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Cloud Computing as a Construction Collaboration Tool for Precast Supply Chain Management

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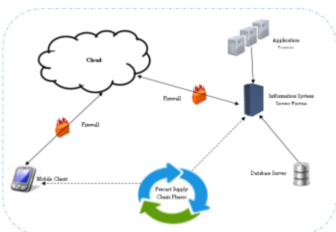
Graphical abstract



Abstract

Precast construction projects are characterized by many activities, the involvement of numerous parties, a lot of effort and enormous processes. Precast supply chain phases are classified as: planning, design, manufacturing, transportation, installation and construction. Achieving integrated construction requires the parties within the precast supply chain phases to have efficient communication and effective collaboration to deliver proper and up-to-date information. The aim of this research is to explore cloud computing technology as the construction collaboration tool and to propose the cloud system architecture for precast supply chain management. The findings in this research are based on a comprehensive review of supply chain management, cloud computing and the precast industry. Findings illustrate that the major obstacles to precast construction are: poor planning and scheduling, less flexibility in design, production lead time, heavy precast components and poor on-site coordination. These obstacles could contribute to the negative consequences for the efficiency and effectiveness of precast project delivery. Therefore, cloud computing technology has valuable potential to mitigate these obstacles and deliver an effective collaboration system within the precast construction industry.

Keywords: Precast construction; collaboration; cloud computing; collaboration tool; supply chain management; coordination

■1.0 INTRODUCTION

A supply chain is a network that seeks to integrate diverse business divisions in order to produce and dispense the products to the consumer [1]. For 150 years the off-site precast construction industry has been one of the core elements of the construction supply chain which is a network of multiple activities including the physical flow of materials, services and products [2] between the clients, architects/engineers, developers, manufacturers, general contractors, subcontractors, suppliers and consultants [2-4]. Precast construction is an efficient method whereby concrete is cast in reusable moulds within a controlled environment (commonly off-site) and then transported and assembled to form the precast structure [5].

On the other hand, for enhancing the competitive advantages and achieving the successful delivery of efficient and effective prefabrication systems, such as precast construction systems, we should consider the involvement of customers/clients [6] and also the skills and knowledge of the professional parties involved within the precast supply chain [7]. Furthermore, precast concrete structures are resistant to fires, winds, hurricanes, floods, earthquakes, wind-driven rain and moisture damage [8]. However, Cheong *et al*. [9] stated that precast construction requires high capital investment in the manufacturing factory where uniform and repetitive processes should achieve greater cost effectiveness for the precast construction projects. Moreover, the crew allocation is important in the precast supply chain phases since it could be a major cause contributing to delays in the precast construction projects and the precast supply chain phases [2]. It should be noted that Green Supply Chain Management (GSCM) could be applied to the precast supply chain phases in order to achieve successful environmental sustainability [10].

To enhance the efficiency and effectiveness of information management in the construction industry, the application of information systems such as mobile applications [11-12], the Sustainable-Construction Planning System (SCPS) [13] and the Executive Information Site Monitoring System (EISMS) [14-15] have been studied. Cloud computing is the delivery and accessing of hardware and software services [16] and applications via the Internet [17]. Cloud computing implementation could mitigate the adverse features of precast projects such as their dynamic and information-intensive, complexities, risks and threats [18-19].

Therefore, the aim of this research is to explore and propose the cloud computing technology which will eventually enhance the success of precast construction.

Supply chain parties within the precast construction industry have many relationships with numerous other parties including the owners/clients, architects/engineers, manufacturers, general contractors [20], consultants, subcontractors, construction managers and suppliers [5]. This requires efficient collaboration [5] and effective communication. Therefore, efficiently and effectively controlling, monitoring and managing the precast construction projects associated with the involvement of various participants within the precast supply chain is indeed difficult and often extremely challenging since there is much information [21] which needs to be effectively accessed at the right time and in the appropriate location, such as the drawings, specifications, checklists and daily reports. However, this research will not discuss the detailed application of Information Technologies (IT) in the precast construction industry, since, in brief, internet technology, web-based information management solutions [22], information systems [23] and applications, such as the real-time monitoring and control of the precast project and precast supply chain management, may facilitate the successful achievement of precast projects according to the pre-determined project objectives [22-23].

This research is classified into 5 sections. The next section will identify the definitions, phases and the problems of precast supply chain phases. In section 3, the cloud computing definitions, models and types will be explored. The system architecture of cloud computing within the precast supply chain management is proposed in section 4. Lastly, in section 5, the major points and potential opportunities to enhance the efficiencies and improve the effectiveness of precast supply chain management will be discussed.

2.0 PRECAST SUPPLY CHAIN MANAGEMENT

Precast construction is a construction system in which the concrete will be cast in the molds and then cured in a controlled environment, transported and assembled to produce the structure [24-25]. The off-site precast industry (client/owner, consultant, designer, manufacturers, transporters, general contractor, sub-contractor, warehousers, retailers, customers and suppliers) has existed since 1850 [2]. As stated by Tatum *et al*. [26], achieving precast construction success requires major consideration of the appropriate implementation within the precast supply chain phases that will also improve precast construction efficiency. Waste is one of the major problems within the construction industry [27] which could be significantly reduced by minimizing on-site activities and through the promotion of the off-site production of components, such as precast components [21, 28-33].

In the 1960s and 1970s there was a significant improvement in research on effective planning and efficient scheduling in precast plants [24]. Other major benefits of precast systems are shown in Table 1.

According to Table 1, the various benefits of precast systems could be applied to the implementation of precast elements particularly for building [3-5, 9, 24, 40, 46-51] such as the precast hollow-core wall [52] especially since heavy civil engineering projects (infrastructure developments) are increasing in number [2, 24, 43, 53-54]. The following part of this research will explain the phases within the precast construction industry.

Table 1 Major benefits of precast construction

Improved Efficiency and Cost-effectiveness	[2, 39]
Enhanced Sustainability	[3-4]
Improving Sustainability via Integrated Design and Lower Creation of Noise	[6]
Mass Production and Less Manpower Resources	[9]
Aesthetic Flexibilities	[25]
Improved Productivity	[34]
Enhanced Buildability	[35]
Speedy Construction	[36-40]
Higher Quality	[37, 41-43]
Durability and Constructability	[42]
Enhanced Health and Safety	[44-45]

2.1 Precast Supply Chain Phases

Supply chain phases within the precast construction industry as illustrated in Figure 1, include: planning [2, 55-57], design [9, 49-50, 58], manufacturing/production [39, 43, 48, 59-60-62], transportation [2, 40, 45, 63-64] and, lastly, the installation/assembly and construction [21, 38, 49, 64-65].

On the other hand, generally, and in case of any issues arising, all of the parties within the precast supply chain phases will refer to the technical (planning) office where the planning (financial plan of costs and time scheduling) and resource management will be created [41].

As illustrated in Figure 1, in the planning phase, all of the documents would be provided for all the precast supply chain phases consisting of the manufacturing scheduling [24]. A variety of reports on such things as manufacturing materials, summary materials, components cost analysis and summary reports, design, manufacturing, transportation, installation and construction schedules are required [41]. In addition, loading lists for the transportation and installation phases, assembly/installation plans, cost estimates [55, 65], executive drawings, bills of quantities, manufacturing/factory drawings, installation and construction drawings will be provided [67]. Meanwhile, in the design phase all regulations, types and bills of materials [5, 65], the drawings [20, 50], and the appropriate building codes [58] will be developed. Furthermore, the quantities, details of time-scheduling, price lists and detailed cost estimations will be prepared by the architects, structural engineers, other designers and consultants [49, 65, 68].

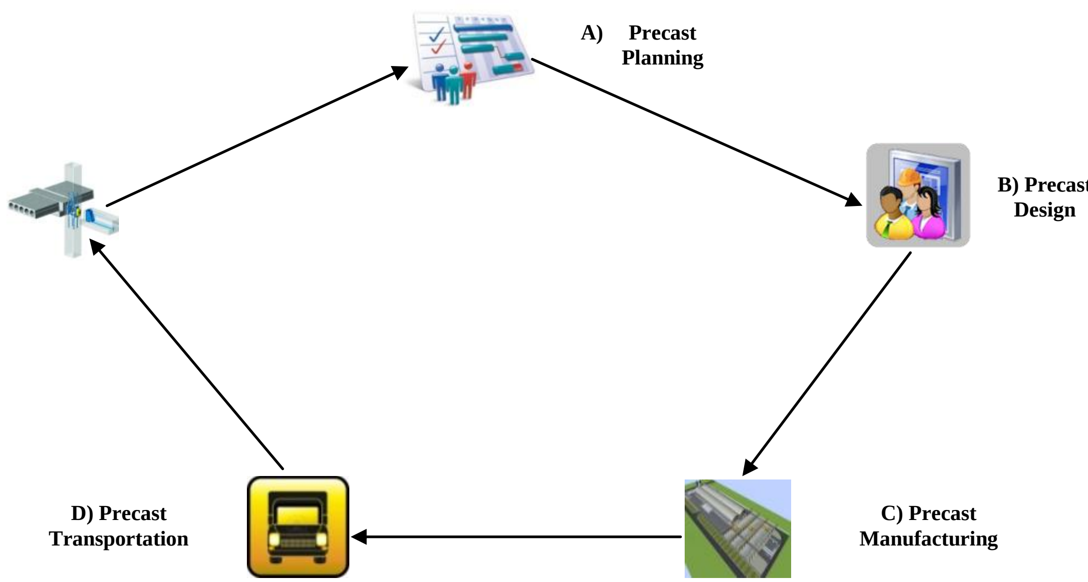


Figure 1 The diagram of the precast supply chain phases, adapted after [9, 39, 41, 49, 51, 55, 60, 65-66]

In the manufacturing phase, precast components production is categorized into several significant sections consisting of the selection of raw materials [39, 60], batching plant, casting and molding zone, demolding and finishing zone, packaging, transportation and, ultimately, the storage yard [9, 59, 69]. In recent years the implementation of the precast system within the construction industry has been significantly enhanced [40]. Consequently, improved performance and reliability in the precast supply chain will be achieved based on the appropriate delivery schedule, quantities, arrival orders [2], unloading sequences and inspections of the precast components produced from the factory or intermediate warehouse which will be transported to the precast construction site [35-36, 70]. Another limitation of component transportation is the acceptable and suitable weight and size of components which are restricted by the load capacities of bridges and pavements and also the horizontal and vertical authorizations for the tunnels, roads, highways, overpasses and underpasses [21, 47].

In the installation and construction phase, all the precast components based on the installation drawings (assembly/montage), time scheduling and instructions which are produced within the precast planning phase will be installed/assembled [67]. A tower crane [9] and mobile crane will be used for the site storage and installation of precast components [71]. In addition, proper site-coordination [49] and appropriate selection of the loading capacity of hoists and tower cranes for the installation of precast components based on their weight and size should be considered [9, 34-36]. The next part of this research will briefly clarify the problems within the precast construction industry.

2.2 Precast Supply Chain Problems

There are various problems within the precast construction industry, as shown in Table 2, that may have adverse consequences for the project objectives causing delays, quality and safety issues and overrun costs. Nevertheless, these identified problems cannot be totally rectified by the construction collaboration tools, such as cloud computing implementation. It should be noted that cloud computing implementation will facilitate and bring up to date the delivery of enormous quantities of information within the precast supply chain phases. Consequently, it is expected that these precast supply chain problems such as the poor planning and scheduling, poor design, production lead time, incorrect deliveries, wrong (inaccurate) components delivered and poor on-site coordination could be improved by utilizing cloud computing.

Table 2 Major problems in precast supply chain phases

Planning (P)	Poor planning and scheduling [2, 49, 57]. Expensive precast components [21].
Design (D)	Less flexibility in design [9]. Size/weight restrictions on truck loads [45]. Poor design [50].
Manufacturing (M)	Hard constraints (mould-element relationship and mould production capacity) and soft constraints (delivery requirements and inventory stock requirements) [24]. Production lead time [34]. Incompetent employees and damage to raw materials [39, 60].
Transportation (T)	Bulky and extremely heavy precast components [3, 9, 21, 34-35, 45-47, 72-73]. Poor capability of lorry cranes for size/weight of components and expensive usage of trailers [34] Incorrect deliveries [39].
Installation and Construction (I&C)	High cost of cranes for component installations and contractor order changes [34-36]. Wrong (inaccurate) components delivered [35-36, 74]. Poor on-site coordination [49].

The following part of this research will reveal the concepts of cloud computing and its development.

3.0 CLOUD COMPUTING

Cloud computing consists of information technologies that can be implemented globally using a network and the Internet anywhere, at any time, and with no concern about having a new infrastructure, employee training and software licenses [18, 75-81]. Different cloud computing definitions will be presented in the next section of this research.

3.1 Definitions of Cloud Computing

The main benefits of cloud computing implementation are: less infrastructure investment, convenience, flexibility, enhanced performance and cost reduction [81-82]. For better and clearer understandings of cloud computing technology, Table 3 explores the different definitions of cloud computing.

Table 3 Cloud computing definitions

Author(s)	Definition
[83]	A cost-effective paradigm which assists in the application of data-intensive computing processes.
[84]	An approach to outsource data with the aim of decreasing the data storage and reducing the management issues.
[85]	A convenient means that has evolved for implementing various computing resources including the servers, networks, applications, storage, and services.
[86]	A group of distributed computers such as data centres and servers providing services and resources via the Internet.

According to the diverse definitions of Table 3, cloud computing is the distribution and implementation of services, resources and applications anywhere and at any time through only the Internet without any concerns about the management, maintenance and ownership.

Cloud computing comprises: public [87], private [88], community [89] and hybrid [90] delivery (deployment) models. Consequently, Ranjan and Zhao [77], Cohen *et al*. [87], Goscinski and Brock [91], You and Huang [92] and Abrishami *et al*. [93] classified the three types of cloud computing as: Infrastructure as a Service (IaaS), such as Salesforce and Amazon web services; Platform as a Service (PaaS), such as IBM and Amazon's EC2 offerings; and lastly, Software as a Service (SaaS), such as Amazon and Google Apps including Google Calendar, Gmail and Google Docs. The following section of this research will propose the architectural system by describing its components within the precast construction industry.

4.0 ARCHITECTURAL SYSTEM OF CLOUD COMPUTING WITHIN THE PRECAST CONSTRUCTION INDUSTRY

Cloud computing is the valuable technology which sends and retrieves the data and various applications by utilizing the internet and central remote servers including the application servers and the database server. The integration of cloud computing, mobile clients (such as the smart mobile devices including the smartphones and tablets), servers and data centers [18-19, 77-79, 92, 94] and logistics management [95] could be applied for the precast supply chain management.

The architectural system of cloud computing for the precast supply chain management is illustrated in Figure 2.

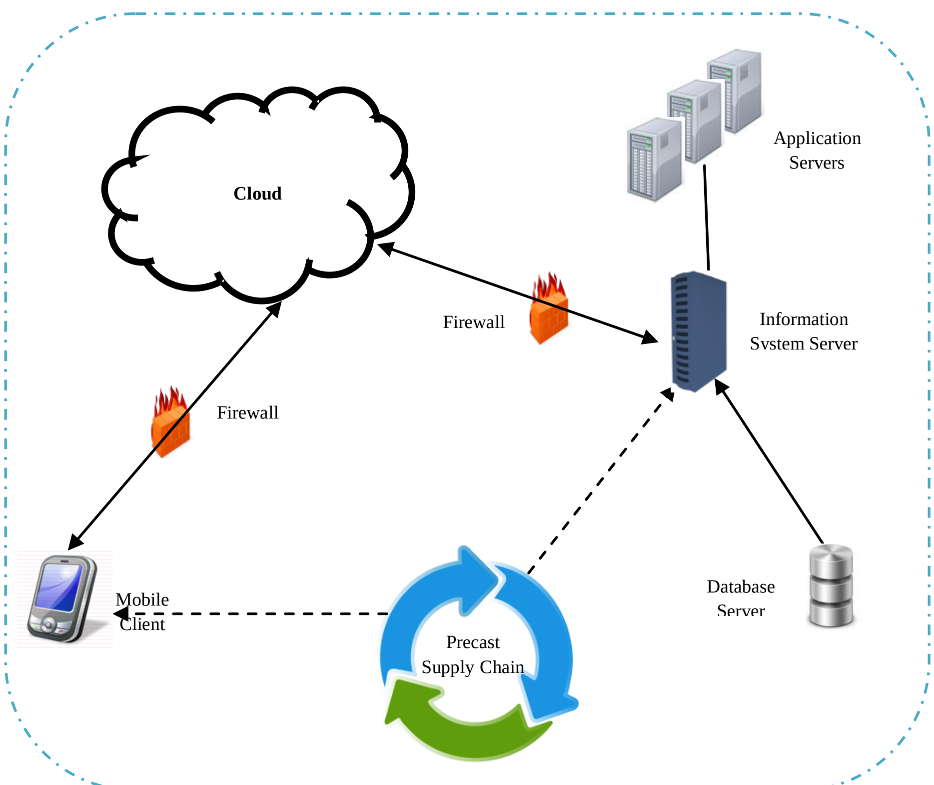


Figure 2 Cloud Computing Information System (CCIS) architecture for precast supply chain management

Figure 2 illustrates that firstly, through the precast supply chain phases, the data will be delivered to the database server and the application servers and secondly, it will be transferred to the Information System server engine (IS server engine). Fundamentally, the Cloud Computing Information System (CCIS) architecture comprises four core components:

(1) The Mobile Client: A smart mobile device-including the smartphones, mobile computers and tablets-that is capable of sending the data and information to the Information System server engine by utilising the cloud. Besides, the mobile client will attain the information from the cloud;
(2) The Firewall: Two firewalls are positioned. The first firewall is between the mobile client and the cloud and the second between the cloud and the IS server engine. The main purpose of these firewalls is for the security of information which will be transferred and delivered to the devices;
(3) IS Server Engine: The data that is delivered by the mobile clients, database server and application servers will be processed via the IS server engine; and
(4) The Cloud Server: The information that is created by the IS server engine, with the firewall authorization will be delivered to the cloud. Moreover, the information from the cloud will be distributed to the mobile client.

The next part of this research will briefly overview the significant points discussed within the research and develop the conclusions which could enhance the collaboration and improve efficiencies and integration along with increasing the productivity of the precast construction industry.

■5.0 CONCLUSION

The expanding complexity of precast supply chain phases necessitates the exchanging of increasing amounts of data and information. There are various problems within the precast construction industry that may have adverse consequences for the project objectives causing delays, quality and safety issues and overrun costs. These precast supply chain problems such as the poor planning and scheduling, poor design, production lead time, incorrect deliveries, wrong (inaccurate) components delivered and poor on-site coordination could be improved by using cloud computing. Therefore, in order to achieve successfully the precast project goals using a timely, cost-effective, high quality, and efficient operative approach, the selection and implementation of the proper construction collaboration tools for the precast supply chain parties and project stakeholders is vital. Moreover, cloud computing will significantly impact on how efficiently and effectively the information systems can be utilised in order to create the services and applications. This collaborative technology could be applied anytime and anywhere globally with not much concern about needing new infrastructure, software licenses and employee training.

Overall, this paper has proposed an intelligent collaborative tool via the cloud computing implementation in order to mitigate the negative consequences of the identified problems within the management of the precast supply chain. Furthermore, the cloud computing implementation within the precast construction industry, will deliver significant opportunities for improving the effectiveness and enhancing the appropriate information flow along with access to data, information and services. This paper is part of an on-going study that finally aims to enhance the evaluation, implementation and applications of cloud computing as one of the core construction collaboration tools.

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