Scientia Iranica A (2016) 23(2), 429–448

Sharif University of Technology
Scientia Iranica
Transactions A: Civil Engineering
www.scientiairanica.com

Integrated collaborative tools for precast supply chain management

M. Abedi[a], M.S. Fathi[b,*], A.K. Mirasa[c] and N.M. Rawai[a]

a. *Faculty of Civil Engineering, Universiti Teknologi Malaysia, UTM Skudai, 81310 Johor Bahru, Johor, Malaysia.*
b. *UTM Razak School of Engineering & Advanced Technology, Universiti Teknologi Malaysia, Jalan Semarak, 54100 Kuala Lumpur, Malaysia.*
c. *School of Engineering & Information Technology, Universiti Malaysia Sabah, Locked Bag 2073, Kota Kinabalu, Sabah, Malaysia.*

Received 1 July 2014; received in revised form 12 January 2015; accepted 30 June 2015

KEYWORDS
Precast construction projects;
Effective communication;
Collaboration;
Integration;
Cloud computing;
Context-aware;
Building information modeling.

Abstract. Precast construction projects are associated with many activities, numerous parties, enormous effort, and different processes. For effective communication, this requires delivering appropriate and up-to-date information to enhance collaboration and improve integration. The purpose of this paper is to develop the system architecture and prototype of Context-Aware Cloud Computing Building Information Modelling (CACCBIM) for precast supply chain management. The findings of this research are grounded on the literature of cloud computing, context-awareness, building information modelling, and, ultimately, the analysis of interviews with stakeholders in precast construction. Findings determine that lack of integration, improper planning and scheduling, poor production timing, poor coordination, lack of good communication among parties, wrong deliveries, and poor control and supervision are the major issues within the precast supply chain. These issues could result in adverse consequences for the objectives and success of the precast project. Eventually, to reduce and eliminate these issues, the proposed prototype will support appropriate deliveries, efficient monitoring, facilitation of coordination, and collaboration with improved communication. It is anticipated that this research will establish a unique perception in the precast construction industry, which will finally enhance its productivity, improve its efficiency, and maximise its effectiveness.

1. Introduction

The precast construction industry is frequently characterised by complexities, non-integrated environments, and fragmentation. Since 150 years ago, the off-site precast construction industry has become one of the core elements of the construction supply chain which consists of the efficient management of various activities contributing to the flow of services, products, and materials [1] among the suppliers, clients, manufacturers, architects/engineers, general contractors, consultants, subcontractors, and developers. It has considerably contributed to improved productivity, cost savings, and decrease in construction time [1-3]. Precast concrete, as a major prefabrication method, is a construction system in which, firstly, concrete is cast [4] in reusable moulds (mostly of steel or wood) and then cured in a controlled environment (commonly off-site); secondly, it is transported to the construction site where it is installed within the construction structure [5-7].

Clients in the precast construction industry are demanding cost-effectiveness, lower construction time, enhanced quality, and delivery of up-to-date information. Hence, one of the effective collaborative tech-

*. *Corresponding author. Tel.: +603-2615 4706; Fax: +603-2615 4430*
E-mail addresses: amohammad22@live.utm.my (M. Abedi); akmirasa@ums.edu.my (A.K. Mirasa)

nologies is cloud computing technology for applying in precast construction industry. As clarified by Chi et al. [8], cloud computing delivers the hardware (IT infrastructure) and software services (applications) of data servers via only the Internet. Moreover, it shares the applications and services (available for 24h/365 days/year) via the ubiquitous internet [9]. Cloud computing technology has been implemented in precast construction projects in order for its dynamic features, difficulties, risks, and information-intensive nature to be dealt with [10,12].

Despite the current evolving technological tools, for instance the cloud computing implementation, managing a large amount of information among numerous stakeholders and precast supply chain parties in precast construction industry is still challenging. Many challenges in the current precast supply chain processes arise through ineffective and low-efficiency access to accurate information at an appropriate time to facilitate urgent decision making. This challenge could contribute to negative influences on the precast construction objectives, such as creating numerous errors, rework, and conflicts resulting in poor productivity and reduced efficiency [13]. Therefore, quick and appropriate access to precast project information via various user contexts with context-aware implementation could contribute to cost saving, enhanced efficiency, greater productivity, and time reduction [14].

Precast construction projects are associated with numerous technical drawings, a lot of information, change orders, and many approvals. Frequently, information is produced in different and unconnected platforms which can be time-consuming and cause difficulties in accessing, sending, and retrieving information. On the other hand, the latest collaborative technologies which have been proposed and implemented within the construction industry are evolved from Building Information Modeling (BIM). Latiffi et al [15] defined BIM as a collection of digital tools for achieving the effectiveness of construction projects. Also, Takim et al. [16] clarified that BIM implementation will help the construction industry to enhance efficiency, increase effectiveness, improve flexibility, and become more innovative. Meanwhile, the current enhanced digitization, improving automation, necessary sustainability, and evolving technologies, such as cloud computing [10-12,17,18], will encourage the utilisation of BIM in the construction industry [19,20]. Consequently, overcoming the issues mentioned in this research will help develop an integrated collaborative (context-aware cloud BIM) prototype for precast supply chain management. This will be described in Section 9 of this research.

This paper is classified into eleven sections. After these introductory remarks in Section 1, this paper will discuss the research scope and the methodological research concept. This is followed by defining the concepts of Precast Supply Chain Management (PSCM). In Section 4, the cloud computing definitions and concepts will be provided. The context-awareness concepts will be presented in Section 5. Section 6 will then set out the definition and benefits of BIM. The qualitative research analysis using NVivo for the semi-structured interviews will be described in Section 7. The system architecture of Context-Aware Cloud Computing Building Information Modelling (CACCBIM) for precast supply chain management will be presented in Section 8. Prototype development of the CACCBIM for Precast Supply Chain Management will be demonstrated in Section 9. The significant points drawn from this research will be explored in Section 10. Finally, the conclusion and future recommendations will be presented in Section 11.

2. Research scope and method

This research has basically considered the application of context-aware cloud BIM within the Precast Supply Chain Management (PSCM) phases: planning, design, manufacturing, transportation, and, lastly, installation/erection and construction of the precast components. It should be noted that this research has selected four various contexts including user, location, information, and time for the context-aware feature in prototype development. This research has concentrated on key parties in the PSCM, including the owners/clients, consultants, architects/engineers, manufacturers, general contractors, subcontractors, construction managers, and suppliers.

Generally, the research procedures are as follow:

1. Over 70 comprehensive items from the literature, related to supply chain management, cloud computing, context-awareness, and BIM, focused on the precast construction industry were consulted. It should be noted that the literature review was mostly based on the main world-wide expert publications from Emerald, Science Direct (Elsevier), Springer, Scopus, Web of Science, IEEE-Xplore, and ASCE;
2. The system architecture of CACCBIM within the precast supply chain management is proposed;
3. Based on the analysis of semi-structured interviews ($n = 19$) consisting of the 4 senior designers, 5 precast technical managers, 2 precast specialists, 6 precast manufacturers, and 2 executive directors within Malaysia's precast construction industry, the CACCBIM prototype for precast supply chain management has been developed;
4. The potential opportunities are proposed in this paper along with future research topics.

It should be notified that the semi-structured interviews are conducted to help identify the details of the user's requirements and expectations for all the precast supply chain phases, including planning, design, manufacturing transportation, installation, and construction. However, the scope of this research will only concentrate on the precast installation and construction phases for the user's requirements and prototypes development. Consequently, since this is an ongoing research, evaluation and validation of the proposed prototype will be presented in future publications. The following section of this research will clarify the definitions, concepts, and benefits of Precast Supply Chain Management (PSCM).

3. Precast supply chain management

The precast system is an efficient construction technique whereby concrete is cast into the reusable moulds and then cured in a controlled environment, transported, and assembled at the precast site [5,21]. On the other hand, Chen et al. [2,3] declared that selection of precast systems, compared to other construction systems, for construction projects should be grounded on the diverse construction characteristics and accessible resources to evade negative consequences such as cost overruns and time delays.

Precast construction systems will lead to improved productivity within the construction industry [1,21], design and aesthetics flexibilities and energy efficiency [6], speedier construction [22], high quality [23], design flexibility [24], improved sustainability [25], lower materials wastage [26], a decreased need for on-site labourers [27], a cost-effective process [28], and improved performance and efficiency [29]. Furthermore, the off-site precast industry (client/owner, consultant, designer, manufacturers, transporters, general contractor, sub-contractor, warehousers, retailers, customers, and suppliers) prevailed in 1850 [1].

3.1. Precast supply chain phases

The parties involved with supply chain phases of precast construction, as illustrated in Figure 1, are classified as: planning, design, manufacturing (production), transportation, installation (assembly), and construction [30-33].

3.2. Precast supply chain problems

One of the earliest studies in identifying precast construction problems [28] found the most common problems in the installation phase to be site location, truck delays, and project cost control. Consequently, inappropriate selection and integration of construction systems could contribute to the difficulties and complication of the construction process, time delays, and, eventually, overrun costs [30]. For the main problems

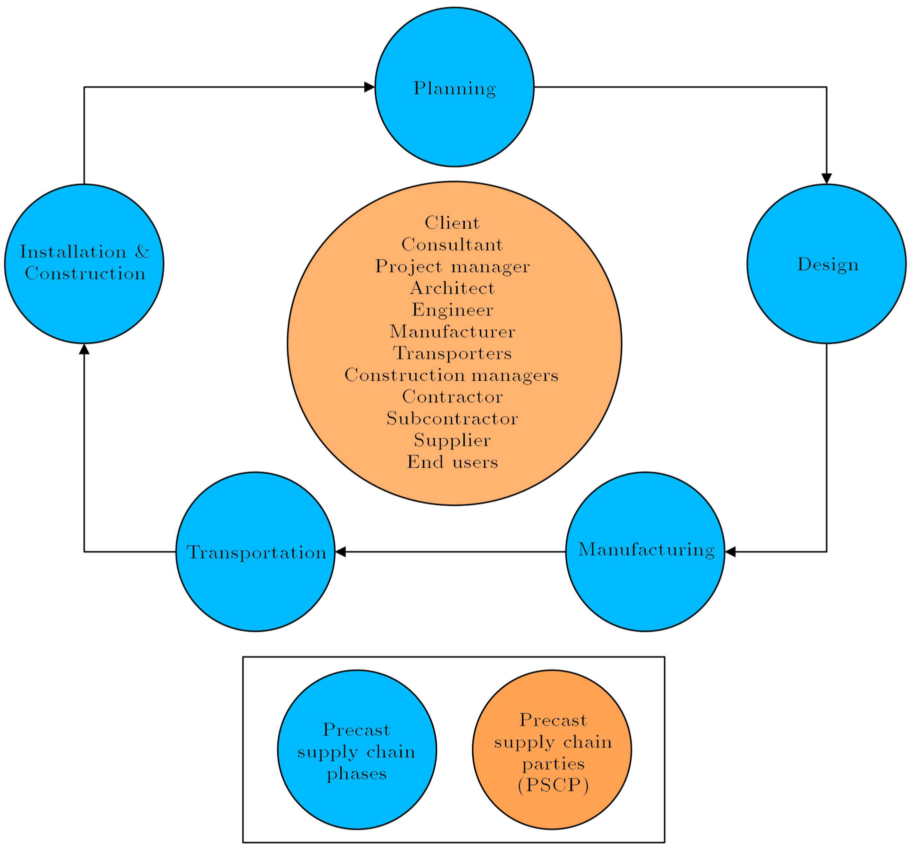

Figure 1. Diagram of the precast supply chain phases.

Table 1. The major problems of precast supply chain phases.

Planning (P)	Poor planning and scheduling [1]. Poor planning, wrong choice and combination of construction systems [30].
Design (D)	Poor communications among designers and manufacturers [34]. Poor design [35].
Manufacturing (M)/ Production (P)	Poor production timing [6]. Expensive skilled labourers, resource allocation problems (e.g. crew of workers and equipment such as machines), complex precast characteristics, and dynamic features of the manufacturing processes [36].
Transportation (T)	Large size (bulky) and heavy (great weight) precast components [2,37,38,39]. Late deliveries and poor weather [38].
Installation and Construction (I&C)	Wrong (inaccurate) components delivered [38,39]. Poor coordination and activities management [37]. Poor specialised contactors and lack of good communication among parties [34].

within the precast supply phases including planning, design, manufacturing, transportation, installation, and construction, see Table 1.

According to Table 1, the major problems associated with the precast construction industry are categorised as: poor planning and scheduling, poor communications between designers and manufacturers, large size (bulky) and heavy (great weight) precast components, poor coordination, and lack of good communication among parties. Moreover, the major problems associated with the precast construction industry, including all the phases of SCM, are classified as: lack of interoperability between software used, loss of information and difficulties in communications [32], poor management of knowledge, poor design, lack of information sharing, double work, and the difficulty of tracking [33]. However, this research prototype development of the context-aware cloud computing building information modelling will solve the major issues in the installation and construction phases, such as poor coordination, lack of interoperability between the software used, loss of information, lack of information sharing, and lack of good communication among parties in order to mitigate, avoid, or eliminate the negative consequences arising from these identified problems for the project objectives such as time, cost, quality, and health.

The next section will present the definitions, delivery, and service models for cloud computing as the key precast construction collaborative tools.

4. Concepts of cloud computing

The IT industry claims that cloud computing is the latest efficient and effective development which requires the internet and application servers to function. It is applied globally at anytime and anywhere via the internet network and does not require new infrastructure, employee training, and software licenses [18,40-43]. The major key components of cloud computing are: ubiquitous network via diverse computing resources such as various networks, different servers, storage capabilities, numerous applications, and delivery services [43]; integration of various technologies including utility computing, virtualization, distributed computing, network storage technologies, and parallel computing [44] for facilitating the implementation of computing processes and data-intensive applications [45]. Consequently, a simple definition of cloud computing is that it is a selection of software and hardware that individuals or organizations can implement anywhere at any time via an internet connection. Hence, this technology could be more efficient and effective compared to the internet (a network of networks) in terms of delivering the computing resources, software, hardware, applications, and services (such as the World Wide Web). Here, the internet is only the universal network connecting various computing devices which communicate and deliver the data and information.

Cloud computing delivery (deployment) uses public, private, community, and hybrid models. Cohen et al. [46] note that the public cloud is a pay-as-you-go open system delivered to any user (public). On the other hand, a private cloud (business closed system) will be delivered only to the specific users assigned to the data-centres [47]. Moreover, community cloud implementation is for a selection of organisations [48] which have shared profits, whereas a hybrid cloud is the integration of public, private, and community clouds [43]. On the other hand, according to Cohen et al. [46], Karamouz et al. [48], Goscinski and Brock [49], and Jiao et al. [50], the cloud computing services models which will be delivered to the users are classified into: SaaS (Software as a Service including Gmail, Google Docs, Google Calendar, etc.), PaaS (Platform as a Service which is selecting a platform for developing the applications), and IaaS (Infrastructure as a Service, for instance selecting storage features, processing types, variety of operation systems, etc.).

The major advantages of cloud computing could be signified as scalable delivery for various computing resources and diverse services of Information Technology (IT). Hence, this research has proposed the private cloud and SaaS within the system architecture and prototypes development. Furthermore, it is an opportunity to apply various computing resources and diverse services of Information Technology (IT) in all industries, particularly the precast construction industries. Consequently, if properly applied and adjusted (Cloud computing is one of the main components of this research system architecture in Section 8 and for developing the prototype of the context-aware cloud computing building information modelling for precast supply chain management in Section 9.), it will eventually enhance the efficiency, increase the effectiveness, improve the communication system, and increase the productivity of the precast construction industry. The next section of this paper will deliberate on the various concepts of context-aware technology.

5. Context-awareness

Context is an extensive concept which is used in various industries such as computer science or construction. According to Ntanos et al. [51], in the computer science, the context includes all the quantifiable factors within the device environment related to its use or the user. Moreover, the comprehensive definition that could be utilized within the context-aware applications is that context is any information which could illustrate an entity's situation. An entity is described as an object, place, or person which is significant to the collaboration and communication between the application and user [52].

After identifying diverse contexts, automatic contextual reconfiguration could be produced (context-awareness) [53], such as decreasing the monitor brightness, identifying the nearby Wi-Fi connectivity, and determining the nearest printer for printing a document [51]. Context-awareness allows applications to be delivered to the end-users to provide a richer experience by improving the user interactions through the changing contextual information [54,55]. On the other hand, context-awareness is determined by environmental factors which are classified as location (where), identity (who), time (when), profile and specific activity (what) towards delivering the appropriate information to related users with consideration of the current context [56]. As clarified by Afridi et al. [57], the main objective of applying the context awareness feature is to increase the productivity and improve the efficiency and mobility of construction parties.

The feature of context-awareness will facilitate an efficient and effective response by the tools according to the environmental changes such as the supply chain phases within the precast construction industry. On the other hand, the comprehensive identification and implementation of the context-aware feature could contribute to enhancement of human-machine interfaces [51,52,56]. Hence, this research has applied the context-aware technology, as illustrated in the system architecture of this research in Section 8. Moreover, the prototype development has applied context-awareness (user context, location context, time context, and information context) as briefly discussed in Section 9. It is expected that through implementing this technology, the appropriate information at the right time in the correct location will be delivered to the parties involved, thereby ultimately enhancing effectiveness, improving the communication system, and increasing productivity within the precast construction industry. The definitions and implementations of Building Information Modelling (BIM) will be described in the following section.

6. Building Information Modelling (BIM)

Building Information Modelling (BIM) development can be perceived as the latest technology entering the construction industry, which could be implemented within the information-intensive precast construction industry to improve productivity of the precast supply chain [57]. As one of the comprehensive definitions, Eastman et al. [58] defined BIM as a digital method of design and construction associated with various processes and numerous people to create, communicate, and facilitate the interoperable information models of buildings. It is a digital prototype delivered to the users which facilitates the visual simulation of the planning, design, construction, and operation phases within a project [15].

As a result, this research has proposed Building Information Modelling (BIM) as illustrated in the system architecture in Section 8. Furthermore, the BIM cloud software, as identified within this research including AutoCAD 360, Tekla BIMsight, Autodesk Revit 2013, and also Bentley STAAD.Pro V8i, has been proposed for prototype development in Section 9. It is expected that by accessing the BIM software from the BIM server via the cloud computing implementation, the parties could efficiently send and retrieve the information that could enhance productivity, improve

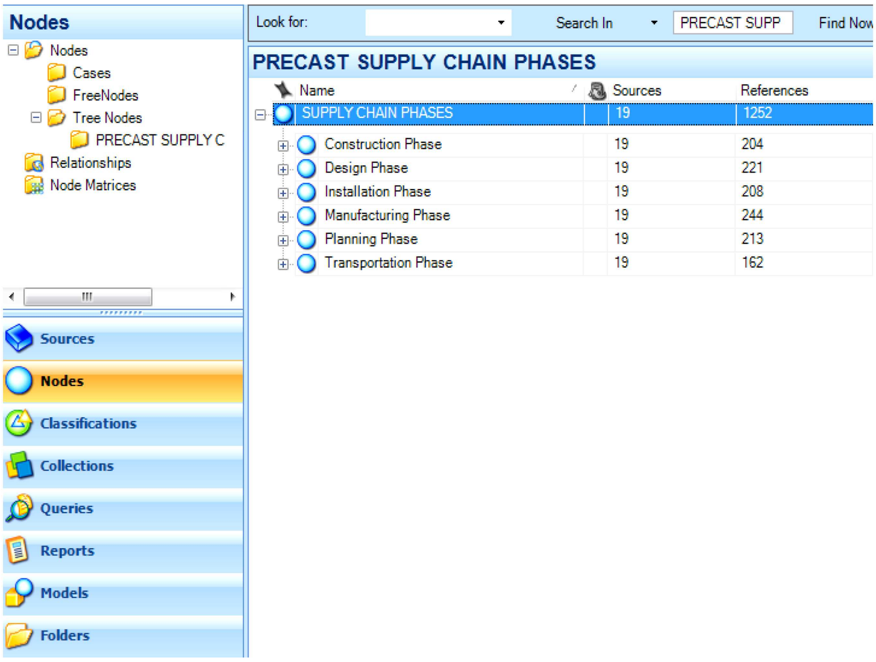

Figure 2. The NVivo nodes of the precast supply chain phases.

the communication system, and increase the efficiency of precast construction industry. The qualitative analysis (user needs analysis from the user requirements studies) of semi-structured interviews with precast supply chain parties along with identifying the major problems and the main software utilisation in the precast supply chain phases will be explained in the next section.

7. Research analysis

This research was accomplished by conducting 19 semi-structured interviews ($n = 19$) with 4 senior designers, 5 precast technical managers, 2 precast specialists, 6 precast manufacturers, and 2 executive directors within Malaysia's precast construction industry. The selected number of respondents ($n = 19$) was based on qualitative data saturation (the situation where no new information can be derived from the data analysis), which eventually occurred in the seventeenth interview [59-61]. However, for better verification, the interviews were conducted up to the nineteenth interview. It should be noted that most of these respondents had considerable knowledge and experience in implementing precast projects through their supply chain phases. On the other hand, if the qualitative data are managed appropriately, they can create significant findings [62,63]. A vast amount of qualitative data is required to be prepared, arranged, and broken into a reduced number of meaningful parts which are then concurrently organised and categorised into specific themes [63-65].

QSR NVivo [64,65] was implemented for the analysis of this qualitative research. This analysis was done in several phases:

(a) Developing documents for semi-structured interviews (respondent's transcripts) and creating the folders;

(b) Assigning the interview analysis variables to nodes in NVivo; and

(c) Creating the NVivo analysis modelling.

7.1. NVivo noding

As shown in Figure 2, the nodes in NVivo are illustrated according to the precast supply chain phases, including planning, design, manufacturing, transportation, installation, and construction.

7.2. Problems within the precast supply chain phases

The major problems within the supply chain phases of the precast construction industry, according to the interviewees, are analysed in NVivo. The results are illustrated in Table 2.

Table 2 demonstrates that lack of integration of precast supply chain phases, as identified by 8 respondents (almost half of the total respondents), is the main significant problem in the precast construction industry. This is due to precast supply chain phases and parties (information flow, communication flow, and process flow) being fragmented and not well integrated into a single process (an integrated system). Lack of ICT collaboration, including the communication tools and collaborative/coordination management tools (online meetings, instant messaging,

Table 2. The major problems in precast supply chain phases.

Major problems	Sources (interview respondents)
Lack of integration	2,3,4,6,7,8,10,11
Lack of ICT collaboration	1,9,16
Inappropriate organizational structure	5,12,13
Poor understanding	15,19
Lack of budget	18
Lack of commitment	14
Ineffective communication	17

time management software or online calendars, social software, voice mails, and video sharing) was agreed by 3 respondents as the other significant issue in the precast construction industry. Hence, this research will focus on solving these 2 mentioned issues by developing a prototype of context-aware cloud computing building information modelling for precast supply chain management in Section 9. However, as mentioned in the research methodology in Section 2, the detailed issues within the installation phase (Table 3) and construction phase (Table 4) of precast construction projects are illustrated in the following tables.

Table 3 demonstrates that most of the respondents (9 respondents) claimed that lack of integration

Table 3. The major problems in the precast installation phase.

Code name (themes)	No. of sources (interview respondents)
1. Poor installation causes	**19**
1.1 Inappropriate organizational structure	3
1.2 Lack of budget	1
1.3 Lack of commitment	1
1.4 Lack of equipment	5
1.4.1 Equipment shortage	2
1.4.2 Lack of special cranes	5
1.5 Lack of ICT collaboration	3
1.6 Lack of integration	9
1.7 Lack of skilled labour	2
1.8 Owner's changes (order changes)	6
1.9 Poor competent contractors	**13**
1.9.1 Inappropriate selection of sub-contractors	6
1.9.2 Inappropriate sequencing of erection and deliveries	3
1.9.3 Lack of capabilities and competencies of the contractors	3
1.9.4 Poor material supply (material delays)	2
1.9.5 Problems of mismatched pieces and connections	4
1.10 Poor coordination	4
1.10.1 Ineffective communication among parties	1
1.10.2 Miscommunication with labourers	2
1.10.3 Poor coordination	2
1.11 Poor on-site controlling and monitoring	**11**
1.11.1 Joint problems	6
1.11.2 Poor assembling	6
1.11.3 Poor controlling and supervision	8
1.11.4 Problems existing in the concrete curing	2
1.11.5 Weak surrounding concrete	2
1.12 Poor timing schedules	3
1.13 Poor understanding	2
1.14 Stocking issues	2

Table 4. The major problems in the precast construction phase.

Code name	**Number of sources (interview respondents)**
1. Ineffective construction causes	**19**
1.1 Inappropriate organizational structure	3
1.2 Lack of Budget	1
1.3 Lack of commitment	1
1.4 Lack of competent suppliers	4
1.4.1 Lack of competent suppliers	3
1.4.2 Poor material supply	2
1.5 Lack of equipment	3
1.6 Lack of ICT collaboration	3
1.6 Lack of integration	6
1.7 Lack of skilled labour	2
1.8 Owner's changes (order changes)	5
1.9 Poor competent contractors	6
1.9.1 Inappropriate selection of sub-contractors	5
1.9.2 Lack of capabilities and competencies of the contractors	2
1.10 Poor coordination	**9**
1.10.1 Ineffective communication among parties	1
1.10.2 Miscommunication with labourers	4
1.10.3 Poor coordination	4
1.11 Poor on-site controlling and monitoring	**8**
1.11.1 Poor on-site controlling and monitoring	7
1.11.2 Problems existing in the concrete curing	2
1.12 Poor timing schedules	5
1.13 Poor understanding	2
1.14 Stocking issues	3

in the processes, information, and communication flow among the parties involved would lead to poor installation of a precast construction. On the other hand, the inappropriate selection of sub-contractors (6 respondents), poor controlling and supervision (8 respondents), and poor coordination (ineffective communication among parties and miscommunication with labourers) would also contribute to poor installation of a precast construction. However, this research seeks to solve the most common issues in the precast installation phase (lack of integration, poor controlling and supervision, and poor coordination) by developing the prototype of context-aware cloud computing building information modelling for precast supply chain management in Section 9. NVivo Modelling of the major problems within the precast installation phase is illustrated in Figure 3.

The next part of this research, as illustrated in Table 4, will explore the major problems within the precast construction phase.

Table 4 demonstrates that most of the respondents (9 respondents) claimed that poor coordination (ineffective communication among parties and miscommunication with labourers) would lead to ineffective construction of precast projects. On the other hand, poor on-site controlling and monitoring (8 respondents), poor competent contractors (6 respondents), and lack of integration (6 respondents) in the processes, information, and communication flow among the parties involved within the construction phase would also contribute to the poor precast construction. However, this research will seek to solve the most common issues in the precast construction phase (poor coordination, lack of integration, and poor controlling and supervision) by developing the prototype of context-aware cloud computing building information modelling for precast supply chain management in Section 9. NVivo modelling of the major problems within the precast construction phase is illustrated in Figure 4.

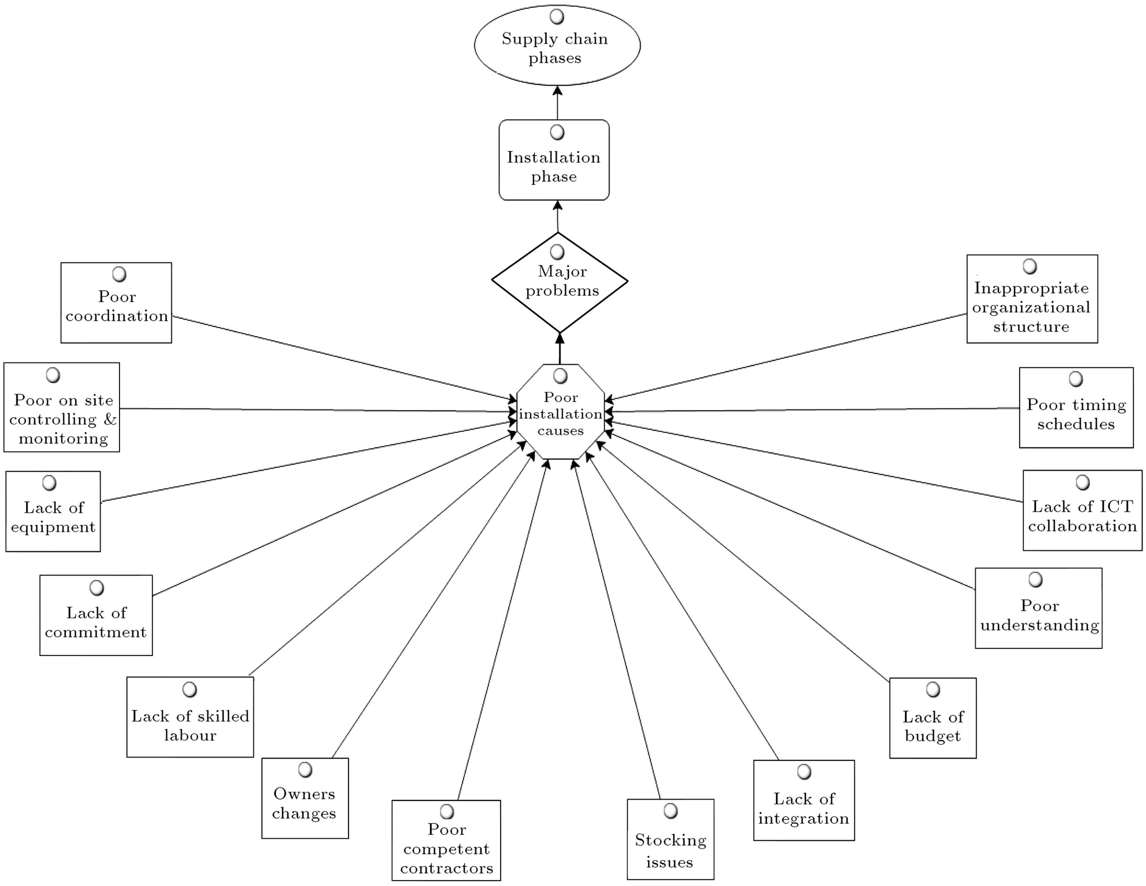

Figure 3. The modelling of major problems in the precast installation phase.

Based on the NVivo interviews analysis, Table 5 shows the main software used within the precast construction industry categorised according to the various supply chain phases.

Table 5 illustrates the significant software used within the precast supply chain phases including: in the planning phase, Microsoft Project Planning (15 respondents); in the design phase, AutoCAD 2D&3D (18 respondents), Revit (3D BIM; 5 respondents), the Tekla Structure (BIM Type; 4 respondents); in the manufacturing phase, STAAD.Pro (11 respondents); in the transportation phase, Microsoft Project Planning (10 respondents); in the installation phase, Microsoft Project Planning (13 respondents); and lastly, in the construction phase, Primavera (12 respondents). However, the BIM software within the precast supply chain phases which is selected for prototype development comprises: Autodesk Revit 2013 [15], Tekla BIMsight [16], Bentley STAAD.Pro V8i [20], and AutoCAD 360 [66]. It should be noted (see Section 8), that this BIM software will be delivered to the clients (such as the mobile computers and smart phones) via the cloud server by connecting to only an internet connection. The next section of this paper will explain the system architecture development of CACCBIM for precast supply chain management.

8. Architectural CACCBIM system for precast supply chain management

Beside the features of lack of integration, poor coordination, and ineffective collaboration, the same information is transferred, processed, handled, deployed, and dispersed all over the precast construction industry. Accordingly, designs are redesigned, information is re-entered, reports are reproduced, materials and precast components are replaced needlessly, etc. These instances of ineffective workflows could decrease efficiency and reduce productivity [41]. Thus, the main goal is to enhance collaboration, increase communication, and improve the initial coordination through facilitating the parties to be in contact earlier within the precast supply chain phases, such as in the design/build method.

It should be noted that commonly in design-build procurement, such as for precast construction, the various parties involved like the contractor and architect should collaborate at the beginning of project. This will enhance the communication with better integration and improve the efficiency and collaboration. On the other hand, any change order which could be caused by precast parties can adversely influence on the precast construction objectives leading to time delays

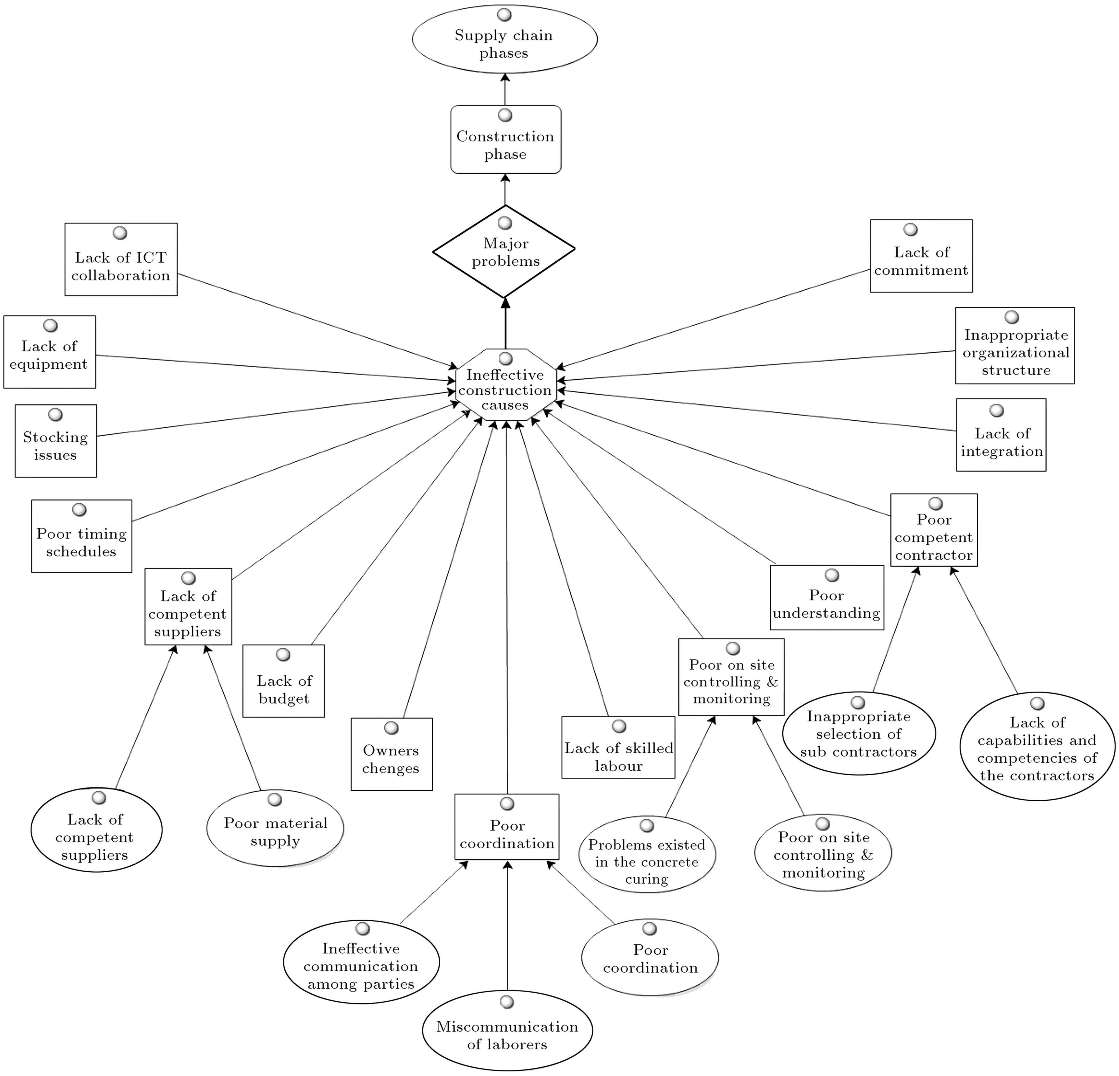

Figure 4. The modelling of major problems in the precast construction phase.

and cost overruns. Consequently, it is anticipated that development of context-aware cloud computing building information modelling applied to precast supply chain management will enable the precast stakeholders and precast supply chain parties, such as designers, owner, manufacturers, contractors, consultants, subcontractors, and suppliers, to have the opportunity to enhance their collaboration with much more accuracy and efficiency than those of the conventional precast construction methods.

It is believed that implementing this integrated, shared, open, collaborative tool will eventually enhance the efficiency and effectiveness compared to other systems, for instance, Virtual Design & Construction (VDC), Building Information Modeling (BIM), Integrated Project Delivery (IPD), etc. This collaborative system will contribute to improved efficiency, enhanced effectiveness, and increased productivity for the precast construction industry. Furthermore, a major component in the proposed system, as explained in the prior parts of this study, comprises Cloud Computing (CC), Context-Awareness (CA), and Building Information Modeling (BIM). This research has proposed the private cloud and SaaS for the proposed architectural system and prototype development. On the other hand, the servers (context-aware information system server engine as CAISSE, general application servers, general database server, cloud server, BIM application server, and BIM database server) and clients (such as the mobile computers, tablets, and smart phones) [10-12,40-42] will receive and deliver the data and information via the cloud server only by connecting to the internet connection. Additionally, a user's context-awareness and BIM cloud computing implementation are the tools which utilise the central remote servers and the internet to retrieve and send various applications and diverse data.

Figure 5 demonstrates that the data is retrieved by application servers (including the BIM applica-

Table 5. The main software utilisation in the precast supply chain phases.

Precast supply chain phases	Precast software	Number of sources
Planning phase	**Planning software selection**	**19**
	1. Microsoft excel (excel sheets)	11
	2. Microsoft project planning (MSP)	15
	3. Primavera	6
Design phase	**Design software selection**	**19**
	1. Drawings software categories	**19**
	1.1 3D Max	3
	1.2 AutoCAD (2D&3D)	18
	1.3 Computer Aided Design and Drafting (CADD)	1
	1.4 Revit (3D BIM)	5
	1.5 Tekla structure (BIM Type)	4
	1.6 V-Ray	1
	2. Engineering and analysis software categories	**17**
	2.1 Concise beam	2
	2.2 Esteem	10
	2.3 Oasys	3
	2.4 Orion	9
	2.5 STAAD.Pro	5
Manufacturing phase	**Manufacturing software selection**	**15**
	1. Manufacturing planning software selection	**12**
	1.1 Microsoft excel (excel sheets)	6
	1.2 Microsoft project planning (MSP)	4
	1.3 SKAKO Planning	2
	2. Manufacturing design software selection	**14**
	2.1 Computer Aided Manufacturing (CAM)	1
	2.2 SKAKO Design	2
	2.3 STAAD.Pro	11
	3. Manufacturing monitoring software selection	**4**
	3.1 SAP Control and monitoring	4
Transportation phase	**Transportation software selection**	**12**
	1. Microsoft excel	4
	2. Microsoft project planning (MSP)	10
Installation phase	**Installation software selection**	**13**
	1. Microsoft excel	3
	2. Microsoft project planning (MSP)	13
Construction phase	**Construction software selection**	**17**
	1. Microsoft project planning (MSP)	10
	2. Primavera	12

tion server) and database servers (including the BIM database server). Subsequently, the received data will be transferred to CAISSE to produce the appropriate information. Moreover, the CAISSE will deliver information to users according to the chosen contexts via the cloud computing implementation. Fundamentally, the architectural system of CACCBIM comprises four core components which are:

1. Mobile client: This includes the mobile device (such as the mobile computers and smart phones) that is able to transfer data and information for

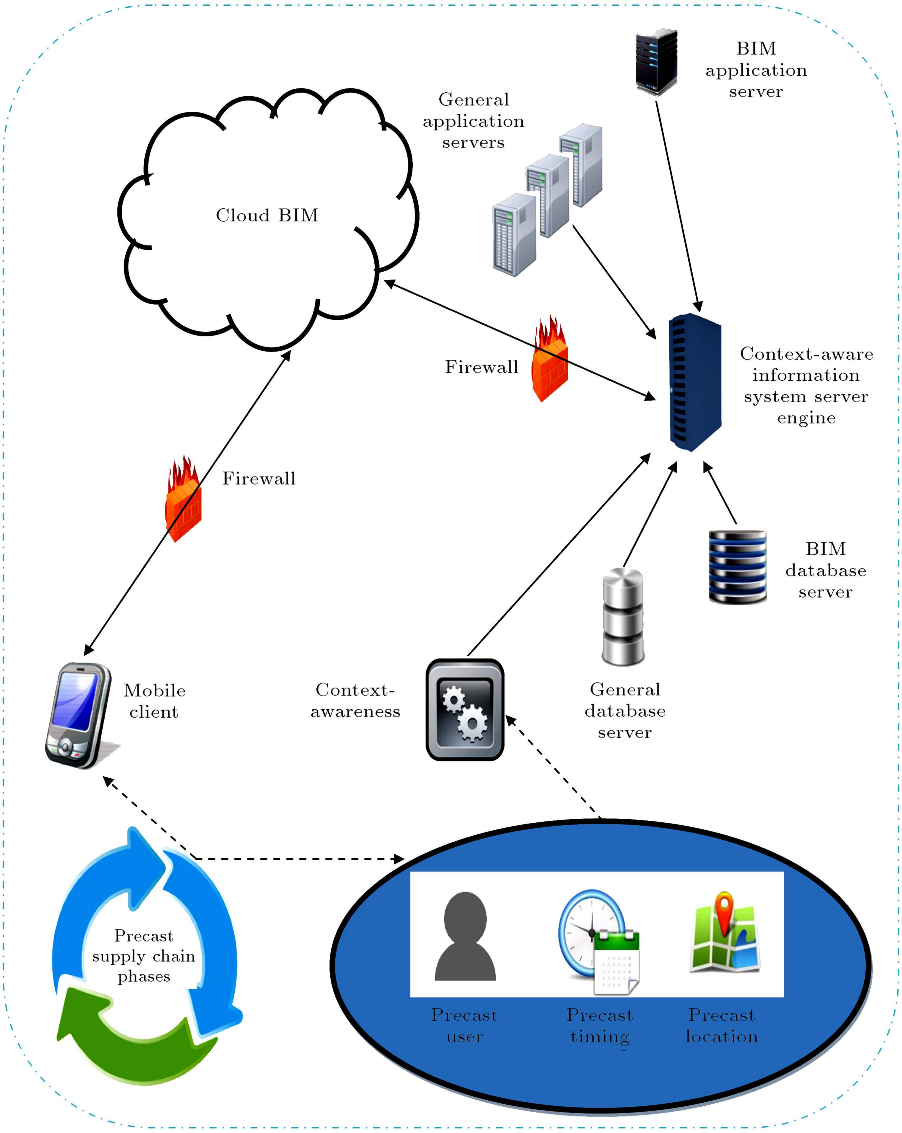

Figure 5. Context-Aware Cloud Computing Building Information Modelling (CACCBIM) architectural system for precast supply chain management.

the CAISSE via the cloud BIM. Furthermore, the mobile client, through the cloud BIM, will get the information;

2. Firewall systems: Two firewalls are proposed as one firewall within CAISSE and BIM cloud, and the second within the mobile client and BIM cloud. These firewalls have been proposed in order to enhance the information security which is transferred as well as delivered via mobile devices;

3. CAISSE: After delivering data via the general application servers, BIM application server, general database server, BIM database server, and mobile clients will be handled via the CAISSE. On the other hand, various user characteristics will be selected according to the specified context, for instance, location, time, activity, weather, identity, preferences, site conditions, roles and responsibility, network type, and accessible bandwidth (user context-awareness). However, it should be noted that this research prototype development, as will be discussed in the next section, is context-aware based on four contexts: the user, location, information, and time;

4. Cloud server for BIM: CAISSE will transmit the produced information to the cloud server through permission of the firewall. This information is then distributed to mobile clients via the cloud server. As described in the previous section, the cloud BIM software identified within this research includes AutoCAD 360, Tekla BIMsight, Autodesk Revit 2013, and also the Bentley STAAD.Pro V8i.

Developing the context-aware applications (for instance user context, location context, information context, and time context) will enhance the opportunities and facilitate the prototype system to deliver produced information with various services related to and appropriate for stakeholders and supply chain parties participating in the precast projects. Prototype developments for the precast construction projects will be explained and illustrated in the following section.

9. Context-Aware Cloud Computing Building Information Modelling (CACCBIM) prototype for precast supply chain management

The prototype development is based on the qualitative data analysis (requirements analysis) based on the views of interview respondents. This prototype has been implemented for two different projects (projects A and B) by identifying the two locations (locations A and B) and has successfully delivered the information and services to the precast users. In order to detect the projects, the locations (A and B) of users (such as the contractor and project manager) in the precast supply chain phases will be identified by applying GPS (Global Positioning System) assisted by Google Maps (detecting latitude and longitude). Therefore, the first stage of this prototype implementation is the Login page (Figure 6). Figure 6 illustrates the first stage of this prototype implementation through which, for instance, the contractor will log into the prototype.

Consequently, after entering the username and password in the Login page, the user identity (user context), the user location, for instance location A or B within the precast supply chain phases (location context), the specific information (information context), and the time of activities (time context) according to the time scheduling (MSP scheduling), for instance the second floor construction, will be identified. Figure 7

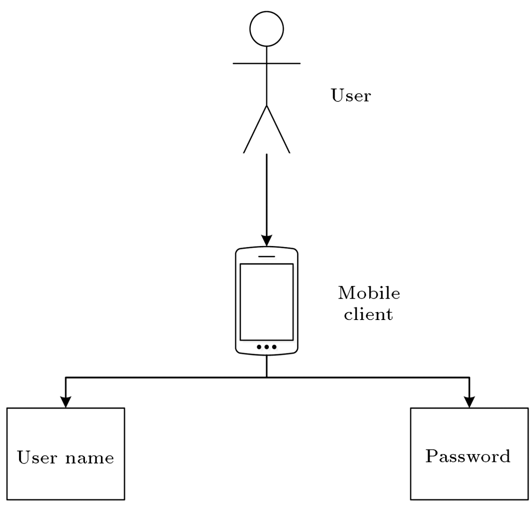

Figure 6. The prototype development login page.

illustrates the prototype for the precast supply chain users (such as the contractor) in location A (project A) of the precast supply chain phases (installation and construction phases) in the construction of the second floor. Meanwhile, Figure 8 illustrates the prototype for the precast supply chain users (such as the project manager) in location B (project B) of the precast supply chain phases (installation and construction phases) in the construction of the second floor . It should be noted that this prototype is context-aware (user context, location context, information context, and time context) and cloud BIM based for delivering the specific information, services, and BIM applications at any time in any place to the particular users within the precast supply chain phases. On the other hand, if the mentioned contexts are not identified, such as the unsuccessful identification of location context (GPS detection failed), then, as illustrated in Figure 9, the users have to select their required information and services, such as which project (A or B), which phase of the precast supply chain phases, or which level (floor) of the precast project they want to enter in order to get the specific information and services.

The precast construction projects can be perceived as information intensive which will require stakeholders and supply chain parties to deliver only up-to-date and appropriate information with specific services in order to successfully achieve their project objectives. Hence, as shown in Figures 7 and 8, the specific information (information context) based on the contractor or project manager (user context), location A/B within the precast construction site (location context), and also the time scheduling and activities of the second floor (time context) will be illustrated. On the other hand, the contractor, project manager, or precast users have access to other features, such as the information related to other supply chain phases, other projects, services, project locations, search, issues, and lastly, the logout page. Consequently, if the precast users, such as the contractor, wish to deliver other information, services, and applications to the other supply chain phases (Figure 10), then they will be able to deliver the information related to the precast supply chain management. Figure 10 illustrates the other precast supply chain phases including the precast planning, design, manufacturing, and transportation phases to which the precast users, such as the contractors, could access.

Meanwhile, if the precast users, such as the contractor, click on the services, they will be able to deliver various kinds of services comprising project team communications, BIM cloud software, and weather information (Figure 11).

After entering the delivery services page (Figure 11), if the precast users, such as the contractor, click on the BIM cloud software page, they have access

Figure 7. 'Project A' dashboard for the CACCBIM.

Figure 8. 'Project B' dashboard for the CACCBIM.

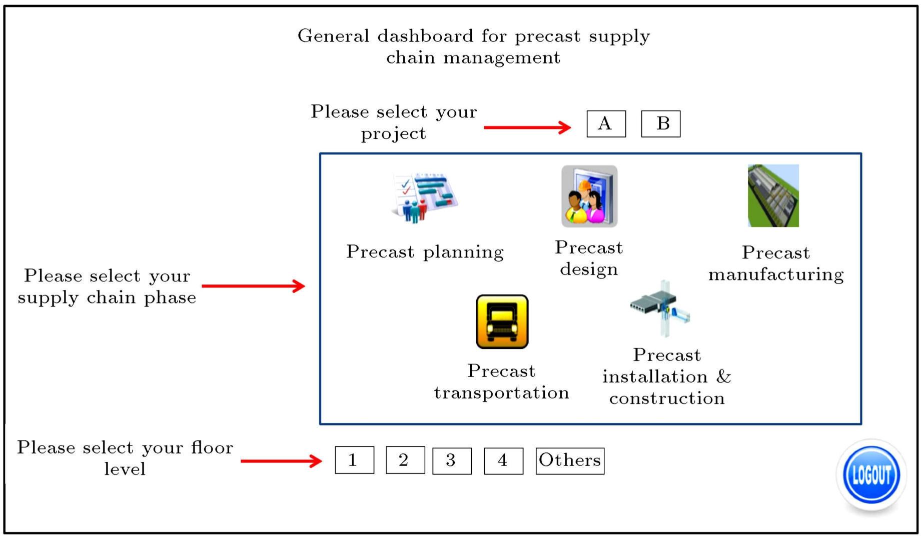

Figure 9. The general (non-context-awareness) dashboard for precast supply chain management.

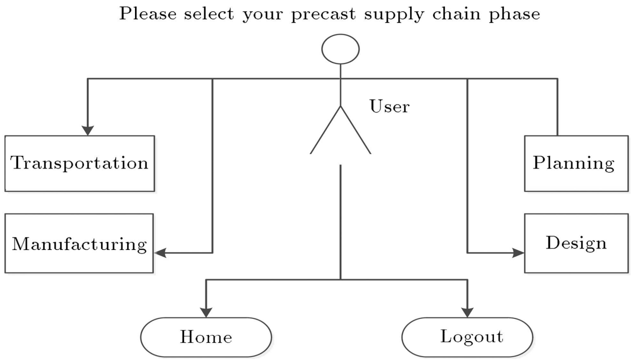

Figure 10. The precast supply chain phases of context-aware cloud computing building information modelling.

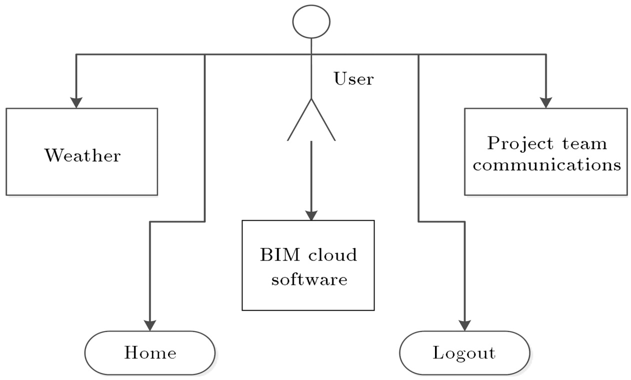

Figure 11. Delivery services of context-aware cloud computing building information modelling.

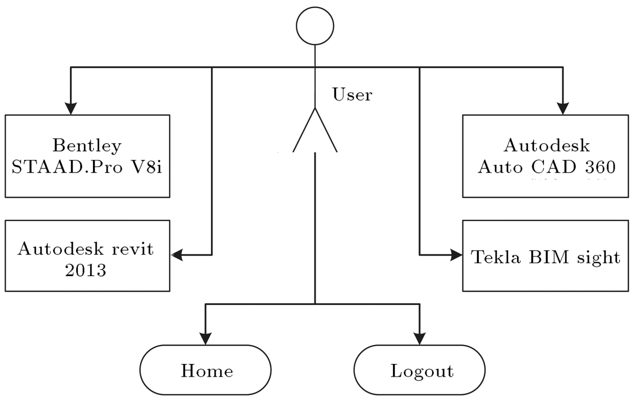

Figure 12. BIM cloud software of context-aware cloud computing building information modelling.

to several BIM Cloud software programs (Figure 12), as identified within this research (Section 6), including AutoCAD 360, Tekla BIMsight, Autodesk Revit 2013, and also Bentley STAAD.Pro V8i. The following section will present the important points of this research.

10. Discussion

Precast construction is an effective construction method in which the concrete is poured into the reusable moulds and then cured in a controlled environment (preferably off-site), transported, and installed on the precast structure. It is classified into diverse supply chain phases including planning, design, manufacturing, transportation, installation, and construction. This study has considered the main parties in the precast supply chain management which are: the architects/engineers, consultants, owners/clients, general contractors, manufacturers, construction managers, subcontractors, and suppliers. Cloud computing technology has increased the opportunities to facilitate accessibility of the information systems. It has created delivery of various services and applications at any time in anywhere through only the internet without any particular requirements to develop new infrastructure, employee trainings, and software licenses.

Context is a single entity or an integration of entities: user preferences, user responsibilities, type and location of the device (tablets, laptops, mobile phone, etc.), time of activities, device type, Wi-Fi networks, and the environmental circumstances. When the context is identified, the automatic contextual reconfiguration will be created (context-awareness), including identification of the nearest printer, brightness settings of monitor, and detecting the closest Wi-Fi connection. This feature will help the users to conveniently access the services and applications by facilitating the user interactions via the changing contextual information. On the other hand, the latest construction approach is determined by the Building Information Modelling (BIM), which will facilitate various people and different processes within the construction lifecycle to produce, communicate, and deliver the building information models. It should be noted that BIM utilisation will enhance communication, reduce waste, improve quality, decrease the safety issues, and maximise efficiency and effectiveness, which could ultimately enhance the success of construction projects.

Boyaval et al. [67] identified valuable and real-time technologies, for instance the Internet, which will facilitate the users to access the information using computing devices such as mobiles and tablets, and thereby become integrated through cloud-based tools. Moreover, the vast amount of useful and useless information has contributed to the construction industry acquiring a huge information environment. Therefore, each user (user's context) at any time and in anywhere is required to access the proper information (context-awareness). Moreover, there are major opportunities to be achieved through the implementation of effective CAID (Context-Aware Information Delivery) technologies.

Information Communication Technologies (ICT) are achieving their core objective which is to deliver a ubiquitous environment within which everyone could conveniently retrieve and send information at any time and from any location (cloud computing). Hence, further research could be grounded on how cloud computing can effectively and efficiently manage the huge volumes of data, such as by using Augmented Reality (AR) [8], Virtual Prototyping (VP) techniques [13], context-aware mobile computing [12,57], the Building Information Model (BIM) [20], hybrid integrated location tracking [68], simulations [67], real time simulators [69], BIM RFID model [70], the model view of the precast national BIM standard [71], BIM Augmented Reality [50], IFC for precast construction [72], and virtual prototyping tools [73]. However, several researchers are addressing this domain as the "CloudBIM" implementation will deliver the unconnected fragmented applications to more shared and dynamic networks which could have the features of automated task allocation [8,47,50].

As explained by Aziz et al. [13], if context-aware mobile computing is applied, then there will be considerable advantages, for instance, the appropriate information at the right time in the correct location which will result in efficient decision-making during the construction lifecycle. Furthermore, Aziz et al. [74,75] proposed facilitating technologies such as Radio Frequency Identification (RFID), location-based services, profiling technologies, ubiquitous computing, Wireless Local Area Networks (W-LAN), and sensor networks for Context-Aware Information Delivery (CAID). Furthermore, to facilitate the efficient achievement of context-aware capabilities, it is necessary to properly select the various user interfaces, localization technologies, and mobile devices. Consequently, if the precast professional parties implement context-awareness, then they do not wish to search through a huge amount of information within the precast supply chain phases. On the other hand, the precast professional parties will access information and services at the right time and in the correct location (in the supply chain phases) that will ultimately increase productivity and enhance effectiveness and efficiency.

The research analysis was based on the 19 semi-structured interviews ($n = 19$) in the precast construction industry of Malaysia consisting of 6 precast manufacturers, 5 precast technical managers, 4 senior designers, 2 executive directors, and 2 precast specialists. It was accomplished in 3 stages: developing documents for semi-structured interviews and creating the folders, assigning the interview analysis variables to nodes in NVivo, and finally creating the NVivo analysis modelling. Subsequently, the system architecture and the prototype of CACCBIM aimed at precast supply chain management were developed. However, the limitation of this study is that the prototype implementation is for the precast installation and construction phases. Nevertheless, this research is a continuous study that will implement this system for other precast supply chain phases including planning, design, manufacturing, and transportation. It should be noted that the future research will implement the proposed prototypes for the field test and evaluation trails with the aim of delivering the real life prototype system for precast supply chain management. The last section will deliberate on the major points emerging from this research.

11. Conclusion

Unlike other main industries, the precast construction industry is enormously project-based. It is characterised with many parties having diverse objectives and different organizational cultures. Since the 19th century, it has been considered as one of the chief elements in the construction supply chain. Precast construction is identified as the effective management of numerous activities, including the flow of materials, products, and services, which has significantly contributed to reduction in construction time, increased productivity, and more cost savings.

The major concern within precast construction is how to facilitate, collaborate, and integrate various parties and stakeholders within the supply chain phases so that their mutual objectives can be attained. They should accomplish the project using a collaborative approach to improve effectiveness, increase productivity, ensure efficient delivery and utilisation of the resources, and ultimately attain the pre-determined objectives to ensure success of the precast construction projects. These pre-determined objectives are commonly associated with project delivery on time, at the specified cost, at a higher quality, and with fewer safety issues.

The increasing complexities of precast construction will necessitate different data and enormous information to be delivered and dispersed in the processes of precast supply chain phases. As a result, to successfully achieve the objectives of precast construction within the allocated time, assigned cost, and at a high quality, applying proper construction collaboration tools aimed for the stakeholders and various parties is fundamental. Hence, this research has proposed the effective precast collaboration tools as a prototype comprising cloud computing, building information modelling, and context-awareness.

This research has identified the major problems within the supply chain phases of precast construction industry in order to mitigate, avoid, or eliminate the negative consequences of these identified problems on the project objectives such as time, cost, quality, and health. The major problems discovered within the precast construction industry are categorised as lack of integration, improper planning and scheduling, poor coordination, lack of good communication among parties, and poor controlling and supervision.

Consequently, developing the system architecture and the prototype of CACCBIM for precast supply chain management is hoped to significantly mitigate these major issues.

Acknowledgment

This work was partly financially supported by Universiti Teknologi Malaysia and the Ministry of Education, Malaysia, under a Fundamental Research Grant Scheme (FRGS) (Grant no: 4F388).

References

1. Al-Bazi, A.F., Dawood, N. and Dean, J.T. "Improving performance and the reliability of off-site precast concrete production operations using simulation optimisation", *J. Info. Tech. Cons. (ITcon)*, **15**, pp. 335-356 (2010).
2. Chen, Y., Okudan, G.E. and Riley, D.R. "Sustainable performance criteria for construction method selection in concrete buildings", *Automat. Constr.*, **19**(2), pp. 235-244 (2010).
3. Chen, Y., Okudan, G.E. and Riley, D.R. "Decision support for construction method selection in concrete buildings: prefabrication adoption and optimization", *Automat. Constr.*, **19**(6), pp. 665-675 (2010).
4. Soutsos, M.N., Tang, K. and Millard, S.G. "The use of recycled demolition aggregate in precast concrete products-phase III: concrete pavement flags", *Constr. Build. Mater.*, **36**, pp. 674-680 (2012).
5. Kaner, I., Sacks, R., Kassian, W. and Quitt, T. "Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms", *J. Info. Tech. Cons. (ITcon)*, **13**, pp. 303-323 (2008).
6. Precast/Prestressed Concrete Institute, *A Guide to Designing with Precast/Prestressed Concrete*, Precast/Prestressed Concrete Institute (PCI), Chicago (2010).
7. Tatum, C.B., Vanegas, J.A. and William, J.M. "Constructability improvement using prefabrication, preassembly, and modularization", Technical Report No. **297**, California, Stanford University (1986).
8. Chi, H.L., Kang, S.C. and Wang, X. "Research trends and opportunities of augmented reality applications in architecture, engineering, and construction", *Automat. Constr.*, **33**, pp. 116-122 (2013).
9. Redondo, E., Fonseca, D., Sánchez, A. and Navarro, I. "New strategies using handheld augmented reality and mobile learning-teaching methodologies, in architecture and building engineering degrees", *Procedia Comput. Sci.*, **25**, pp. 52-61 (2013).
10. Abedi, M., Rawai, N.M., Fathi, M.S. and Mirasa, A.K. "Construction collaboration tools for precast supply chain management", *Proceedings of the 9th International Conference of Geotechnical & Transportation Engineering (GEOTROPIKA) and the 1st International Conference on Construction and Building Engineering (ICONBUILD) - GEOCON2013*, Persada Johor International Convention Centre, Malaysia, pp. 282-291 (2013).
11. Abedi, M., Fathi, M.S. and Rawai, N.M. "The impact of cloud computing technology to precast supply chain management", *Int. J. Con. Eng. Mgt.*, **2**(4A), pp. 13-16 (2013).
12. Abedi, M., Rawai, N.M., Fathi, M.S. and Mirasa, A.K. "Cloud computing as a construction collaboration tool for precast supply chain management", *Journal Teknologi*, **70**(7), pp. 1-7 (2014).
13. Aziz, Z. "Supporting site-based processes using context-aware virtual prototyping", *J. Archit. Eng.*, **18**(2), pp. 79-83 (2012).
14. Aziz, Z. "Context aware information delivery for mobile construction workers", Ph.D. Thesis, Loughborough University, Leicestershire, U.K (2005).
15. Latiffi, A.A., Mohd, S., Kasim, N. and Fathi, M.S. "Building Information Modeling (BIM) application in Malaysian construction industry", *Int. J. Con. Eng. Mgt.*, **2**(4A), pp. 1-6 (2013).
16. Takim, R., Harris, M. and Nawawi, A.H. "Building Information Modeling (BIM): A new paradigm for quality of life within architectural, engineering and construction (AEC) industry", *Procedia Soc. Behav. Sci.*, **101**, pp. 23-32 (2013).
17. Modi, C., Patel, D., Borisaniya, B., Patel, A. and Rajarajan, M. "A survey on security issues and solutions at different layers of cloud computing", *J. Supercomput.*, **63**(2), pp. 561-592 (2013).
18. Rawai, N.M., Fathi, M.S., Abedi, M. and Rambat, S. "Cloud computing for green construction management", *Proceedings of Third International Conference on Intelligent System Design and Engineering Applications (ISDEA)*, China, Hong Kong, pp. 432-435 (2013).
19. Porwal, A. and Hewage, K.N. "Building Information Modeling (BIM) partnering framework for public construction projects", *Automat. Constr.*, **31**, pp. 204-214 (2013).
20. Volk, R., Stengel, J. and Schultmann, F. "Building Information Modeling (BIM) for existing buildings-literature review and future needs", *Automat. Constr.*, **38**, pp. 109-127 (2014).
21. Chan, W.T. and Hu, H. "Constraint programming approach to precast production scheduling", *J. Constr. Eng. Manage.*, **128**(6), pp. 513-521 (2002).
22. Gibb, A. and Isack, F. "Re-engineering through preassembly: Client expectations and drivers", *Build. Res. Inf.*, **31**(2), pp. 146-160 (2003).

23. Arditi, D., Ergin, U. and Gunhan, S. "Factors affecting the use of precast concrete systems", *J. Archit. Eng.*, **6**(3), pp. 79-86 (2000).

24. Jianguo, C., Jian, F., Zan, W., Yao, C. and Yafei, L. "Investigation of a precast concrete structure system", *Proceedings of the International Conference on Information Management, Innovation Management and Industrial Engineering (ICIII'08)*, Nanjing, China, **3**, pp. 449-452 (2008).

25. Demiralp, G., Guven, G. and Ergen, E. "Analyzing the benefits of RFID technology for cost sharing in construction supply chains: A case study on prefabricated precast components", *Automat. Constr.*, **24**, pp. 120-129 (2012).

26. Polat, G. "Factors affecting the use of precast concrete systems in the United States", *J. Constr. Eng. Manage.*, **134**(3), pp. 169-178 (2008).

27. Sacks, R., Eastman, C.M. and Lee, G. "Process model perspectives on management and engineering procedures in the precast/prestressed concrete industry", *J. Constr. Eng. Manage.*, **130**(2), pp. 206-215 (2004).

28. Martí, J.V., Gonzalez-Vidosa, F., Yepes, V. and Alcalá, J. "Design of prestressed concrete precast road bridges with hybrid simulated annealing", *Eng. Str.*, **48**, pp. 342-352 (2013).

29. Goodier, C.I., Dainty, A.R.J. and Gibb, A.G.F. "Manufacture and installation of offsite products and mmc: market forecast and skills implications", *Report for CITB Construction Skills*, Loughborough University, pp. 1-44 (2006).

30. Mlinarić, V. and Sigmund, Z. "Problems in large scale precast construction projects", *Proceedings of CIB Joint International Symposium 2009: Construction Facing Worldwide Challenges*, Dubrovnik, Croatia, pp. 182-188 (2009).

31. Wu, P. and Low, S.P. "Lean management and low carbon emissions in precast concrete factories in Singapore", *J. Archit. Eng.*, **18**(2), pp. 176-186 (2012).

32. Persson, S., Malmgren, L. and Johnsson, H. "Information management in industrial housing design and manufacture", *J. Info. Tech. Cons. (ITcon)*, **14**, pp. 110-122 (2009).

33. Ikonen, J., Knutas, A., Hämäläinen, H., Ihonen, M., Porras, J. and Kallonen, T. "Use of embedded RFID tags in concrete element supply chains", *J. Info. Tech. Cons. (ITcon)*, **18**, pp. 119-147 (2013).

34. Polat, G. "Precast concrete systems in developing vs. industrialized countries", *J. Civil. Eng. Manage.*, **16**(1), pp. 85-94 (2010).

35. Kiong, N.B. and Akasah, Z.A. "Maintenance factor for precast concrete in IBS: A review", *Proceedings of National Postgraduate Conference (NPC)*, Universiti Teknologi PETRONAS, Malaysia, pp. 1-6 (2011).

36. Al-Bazi, A. and Dawood, N. "A decision support system for pre-cast concrete manufacturing planning: An innovative crew allocation optimiser", *Proceedings of CSCE 2009 Annual General Meeting & Conference*, Canada, pp. 1-12 (2009).

37. Pheng, L.S. and Chuan, C.J. "A study of the readiness of precasters for just-in-time construction", *Work Study*, **50**(4), pp. 131-140 (2001).

38. Pheng, L.S. and Chuan, C.J. "Just-in-time management of precast concrete components", *J. Constr. Eng. Manage.*, **127**(6), pp. 494-501 (2001).

39. Jang, W.S. and Skibniewski, M.J. "A wireless network system for automated tracking of construction materials on project sites", *J. Civil. Eng. Manage.*, **14**(1), pp. 11-19 (2008).

40. Abedi, M., Fathi, M.S. and Rawai, S. "Cloud computing technology for collaborative information system in construction industry", *Proceedings of the 18th International Business Information Management Association (IBIMA)*, Istanbul, Turkey, pp. 593-602 (2012).

41. Fathi, M.S., Abedi, M., Rambat, S., Rawai, S. and Zakiyudin, M.Z. "Context-aware cloud computing for construction collaboration", *J. Clou. Comput.*, pp. 1-11 (2012).

42. Fathi, M.S., Abedi, M. and Rawai, M.N. "The potential of cloud computing technology for construction collaboration", *Appl. Mech. Mater.*, **174-177**, pp. 1931-1934 (2012).

43. Mell, P. and Grance, T. "The NIST definition of cloud computing", *National Institute of Standards and Technology, Special Publication*, **800-145**, pp. 1-3 (2011).

44. Liang, F. and Luo, Y. "A framework of the civil engineering CAD experimental platform based on cloud computing", *Proceedings of the 2013 International Conference on Construction and Real Estate Management (ICCREM)*, Karlsruhe, Germany, pp. 577-586 (2013).

45. Rezguia, A., Malik, Z., Xia, J., Liu, K. and Yang, C. "Data-intensive spatial indexing on the clouds", *Procedia Comput. Sci.*, **18**, pp. 2615-2618 (2013).

46. Cohen, J., Filippis, I., Woodbridge, M., Bauer, D., Hong, N.C., Jackson, M., Butcher, S., Colling, D., Darlington, J., Fuchs, B. and Harvey, M. (2013). "RAPPORT: Running scientific high-performance computing applications on the cloud", *Philosophical Transactions of the Royal Society of London Series A, Mathematical Physical & Engineering Sciences*, **371**(1983), pp. 1-15 (1983).

47. Zhang, L. and Issa, R.R.A. "Comparison of BIM cloud computing frameworks", *Proceedings of Computing in Civil Engineering*, Reston, Florida, USA, pp. 389-396 (2012).

48. Karamouz, M., Zahmatkesh, Z. and Saad, T. "Cloud computing in urban flood disaster management", *Pro-*

ceedings of World Environmental and Water Resources Congress 2013: Showcasing the Future, Ohio, pp. 2747-2757 (2013).

49. Goscinski, A. and Brock, M. "Toward dynamic and attribute based publication, discovery and selection for cloud computing", *Future Gener. Comput. Syst.*, **26**(7), pp. 947-970 (2010).

50. Jiao, Y., Zhang, S., Li, Y., Wang, Y. and Yang, B. "Towards cloud augmented reality for construction application by BIM and SNS integration", *Automat. Constr.*, **33**, pp. 37-47 (2013).

51. Ntanos, C., Botsikas, C., Rovis, G., Kakavas, P. and Askounis, D. "A context awareness framework for cross-platform distributed applications", *J. Syst. Soft.*, **88**, pp. 138-146 (2014).

52. Dey, A.K., Abowd, G.D. and Salber, D. "A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications", *Hum-Comput. Interact.*, **16**(2-4), pp. 97-166 (2001).

53. Schilit, B.N., Adams, N. and Want, R. "Context-aware computing applications", *Proceedings of the Workshop on Mobile Computing Systems and Applications, Institute of Electrical and Electronics Engineers (IEEE)*, Santa Cruz, CA, pp. 85-90 (1994).

54. Akula, M., Lipman, R.R., Franaszek, M., Saidi, K.S., Cheok, G.S. and Kamat, V.R. "Real-time drill monitoring and control using building information models augmented with 3D imaging data", *Automat. Constr.*, **36**, pp. 1-15 (2013).

55. Chihani, B., Bertin, E. and Crespi, N. "Programmable context awareness framework", *J. Syst. Soft.*, **92**, pp. 59-70 (2014).

56. Aziz, Z., Anumba, C. and Law, K. "Using context-awareness and web-services to enhance construction collaboration", *Proceedings of Joint International Conference on Computing and Decision Making in Civil and Building Engineering*, Montreal, Canada, pp. 3010-3019 (2006).

57. Afridi, A.H. and Gul, S. "Method assisted requirements elicitation for context aware computing for the field force", *Proceedings of the International Multi Conference of Engineers and Computer Scientists (IMECS)*, Hong Kong, pp. 1008-1013 (2008).

58. Eastman, C., Teicholz, P., Sacks, R. and Liston, K., *BIM Handbook: A Guide to Building Information Modelling for Owner, Managers, Designers, Engineers, and Contractors*, New Jersey: John Wiley and Sons (2008).

59. Glaser, B.G. and Strauss, A.L., *The Discovery of Grounded Theory*, Chicago: Aldine (1967).

60. Robson, C., *Real World Research* (2nd Edition), MA & Oxford: Blackwell Publishing (2002).

61. Creswell, J.W., *Qualitative Inquiry & Research Design (2nd Edition)*, California: Sage Publications (2007).

62. Bazeley, P., *Qualitative Data Analysis with NVivo*, London: SAGE Publications (2007).

63. Miles, M.B. and Huberman, M., *Qualitative Data Analysis: An Expanded Sourcebook* (2nd Edition), Sydney: SAGE Publication (1994).

64. Ishak, N.M. and Bakar, A.Y.A. "Qualitative data management and analysis using NVivo: An approach used to examine leadership qualities among student leaders", *Edu. Res. J.*, **2**(3), pp. 94-103 (2012).

65. Davies, C.R., Knuiman, M., Wright, P. and Rosenberg, M. "The art of being healthy: A qualitative study to develop a thematic framework for understanding the relationship between health and the arts", *BMJ Open.*, **4**, pp. 1-10 (2014).

66. Alwisy, A., Al-Hussein, M. and Al-Jibouri, S. "BIM approach for automated drafting and design for modular construction manufacturing", *Proceedings of Computing in Civil Engineering*, Reston, Virginia, USA, pp. 221-228 (2012).

67. Boyaval, S., Bris, C.L., Lelièvre, T., Maday, Y., Nguyen, N.C. and Patera, A.T. "Reduced basis techniques for stochastic problems", *Arch. Comput. Meth. Engng.*, **17**(4), pp. 435-454 (2010).

68. Akula, M., Dong. S., Kamat, V.R., Ojeda, L., Borrell, A. and Borenstein, J. "Integration of infrastructure based positioning systems and inertial navigation for ubiquitous context-aware engineering applications", *Adva. Eng. Info.*, **25**(4), pp. 640-655 (2011).

69. Chinesta, F., Leygue, A., Bordeu, F., Aguado, J.V., Cueto, E., Gonzalez, D., Alfaro, I., Ammar, A. and Huerta, A. "PGD-based computational vademecum for efficient design, optimization and control", *Arch. Comput. Meth. Engng.*, **20**(1), pp. 31-59 (2013).

70. Costin, A., Shaak, A. and Teizer, J. "Development of a navigational algorithm in BIM for effective utility maintenance management of facilities equipped with passive RFID", *Proceedings of Computing in Civil Engineering, Los Angeles*, California, pp. 653-660 (2013).

71. Eastman, C.M., Sacks, R., Panushev, I., Venugopal, M. and Aram, V. "Precast concrete BIM standard documents: model view definitions for precast concrete", *Precast/Prestressed Concrete Institute Report*, **1**, pp. 1-53 (2010).

72. Venugopal, M., Eastman, C.M. and Teizer, J. "Formal specification of the IFC concept structure for precast model exchanges", *Proceedings of Computing in Civil Engineering*, Reston, Florida, USA, pp. 213-220 (2012).

73. Moens, D. and Vandepitte, D. "Recent advances in non-probabilistic approaches for non-deterministic dynamic finite element analysis", *Arch. Comput. Meth. Engng.*, **13**(3), pp. 389-464 (2006).

74. Aziz, Z., Anumba, C.J. and Peña-Mora, F. "A roadmap to personalized context-aware services delivery in construction", *J. Info. Tech. Cons. (ITcon)*, **14**, pp. 461-472 (2009).

75. Aziz, Z., Anumba, C.J. and Peña-Mora, F. "Using context-aware wireless technologies to support teaching and learning in built environment", *Int. J. Constr. Edu. Res.*, **6**(1), pp. 18-29 (2010).

Biographies

Mohammad Abedi received his BS degree in Civil Engineering from the Islamic Azad University of Iran in 2007. He pursued his higher education at Universiti Teknologi MARA (UiTM), Malaysia, where he obtained his MS degree in Integrated Construction Project Management in 2010. Mohammad Abedi is currently pursuing his studies as a PhD candidate in the Faculty of Civil Engineering (Construction Management), Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia. His research area is mainly focused on: construction project management, Precast Supply Chain Management (PSCM), Information Technology (IT), Construction Collaboration Tools (CCT), cloud computing, Building Information Modeling (BIM), and mobile computing. He has published more than 20 technical papers in a variety of journals and international conferences.

Mohamad Syazli Fathi is currently a Deputy Director in the Centre for General Courses and Curriculum (CGCC) and Head of Construction Quality & Maintenance (CQM) Research Group at Universiti Teknologi, Malaysia, Kuala Lumpur. Previously, he held a post as Head of Civil Engineering Department at UTM Razak School of Engineering & Advanced Technology. He received both his Civil Engineering degree and master degree from Universiti Teknologi Malaysia. He then furthered his study after several years in the industry and received his doctorate from Loughborough University, United Kingdom. His research interests are in the fields of decision support system, construction programme, project management, context-aware computing, mobile applications, interlocking blockwork system, building, and infrastructure maintenance.

Abdul Karim Mirasa is a Professor in Civil Engineering and currently Head of Civil Engineering Department in the Faculty of Engineering, Universiti Malaysia Sabah. He received his undergraduate degree from University of Strathclyde, United Kingdom, master degree from University of Newcastle upon Tyne, United Kingdom, and doctorate from Universiti Teknologi Malaysia. Previously, he was the Director of Bureau of Innovation and Consultancy and Dean of Faculty of Civil Engineering, Universiti Teknologi Malaysia. He is also a Member of Institution of Engineer Malaysia (MIEM) and Professional Engineer with Board of Engineers Malaysia (P.Eng). His research interests are in the area of appraisal and repair of reinforced concrete structures damaged during earthquake and properties and behavior of concrete with ultrafine POFA.

Norshakila M. Rawai received the Diploma and BEng degree (with honors) in Civil Engineering from Universiti Teknologi Malaysia, Malaysia in 2006 and 2009, respectively. Currently, she is doing her PhD degree in Civil engineering (Construction Management) in the Faculty of Civil Engineering at Universiti Teknologi Malaysia, Skudai, Johor, Malaysia. Her research interests include: construction project management, project management information system, construction collaboration tools, cloud computing, mobile computing, and mobile applications. She has published more than 10 technical papers in a variety of journals and international conferences.