat[a]
2009	Investigation of algorithms for identification of contextual data in location-aware applications, based on a dynamic user-viewpoint tracking scheme in which mobile users' spatial context is defined by position and three-dimensional head orientation.	Khoury and Kamat[b]
2013	Development of low-cost mobile AR-based tool for facility managers which reduces data overload inefficiencies and enhance situation awareness	Irizarry et al.
2013	Investigation of mobile AR system which enables a project's workforce to query and access 3D information on-site by utilising photographs taken from standard mobile devices. The user's location is derived from a 3D point cloud model generated from a set of pre-collected site photographs which is compared agains the users's images.	Bae et al

3.3GIS implementation in the construction sector

GIS is a system to capture, store, manipulate, analyse, manage and present all types of geographical data (Sweeney, 1999). A comprehensive review of the application of GIS in construction activities was performed by Bansal (2007), presenting solutions like: subsurface profiling, construction cost estimation and quantity take-offs, materials layout at construction site, construction site layout, real-time schedule monitoring systems, route planning and topography visualisation.

Some research projects find relevant to develop a BIM-GIS system where the benefits of both technologies are brought together into a single model, which can maximise both values. Some studies addressed the application of GIS in BIM environments and building information models in the geospatial domain. For example, Peña-mora *et al*. (2010) recognised the need to integrate different IT technologies such as GIS and digital building information, in one reliable platform for emergency response management. Also, Choi *et al.* (2008) established a prototype system to share the building information models among indoor GIS applications.

3.4Case study: HS2 stakeholders' integration in the UK via Cloud computing

HS2 is a planned high-speed railway in the United Kingdom linking London, Birmingham, the East Midlands, Leeds, Sheffield and Manchester. It would be the second high-speed rail line in Britain, after High Speed 1 (HS1) which connects London to the Channel Tunnel. Work on the first phase is scheduled to begin in 2017, reaching Birmingham by 2026, Crewe by 2027, and fully completed by 2033.

Mott MacDonald was appointed to provide civil and structural services for HS2. They were also appointed to two work packages: covering environmental and land referencing services. One of the main challenges for this project during the planning stage was to create a central, trusted source of real-time information which stimulates close collaboration and communication between all stakeholders, wherever in the world they may be. The magnitude of information in this project that needs to be collected, curated and controlled during the planning stage seemed completely unworkable. According to Louise Walker, Mott MacDonald HS2 GIS manager:

> *"Land referencing had not been carried out in the UK on this scale for many years. It is a process whereby the client's team gains a full understanding of the geography, ownership rights, access and a host of other environmental factors, which are vital to progressing to the detail design stage. In this case, the scope involved 3000 land owners and more than 5000 individual land titles, covering 220 km^2"*

To address this challenge, Mott MacDonald had to work with 30 external sub-consultancies, which generated numerous geological, historical, ecological and land ownership data. All this information represented in a range of spatial and non-spatial formats such as 3D models, GIS models, spreadsheets, documents and images. Since the 30 external sub-consultancies were scattered all over the UK and ranged from small businesses to large firms, the challenge was how to enable a team of this size to collaborate on such a large project.

According to Andrew Sheekey, Mott MacDonald GIS manager, the selected approach for information sharing was the following:

> *"… we built a system that combines GIS, BIM and big data processes to host all the information necessary to support decision making, technical assessment and problem solving."*

This new system was divided into two applications that have been successfully deployed on the HS2 project: Gigi and Apollo. Gigi consists of a platform of 2.1TB of data and 400 users from 24 different organisations working on HS2. This platform provides a visual display of over 1500 datasets from more than 80 suppliers covering 14 environmental topics. The 2.1TB of information uploaded to Gigi were compound by 1600 layers of information. Gigi is also linked to CAD and BIM data models to keep design team information up to date. Apollo facilitated land referencing tasks, such as creating and recording proof of land ownership, together with facilitating land access and environmental surveys. Both Apollo and Gigi enabled information to be managed, checked and edited at any time by a desktop computer or via tablet or smart phone.

5 Challenges and solutions in the AEC sector via the implementation of mobile devices

Current challenges in the industry are established differently depending on the approach and objective of the research paper or company performing the analysis. For example, Ofori (2000) addresses the challenges in the construction industries in developing countries, mentioning only four challenges, namely: Industry development, globalisation, culture and environment. On the other hand, Proverbs *et al.* (2000) established the main challenges facing the UK construction sector at the time, generating nine main challenges, namely: public perception; tendering problems; procurement problems; design challenges; finance; human resources; productivity; materials; and technology.

After over a decade of development in the industry, trending research in sustainability exposed a new set of categorisation for these challenges, one example is Häkkinen and Belloni (2011) which addressed the following barriers for sustainable building on the basis of literature review and interviews carried out in Finland: Steering and regulations; role of clients; procurement and tendering processes; scheduling of task; project networking; knowledge and common language; availability of integrated methods; and innovation. Another good example is Ayarka *et al.* (2011) which presents the following challenges for successful implementation of lean construction: Finance, politics, management, technical, socio-cultural and knowledge. This paper addresses groups the challenges for the AEC sector in the following categories: Design; Materials; finance; management; and knowledge.

Material-related challenges and solutions

The main issues in regards to material management are a lack of environmentally sustainable materials and waste management. By implementing CC, the industry can offer a solution for monitoring the entire material lifecycle, from fabrication to disposal. Also, by integrating CC with AR and BIM, a solution can be elaborated for displaying material-related information from a BIM dataset through a user-friendly interface based on AR.

Financial challenges and solutions

Regarding finance, the industry has always had a fear of higher investment costs and long payback periods. With new sustainability trends in the AEC sector, the additional cost of enhancing sustainable practices in the industry presents itself as a barrier. The idea behind the implementation of technologies like AR, BIM, GIS and CC is enhancing productivity, cross-communication and decreasing errors during the project's execution; this eventually translates into more revenue or fewer expenses in a project.

Design challenges and solutions

Over-specification is one of the main issues related to design, as a consequence, some buildings might have unnecessary number of features and areas (Proverbs *et al.* , 2000). Technologies like BIM enable designers to execute a much faster design cycle, especially when many design iterations and changes are made. The integration of mobile devices and MCC in a construction project, would enable users to access BIM and GIS data ubiquitously from smartphones and tablets.

Knowledge challenges and solutions

Knowledge-related issues consist of a lack of the necessary skillset or technical knowledge for a specific task in a project. Ayarkwa *et al.* (2011) address this issue highlighting the lack of professional knowledge and ignorance about sustainability and sustainable design. An appropriate solution for this issue would be enabling tablets and smartphones to implement AR technology to display relevant and context-aware information to its users, which will depend on their location and their function within the project. This implementation of AR should be linked to BIM and GIS datasets and based on a Cloud infrastructure.

Management challenges and solutions

Some of the top challenges in programme management in the UK construction industry are late delivery of projects, lack of knowledge to evaluate risks, and lack of cross-functional communication (Shehu and Akintoye, 2010). Technologies like BIM, GIS and AR enable managers to visualise the whole project lifecycle and increase productivity, for example, managers can use BIM and GIS to position crane equipment withing a project, they can also use GIS and AR to visualise the growth of natural elements like trees and make decisions depending on how the surrounding nature will change in future years. Another alternative is to mix BIM and AR to visualise important features of the project overlaid in the real world. All of this can be done on smartphones and tablets thanks to MCC.

4. Conclusions

As stated by Box (2014) the construction industry has a high degree of decentralisation of information, and it could very well benefit from an increase in productivity and a decrease in errors and delays. The integration of technologies like AR, BIM, GIS and CC into mobile devices such as tablets and smartphones enables the industry’s workforce to increase cross-communication and adopt modern management techniques.

It has been found that these technologies can be mixed with each other to provide more complex solutions. For example, AR can obtain information from a BIM or GIS dataset, or BIM and GIS can work together in order to define the positioning of heavy equipment on the job site. One technology that seems common for all the previously mentioned is CC. Nowadays, CC is necessary for providing ubiquitous data access to the users. Also, MCC can also work together with AR, BIM or GIS to provide technical information on mobile devices.

A case study was discussed in regards to the HS2 project in the UK. In this project, managers opted for developing their own solution in which they integrated CC, BIM, GIS and other technologies. This allowed them to save time and increase cross-communication with the project’s stakeholders. Nevertheless, AR was not considered for this solution, because currently, AR has not proven itself as a must-have technology. Consequently, integrating BIM or GIS is something that managers understand, however, there is no need to integrate AR in a project. Future development and implementation of AR might lead to proven benefits that could change the industry perception.

5. References

Anumba, C. and Aziz, Z. (2006), "Case studies of intelligent context-aware services delivery in AEC/FM",, *Intelligent Computing in Engineering and Architecture* Springer, pp. 23-31.

Ayarkwa, J., Agyekum, K. and Adinyira, E. (2011), "Barriers to Sustainable Implementation of Lean Construction in the Ghanaian Building Industry", *THE SIXTH BUILT ENVIRONMENT CONFERENCE JOHANNESBURG SOUTH AFRICA 31 JULY–2 AUGUST 2011*, pp. 67.

Bae, H., Golparvar-Fard, M. and White, J. (2013), "High-precision vision-based mobile augmented reality system for context-aware architectural, engineering, construction and facility management (AEC/FM) applications", *Visualization in Engineering,* Vol. 1, No. 1, pp. 1.

Bansal, V.K. (2007), "Potential of GIS to find solutions to space related problems in construction industry", *World Academy of Science, Engineering and Technology,* Vol. 8, pp. 307-310.

Behzadan, A.H., Aziz, Z., Anumba, C.J. and Kamat, V.R. (2008), "Ubiquitous location tracking for context-specific information delivery on construction sites", *Automation in Construction,* Vol. 17, No. 6, pp. 737-748.

Box (2014), "The Information Economy: A study of Five Industries".

Chen, H., Chang, K. and Lin, T. (2016), "A cloud -based system framework for performing online viewing, storage, and analysis on big data of massive BIMs", *Automation in Construction,* .

Chi, H., Kang, S. and Wang, X. (2013), "Research trends and opportunities of augmented reality applications in architecture, engineering, and construction", *Automation in Construction*, Vol. 33, pp. 116-122.

Choi, J.W., Kim, S.A., Lertlakkhanakul, J. and Yeom, J.H. (2008), "Developing ubiquitous space information model for indoor gis service in ubicomp environment", *Networked Computing and Advanced Information Management, 2008. NCM'08. Fourth International Conference on*, IEEE, pp. 381.

Chong, H., Wong, J.S. and Wang, X. (2014), "An explanatory case study on cloud computing applications in the built environment", *Automation in Construction,* Vol. 44, pp. 152-162.

Dias, J.M.S., Santos, P., Diniz, N., Monteiro, L., Silvestre, R. and Bastos, R. (2002), "Tangible interaction for conceptual architectural design", *Augmented Reality Toolkit, The First IEEE International Workshop*, IEEE.

Fink, A. (1998), "Conducting research literature review: from paper to the internet".

Golparvar-Fard, M., Pea-Mora, F., Arboleda, C.A. and Lee, S. (2009), "Visualization of construction progress monitoring with 4D simulation model overlaid on time-lapsed photographs", *Journal of Computing in Civil Engineering,* Vol. 23, No. 6, pp. 391-404.

Häkkinen, T. and Belloni, K. (2011), "Barriers and drivers for sustainable building", *Building Research & Information*, Vol. 39, No. 3, pp. 239-255.

Irizarry, J., Gheisari, M., Williams, G. and Walker, B.N. (2013), "InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach", *Automation in Construction,* Vol. 33, pp. 11-23.

Kamat, V.R., Martinez, J.C., Fischer, M., Golparvar-Fard, M., Pea-Mora, F. and Savarese, S. (2010), "Research in visualization techniques for field construction", *Journal of Construction Engineering and Management,* Vol. 137, No. 10, pp. 853-862.

Khoury, H.M. and Kamat, V.R. (2009), "Evaluation of position tracking technologies for user localization in indoor construction environments", *Automation in Construction*, Vol. 18, No. 4, pp. 444-457.

Khoury, H.M. and Kamat, V.R. (2009), "High-precision identification of contextual information in location-aware engineering applications", *Advanced Engineering Informatics,* Vol. 23, No. 4, pp. 483-496.

Mell, P. and Grance, T. (2011), "The NIST definition of cloud computing".

Milgram, P. and Colquhoun, H. (1999), "A taxonomy of real and virtual world display integration", *Mixed reality: Merging real and virtual worlds*, Vol. 1, pp. 1-26.

Ofori, G. (2000), "Challenges of construction industries in developing countries: Lessons from various countries", *2nd International Conference on Construction in Developing Countries: Challenges Facing the Construction Industry in Developing Countries, Gaborone, November*, pp. 15.

Pea-Mora, F., Chen, A.Y., Aziz, Z., Soibelman, L., Liu, L.Y., El-Rayes, K., Arboleda, C.A., Lantz Jr, T.S., Plans, A.P. and Lakhera, S. (2010), "Mobile ad hoc network-enabled collaboration framework supporting civil engineering emergency response operations", *Journal of Computing in Civil Engineering,* Vol. 24, No. 3, pp. 302-312.

Proverbs, D.G., Holt, G.D. and Cheok, H.Y. (2000), "Construction industry problems: the views of UK construction Directors", *16th Annual ARCOM Conference*, pp. 73.

Sattineni, A. and Schmidt, T. (2015), "Implementation of Mobile Devices on Jobsites in the Construction Industry", *Procedia Engineering,* Vol. 123, pp. 488-495.

Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B. and Schmalstieg, D. (2009), "Handheld augmented reality for underground infrastructure visualization", *Personal and ubiquitous computing,* Vol. 13, No. 4, pp. 281-291.

Shehu, Z. and Akintoye, A. (2010), "Major challenges to the successful implementation and practice of programme management in the construction environment: A critical analysis", *International Journal of Project Management,* Vol. 28, No. 1, pp. 26-39..

Shin, D., Jung, W. and Dunston, P.S. (2008), "Camera constraint on multi-range calibration of augmented reality systems for construction sites".

Sweeney, M.W. (1999), "Geographic information systems", *Water Environment Research,* Vol. 71, No. 5, pp. 551-556.

Teuteberg, F. and Wittstruck, D. (2010), "A systematic review of sustainable supply chain management", *Multikonferenz Wirtschaftsinformatik 2010,* , pp. 203.

Wang, X. and Dunston, P.S. (2007), "Design, strategies, and issues towards an augmented reality-based construction training platform".

Wang, X. (2009), "Augmented reality in architecture and design: potentials and challenges for application", *International Journal of Architectural Computing,* Vol. 7, No. 2, pp. 309-326.

Wang, X. (2007), "Using augmented reality to plan virtual construction worksite", *International Journal of Advanced Robotic Systems,* Vol. 4, No. 4, pp. 501-512.

Wang, X. and Phillip S.. Dunston (2009), *Mixed Reality-based Collaborative Virtual Environments: Specification, Prototype, and Evaluation in Design and Construction* VDM Publishing.

Yabuki, N. and Li, Z. (2007), "Cooperative reinforcing bar arrangement and checking by using augmented reality", *International Conference on Cooperative Design, Visualization and Engineering,* Springer, pp. 50.