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A Study of the Potential of Cloud/Mobile BIM for the Management of Construction Projects

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Abstract: Successful management of construction projects in the Building Information Modelling (BIM) era of the 21st Century should include intelligent systems to support construction project teams in making informed decisions. Project teams are routinely faced with contractual obligations to deliver projects to meet key construction parameters such as cost, time, quality and more recently stringent sustainability requirements. These sorts of pressures are no longer new as widely acknowledged by experienced project managers, contract administrators and clients. The poor performance of one or more of the aforementioned parameters will undoubtedly compromise the entire project, thus leading to the dissatisfaction of clients. This paper explores the use of mobile/cloud BIM in facilitating the adoption of an integrated approach to project delivery through automated or semi-automated dynamic information sharing processes with the ultimate goal of improving construction performance. The adopted methodology involved the use of an online-administered questionnaire survey and in-depth interviews. The study identifies the adoption and uptake of cloud/mobile BIM technologies and the benefits and barriers.

Keywords: BIM; collaboration; construction; defects; dynamic information sharing

1. Introduction

The construction industry is one of the important sectors of the U.K. economy, contributing roughly 6.1% to the national average [1]. Whilst the U.K. construction industry has sought innovative strategies for generations (e.g., see Egan (1998) [2], Latham Report (Latham 1994) [3]), the recent interest in Building Information Modelling (BIM) provides an impetus to explore how BIM triggers improved construction industry performance. For generations, the industry has suffered from many different performance challenges such as low productivity, time and cost overruns, as well as failure to meet the client's project objectives and value for money [4,5]. This has resulted in numerous conflicts, disputes and litigations in the industry, e.g., [6]. Many reasons have been cited as causes for the sector's inherent problems such as the fragmented nature of project development and disintegrated project teams. Interestingly, Anumba et al. (2002) pointed out that the problem of project failure is, on many occasions, exacerbated by ineffective information communication amongst transient project teams [7,8]. Other studies cited the lack of adequate, efficient and effective project stakeholder integration, e.g., [9]. Furthermore, collaboration and data exchange using paper-based project documentation is still commonplace in the construction sector [10]. In addition, collaboration of project teams in construction is still a challenge and indeed critical for successful management of varied project information. While information and communication technologies such as BIM are no doubt a game changer and play a huge role in construction projects, there is a need to widen the current understanding surrounding mobile/cloud BIM research. While it is obvious that speedy data flow has the potential to trigger enhanced efficiencies and effective communication between project teams, little research seems to point in the direction of mobile/cloud BIM, particularly during the management of onsite construction project activities.

It is therefore unsurprising that the U.K.'s construction industry has recently seen the rapid emerging use of mobile/cloud BIM computing technology, e.g., [11]. For example, it is now common to see the use of mobile devices such as smartphones, tablets and iPads at construction sites. Further, the use of cloud BIM systems such as BIMXtra, A360, etc., has been on the surge in connecting communications between office staff and onsite workers. These recent developments have witnessed site teams having the ability to view and provide responses to site issues directly from their mobile/cloud devices over the wireless network. A mobile BIM device refers to any type of handheld computer that is extremely portable and can be used in managing BIM models. The common devices include notebook computers, Personal Digital Assistants (PDAs), tablet PCs, Ultra Mobile PCs (UPMCs) and mobile phones. Cloud BIM platforms (also often referred to as mobile platforms) are web-based platforms for managing BIM models. Common data environments are amongst the leading cloud BIM platforms being recommended for use in delivering BIM-compliant projects. Cloud BIM platforms generally thrive on the development of compatible applications (apps) and the availability of reliable (speed) mobile network such as 3G or 4G. For better user-experience, apps are being developed for the iPhone Operating System (iOS), Android, Windows phone and other platforms, if existing, and the size of models in mobile systems should be scaled down from their counterparts in desktop systems [12]. Therefore, the cloud BIM has the ability to connect to any mobile device through apps.

Mobile and cloud BIM technologies are key technologies in the field of cloud computing. According to the National Institute of Standards and Technology (NIST), cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storages, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [13].

However, perhaps partly because of the emerging nature of BIM, very limited studies have considered the adoption of mobile BIM [14]. This is in contrast with a surge in the number of peer-reviewed literature about studies related to core BIM technologies, e.g., [11,15]. Furthermore, while cloud/mobile BIM (e.g., BIMXtra and A360) have corresponding apps in mobile devices (iPad, iPhone, etc.), studies that reveal their connection are limited and rare.

This study therefore aims to investigate the impact of mobile/cloud (BIM) computing technology use onsite in managing construction project activities. Attainment of this aim invites pursuing the following objectives:

- establish the state-of-the-art of emerging mobile/cloud BIM and mobile devices used at construction sites;
- investigate how the mobile/cloud BIM systems are used at the construction site;
- investigate the opportunities and effect of mobile/cloud BIM systems usage at the construction site;
- investigate the challenges of mobile/cloud BIM technology and applications in construction site activities; and
- develop or propose a BIM-supported framework that uses mobile/cloud BIM technology for managing projects onsite.

2. Literature Review

2.1. Collaboration Practices in Construction Projects

Baiden et al. (2006) defined a typical construction project as a collaborative exercise involving participants from various organizations who come together and form a construction project team [16]. Typically, a construction project team consists of a wide range of disparate professionals such as clients, architects, structural engineers, building services engineers, quantity surveyors, contractors and material suppliers [7,8,17]). The team is often temporary with a common objective of delivering the project, within a specific contractual period of time and stated budget. Zhang and Ng (2012) emphasised the need for the professionals to collaborate in order to successfully deliver the project [17]. This is achievable by sharing their expertise, establishing common ground, seeking effective solutions collectively and improving project delivery efficiency. Traditionally and still in common practice, project teams are selected based on their technical and financial capabilities and the competitiveness of the design and tender sum. Construction projects usually require collaborative working between members of a project team [7,8]. Bishop et al. (2008) stated that with a construction project, it generally commences with the client's decision to invest in a development [18]. Traditionally, after the appointment of a designer/architect as the project lead, the main contractor may be appointed through a tendering process. As such, the onus remains on the main contractor to assume complete responsibility for managing the construction process. The main contractor may then appoint specialist contractors as perceived fit, also depending on their workload structure.

Most times, it is assumed that project teams understand and respect the input of others, their roles and responsibilities. It therefore follows that collegial relationships amongst project-teams may benefit from regular meetings, open dialogue and apportionment of risk, which in turn produce an atmosphere of mutual trust. Based on such an understanding, it can even be argued that where there is timely sharing of information, emerging problems may be resolved easily, particularly when all team members participate towards a common goal. Moreover, the project team is motivated by a fair method of pain-share and gain-share, which ultimately means that the client and the supply chain achieve a reasonable profit or indeed value for money [19]. It is important to note that the preceding statements are to a great degree underpinned by the collaboration ethos. Constructing Excellence (2011) defined collaborative working as working together within a borderless team to achieve common goals delivering benefit for everyone involved through mutually beneficial alignment [20]. Anumba et al. (2002) identified four types of collaboration models [7,8]. The modes of collaboration in a project have been grouped into four main categories depending on the nature of separation and pattern of communication [7,8]. For construction projects, collaboration could be face-to-face, i.e., occur at the same time in the same place (synchronous) or at the same time in different places (synchronously distributed). It could still occur different times in the same place (asynchronous) or at different times in different places (asynchronously distributed). Out of the four models, synchronous distributed collaboration appears to be the most advanced. A classification of existing collaboration communication processes (Figure 1) suggests that BIM and related cloud services have the potential of achieving face-to-face or distributed collaboration synchronously and asynchronously. Furthermore, Anumba et al. (2002) noted that the models were dependent on the nature of separation and pattern of communication between project players [7,8].

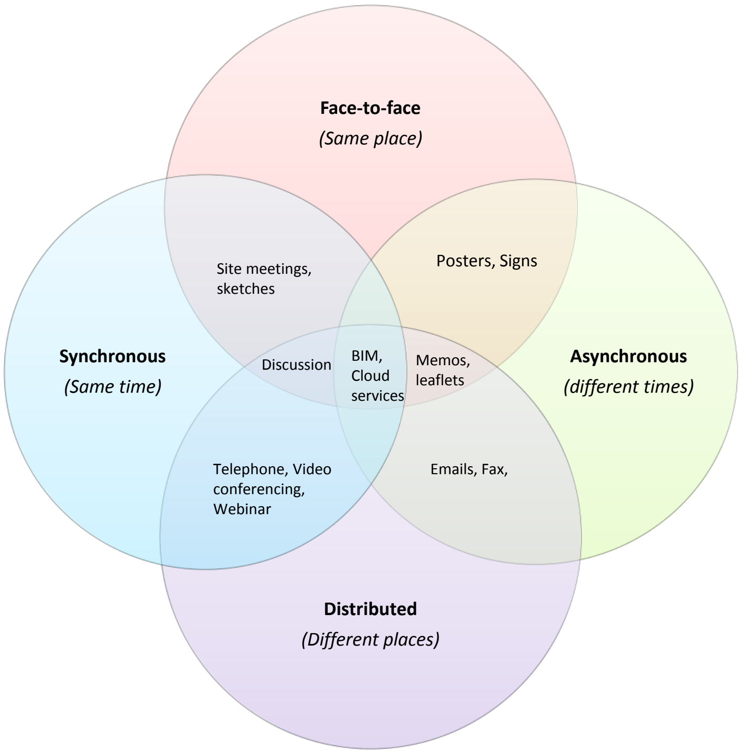

Figure 1. Forms of collaboration in construction projects.

2.2. Building Information Modelling: An Overview

In the literature, various definitions have been attributed to BIM. Eastman et al. (2011) stated that BIM consists of more than just being a technology change, but also a process change [21]. The U.S. National Institute of Building Sciences (NBS, 2007) defined BIM as a "digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition" [22]. Theoretically, BIM is about virtually mimicking a construction project, using computer software. Such simulation incorporates geometric content, as well as information on every aspect of the project throughout its life span [23]. BIM has been hailed as a solution for tackling construction industry production problems [14,21]. The adoption of BIM has been viewed as an important step in improving productivity and predictability [11,24]. Consequently, various governments are now strongly recommending the use of BIM in their construction industries. In the U.K., for example, from April 2016, the government made it mandatory for all central government-procured construction projects to be delivered using BIM Level 2. BIM Level 2 is a managed 3D environment held in separate discipline BIM tools with data attached. Studies about BIM implementation in the construction industry are now common [25–27]. The studies reveal that BIM is mostly used in generating construction information with less emphasis on its distribution amongst project partners. Effective communication and/or sharing of information are essential in ensuring greater participation and in meeting project requirements. Using BIM in silos restricts project actors' access to a common set of data or information and has been critiqued in the literature [14,28]. Cloud BIM technology provides a framework to break the silos of working practices [14,23]. Cloud BIM can lead to higher levels of cooperation and collaboration. Furthermore, cloud BIM can provide an effective real-time communication platform for project team members. A BIM project has been envisioned by Koskela et al. (2013) as people and process-led, whereby BIM tools act as enabling tools for construction project collaboration [29]. Therefore, as such, striking a balance between people, process and technology is vital for its successful adoption.

2.3. Cloud/Mobile BIM for Collaboration

Recently, the construction industry has seen a rapid increase in the use of mobile/cloud BIM computing technology in construction projects. It has been used for collaborative communication purposes through mobile devices like PCs, smartphones, tablets PCs and iPads [b28]. BIM is being integrated with cloud computing technologies, creating an innovative working pattern streamlining communication with the onsite processes. Indeed, cloud computing technology promises to offer enhanced accessibility of project data and site images simply by remotely linking mobile devices with a dedicated remote server. The mobile/cloud BIM technology promises to offer higher levels of cooperation and collaboration. One of its major strengths is in the ability to offer a real-time communication platform for project team members and other external stakeholders. Mainly, mobile/cloud-BIM technology offers: (i) actual-time monitoring of progress, (ii) coordination, (iii) clash detection and (v) data sharing amongst project teams regardless of location, inter alia. Professionals have acknowledged the usage of mobile/could BIM technology in construction activities resulting in enhanced communication amongst site-based teams. Not only does it prevent unnecessary delays, but also, arguably, avoids the possibility of conflicts onsite. A number of peer-reviewed articles have substantiated the afore-mentioned benefits of mobile/cloud BIM technologies (e.g., [14,24,30,31]). The real-time cloud-based collaborative BIM platform used through mobile devices is enabling users to virtually communicate [14]. Site teams are now able to view and make responses to site issues directly from their mobile/cloud devices. That has been seen as enhancing communication between project teams onsite. It therefore prevents unnecessary delays, which sometimes result in conflicts onsite. Cloud/mobile BIM technology facilitates the remote exchange of data wirelessly through the Internet. Matthews (2012) reiterated in their findings that construction sites need to adapt their onsite processes to accommodate mobile/cloud-based and structured data entry [30]. The authors emphasised that this was the only way significant benefits could be offered. To them, benefits were both in terms of convenience and also the efficiency of communication between site- and office-based staff. Matthews (2012) concluded in their research that despite the challenges of implementing mobile/cloud-based BIM, its use onsite is of great interest amongst the site teams [30].

In 2014, Chong et al. added that cloud/mobile computing technology with BIM is helping propel innovation and collaboration in construction projects further [31]. For the diverse and distributed site teams to collaborate on a project, Juan and Zheng (2014) stated that the continuous flow of data is required [32]. The authors emphasised that such data have to be consistently accurate and available anytime to the project teams. Cloud BIM is a model-based information management system, which is used to coordinate large, diverse, and distributed project participants, site activities and organise projects effectively. Chong et al. (2014) viewed mobile/cloud BIM technology as enabling higher levels of cooperation and collaboration [31]. It was seen as a more effective virtual-time communication ground for project participants. Wong et al. (2014) stated that in the construction stage, mobile/cloud BIM technology helps with tracking progress, schedule coordination of construction and getting rid of clashes due to design mistakes [14]. The conclusion reached suggested that mobile/cloud technology can perform actual-time monitoring of progress, coordination, clash detection and data sharing amongst project teams regardless of location. A review of mobile/cloud BIM computing technology found that interoperability was the key to the success of mobile/cloud BIM technology implementation [24,28]. Wang and Chong (2015) cited contractual issues, lack of ownership of shared data and contractual inadequacies as the main barriers to mobile/cloud BIM technology adoption and integration [24]. Mahamadu et al. (2013) advocated for further research in dealing with the data security, ownership and stability issues [33]. The authors believed that will foster secure collaboration in using mobile/cloud-BIM technologies. The willingness to collaborate and cultural differences are still considered as strongholds to the implementation of mobile/cloud BIM technology. Moreover, it was concluded that training time and costs are a major hindrance to the mobile/cloud technology BIM adoption. Research lamented the lack of qualified professionals and experts in BIM implementation and adoption in the construction sector [10,24,34,35]. However, the authors recommend that 'industry captains' and professional bodies facilitate continuous professional development training and incorporate mobile/cloud BIM technology into professional and tertiary education. Chong et al. (2014) on the other hand recommended the use of open standard file formats to facilitate the sharing and exchange of data between different systems and vendors [31]. Furthermore, the authors advocated for a central web-hosted server as a way of encouraging transparency and long-term cloud development. Whereas, issues regarding ownership and intellectual property rights invite further attention, whereby a construction contract is tailored to accommodate such requirements. Other researchers advocate for a common data environment, given the data exchange platform and indeed encourages the collaboration of project teams.

2.4. Common Data Environment for Collaboration

A Common Data Environment (CDE) serves as a single source of information for storing, sharing and managing documents in graphical, structured and unstructured form (BSI, 2013) [36]. CDE encourages parties to use the same/related (interoperable) systems and platform to work collaboratively together. Project data in different locations and formats can be connected into a single source and federated. The organization can therefore interact across project teams and collaborate more efficiently, avoiding confusions, omissions, repetitions and errors Such an interaction can be achieved using a myriad of devices including mobile platforms such phones and tablets. CDE is largely classed as a BIM Level 2 maturity tool where project design outputs are produced in 3D models and are managed by different professional platforms. The concept of CDE is not new in the software development domain. Early definitions of CDE include 'a virtual space where in all the stakeholders of a project, even if distributed by time and space, may negotiate, brainstorm, discuss, share knowledge and labour together to carry out some task, most often to create an executable deliverable and its supporting artefacts' [37]. CDE can be used across various domains. Examples of such domains include (i) non-software domains, (ii) asset management, (iii) information services, (iv) infrastructure, (v) community and (vi) software development (vii) construction, manufacturing and (viii) electronics industries [37].

In the preceding sections, the rationale for adopting collaborative working approaches has been examined. The examination culminated in discussions about the use of BIM, cloud BIM, mobile BIM and CDE for fostering collaboration in the delivery of construction projects. However, the key questions yet to be answered are: What are the emerging mobile/cloud BIM technologies currently being used in the construction industry? How are they being used? What are their benefits and impacts on construction projects? What are the challenges associated with their implementation?

3. Research Method

Given that this study is exploratory and the nascent nature of cloud/mobile BIM use in construction where very little peer-review research exists, a mixed research method was adopted. A major advantage of blending research methods is that "it enables the researcher to simultaneously answer confirmatory and exploratory questions, and therefore verify and generate theory in the same study" ([38], p. 15). The two methods that were blended are quantitative and qualitative methods.

Firstly, the quantitative approach was adopted. Given that this study seeks to understand the different types of cloud/mobile BIM technologies being used in practice, a quantitative approach is more appropriate in capturing the numbers. A questionnaire was designed using Survey Monkey, an online survey tool, administered through two main online platforms (See Appendix A in the Supplementary Material). Firstly, the questionnaire was administered through a widely-used and acknowledged online professional platform, LinkedIn, and several professional forums on Facebook. By browsing through online professional profiles on LinkedIn, about 700 professionals with a background in BIM were identified; of which a message of invitation was delivered to the potential informants before sending the questionnaire sequentially. The recruitment of informants from social media, e.g., Facebook and LinkedIn, is now becoming too common [39]. The questionnaire consisted of close-ended opinion questions, which required the respondent to rate checklists, grid checklists, rank and specify by addition if not found in the provided choices. That initiated specific responses such as most frequent, more frequent, frequent, less frequent or never. Out of the 700, 162 provided complete feedback. Secondly, it was handed to BIM professionals during the Oxford BIM regions events held at Oxford Brookes University, Oxford, U.K., in 2016. Through two successive BIM events, the questionnaire was handed to 100 participants, and 36 provided complete responses to the questions on the questionnaire. In total, the number of respondents was 198 (i.e., 162 + 36), representing a 24.75% ((198/800) × 100)) response rate. Although, this rate appears low, it is however significant compared to most studies in the field. For instance, Akintoye (2000) and Dulami et al. (2003) argued that the normal response rate in the construction industry for postal questionnaires is around 20%–30% [40,41].

Once the results were collected, the Microsoft Excel spread sheet software application was employed to manipulate the quantitative data. That data were generated from the online Survey Monkey, which consisted of nine closed questionnaires. Percentages were calculated, and pie charts and bar graphs were produced for responses.

Secondly, a qualitative approach was adopted. Research about mobile/cloud BIM technology is scarce. Therefore, in-depth knowledge is required to understand the state and application in practice. Thus, in-depth qualitative interviews were more appropriate and adopted (See Appendix B in the Supplementary Material). From the list of respondents from the quantitative study, 15 were identified based on their expertise to participate in in-depth interviews. Email invites attached with interview questions were sent out to those BIM experts prior to the actual face-to-face or telephone interview. Five BIM experts agreed to be interviewed. Each was interviewed with two on a face-to-face basis, while the other three were over the phone. The interviews offered the opportunity to freely probe certain areas and ask specific questions in the duration of the interview. Therefore, it resulted in high quality and detailed qualitative data. The qualitative interview feedbacks obtained were analysed for any trends, themes, deviations, similarities and conclusions to be drawn. The analyses of the questionnaire and in-depth interview feedback will be discussed in the ensuing section.

4. Analysis of Results

4.1. General Information about Respondents

The respondents were all BIM professionals working in the U.K. construction industry. Those BIM professionals had different levels of expertise as shown in Table 1. It was shown that 39.39% were from building works contracting, followed by project consultancy and civil and engineering, which both had about 20%. Architectural firm and others were both around 10%. Respondents from large organizations of more than 250 employees accounted for more than 57.58%.

Table 1. General information about respondents (N = 198).

	Construction organization type	Response count	Response percentage
Business type	Architectural firm	24	12.12%
	Civil and Engineering	36	18.18%
	Building works contractor	78	39.39%
	Project consultancy	42	21.21%
	Public works contractor	0	0.00%
	Other	18	9.09%
	Total	198	
Organization sizes	Up to 10	30	15.15%
	Up to 50	36	18.18%
	Up to 250	18	9.09%
	>250	114	57.58%
Expertise level	Very little or none	18	9.09%
	Beginner	48	24.24%
	Intermediate	72	36.36%
	Expert	60	30.30%
	Total	198	

4.2. Analysis of Survey Questionnaire

4.2.1. Objective (a): Establish the State-Of-The-Art of Emerging Mobile Devices and Cloud BIM Used Onsite

The research sought to establish which state-of-the-art emerging mobile devices are used onsite. Using a Likert scale of 5–1 (i.e., most often, more often, often, less often and never), the respondents were asked to rate the devices commonly used. The findings are presented in Table 2. The results revealed that iPads and iPhones were the most popular devices used onsite followed by Samsung smartphones and Samsung tablet PCs. Blackberry, Sony and HTC were the least with some of them not in use at all. The most popular devices used are iPads, iPhones and Samsung smartphones. The most popular mobile/cloud BIM are Autodesk Navisworks, Solibri Model checker and BIM360 Glue (see Table 3).

Table 2. Most common mobile devices.

Mobile Device	Most Often	More Often	Often	Less Often	Never	Response Count
iPad	36	18	24	36	36	150
iPhone	18	24	24	36	48	150
Samsung smartphone	12	36	0	24	66	138
Samsung note	24	12	6	18	78	138
Tablet PC	6	6	8	42	66	138
Blackberry	0	0	0	6	78	84
Sony	0	0	0	6	120	126
HTC	0	0	6	6	114	126

Table 3. Cloud BIM software applications.

Mobile/Cloud BIM Application	Most Often	More Often	Often	Less Often	Never	Total Responses
BIM360	12	12	24	24	84	156
BIMx	6	0	0	12	114	132
Vico Office Suite	0	0	0	0	132	132
Vela Field BIM	0	0	0	6	126	132
Bentely Construction	0	0	6	12	114	132
Tekla BIM Sight	0	0	18	12	108	138
Autodesk Naviswork	90	12	24	18	42	186
Solibri model checker	18	36	6	12	72	144
BIM360 Glue	18	6	12	12	90	138
A360 CAR	0	0	0	0	132	132
BIM360 Planning	0	0	0	0	132	132
Autodesk A360	6	12	18	18	90	144
BIM Server	0	12	0	6	114	132
BIM19	0	0	0	0	132	132

4.2.2. Objective (b): Investigate How the Mobile/Cloud Devices Are Used Onsite

The research sought to establish which emerging mobile BIM apps are used onsite. The results are presented in Table 4. It emerged that mobile BIM apps were mostly being used for collaborative purposes in construction projects such as virtual communication between relevant project stakeholders.

Table 4. Mobile/cloud BIM uses.

Cloud BIM Uses	Most Frequent	More Frequent	Frequent	Less Frequent	Never	Responses Count
Accessing and sharing real-time data	42	30	30	30	42	174
Requesting information and change orders	36	30	30	24	60	180
Communicating with other key organizations	30	36	66	18	30	180
Monitoring work tasks and resources	36	6	12	42	78	174
Detecting potential clashes due to design errors	36	30	54	12	48	180
Collecting and retrieving progress information	30	12	30	18	78	168
Liaising with and updating the progress of the project	30	6	24	30	78	168
Coordinating partners and working groups engaged	18	36	48	24	48	174
Recording and managing project progress	24	12	30	48	54	168
Coordinating construction schedules	6	24	24	30	84	168
Others						18

Other uses that emerged are the use of mobile BIM apps for teaching and demonstrating projects to onsite project teams, as well as engaging main clients and other stakeholders who have no access or the skills to use the software.

4.2.3. Objective (c): Investigate the Opportunities and Effect of Mobile/Cloud Devices Used Onsite

The study aimed to establish the opportunities and effects of mobile/cloud BIM apps' use in onsite construction projects. Table 5 reveals that communication is the benefit with the highest score.

Table 5. Mobile/cloud BIM benefits.

Benefits	Highly Significant	Significant	Less Significant	Not Significant	Response Count
Timeline reduction	24	54	48	36	162
Effective and efficient communication	72	66	18	18	174
Reduction of project cost	18	72	42	30	162
Accuracy increase	42	84	24	24	174
Improved information flow	66	84	12	12	174
Quality increase	42	54	42	24	162
Risk reduction	42	66	42	18	168
Waste reduction	12	48	90	12	162
Optimised project scope	6	54	66	36	162
Synchronised project team	42	90	24	18	174
Seamless integration in project processes	24	60	48	30	162
Others					36

4.2.4. Objective (d): Investigate the Challenges of Mobile/Cloud BIM Devices and Applications in Construction Site Activities

This study aimed to investigate the challenges for the adoption of cloud BIM at construction sites. The results are presented in Table 6. Based on the results, skills shortage and competencies are the most significant factors hindering the uptake mobile/cloud BIM for use in onsite construction projects.

Table 6. Mobile/cloud BIM barriers.

Hindrance Factors	Highly Significant	Significant	Less Significant	Not Significant	Response Count
Lack of trust with data security and privacy	42	78	42	12	174
Lack of vision and strategy	42	54	66	18	180
Data ownership and confidentiality	48	42	66	12	168
Lack of audit trail	18	54	54	48	174
Lack of skills and competencies	84	36	42	12	174
Cultural differences	30	42	30	72	174
Lack of transparency	6	54	48	66	174

Table 6. *Cont.*

Hindrance Factors	Highly Significant	Significant	Less Significant	Not Significant	Response Count
Current project contracts inadequacy	24	42	48	48	162
Job insecurity	6	12	42	102	162
Fragmented project nature	6	42	54	60	162
Lack of shared vision	36	42	36	54	168
Lack of web access	24	30	66	48	168
High cost of cloud BIM	12	54	66	36	168
Lack of interoperability	30	54	48	24	156
Other					

4.2.5. Objective (e): Develop or Propose a BIM-Supported Framework that Uses Mobile/Cloud BIM Technology for Managing Projects Onsite

This study aimed to establish factors that can enhance the uptake of mobile BIM at construction sites. The results are presented in Table 7. The results show the Internet access, interoperability, unlimited data access and project team collaboration are the most important strategies. However, Internet access was shown to be a secondary factor because it is now readily available country wide at least in the UK.

Table 7. Support strategies for the adoption of mobile BIM.

Factors	Most Important	More Important	Important	Less Important	Not Important	Responses Count
Internet access	78	24	54	18	0	174
Unlimited data access	60	36	60	18	0	174
Interoperability	90	30	48	6	0	174
Shared data ownership and management	36	54	66	18	0	174
Standard file exchange format	36	78	48	12	0	174
Legal and security	24	54	60	36	0	174
Efficiency and reduced costs	42	36	72	24	0	174
Project team collaboration	72	54	36	6	0	168
New procurement methods	24	18	54	42	12	150
Integrated shared BIM	30	48	54	36	6	174
Government initiative	12	30	42	42	48	174
Simple and flexible cloud BIM infrastructure	24	60	48	30	12	174
Availability of mobile devices	18	42	36	30	42	168
Others						24

4.3. *Analysis of Interview Feedback*

4.3.1. Background of Interviewees

In order to discuss the interview feedback, it is imperative to provide the profile of the informants (see Table 8). This provides the basis upon which to ascertain the credibility and reliability of the feedback.

Table 8. Profile of informants.

Interviewee	Background
Interviewee 1 (C/M BIM-I (1)):	Work address: London Professional expertise: working for a consultancy firm and expert in mobile/cloud BIM technology. Organization profile: less than 50 employees.
Interviewee 2 (C/M BIM-I (2)):	Work address: Birmingham Professional expertise: working for an architectural firm and intermediate expert in mobile/cloud BIM technology. Organization profile: 10 employees.

Table 8. *Cont.*

Interviewee	Background
Interviewee 3 (C/M BIM-I (3)):	Work address: Oxford Professional expertise: working for a building works contractor and intermediate expert in mobile/cloud BIM technology. Organization profile: less than 250 employees.
Interviewee 4 (C/M BIM-I (4)):	Work address: Oxford Professional expertise: working for a consultancy firm and intermediate expert in mobile/cloud BIM technology. Organization profile: more than 250 employees.
Interviewee 5 (C/M BIM-I (5)):	Work address: Oxford Professional expertise: working for a consultancy firm and expert in mobile/cloud BIM technology. Organization profile: more than 250 employees.

C/M BIM-I, Cloud/Mobile BIM-Informant.

4.3.2. Interviewees' Feedback

Response to Question 1: Mobile devices used in construction activities or are you aware of these in your organization:

- Cloud/Mobile BIM-Informant (C/M BIM-I) (1): For Question 1, the interviewee cited all four popular mobile devices that have been used within their organization. These include iPhones, iPads, Samsung smartphones and tablet PCs (Samsung).
- C/M BIM-I (2): For Question 1, the interviewee stated that in their organization, iPads and iPhones were mostly used.
- C/M BIM-I (3): For Question 1, the interviewee stated that Samsung smartphones and Samsung tablets mostly and occasionally iPads were used.
- C/M BIM-I (4): For Question 1, the interviewee stated that iPads, iPhones, Samsung smartphones and Samsung tablets were used.
- C/M BIM-I (5): For Question 1, the interviewee stated that iPads, iPhones, Samsung smartphones and Samsung tablets were often used. Just like all of the interviewees, these are the mobile devices in use in the telecommunications market in the UK.

Response to Question 2: Main uses/applications of mobile devices in construction projects:

- C/M BIM-I (1): For Question 2, the interviewee named a number of software applications used by their organization. Some of them were in-house products. C/M BIM-I mentioned that Huddle (similar to Dropbox) was widely used as an information management system that provides a collaborative platform. Typically, it was used to share and access project information with external stakeholders with different firewall online. Also, the use of BIM 360 field and BIM 360 glue, was commonplace with their contractors, given its ability to be used as a graphical tool, thus viewing models in 3D. It was frequently used for collaborating in the cloud as software as a service. The cloud provision service was offered by Amazon. In trying to move away from the use of applications to new technology, the focus was more on mobile web-based applications. The strategy adopted was the change of the data management system, which offered complete access to data using a cloud-based web platform, offering secure access for an open system. Adoption of such a system had the ability to reduce maintenance costs, and offered little or no security of the cloud-based system impediments, given that this aspect was managed by a service provider.
- C/M BIM-I (2): For Question 2, the interviewee stated that the most commonly used package was Assemble BIM 360 software application within their organization. It was noted however that the C/M BIM-I (2)'s organisation was not heavily involved with mobile/cloud BIM technology.
- C/M BIM-I (3): For Question 2, the informant mentioned that Navisworks software applications was used very often within their organization. Typically, it was used for: (a) clash detention,

(b) model assimilation, and (c) model view. The informant stated that smartphone devices are used for uploading models for viewing any clashes, especially mechanical and electrical components, through detection tools such as Navisworks software collaborative.

- C/M BIM-I (4): For Question 2, the interviewee stated that Autodesk ReCap and Navisworks were typically used as the mobile/cloud BIM application. After the collection and importation of the data into Autodesk ReCap, accessibility across the project team was easier. Furthermore, they virtually check highlights on missing elements and make corrections using the Navisworks software application.
- C/M BIM-I (5): For Question 2, the interviewee stated that Asta Site is commonly used on their site for programming. The software is installed into the site manager's phone. As the manager moved onsite, the models were uploaded and the progress made on the project was subsequently revealed and simultaneously sent to all the respective project stakeholders. The other application used for snagging and general clash detection was BIMXtra, from Clear-Box.

Response to Question 3: What cloud BIM applications do you use or are you aware of and how are they applied in your organization?

- C/M BIM-I (1): For Question 3, the interviewee stated that mobile/cloud BIM technology is used for sharing data without having to necessarily go onsite/in the field. The informant remarked that some projects are very large construction sites, which can now be accessed easily without having to travel much to collect project information. The informant praised cloud applications, given their ability to offer viable solution for collaboration with all stakeholders in different locations. Furthermore, the interviewee noted also that most of the information is set out using BIM in construction projects with input linked to mobile devices. More recently, interviewee's organisation is trying out augmented reality, which is at the time of the interview was still in the early stage of development. Typically, it was used for marketing such as exhibiting to clients. Uses are specific to the organization's core business. The interviewee commented that the market for mobile/cloud BIM technology has not matured as of yet, with different organizations trying new applications that are still not used by anyone else.
- C/M BIM-I (2): For Question 3, the interviewee stated two uses only: that it is used for navigation and visual inspection by top management for the projects in which they are involved.
- C/M BIM-I (3): For Question 3, the informant stated that their organization employed mobile/cloud BIM technology mainly for effective and efficient communication collaboratively with project stakeholders across locations. Furthermore, the informant commented that use of mobile/cloud BIM for detecting clashes and correcting errors in the model before the project is constructed was commonplace.
- C/M BIM-I (4): For Question 3, the interviewee was of the view that the main uses/applications of mobile/cloud BIM technology in construction projects were virtual model accessing and viewing. The interviewee further referred to the use of mobile/cloud BIM for communicating with project stakeholders, both onsite, as well as offsite.
- C/M BIM-I (5): For Question 3, the interviewee stated that mobile/cloud BIM technology was used in a common data environment through Conject or viewpoint software for document management and contract management. The interviewee claimed that New Engineering Contract (NEC) has been built into the software, and instructions, variations, warnings are issued in Conject. It is also used for audit trails, as well. The interviewee commended that it is a great communication tool used collaboratively by the project stakeholders.

Response to Question 4: Benefits if any of mobile/cloud devices use in your organization:

- C/M BIM-I (1): For Question 4, a number of qualitative benefits were sited. For example, the interviewee stated that it reduced time for information upload into data systems, where structured data are easily stored and accessed. The interviewee stated that mobile/cloud devices offered easy access and sharing capabilities with internal and external project stakeholders. The literature supported these claims. However, no actual figures were given to substantiate the claims.

- C/M BIM-I (2): For Question 4, only qualitative benefits were stated by the interviewee in that it saved time because it eliminated clashes and reworks. The informant added that it helped to facilitate collaboration amongst stakeholders. That was through easy access of project information and the virtual sharing of data. No quantifiable benefits were given, as the respondent cited difficulty in obtaining such data off hand.
- C/M BIM-I (3): For Question 4, the informant cited qualitative benefits such as mobile/cloud BIM facilitates collaboration of the supply chain. Furthermore, the informant said that it creates an environment for understanding the project better. More importantly to them was that it makes collaborative planning of project work easier for its success. No quantifiable benefits were given.
- C/M BIM-I (4): For Question 4, the interviewee stated that the qualitative benefits for mobile/cloud BIM technology in their organization are that it made it easier to monitor each panel's fabrication for the project. The informant added that it also helped them with inspections and planning project tasks easily. However, quantitative benefits were not stated even though the interviewee seemed to be of the view that the benefits were significant.
- C/M BIM-I (5): In Question 4, the interviewee highlighted many benefits for using mobile/cloud BIM in their organization. The interviewee stated that the organisation has total control of all that happens in the project onsite without necessarily being onsite. All the communication done virtually gives them the ability to monitor and follow all project activities. The interviewee also highlighted a number of benefits such as: reduction in the number of site visits given the ability to view the project virtually; timing savings as queries and clashes were identified early and rectified before actual project construction. Quantitatively, the interviewee claimed that in one research project, 95% waste management was achieved due to reduced rework and minimised over ordering. While 80% was achieved post contract change, and because of the adoption of Navisworks, clash detection and visualisation were attainable. The interviewee stated that the models are shown to the client who instructs about variations before actual project construction, which saved time and cost, as well. Furthermore, it was noted that because of the design detail due to design thoroughness, therefore, there were less variations and unnecessary changes. Exact quantities are generated from the model in their organization using Bitcon software hosted by Elecosoft. Federated models are converted into Industry Foundation Class (IFC) files that were uploaded into the estimating software. The interviewee stated that the estimating software has a cost library, their historical cost data, Spons cost information and templates. The interviewee argued that ensured exact quantities were easily generated by a user-friendly system. Furthermore, the informant commented that project data were presented and displayed in a manner which made it easier for clients to read and understand. Although the quantitative benefits stated could not be corroborated by the literature, the interviewee seemed so confident so as to give the figures and was quite happy about being at the forefront of the new technology.

Response to Question 5: Challenges and barriers you are aware of about mobile/cloud BIM use in construction site activities; in short, explain how these problems could be overcome?

- C/M BIM-I (1): For Question 5, the interviewee stated a number of barriers and challenges of mobile/cloud BIM technology adoption. The interviewee was concerned about the temperamental mobile devices used, which are prone to damage given the harsh site conditions. The interviewee stated that the lack of security confidence for cloud-based systems was an issue. For example, a client like the Ministry of Justice has a protocol to use only their own verifiable systems. That showed that their system is still inadequate in adapting to client's needs. The cost of the software especially to small organizations is seen as a barrier, as well. The interviewee lamented the skill shortage in the construction sector currently for BIM professionals. That seems to be the trend currently: that large organizations are the ones keen to invest in new technologies. File formats were stated as a huge challenge when sharing data. The interviewee argued that interoperability due to a lack of standardised file formats, incompatibility and the unstructured nature of data create a challenge for the industry as a whole. However, the interviewee recommended that organizations could work toward s an open standard format such as the IFC, because currently, it is the only standard format on offer.

- C/M BIM-I (2): In Question 5, the interviewee stated that the barriers and challenges of mobile/cloud BIM technology use in construction activities were many. The interviewee mentioned the high cost of the technology and change resistance by project teams to new technology usage as the major ones. The interviewee felt that people sometimes can resist change if it is not managed appropriately, especially with new technology. The interviewee said that could be overcome with support through the right training to successfully implement it. The interviewee also viewed applications of mobile/cloud BIM technology as a system with less tools that are harder to navigate. That is, however, not supported by the research. However, the interviewee recommended that there was a need to make them simpler or user friendly, which could help users of the new technology learn it quickly to appreciate the benefits it promises.
- C/M BIM-I (3): In Question 5, the interviewee posited that the barriers and challenges for mobile/cloud BIM technology use in construction site activities were the high costs associated with the new technology. The interviewee recommended the use of uniform file formats and a common data environment in exchanging information across firewalls. The interviewee reiterated the willingness to adapt (culture change resistance).
- C/M BIM-I (4): For Question 5, the interviewee stated that the challenges and barriers of mobile/cloud BIM use in construction activities was the lack of knowledge of the new technology. The interviewee believed that cultural change was needed to overcome negativity with that new technology. Therefore, the interviewee suggested that could be overcome by providing the right training. In addition, the interviewee stated that finding the appropriate software applications to use can be a challenge, but thoroughly researching the right operating systems can help.
- C/M BIM-I (5): For Question 5, the interviewee pointed out one of the barriers as the lack of awareness about mobile/cloud BIM benefits by the project teams. The interviewee lamented about the skills' shortage besetting the construction industry as a whole. The interviewee also remarked that minimal relevant training is offered to professionals due to less investment in training of project teams. The interviewee thought the government lacked in the monitoring of mobile/cloud BIM technology use, which means each one is doing more or less what has been ordered. Furthermore, the interviewee considered challenges such as the need to get site teams on-board about mobile/cloud BIM technology. The interviewee claimed that project teams were working in silos. That could possibly be overcome by working together collaboratively between stakeholders. The interviewee interpreted the ratio of BIM technology:BM people as 20:80 with the emphasis of putting more resources toward the people aspect of BIM, thus investing in their training. It is important to note that this technology:people ratio cannot be verified by the literature.

Response to Question 6: What recommendations do you have for the adoption of mobile/cloud BIM technology for managing construction activities?

- C/M BIM-I (1): For Question 6, the interviewee recommended that for mobile/cloud BIM technology to be adopted, mobile/cloud BIM should be user-friendly. The interviewee felt that for people, since a new technology is harder to use, most times it was easier for the users to revert back to the old system.
- C/M BIM-I (2): For Question 6, the interviewee recommended that campaign initiatives and training of project teams can help with the adoption of mobile/cloud BIM technology. The interviewee reiterated that mobile/cloud BIM as a new technology in the construction

industry requires some good campaign initiatives. The interviewee claimed that the project teams' awareness of it will make them appreciate its benefits.

- C/M BIM-I (3): In Question 6, the interviewee recommended parties to agree and adopt uniform file formats as the key to the adoption of mobile/cloud BIM technology in construction. The interviewee also encouraged collaboration earlier in the construction process. The interviewee explained that will mean using procurement systems that promote early contractor involvement in the project. Training and educating project teams on mobile/cloud BIM technology use was highly recommended. Moreover, for project teams to appreciate the benefits, it is critical that the knowledge was teams understand the to they need to know how to use it well.
- C/M BIM-I (4): For Question 6, the interviewee recommended the standardisation of file formats for information exchange and that project teams be educated from top to bottom. The interviewee reiterated the need to use much simpler systems, as too complex ones discourage teams from using them. As is the case with some new technology, when users stumble across a problem, it may be easier to revert back to old ways.
- C/M BIM-I (5): In Question 6, the interviewee recommended that for the adoption of mobile/cloud BIM technology, the key thing was having the right training and awareness of its benefits. The interviewee underscored the importance of investing more in time and people, remarking that it is not about technology, but people. Quote: "Embed the right attitude into the company culture from top to bottom". The interviewee emphasised that the drive should be with the contractor to use mobile/cloud BIM technology. Exhibiting those benefits to the client will help them appreciate the better quality and the cost savings brought about by the use of mobile/cloud BIM technology. The literature agrees that people are more critical than the technology being adopted or implemented [10,37,38].

5. Discussion of Findings: Quantitative and Qualitative Comparison

The qualitative results reveal a number of interesting insights, given that the data was exploratory in nature, as such, it was possible to deduce some grounded theories from the interviewees. The probing helped to focus them and prompt them for more information, which they willingly gave out. The quantitative results were easy to follow and explain, yet the qualitative results had too much information, which was not related sometimes. Feedback from the quantitative and qualitative research methods largely corroborated each other, although some subtle differences were noted. Furthermore, efforts to corroborate some findings with the literature were challenging. For example, an interviewee stated that it was viable to use mobile/cloud BIM technology for contract management, however, no studies corroborate this view. That notwithstanding, using mixed methods (quantitative, qualitative and literature review) served the purpose of validation of the results.

Findings from the quantitative and qualitative studies revealed the same state-of-the-art emerging mobile phones used onsite for managing construction activities. Furthermore, the feedbacks from both methods revealed that architectural and consultancy organizations had a higher number of participants, especially for those who were experts in mobile/cloud BIM technology.

This research uncovered that the main mobile devices used onsite are iPhones, iPads, Samsung smartphones and tablet PCs. These devices are the state-of-the-art mobile phones in the U.K. mobile communications market. Most of the respondents acknowledged the qualitative benefits of these mobile/cloud devices. Using mobile/cloud BIM technology allowed them to remotely view and exchange data over a wireless network such as the web using the mobile devices. Therefore, mobile/cloud computing technology together is used for many activities onsite. Its use is not limited to any specific onsite project activities, as a number of uses were cited by the respondents. However, the most popular use of mobile/cloud BIM was for collaborative purposes. This is quite important in construction practice as collaborative working and effective communication are critical for every construction project [42,43]. In the survey, only one respondent cited quantifiable benefits of mobile/cloud BIM technology use in their organization. In their research project, 95% waste management was achieved due to reduced rework and minimised over-ordering. Furthermore, 80% of post contract change was achieved by using Navisworks to detect clashes and visualisation. These seemed too generous figures and were difficult to verify using existing literature. The reduction of time and costs was achievable because clashes and omissions are identified earlier and corrected before the actual construction is carried out. That reduces rework or change instructions.

The results revealed that the mobile/cloud BIM technology experiences problems in its adoption and implementation onsite because of the reliance on in-house systems, as such, unable to share or exchange files with external stakeholders. The other problem is further exacerbated by the functionality of the system in terms of adoption across multiple stakeholders. One interviewee cried foul about a client such as the Ministry of Justice, who stated the needs that they had problems addressing. From the results, it can be said that mobile/cloud BIM technology is adopted mainly by large organizations. More mobile/cloud BIM respondents for this study were from large organizations. That could be due to the resources of large organizations, making them able and willing to invest in the new technology. The other trend shown by the results was that the architectural and consultancy respondents were the majority. Can it be said the mobile/cloud BIM technology is only for a few select, and if so, why that disparity? Only one respondent cited the use of mobile/cloud BIM technology for quantities and cost information. Can it be said that cost managers are slow to technology uptake currently, and if so, why? Currently, the industry is reported to be facing shortages of qualified personnel and experts for BIM adoption and implementation. This corroborates other studies (e.g., [10,B37(34),B38(35)]) that argued the lack of skills and competencies to be significant barriers hindering the uptake of BIM technologies. The second major barrier is data ownership, confidentiality and lack of trust. This corroborates studies by Wang and Chong (2015) [24]. The study recommended investing more in training to promote new technology. One respondent remarked that people are more critical in technology adoption. Other recommendations were stated, particularly the use of standardised file formats for information exchange between different teams. The provision of unlimited data and Internet access were also cited as important strategies for the adoption of mobile/cloud BIM technologies. The use of interoperable file formats, Internet access and unlimited data as key strategies to the adoption of mobile/cloud BIM technologies have been corroborated in other literature, e.g., [24,31].

To facilitate understanding, the research findings are summarized in Table 9.

Table 9. Summary of research findings.

Objectives	Outcomes
a) emerging mobile/could BIM and mobile devices	The most popular devices used are iPads, iPhones and Samsung smartphones. The most popular mobile/cloud BIM are Autodesk Navisworks, Solibri Model checker and BIM360 Glue.
b) uses of mobile/cloud BIM	The most popular use of mobile/cloud BIM was for collaborative purposes. This is quite important in construction practice as collaborative working and effective communication are critical for every construction project [42,43]. Mobile/cloud BIM technology was used to remotely view and exchange data over a wireless network such as the web using mobile devices.
c) opportunities/effects of mobile/cloud BIM	The use of mobile/cloud BIM led to effective and efficient communication between project partners.
d) challenges of mobile/cloud BIM adoption	The lack of skills and competencies, data ownership, confidentiality and lack of trust are key barriers to the adoption of mobile/cloud BIM. This corroborates studies by Wang and Chong (2015) [24].
e) framework for managing project using cloud/mobile BIM	The use of interoperable file formats, Internet access and unlimited data as key strategies to the adoption of mobile/cloud BIM technologies have been corroborated in other literature, e.g., [24,31].

6. Conclusions

The research established the state-of-the-art emerging devices used onsite for managing construction activities as iPads, iPhones, Samsung smartphones and tablets PCs. The major uses cited were virtual exchange and viewing of project information. Some used it for clash detection, collaborative working and monitoring site progress. Different software is used depending on what is available on the market, although Autodesk products seem popular. Furthermore, it emerged that some organizations have developed their own in-house software applications, used alongside BIM for communication purposes. Many benefits were identified such as cost and time savings. This also encourages team collaboration and provides a platform for easy data access. Furthermore, a number of barriers to mobile/cloud BIM technology adoption were also identified. For example, the integrity or trustworthiness of third parties was an issue, as cloud services are often provided by a number of third parties through other cloud providers. A major recommendation from the study was the need to overcome the barriers to cloud/mobile BIM such as the provision of the right training and educating team members, so as to appreciate the benefits of the technology. Furthermore, the use of open standards files with a centralised database server to encourage openness was also recommended.

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