Automation in Construction 44 (2014) 152–162

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

An explanatory case study on cloud computing applications in the built environment

Heap-Yih Chong [a,b,*], John Son Wong [a], Xiangyu Wang [b,c]

[a] Faculty of Engineering & Science, Universiti Tunku Abdul Rahman, Malaysia
[b] Australasian Joint Research Centre for Building Information Modelling (BIM), School of Built Environment, Curtin University, Australia
[c] Department of Housing and Interior Design, Kyung Hee University, Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 12 September 2013
Received and revised form 21 February 2014
Accepted 15 April 2014
Available online 4 May 2014

Keywords:
Cloud computing
BIM
Project management
Critical review
Information management

ABSTRACT

Fragmentation of practices is one of the key issues in the built environment. However, with advances in Information and Communication Technology (ICT), particularly cloud computing, the fragmentation of working practices can be potentially overcome. The technology could enhance communication and information flow in various stages along a project life cycle. Due to the increasing demands and the newly developed cloud computing applications, it is critical to review and identify the appropriate cloud computing applications in the built environment. A total of forty two cloud computing applications consisting of general cloud applications, Building Information Modelling (BIM), and project management cloud applications were selected and critically reviewed. A decision-making model was also developed to assist parties in selecting a suitable application. The explanatory case study has discovered numerous possible cloud computing applications in various disciplines, for example, Google Apps, Autodesk BIM 360, and Viewpoint are the applications with the most features. The findings contribute to creating a certain awareness and an insight to reduce the fragmented working practices in the built environment.

1 . Introduction

Fragmented work practices are a common scenario due to many individual participants in a project, each having their own objectives and goals [7]. This situation becomes worse when the project life cycle involves many stages, from conception to construction to demolition [6]. Fragmentation will lead to poor communication and decreased efficiency in the industry [14].

The highly fragmented situation has to be overcome in order to manage the project life cycle more efficiently. Application of information and communication technology (ICT) is able to manage the project risks and enhance the coordination [31]. Cloud computing is also known as 'shared computing' in the past decades. It is recognized as an advanced computing technology where software and hardware are delivered as a platform for collaborative service through the network. In recent years, cloud computing technology has begun to become even more popular as to support processing and interchanging of voluminous data, modular interactivity and inter-application communications. Moreover, the easy access to and availability of the internet have also promote the concept of sharing in cloud computing.

Many applications can be delivered through cloud computing, such as project management, database management, and the recent emerging technology called Building Information Modelling (BIM). A BIM project is able to create more collaboration within project teams, improved profitability, reduced costs, better time management and improved customer/client relationships [3]. Previous studies on BIM have been focused on the implementation and the adoption frameworks of BIM [2,12,25,29]. Some researchers have suggested that BIM must instead be upgraded with new technologies such as cloud computing [24] and augmented reality [19,29], which are able to enhance design coordination or even facility management [30]. It can improve the project in cost, value and carbon performance by exchanging information in the cloud [21]. This technology is going to play an integral part of future BIMs [8]. Some attempts were carried out, especially on the pilot frameworks of various aspects of management [7,13].

Therefore, due to the increasing demands and the increasing newly developed cloud computing applications that are constantly being designed in the market, there is a need to conduct an explanatory case study research to review and identify the appropriate cloud computing applications in the built environment. Therefore, the research objectives are (a) to critically review and compare current cloud computing applications and related tools and platforms in the built environment and (b) to develop a decision-making model for the selection of a cloud computing application in the built environment.

This research will assist the parties involved to make informed decisions in selecting suitable applications for their projects, and subsequently

* Corresponding author at: Australasian Joint Research Centre for Building Information Modelling (BIM), School of Built Environment, Curtin University, Australia.
E-mail addresses: heapyih.chong@curtin.edu.au, heapyihchong@gmail.com (H.-Y. Chong).

http://dx.doi.org/10.1016/j.autcon.2014.04.010
0926-5805/

the process of project delivery could be tremendously improved through a more efficient and collaborative manner of managing the information flow in the project.

2 . Cloud computing

Cloud computing is a shared computing technology where software and hardware are delivered as a service through the real-time network, for instance, the internet. The most common definition of cloud computing has been defined by the National Institute of Standard and Technology (NIST) [18] as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction".

Generally, cloud computing services can be categorized into three main types of services: Infrastructure as a Service, Platform as a Service and Software as a Service. These services can then be accessed through a cloud client which could be a web browser, mobile app, and so on.

Infrastructure as a Service (IaaS) is a service where the hardware is hosted by the service provider and the customer only pays for the use of the hardware [32]. The IaaS can be further divided into Software Infrastructure as a Service (SIaaS) and Hardware Infrastructure as a Service (HIaaS). SIaaS is described as a stand-alone cloud service that only supports a specific application, but not the whole application software; whereas HIaaS is a virtual or physical hardware resource that provides a service, for example, Microsoft SQL [23]. The hardware provided can be described as an infrastructure of servers that can provide services such as storage, computing ability, virtualization, etc. The main advantage of this form of service is that it dramatically decreases the hardware cost for users, as only the minimum requirements for hardware will be required. This type of service is defined as the capability provided to the user to acquire processing, storage, networks and any other applications available on the infrastructure for rent [17]. It is also stated that the user will not be able to control the infrastructure but will be able to control the applications used through the infrastructure.

There are several notable components that IaaS services should also include. These components serve as a utility computing service and billing model, automation of administrative tasks, dynamic scaling, desktop virtualization, policy-based services and internet connectivity [4]. Currently, there are several notable providers, such as Amazon's EC2, GoGrid's Cloud Servers and Joyent [27].

On the other hand, compared with the IaaS model, where only hardware is provided through the cloud, the Platform as a Service (PaaS) model is a model where hardware and a certain amount of application software are provided together as a set to the user, as described by Bhardwaj [4], who also observes that PaaS is an application development and deployment application service provided to the user over the internet. PaaS is a development environment which is supplied as a service. PaaS is reported to act as a distribution platform server where the service provider provides services such as a developed environment, server platform and hardware resources, which are then used by the user to develop their own application and then supplied to other users across the internet [34]. The PaaS model gives the user the capability to deploy onto the cloud infrastructure or applications created by the user using programming languages, libraries, services and tools supported by the provider [17]. Some of the PaaS service providers listed by Zhang and Sultan, [28,34], are Google App Engine, Force.com, 800 APP, Microsoft's Azure and Amazon web service.

The last of the cloud computing models is Software as a Service (SaaS). In this model, the user can use applied software which is already provided by the service provider on their server [34]. Through this model, users can easily access the software through a browser and are charged on a per user or time used basis. It was asserted by Zhang et al. that this is the best way for a small business to take advantage of cloud computing technology as it is the simplest to use. The users do not get to manage or control the cloud infrastructure, network, servers, operating system, storage or even the application capabilities [17]. However, they may be able to control the user-specific application configuration settings. Some examples of applications provided through the SaaS model are productivity applications such as word processing, spreadsheets, etc. More complex programs such as those for Customer Relationship Management (CRM) and Enterprise-Resource Management (ERM) can also be provided through this model [28].

This service model of cloud computing typically hosts and manages applications which are then available to users through the web. However, this does not necessarily mean the service provider also provides PaaS or IaaS. Bhardwaj et al. mentioned in their paper that a SaaS provider may be running on other cloud providers for PaaS and IaaS, and is thus only providing the applications and software. Some SaaS service providers were also listed by Bhardwaj [4]. They are Oracle CRM on demand, Salesforce.com and Netsuite. Also, several SaaS providers such as Google Doc, Google Apps, Zoho Office, Yahoo mail, WebEx and Microsoft Office Live were reported [28,34].

Apart from that, it is worth to highlight some evolving technologies in relation to cloud computing [10,15,20], namely, Server-based Computing or being described as "thin-client computing", Hosted Client Computing, Web-based applications, and Rich Internet Application. These are relatively new technologies for the applications that would be hosted or run in the server or internet under different circumstances to ensure the connectivity and consistent functioning of the applications. Overall, the taxonomy of cloud computing is required to configure with a number of resources, namely, networks, servers, storage, applications, and services as illustrated in Fig. 1 [9].

2.1. The need for cloud computing

Cloud computing has been increasingly popular in the past few years as it continues to prove that it gives substantial advantages to users who adopt this technology. These advantages have also been extensively discussed by many researchers and academicians around the world.

There are four main reasons why cloud computing is attracting more and more users [28]. The first reason is that it provides elasticity or flexibility, as users are free to request the amount of resources they need from the cloud, for example, the size of storage or servers. The next reason is that cloud computing is economical. This is because users only pay for what they use. For example, if the user only uses two servers they will only pay for those two. The third reason stated in the paper is that this technology is reliable because most of the services provided are fault-tolerant and are highly available. Finally, it is maintained by Tao et al. that cloud computing is more user-friendly and on demand, as the services are tailored to individual requirements.

One of the main benefits is that cloud computing dramatically lowers the cost of entry for small firms who are trying to benefit from computer-intensive business analytics that were previously only accessible by large firms as they are extremely costly. Cloud computing has leveled the playing field for all parties. This lowered cost also opens up vast opportunities to third-world countries that may have been left behind in the IT revolution and have no access to these capabilities. These computing services can then be used to create endless possibilities of innovative IT applications, software and products. Some of the many promising start-ups, such as 37 Signals, Jungle Disk, Gigavox and SmugMug, are results of substantially lower IT investments compared with a few years ago; thus cloud computing can be a catalyst for increasing IT innovation [16].

Besides, cloud computing makes it easier for companies to scale their services, whether up or down, as the resources can be deployed very fast from the cloud. This in turn results in more efficient use of resources. For example, if a company suddenly requires more resources to meet higher demand they can quickly acquire the resources needed from the cloud, so avoiding potential loss of profit. On the other hand, if the company needs to scale down from low demand they can easily