



Towards Facilitating Team Collaboration During Construction Project Via The Development of Cloud-Based BIM Governance Solution

by

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Cardiff University School of Engineering

Declaration

This work has not previously been accepted in substance for any degree and is not currently submitted in candidature for any degree.

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Dedication

*To my father's spirit
who taught me to be a passionate in what I am doing*

*To my lovely mother
who taught me love and kindness*

*To my wife
who is always my source of motivation*

*To my family
for their support and encouragement*

Quotations



”O my Lord! advance me in knowledge”
Holy Quran: Surah Ta-Ha; 20:114

Abstract

Construction projects involve multi-discipline, multi-actor collaboration, and during their lifecycle, enormous amounts of data are generated. This data is often sensitive, raising major concerns related to access rights, ownership, intellectual property (IP) and security. Thus, dealing with this information raises several issues, such as data inconsistency, different versions of data, data loss etc. Therefore, the collaborative Building Information Modelling (BIM) approach has recently been considered a useful contributory technique to minimise the complexity of team collaboration during construction projects. Furthermore, it has been argued that there is a role for Cloud technology in facilitating team collaboration across a building's lifecycle, by applying the ideologies of BIM governance. Therefore, this study investigates and seeks to develop a BIM governance solution utilising a Cloud infrastructure. The study employed two research approaches: the first being a wide consultation with key BIM experts taking the form of: (i) a comprehensive questionnaire; followed by (ii) several semi-structured interviews. The second approach was an iterative software engineering approach including: (i) Software Modelling, using Business Process Model Notation (BPMN) and Unified Modelling Language (UML), and (ii) Software Prototype Development. The findings reveal several remaining barriers to BIM adoption, including Information Communication Technology (ICT) and collaboration issues; therefore highlighting an urgent need to develop a BIM governance solution underpinned by Cloud technology, to tackle these barriers and issues. The key findings from this research led to: (a) the development of a BIM governance framework (G-BIM); (b) definition of functional, non-functional, and domain specific requirements for developing a Cloud-based BIM Governance Platform (GovernBIM); (c) development of a set of BPMN diagrams to describe the internal and external business procedures of the GovernBIM platform lifecycle; (d) evaluation of several fundamental use cases for the adoption of the GovernBIM platform; (e) presentation of a core BIM governance model (class diagram) to present the internal structure of the GovernBIM platform; (f) provision of a well-structured, Cloud-based architecture to develop a GovernBIM platform for practical implementation; and (j) development of a Cloud-based prototype focused on the main identified functionalities of BIM governance. Despite the fact that a number of concerns remain (i.e. privacy and security) the proposed Cloud-based GovernBIM solution opens up an opportunity to provide increased control over the collaborative process, and to resolve associated issues, e.g. ownership, data inconsistencies, and intellectual property. Finally, it presents a road map for further development of Cloud-based BIM governance platforms.

List of publications

- **Publications in leading Journals**

- Alreshidi E, Mourshed M, Rezgui Y, Cloud-based BIM governance platform requirements and specifications: software engineering approach using BPMN and UML, *Journal of Computing in Civil Engineering* , (2015) ISSN 0887-3801 DOI: 10.1061/(ASCE)CP.1943-5487.0000539
- Alreshidi, E., Mourshed, M. & Rezgui, Y. Identifying the requirements of a BIM governance model during a construction project across supply-chain. *Requirements Engineering* (2015) (under revision).
- Alreshidi, E., Mourshed, M. & Rezgui, Y. Factors for effective BIM governance. *Automation in Construction* (2015) (under review).
- Alreshidi, E., Mourshed, M. & Rezgui, Y. Towards Cloud-based BIM Governance Platform: Prototype Development.(2015), (prepared for submission to *IEEE Transactions on Service Computing*).

- **Published conference papers**

- Alreshidi, E., Mourshed, M. & Rezgui, Y. Exploring the Need for a BIM Governance Model: UK Construction Practitioners' Perceptions. *Computing in Civil and Building Engineering* (2014), 2014. ASCE, 151-158.
- Alreshidi, E., Rezgui, Y. & Mourshed, M. 2014. Requirements for Developing BIM Governance Model: Practitioners' Perception. *Edinburgh International Conference Centre (EICC) Edinburgh*. Edinburgh: Edinburgh University. <http://goo.gl/8L2CR1>
- Alreshidi, E., Mourshed, M. & Rezgui, Y. Cloud-BIM Governance Solutions: Current Situations and Future Directions.(2016), (Accepted by ICCCBE 2016 Conference, Japan).
- Alreshidi, E., Mourshed, M. & Rezgui, Y. The Development Process of a Cloud-based BIM Governance Platform.(2016), (Accepted by ICCCBE 2016 Conference, Japan).

List of Acronyms/Abbreviations

- **BIM** Building Information Modelling
- **ICT** Information Communication Technologies
- **API** Application Program Interface
- **MEP** Mechanical, Electrical and Plumbing
- **CAD** Computer-Aided Drawing
- **ERP** Enterprise Resource Planning
- **IFC** Industry Foundation Classes
- **CIC** Construction Industry Council
- **RIBA** Royal Institute of British Architects
- **PII** Personal Indemnity Insurance
- **BPMN** Business Process Modelling Notations
- **UML** Unified Modelling Language
- **IDEF** Integrated Definition for Function Model
- **SysML** System Modelling Language
- **PIMs** Project Information Management solution
- **EDMS** Electronic Documents Management Server
- **SLA** Service Level Agreement
- **CSP** Cloud Service Provider
- **AWS** Amazon Web Services
- **EC2** Amazon Elastic Compute Cloud
- **GCP** Google Cloud Platform
- **IDE** Interactive Development Environment

- **GovernBIM** Cloud-based BIM governance platform
- **G-BIM** Successful factors for BIM governance Framework
- **AEC** Architecture, Engineering and Construction
- **IaaS** Infrastructure-as-a-Service
- **PaaS** Platform-as-a-Service
- **SaaS** Software-as-a-Service
- **HTTP** Hyper Text Transfer Protocol
- **CDN** Content Delivery Network
- **VMs** Virtual Machines
- **NFS** Network File System
- **RAM** Random Access Memory
- **MVC** Model View Controller
- **MVP** Model View Presenter
- **GUI** Graphical User Interfaces
- **AJAX** Asynchronous JavaScript and XML
- **GWT** Google Web Toolkit
- **CSS** Cascading Style Sheets
- **SQL** Structured Query Language
- **HTML** HyperText Markup Language

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Introduction

1.1 Introduction

The aim of this chapter is to provide an overview of this thesis. Therefore, it begins by detailing the research background, focusing on Building Information Modelling (BIM), BIM, Collaboration, BIM Governance, and Cloud Computing. Then follows a discussion on the rationale and motivation for the study. The chapter continues by setting out the research aim and objectives and the research hypotheses and questions. Next, a summary of the methodology underpinning the study and the research scope is presented. This is followed by the main contributions the research offers to the body of knowledge and then an outline of the thesis' structure.

1.2 Overview

Construction projects involve complex activities and processes during their lifecycle (Cesarotti et al., 2014), requiring construction team members from different backgrounds to collaborate to minimise project complexity, and complete construction projects within a set budget and to a timetable (Cesarotti et al., 2014). Collaboration among teams can play a vital role in the building management overall, facilitating the achievement of objectives predetermined in collaboration with a client (Hobbs, 1996). It also involves co-workers sharing information and processes by interacting, communicating, exchanging, coordinating and approving; that is, sharing visions between stakeholders and maximising team effort on a particular job (Ilich et al., 2006). BIM has become an essential tool in the construction industry (Bryde et al., 2013). In recent years it has attracted the attention of many researchers, as evidenced by the growing number of case studies demonstrating the benefits of using BIM technology for constructing models e.g.(Barlish and Sullivan, 2012;Liu and Zhang, 2014;Volk et al., 2014;Azhar, 2011).

BIM seeks to allow stakeholder's collaboration at different stages of the building lifecycle (Motamedi and Hammad, 2009). Thus, the role of BIM is to facilitate stakeholder collaboration at different stages of a building's lifecycle (e.g. enabling stakeholders to insert, extract, update, or modify information during the BIM process) (Azhar et al., 2012). However, BIM is also emerged as a new way to manage information flow during the lifecycle of construction projects (Motamedi and Hammad, 2009). During a project that is handled in a collaborative way by people of multiple disciplines and multiple actors, many issues can arise (e.g. trust, lack of clarity regarding roles and responsibilities, interoperability, etc.) (Holzer, 2007, Rezgui et al., 2013, Wong et al., 2014). These issues can all act to hinder the effective use of BIM in the building sector (Arayici et al., 2012). Although practitioners aim to maintain collaborative work environments, they nonetheless encounter challenges in many parts of the world, specifically with respect to the development of fully integrated multi-disciplinary collaborative modes of operation, which necessitate a specific tool to facilitate the adoption of BIM (Gu and London, 2010, Singh et al., 2011)

The development and deployment of integrative and collaborative technologies to suit the construction industry is a singular task because of the unique nature of the industry (Shen et al., 2010). Successful technological implementation requires the establishment of procedures for both electronic and manual operations (Ilich et al., 2006). There are several BIM servers, commercial and open-source, which have been developed to assist team collaboration in BIM-based collaborative environments (e.g. RevitServer, BIMServer). However, these solutions tend to be either owned by a software vendor, or lack an overall data governance model (Rezgui et al., 2013). Recent studies (Beach et al., 2013, Rezgui et al., 2013) have strongly indicated that the development of a BIM governance model with its underlying Cloud environment will positively facilitate team collaboration during a construction project's lifecycle (Alreshidi et al., 2014).

Cloud Computing is a new emerging technology in BIM research and development (Jiao et al., 2012). The Cloud concept was introduced in 2004 (A Vouk, 2008). However, awareness of Cloud had increased since 2007, when IBM and Google announced a Cloud collaboration project (Lohr, 2007). Cloud technologies have since made a major contribution to the underlying technological aspects of BIM research and development (Zhang and Issa, 2014). Over nearly 30 publications concerning Cloud implementation in BIM have been identified recently, and this number is growing (Wong et al., 2014). Despite the fact that there are concerns about using Cloud (e.g. security and privacy), many researchers have adopted Cloud for their BIM research and development, due to its po-

tential benefits when serving the construction domain (Redmond et al., 2012). However, the emerging Cloud-BIM technologies are typically enabling solutions, aimed at dealing with the standalone nature of traditional BIM and providing an effective real-time communication platform for project team members (Chong et al., 2014).

This research is a multi-disciplinary research interested in how Cloud computing technologies can be utilised to solve problems that arise in the construction industry, within a particular domain, and to assist the development of Cloud-based BIM governance platforms to facilitate team collaboration and minimise issues emerging during collaboration. This chapter begins by presenting an overview, and this is then followed by an introduction of the research rationale, the main research aims and objectives. After this, several research questions are then asked. The overall proposed methodology is then highlighted, followed by the scope of the research and the contribution to the overall body of knowledge. Finally, the structure of the thesis is then highlighted.

1.3 Research rationale and motivation

The construction industry is highly fragmented by nature (Succar, 2009, Eastman et al., 2008, Motamedi and Hammad, 2009, Fathi et al., 2012). Thus, construction projects suffer from a lack of integration, contain complex processes and activities, and are extremely regulated data intensive project-based industries dependent on a wide range of different professions and firms (Naderpajouh and Hastak, 2014). A project's lifecycle not only involves traditional architecture, structures, mechanical and electrical disciplines, but also consideration of new disciplines, such as energy and the environment (Rezgui and Miles, 2011).

When team members collaborate with one another, this results in a need to share and process massive amounts of data (Rezgui and Zarli, 2006, Anumba et al., 2008), and might bring risks to project objectives delivery, thus having a negative effects on a project's success (Fathi et al., 2012). Project failure has been relatively common in recent years, the most significant reason being cited is the lack of effective project team collaboration and integration across the supply chain (Dainty et al., 2006, Zavadskas et al., 2010, Government, 2011). Moreover, problems in data sharing can also negatively affect a project's lifecycle, due to inappropriate information management systems leading to delays and waste during construction (Howard and Bjrk, 2008). In addition to what is reported above, there have been several barriers to BIM adoption in the current construction industry (Singh et al., 2011, Gu and London, 2010, Ashcraft, 2008). These barriers includes

socio-organisational barriers e.g. Trust, Technical barriers e.g. lack of interoperability, and Financial barriers e.g. cost of BIM software. Therefore, there is a need to tackle barriers to BIM adoption to achieve success in the industry worldwide (Ashcraft, 2008). There is also a need for further investigations and consultations to explore the nature and causes of barriers to BIM, as a means to enhance current BIM collaborative solutions.

Many commercial Cloud storage technologies have become popular in recent years. However, it has been argued that Cloud services are still relatively unreliable and unsecure (Ahmad and Janczewski, 2011). However, the majority of commercial Cloud-based BIM solutions do not account for the process dimension of a given project across its supply chain and lifecycle as a factor when accessing storage strategies (Beach et al., 2013). Moreover, current Cloud-based BIM storage solutions are inclined to be proprietary, and the data access is regulated according to company policy (Rezgui et al., 2013). While it is possible that commercial Cloud-based storage solutions could be used, there is lack of clarity about how these solutions work, and there is a need to set up a framework or schema to illustrate how people could work together using one. In other words, a control model could be imposed on a Cloud Service Provider (CSP) to guarantee access to stored data is based on actors' roles and their access rights.

In addition to the need to change current collaboration protocols and procedures, the adoption of a BIM governance solution with support of Cloud environments is highly recommended to facilitate team collaboration across a building's lifecycle (Rezgui et al., 2013). However, further enhancements and developments for such a model must be based on real scenarios and business cases. Since, the amount of data generated during collaboration on construction projects is massive; this can impose a need for a sustainable storage solution (Curry et al., 2013). This solution might take the form of a dynamic model that stores and manages data via an easy to use access interface. As construction project's data is sensitive, any storage model must be highly secure, although it should remain accessible to the many stakeholders who may need/require it, and should afford authorised access to the stored data (Beach et al., 2013). Therefore, Cloud could be the best option for hosting a BIM governance solution (Succar, 2009, Redmond et al., 2012). The use of Cloud storage might, therefore, be particularly suitable for storing data about the built environment for a number of reasons, such as accessibility, scalability, massive storage, and high-performance capabilities (Beach et al., 2011, Jiao et al., 2012).

There is currently a lack of comprehensive BIM data governance studies within current research and development in BIM. Therefore, there is a general consensus that a generic

data governance model is needed to facilitate the adoption of BIM in a collaborative environment, to assist team members during a building's lifecycle by underpinning the Cloud environment (Beach et al., 2013). Moreover, there is a limited adoption of Cloud in BIM, which is heavily focused on the design and construction phases. Hence, Cloud adoption in BIM is still in its early stages (Wong et al., 2014). Although Cloud technology has seen rapid growth in the IT field, fewer than 50 publications have presented advanced studies and implementation of Cloud-based solutions in BIM (Wong et al., 2014). According to the latest study, conducted by (Wong et al., 2014) there are three major challenges facing Cloud-BIM adoption; these are: (a) lack of clarity over who is owner responsible, and liability of Cloud-BIM models, (b) a shortage of experts and technicians who can create, update and maintain BIMs in the Cloud, and (c) the necessity for specialised education and training on new Cloud-BIM technologies, since implementing Cloud-based BIM solutions is hindered by socio-organisational and legal issues.

Therefore, the incentive behind this research is three-fold. First, there is a total lack of evidence in terms of studies, surveys, and documentation regarding the current situation with BIM governance for facilitating team collaboration across a project's lifecycle. Second, there are no proper BIM governance models offering implementation of technical storage solutions. Third, the researcher wishes to contribute his Computer Science knowledge and experience to enhance the overall context of adopting BIM in the current Built Environment via the development of a Cloud-based BIM governance platform, to help it migrate from its current status to become more advanced via the use of Cloud computing environments to govern BIM processes. Furthermore, the most interesting part of the study is that little research has been done to combine the new technologies of BIM and the Cloud computing (Wong et al., 2014), making this a good opportunity to contribute to this field and bridge the gap between Cloud researchers and BIM researchers.

1.4 Aim and objectives

The aim of this research is to investigate the requirements, suitability, and industry readiness and perception of BIM-based collaborative construction; and thus to develop a Cloud-based BIM governance platform to facilitate team management and collaboration across the project lifecycle and throughout the supply-chain, as well as to evaluate the use of a distributed computing environment (e.g. Cloud Computing) for governing and managing BIM data for the built environment. To meet this aim, the objectives of this research are to:

- **Objective 1:** Conduct a critical “state-of-the-art” review of: (a) barriers to BIM

adoption, highlighting socio-organisational, legal, financial, contractual and technical aspects; (b) current BIM collaboration practices, solutions, and limitations; and (c) existing BIM governance solutions related to efforts in the construction industry; and (d) Cloud technologies, specifically the potential benefits and drawbacks that they offer to BIM related research and development.

- **Objective 2:** Investigate and identify barriers to BIM adoption, concentrating on those inhibiting team collaboration, in view of socio-organisational, legal, financial, contractual and technical barriers. Also, consider data related issues affecting the collaboration process.
- **Objective 3:** Explore the need to develop a BIM governance solution to facilitate team collaboration during a construction project's lifecycle, as well as to identify the requirements for developing a Cloud-based BIM governance platform.
- **Objective 4:** Review existing BIM-related collaboration solutions, standards and practices to gain an in-depth understanding of the team collaboration process in the construction industry and understand the way that teams set up a collaborative environment.
- **Objective 5:** Investigate collaborative environmental practices throughout a BIM-based project, within leading BIM-based construction companies, to identify the business processes involved in establishing, managing and dismantling Cloud-based BIM governance solutions. Describe the internal and external business processes and functionalities of a Cloud-based BIM governance platform, to identify essential activities and key use cases to establish, configure, manage, and present a Cloud-based BIM governance platform during its lifecycle, within a construction project.
- **Objective 6:** Investigate existing Cloud-BIM solutions to define Cloud software architecture for implementing and hosting a Cloud-based BIM governance platform over a selected Cloud Service Provider (CSP). Then develop a Cloud-based prototype to test and validate the results from the previous stages and to explore the potential role of Cloud computing in hosting BIM governance solutions.
- **Objective 7:** Implement various testing and validation techniques for the developed platform and further propose recommendation for future research and development.
- **Objective 8:** Document the outcomes from each stage and identify directions for future research in BIM governance and collaboration, and explore policy implica-

tions for BIM enabled construction from validation results in objective 7 and lessons learned during development and implementation (objectives 1 to 7).

1.5 Research hypotheses and questions

This research on a Cloud-based BIM governance platform is underpinned by the following hypotheses: “Multi-actor collaboration in the fragmented construction industry requires an interoperable solution, considering the heterogeneity among people, processes and data. Cloud-enabled, distributed computing based BIM-governance that factor in trust, legal and contractual aspects is an appropriate solution to address these challenges.

- **RQ1:** *“What is the current status (including barriers and opportunities) of BIM practices and adoption in the construction industry, especially for collaboration between people (e.g. team members) and products (software) where data plays a central role?”*
- **RQ2:** *“How can the identified barriers from RQ1, the ones related to data management and governance, be addressed to enhance collaboration between people and products, and to increase BIM adoption during a construction project’s lifecycle, in particular, using Cloud Computing technologies?”*
- **RQ3:** *“Can the findings from RQ2 be applied to develop a process-centric solution for facilitating enhanced collaboration across a building lifecycle that addresses the barriers identified in RQ1?”*
- **RQ4:** *“Does the solution developed in response to RQ3 address existing challenges for collaboration?”*

1.6 Methodology

This research concerns the development of a Cloud-based BIM governance solution; henceforth, a software development lifecycle is the most appropriate lifecycle to underpin this research. An iterative approach is chosen for its many advantages (discussed in Chapter 3) over other software lifecycles. Figure 1.1 illustrates the overall lifecycle of this Ph.D. methodology.

The starting point of the methodology involves conducting a critical review focused on the following principal elements: BIM, its benefits, and barriers to adoption, BIM collaboration, data governance efforts in BIM, and Cloud Computing with implementation

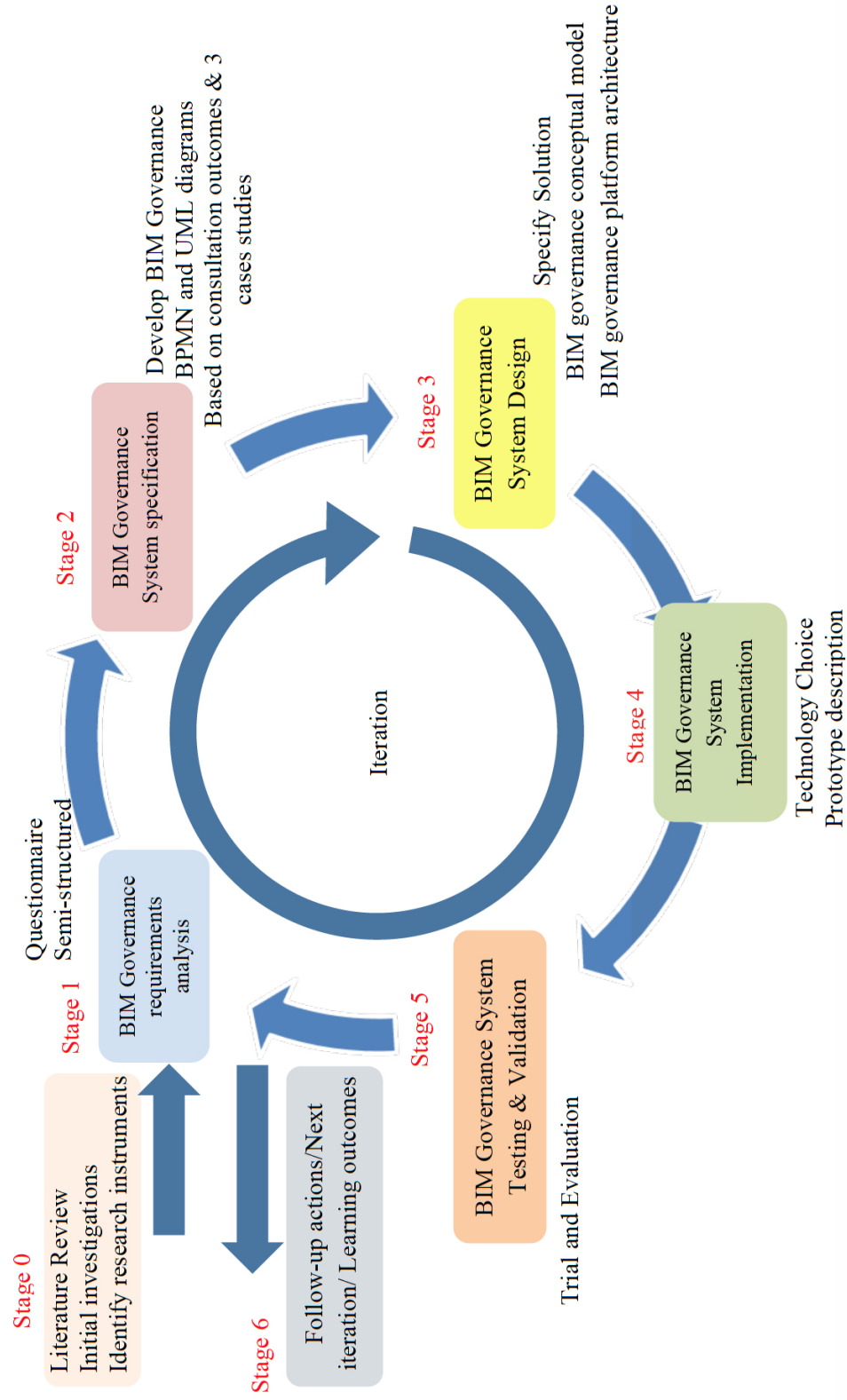


Figure 1.1: Proposed iterative approach for developing a Cloud-based BIM governance platform

efforts in BIM. This is followed by wide consultation with BIM professionals comprising, (a) comprehensive questionnaire, and (b) semi-structured interviews. A comprehensive questionnaire will target construction practitioners to identify current barriers to BIM adoption, Information Communication Technologies (ICT) and collaboration practices and solutions as well as identifying the need to develop a BIM governance solution. After this, several semi-structured interviews with BIM experts will be conducted to gather more detailed information about the development of Cloud-based BIM governance solutions, followed by an analysis of current collaboration practices and management solutions within three selected BIM-implementation construction companies, with a strong emphasis on the socio-organisational, technical, contractual, and legal aspects underlying collaborative environments. A general investigation of BIM-related documentation; e.g. collaboration manuals, BIM standards, etc., will support this. A combination of BPMN and UML modelling approaches underpinned by software engineering approaches will be used to develop a set of requirements and specifications for GovernBIM platform. Then, a set of collaborative tools and practices commonly used in such projects will be identified, with the aim of understanding their Application Program Interface (API), interfaces and communication mechanisms, and their information management and governance requirements. Finally, a convenient Cloud environment will be chosen (i.e. Google Infrastructure), in order to develop the initial version of the GovernBIM platform prototype. Testing and validation will be done to test the functionalities of the platform, as well as the capabilities for hosting the Cloud environment. Table 1.1 illustrates the link between the research methodology for developing Cloud-based GovernBIM platform and its specifications and technical design, in contrast with the aims and objectives of this Ph.D.

1.7 Research scope

Data governance has been investigated in several domains (e.g. in (ICT)) (Al Omari et al., 2012), banking systems (de Abreu Faria et al., 2013), and health (Reeves and Bowen, 2013). Since this study aims to develop a Cloud-based BIM governance solution, investigation in this area has concentrated on the following domains: BIM, ICT and BIM collaboration practices and tools, BIM governance, and Cloud Computing. Although, all the previous research domains will be investigated, this research is specifically located at the intersection of all these research domains. Therefore, this research is a multi-disciplinary study, meaning its outcomes will be beneficial to researchers in all the aforementioned domains. Figure 1.2 illustrates the scope of this research.

Table 1.1: Proposed research methodology for a Cloud BIM governance platform in line with the research objectives

Research Stages	Targeted objectives	Stage description	Used instruments /techniques	Outcomes/contributions
Stage 0 Planning and investigation	Objective 1 Objective 2	Conduct a literature review, initial investigation into existing solutions, brainstorming, and identifying and agreeing on the suitable research instruments for this research. As well as identifying potential research instruments to be used during the investigation. The findings at this stage contribute to the following stage.	<ul style="list-style-type: none"> - Theoretical study - Brainstorming - Comprehensive questionnaire 	<ul style="list-style-type: none"> - Research hypotheses - Aim and objectives - Potential research instruments
Stage 1 Date collection and requirements analysis	Objective 3 Objective 4	Collect primary data for developing a Cloud-based BIM governance solution, this stage includes development of a comprehensive questionnaire followed by semi-structured interviews, targeting UK construction practitioners and BIM experts. Moreover, one of the outcomes of this stage is a factors scheme for successful BIM governance.	<ul style="list-style-type: none"> - Comprehensive questionnaire - Semi-structured interviews - Relevant documentation e.g. standards - Existing BIM collaboration solutions and manuals 	<ul style="list-style-type: none"> - Review of current ICT and collaboration status - BIM experts' requirements for developing Cloud-based BIM governance platform - Factors scheme for successful BIM governance
Stage 2 Cloud-based BIM governance platform Modelling and specifications	Objective 5	Alongside the results from previous stages, this stage includes defining the specifications for a Cloud-based BIM governance platform by converting the data collected from the cases studies into several visualised BPMN and UML diagrams; i.e. (Use cases and Class diagrams) using VisualParadigm modelling software.	<ul style="list-style-type: none"> - Cases studies collaboration process analysis of selected BIM-leading companies - Modelling using BPMN and UML 	<ul style="list-style-type: none"> - BPMN diagrams describing the entire lifecycle of a BIM governance platform. - Fundamental use case diagrams that describe GovernBIM platform functionalities - Class Diagram to describe the internal data structure of GovernBIM platform
Stage 3 Cloud-based BIM governance platform's solution design	Objective 6 Objective 7	Analyse the gathered requirements using a requirements engineering approach (Sommerville, 2007). This stage involves specifying a solution for a BIM governance model; i.e. Cloud-based BIM governance conceptual model and a BIM governance solution and implementation architecture. However, a review of existing Software-as-service architecture and design patterns is conducted before designing and agreeing with the researcher on the best architecture for the solution developed.	<ul style="list-style-type: none"> - Review existing collaborative BIM solutions - Investigate different SOA architectures and design patterns - Brainstorming - Design and creation 	<ul style="list-style-type: none"> - GovernBIM platform implementation architecture
Stage 4 Technical implementation	Objective 7	Prototype implementation for the BIM governance solution, based on the selected Cloud computing technology. At this stage the researcher has to adopt a Google Cloud infrastructure to develop and test the GovernBIM platform.	<ul style="list-style-type: none"> - Selection of the implementation environment - Prototyping using Java-based programming IDE 	<ul style="list-style-type: none"> - GovernBIM platform prototype - GovernBIM platform API
Stage 5 Testing and validation	Objective 7 Objective 8	This stage involves an evaluation of outcomes as well as the prototype developed for the Cloud-based GovernBIM platform, through various testing and evaluation techniques.	<ul style="list-style-type: none"> - Implementation environments - Prototyping - Testing and validation 	<ul style="list-style-type: none"> - Error detection - Further recommendations
Stage 6 Documentation/p reparation for next iteration	Objective 8	This stage involves taking follow up actions based on the outcomes and results from previous stages. In addition, at this stage, documentation is done to keep a record and track the changes made to the platform. This includes any future work necessary to improve outcomes, as well as the platform functionalities developed.	<ul style="list-style-type: none"> - Documentation 	<ul style="list-style-type: none"> - Documentation - Future roadmap for BIM governance platform research and development

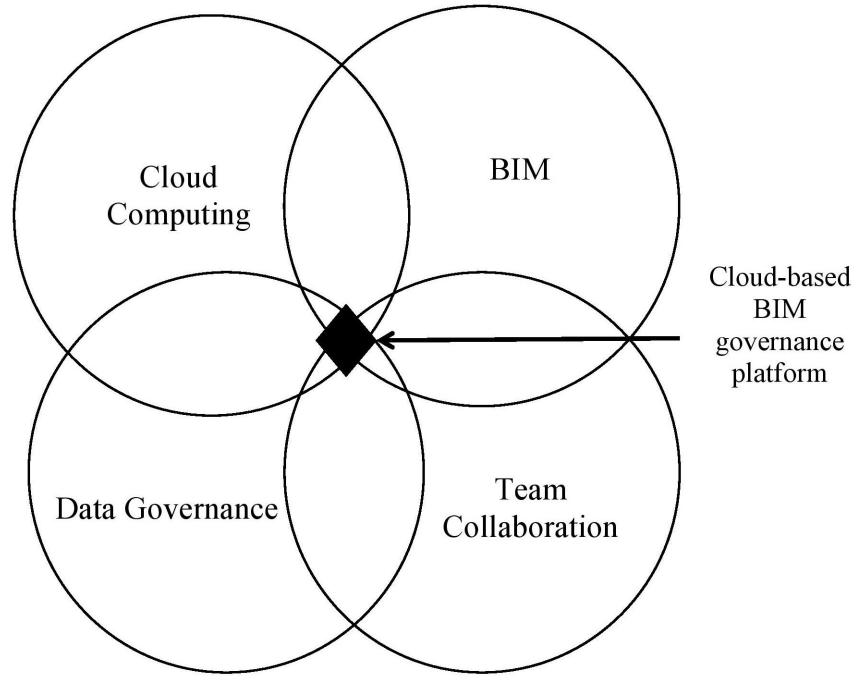


Figure 1.2: Scope of this research

- **BIM.** This research will focus on only one aspect of BIM (i.e. BIM as a collaborative and management approach), as virtualisation of building models is not taken into consideration at these stages of Cloud platform development. Integrating Industry Foundation Classes (IFC) is a crucial factor in the development of an integrated solution. However, because this research established the foundation of a Cloud-based GovernBIM platform, the integration of a GovernBIM platform and IFC is outside the scope of this research, and will only be included in future work.
- **BIM collaboration practices and tools.** Team collaboration is the main driver for establishing BIM governance research, as the collaboration process results in several issues (e.g. ownership, IPRs, etc.). Therefore, the requirements for developing a BIM governance solution must be taken under consideration. Thus, this research will target construction practitioners to discover their needs and requirements by employing a broad consultation process using mixed-methods. Existing BIM collaboration solutions have different software architectures and different internal/external data structures that are not well suited to the implementation of Cloud environments. Nevertheless, there is a need to define a suitable implementation architecture for the proposed Cloud-based BIM governance platform. Hence, paper-based collaboration standards in the UK e.g. BS1192:2007, PAS1192-3 will be partially implemented, due to the researcher's limited knowledge of the construc-

tion domain and related terminology.

- **BIM governance.** There have been limited studies concerning this topic, therefore this study will focus on identifying key requirements to develop a Cloud-based BIM governance platform. Based on the requirements identified it will define its specifications using BPMN and UML as well as defining Cloud implementation architecture. Finally, it will develop a practical solution for technical implementation of the platform. Thus, the governance model developed at this stage will concentrate on sharing documents at the documentation-level and not explore details at the objects-level. Non-functional requirements, such as memory optimisation, performance and high-security functionalities will be side-lined in the technical development.
- **Cloud Computing.** Cloud Computing is the most suitable computing environment for hosting and testing the GovernBIM platform development process. The choice of hosting environment will involve reviewing several Cloud Service Providers (CSPs) and exploring their services and limitations and then selecting the most convenient environment for developing the GovernBIM platform prototype. Since there are existing hosting Cloud environments, this study does not aim to develop a Cloud infrastructure but to examine it, and subsequently, use it to underpin the development of the platform.

1.8 Main contributions to the body of knowledge

BIM governance is a relatively new area of research within the field of BIM. Therefore, this research contributed to the body of knowledge as follows:

- Updated current research and development in the Cloud-BIM field with results obtained from wide consultation with BIM experts in the construction industry field.
- Extended the existing research and development of BIM governance and expanded the foundations of previous work conducted in this field by completing the following:
 - Identified the need to develop a BIM governance solution with the support of Cloud technologies;
 - Developed a theoretical BIM governance successful factors scheme to support any future development of BIM governance solutions;

- Identified and categorised key important requirements for developing the Cloud-based BIM governance platform BIM experts;
 - Investigated the collaboration process through observation and by using several BPMN diagrams to describe the internal and external business processes required to set-up, configure, manage, and use the GovernBIM platform, i.e. a GovernBIM platform lifecycle;
 - Translated the collected requirements and factors into several UML Use Cases diagrams that describe the functionalities of GovernBIM platforms;
 - Developed a GovernBIM platform UML Class diagram to describe the internal structure of a GovernBIM platform, i.e. a BIM governance model; and
 - Developed a GovernBIM platform software architecture based on Service Oriented Architecture (SOA) combined with a Model-View-Controller (MVC) pattern.
- Implemented a GovernBIM platform prototype over a selected Cloud infrastructure, and tested and validated the potential role of Cloud technologies towards supporting BIM governance solutions.
 - Supplied an open source GovernBIM platform and Java-based APIs for Cloud-BIM developers, to extend research and develop a GovernBIM platform.
 - Proposed a road map for future research and development of a Cloud-based BIM governance platform.

1.9 Structure of the thesis

- **Chapter 2 - Literature review:** this chapter presents an in-depth, critical, literature review for this study. The literature selection is based on the overall aims of the thesis, as outlined above, and reviews the relevant aspects of BIM, its benefits and adoption barriers, Collaborative BIM, BIM governance, Cloud Computing, and Cloud efforts in BIM.
- **Chapter 3 - Research methodology:** this chapter includes a review of the research principles, describes the derivation of the research questions for the thesis, and the chosen methodology, including the methods and survey instruments developed to collect the necessary data.

- **Chapter 4 - BIM experts' consultation for developing BIM governance solution:** this chapter presents the outcomes of the consultation stage, which employed a comprehensive questionnaire and semi-structured interviews. It highlights current barriers to BIM adoption, current ICT and collaboration practices within typical construction projects, the role of distributed environments in addressing existing issues with the data generated. Moreover, it discusses BIM experts' opinions about BIM governance research, presenting in depth results and analysis, based on the semi-structured interviews conducted. Furthermore, it presents the BIM experts' requirements for any Cloud-based BIM governance solution. Finally, it presents the proposal for a theoretically effective BIM governance framework (G-BIM).
- **Chapter 5 - Cloud-based BIM governance platform's technical requirements and specifications:** this chapter presents the outcomes of the BPMN and UML modelling approach when analysing the collaborative BIM processes involved in a collaboration environment within three BIM-leading construction companies. This is followed by the resultant BPMN diagrams for the GovernBIM platform's lifecycle. Several use cases are presented to describe the functionalities of the GovernBIM platform. A UML class diagram presents the core BIM governance model providing the internal data structure of the GovernBIM platform. Finally, a well-structured GovernBIM platform architecture for practical implementation.
- **Chapter 6 - Cloud-based BIM governance platform implementation and validation:** this chapter draws together the key elements from the literature review, the research context, and the results analysis to determine the themes required for the developed BIM governance model, and its implementation on Cloud storage, as proposed by the researcher, providing the theoretical foundation for the discussion itself. Moreover, this chapter presents the results of the GovernBIM platform prototype development stage, and proposes further recommendations to improve on current research and development.
- **Chapter 7 - Conclusion:** this chapter concludes the thesis. It includes: highlighting activities undertaken in this research, followed by a section addressing the answers to the research questions, study achievements and key findings, the limitations of the research, and recommendations for future research.

There are several appendices for reference, and these contain copies of the questionnaire, a semi-structured interview guide, GovernBIM platform screenshots, platform's Java-based

APIs code structure, validation guide, and skills & achievements certificates. Figure 1.3 illustrate this thesis structure.

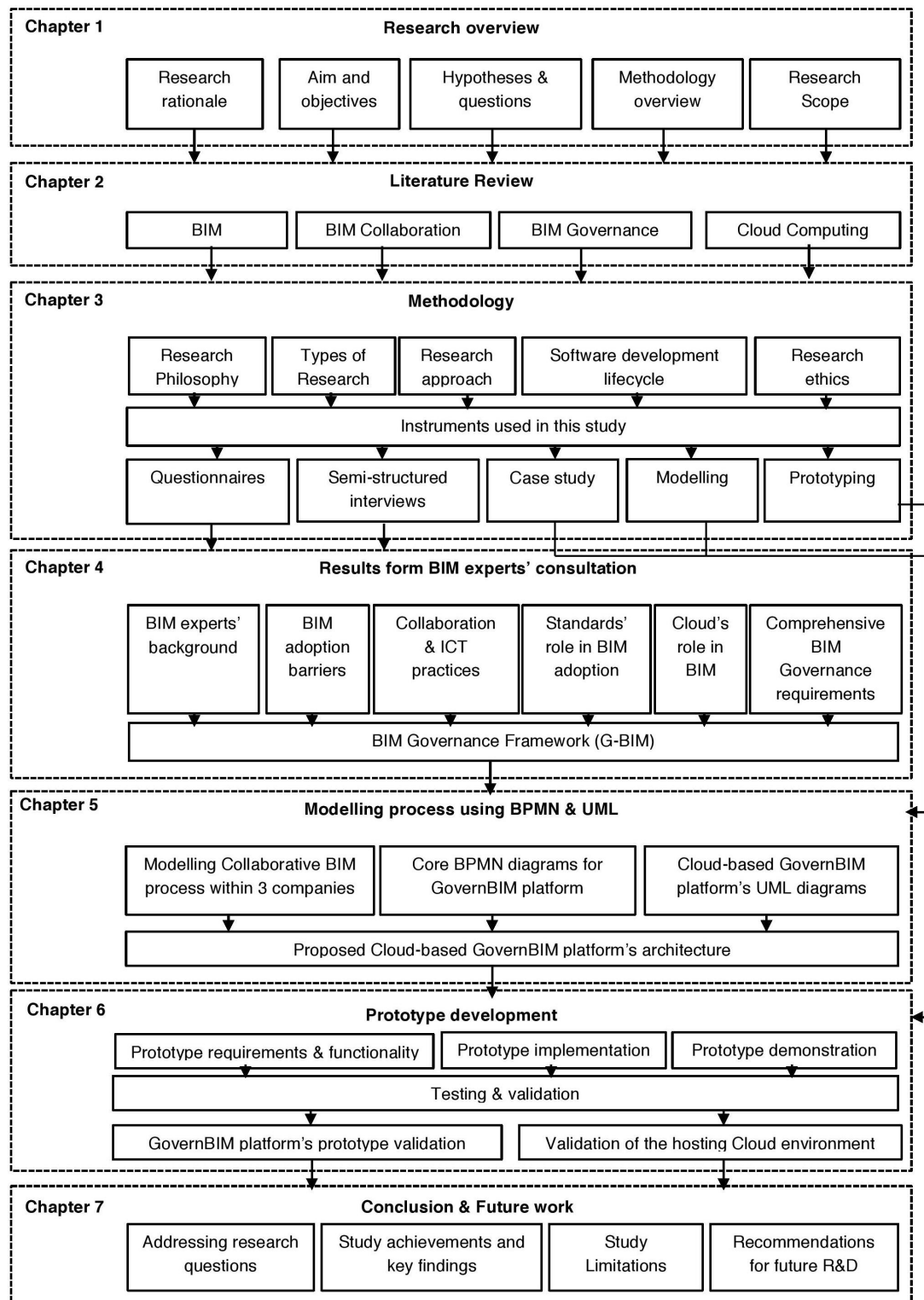


Figure 1.3: Ph.D. thesis structure

1.10 Summary

The construction industry is highly regulated and fragmented. The lifecycle of a construction project not only involves collaboration between team members, but also contains intensive activities between those members. This results in many issues, e.g. massive amounts of data, data accessibility, trust, and legal disputes. The use of BIM as a collaborative approach has contributed positively and partially toward solving some of these issues. There are already BIM-based solutions to help manage collaborative environments, however, their internal and external data management and governance policies follow the developing company's design and policies. Furthermore, Cloud Computing has become key substance to innovative solutions in BIM research and development because of the many features it offers. This highlights the importance of utilising Cloud technologies to underpin and host the development of a BIM governance solution. There are a limited number of studies on BIM governance and its implementation on Cloud infrastructure, however, this study aims to explore additional aspects related to developing a Cloud-based BIM governance solution with a specific focus on BIM experts' requirements, the external and internal process of a Cloud-based BIM governance platform's lifecycle, and the technical implementation architecture of such a platform.

2.1 Introduction

This chapter begins by investigating the concept of BIM, its adoption levels worldwide, and related benefits, and barriers. Secondly, it highlights the current state of collaborative BIM aspects, taking into account: team collaboration, collaborative BIM frameworks, and collaborative BIM solutions. Thirdly, it explores BIM governance areas with respect to: existing data governance frameworks, Cloud specific governance frameworks, and the previous efforts resulting from Governing BIM in the construction domain. Finally, it examines Cloud computing definitions, important concepts, and infrastructure, providing an overview of famous Cloud providers, emphasising the benefits and drawbacks of utilising Cloud in BIM technology development, and underlining the significant efforts towards adoption of Cloud technologies in BIM research and development.

2.2 Building Information Modelling (BIM)

BIM, as a concept, has existed since the 1970s (Eastman, 1974, Eastman et al., 2011), but as a term Building Information Model first appeared in a paper prepared by Nederveen et al. (Van Nederveen and Tolman, 1992). However, the terms Building Information Model and Building Information Modelling (including the acronym “BIM”) were not in common use until Autodesk released a white paper entitled “Building Information Modelling” in 2002 (AutoDesk, 2002). A number of BIM definitions have been reported. According to the National BIM Standard (NBIMS) (NBIMS, 2007) BIM is:

“[A] digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward. A basic premise of BIM is collaboration by different stake-

holders at different phases of the lifecycle of a facility to insert, extract, update, or modify information in the BIM process to support and reflect the roles of that stakeholder. The BIM is a shared digital representation founded on open standards for interoperability.”

Azhar et al. (2007) offer the following definition for the purpose of comparison, stating that:

“BIM is concerned with the development and use of a computer-generated model to simulate the planning, design construction and the operation of a building. The resulting model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility from which views and data appropriate to various users’ needs can be extracted and analysed to generate information that can be used to make decisions and to improve the process of delivering the facility.”

BuildingSmart (2012) defines BIM:

“[A]s a new approach to being able to describe and display the information required for the design, construction and operation of constructed facilities. It is able to bring together the different threads of information used in construction into a single operating environment thus reducing, and often eliminating, the need for the many different types of paper document currently in use. To use BIM effectively however, and for the benefits of its use to be released, the quality of communication between the different participants in the construction process needs to be improved.”

Another accepted definition of BIM is

“[A] digital representation of physical and functional characteristics of a facility. As such, it serves as shared resources for information about a facility and forms a reliable basis for decisions during its lifecycle from inception onward. BIM also refers broadly to the creation and use of digital models and related collaborative processes between companies to leverage the value of the models.” (McGraw-Hill Construction, 2010)

According to the latest NBS Report (NBS, 2013), 74% (out of the 1350 participants reported on) of workers in the UK construction industry stated that the term BIM is not sufficiently clear. Some practitioners understood BIM to be a software application, whereas others see it as a process for designing and documenting building information.

However, others see it as a completely new approach to practice, arguing that the profession requires the implementation of new policies, contracts and new relationships to support the connection between stakeholders in a project (Aranda-Mena et al., 2009).

In this research BIM will be used to refer to the process of generating and managing data and information about a building, throughout its entire lifecycle from concept design to decommissioning (Howard and Bjrk, 2008). Moreover, this research examines BIM as a collaborative management solution. Thus, the most suitable definition as understood in the context of this research is that taken from the information technology and computer science perspective, which holds that BIM is the process of gathering, managing and modelling information about a building during its lifecycle, based upon consideration of a range of different aspects, including supply-chain needs and the building's lifecycle (Rezgui et al., 2013).

2.2.1 Worldwide BIM adoption

The enormous benefits of BIM, have inspired many countries to adopt and use it. This section explains BIM adoption levels within different countries worldwide, showing the variation in BIM adoption levels, followed by BIM adoption maturity levels, highlighting current levels of BIM adoption. This is concluded by a summary with regard to the relationship between levels of BIM adoption, and the issues raised during the adoption process.

BIM adoption in European countries. A European survey conducted by (McGraw-Hill, 2010) revealed that BIM adoption in Europe was nearly 36%. The levels of BIM Adoption in the UK, France and Germany were 35%, 38% and 36% respectively (Sawhney, 2014). In the UK, the government started push the construction industry towards BIM adoption in early 2010, setting a target to adopting BIM as a collaborative approach by 2016 (BIMTaskGroup, 2011). This initiative was intended primarily to satisfy the UK Government Construction Client Group's demand to reduce capital costs and the carbon burden generated by the construction and operation of the built environment by 20% (McGraw-Hill, 2014a). In 2013, the NBS National BIM conducted a survey targeting construction practitioners around the UK. Nearly 1350 professionals and organisations from different disciplines participated in this survey. Nearly 71% of respondents agreed that BIM is the 'future of project information' and 39% confirmed that they were already using BIM. Nonetheless, fewer than half of all respondents were aware of the different implementation levels of BIM. There is a lack of clarity surrounding BIM, with 74% of individuals agreeing that 'the industry is not clear enough on what BIM is yet'. Just

one-third of those who are clear about BIM reported being *very* or *quite* confident in their BIM knowledge and skills. However, in the case of BIM adopters, more than half believed that BIM had resulted in greater cost efficiencies, whilst nearly three-quarters reported that BIM had increased the level of coordination over construction documents (NBS, 2013).

BIM adoption in Finland dates to 2002. According to Henttinen (2012), total adoption of BIM in Finland is nearly 20-30%. Within the public sector, the level of BIM adoption in projects is about 20%, but their future intentions range to 50%. However, BIM adoption is below 10% in the private sector, largely because few clients are interested in adopting it. Moreover, large construction companies report a level of BIM adoption of 40-50%, whilst small construction companies are, in many cases, totally unfamiliar with BIM. As reported by (McGraw-Hill, 2010), in France the BIM adoption rate has reached 38%. Unlike the UK and Germany, engineers 44% are marginally ahead of architects 40% with regard to BIM usage and adoption. Nevertheless, architects in France began to move toward BIM adoption earlier, with 51% having 5 or more years of experience, compared to 37% of engineers. A very high percentage of French adopters 72% use BIM for 30% or more of their projects. Architects are leading the heavy adoption of BIM 83%. Contractors are among those least likely to use BIM, with only 26% using it for 30% or more of their projects. Nevertheless, this level is expected to rise to 50% in the near future.

In the same report, (McGraw-Hill, 2010) revealed low level BIM adoption in Germany, with adoption being led by architects 43%, followed by engineers 33% and contractors 24%. However, in a small variance from the other surveyed countries, 23% of German adopters began using BIM over 3 years ago, with the majority of BIM users in Germany 51% having adopted BIM in the last 3 years only. German BIM adopters as a group use BIM 47% for 30% or more of their projects. These projects are led by architects, and nearly 77% then involve engineers 53%. Contractors are adopting BIM for 10% in 30% or more of their projects. Nonetheless, as with the other countries surveyed, heavier BIM adoption is predicted.

BIM adoption in North America. The USA appears to be the leader in terms of global usage of BIM (Sawhney, 2014). In the USA, the General Services Administration (GSA), which pioneered BIM adoption for public sector projects, has developed a suite of BIM guidelines and standards, believed by many to have resulted in over 70% of the projects in the USA adopting BIM (Sawhney, 2014). According to (McGraw-Hill, 2012), Levels of BIM Adoption in North American industry increased from 28% in 2007 to 71%

in 2012. Contractors 74% have surpassed architects 70% and engineers 67% in their use of the tool. Although the western US still leads at 77%, the formerly lagging North-eastern US jumped from 38% in 2009 to 66% in 2012. Other US regions and Canada remain close to the growing national average. However, nearly 90% of large and medium-to-large organisations are adopting and using BIM, compared to 49% small ones. Nevertheless, although there are fewer non-BIM users, many of those are increasing their resistance; this is especially true of architects, 38% of whom say they will not use BIM.

BIM adoption in Asia. BIM adoption in China's construction industry remains limited despite the size of the industry in China, although it has gained popularity since 2008 (Liu and Zhang, 2014). In Hong Kong, the Housing Authority set an ambitious target to use BIM for all of its new projects by the end of 2014. The authority developed a set of modelling standards and guidelines to inform effective model creation, management and communication among BIM users to support this initiative (Sawhney, 2014). Liu and Zhang (2014) survey found that 73% of their respondents, drawn from within China's construction industry, had never adopted BIM, and only 22% of considered themselves to be familiar or very familiar with BIM software. The findings reported in their survey revealed that in some projects where BIM was trialled, it was later abandoned because of lack of familiarity with BIM (i.e. the participants had insufficient knowledge of BIM). It also identified lack of management level commitment as responsible for low BIM adoption rates. Where it was used in construction projects, this was commonly at the preliminary design stage, the detailed design stage, and the construction stage. Few projects used BIM at the planning stage, or during the operation and maintenance stages (Liu and Zhang, 2014).

In the Middle East, a survey conducted in 2011 by (Sharif, 2011), found that 80% of respondents in the construction sector were aware of BIM technology. However, 54% of respondents identified themselves as non-BIM users, despite previous exposure, and in some cases even training. Of those utilising BIM, 25% described themselves as engaged in 'beginner level' deployment of BIM for visualisation, and as ill-equipped to use it for advanced BIM processes. Consultants and contractors were more interested in adopting BIM than other group. Furthermore, developers were among the highest percentage of BIM users within their sector.

With regard to BIM adoption in India, a study conducted by (Sawhney, 2014) showed that 22% of respondents are currently using BIM, and 27% of respondents are aware of, and actively considering, BIM usage. Remarkably, 43% of respondents claimed to

be aware of BIM were not sure about how to implement it within their organisations. Furthermore, 8% of respondents were not aware of BIM. According to (McGraw-Hill, 2014a), the overall level of BIM adoption in South Korea stands at 48%. The Public Procurement Service in South Korea has mandated compulsory use of BIM for all private sector projects over US\$ 40 million, and for all public sector projects by 2016. The same report demonstrates that South Korean contractors have shown a 65% BIM adoption rate overall.

Singapore adopted and implemented the world's first BIM-based rapid building information system (McGraw-Hill, 2014a). The Building and Construction Authority (BCA) led a multi-agency effort in 2008 to implement "e-submission", a model-based submission system (McGraw-Hill, 2014a). The e-submission system streamlines the process for regulatory submission; project teams only need to submit one BIM, which contains all the information necessary to meet the requirements of Singapore's regulatory agencies (McGraw-Hill, 2014a). In 2010, architectural 3D models were accepted for approval via e-submission by nine regulatory agencies. In the following year (2011), Mechanical, Electrical and Plumbing (MEP) and structural BIM models were accepted via e-submission. The number of projects accepted for approval via e-submission is close to 200 (McGraw-Hill, 2014a). Singapore has also put in place a plan to fund BIM adoption, with a budget of US\$ 20 million for BIM and related technologies, to benefit the Singaporean construction sector (McGraw-Hill, 2014a).

BIM adoption in Australia and New Zealand. A recent survey conducted by (McGraw-Hill, 2014b) revealed the level of BIM adoption in Australia and New Zealand. It showed that the majority of organisations in Australia use BIM. Nearly half of BIM users have been engaged with BIM for more than 3 years, and the majority of BIM users foresee a strong increase in BIM adoption and implementation. Nearly 51% of BIM users are adopting BIM for more than 30% of their projects. This is predicted to rise to three-quarters 74% of users by 2015. Design professionals are guiding contractors as users, with 61% currently using BIM for 30% or more of their work. Above half 56% of all design professionals are anticipated to be very heavy users of BIM in two years' time.

Although many countries are adopting BIM, there remains a need for a global collaboration in BIM research and development, in order to fully make use of BIM, and to tackle BIM adoption obstacles. A common issue among BIM adopting countries is effective collaboration between team members; e.g. ownership, IPRs, and data loss. However, as it would be impossible to collectively manage the entire process of team collabora-

tion during a construction project, this governance model divides the process into stages. Beside the issue of fragmentation, different data formats are exchanged, processed and distributed among team members. However, this data changes regularly; e.g. drawings are redrawn, quantities are recounted, and so on, leading to a decline in workflow productivity. Therefore, the ultimate objective of a BIM governance solution is to enhance early coordination and communication among team members, as well as to improve collaboration between team members, by allowing them to share and exchange their data across a secure, outsourced, data governance platform. This solution will guarantee that data ownership and IPR are tracked, checked, and preserved throughout the entire collaboration process during a construction project, thereby allowing shared data to be available, consistent and reliable.

2.2.2 BIM maturity levels

Due to the various concepts and adoption levels of BIM, a model was devised for BIM maturity by the (BIMTaskGroup, 2011), to clarify expected levels of efficiency, and supporting standards and guidance notes, and their relationship with each other, concerning how they can be applied to projects and contracts within the industry (BIMTaskGroup, 2011). The purpose of determining these levels from 0 to 3 types is to categories technical and collaborative work, to enable a brief understanding and description of BIM, as well as an understanding of the BIM processes, tools, and techniques. In essence, it aims to demystify the term “BIM”, to make its identification a clear and transparent component of the supply chain, enabling the client to understand the offer of the supply chain (BIMTaskGroup, 2011). However, production of this indicator maturity recognises that different client and building their organisation currently supply on a different level is approaching to BIM and a structured learning development over a period of time. Figure 2.1 illustrates BIM maturity levels (Howard and Bjrk, 2008).

- **Level 0:** building data in 2D Computer-Aided Drawing (CAD) or perhaps unmanaged, with paper (or electronic paper) as a mechanism likely to exchange data.
- **Level 1:** building data is managed in 2D CAD in 3D enabled virtual environment. The coordination process is done on the basis of the BS1192: 2007 standard (BSI, 2007), providing a shared data environment, and some standard data structures and shapes. Trade data is managed by independent finance, and cost management packages, with no integration.
- **Level 2:** At this level, the building data is managed in a 3D enabled virtual environment, while allowing connections (e.g. relational) to other sources of discipline-

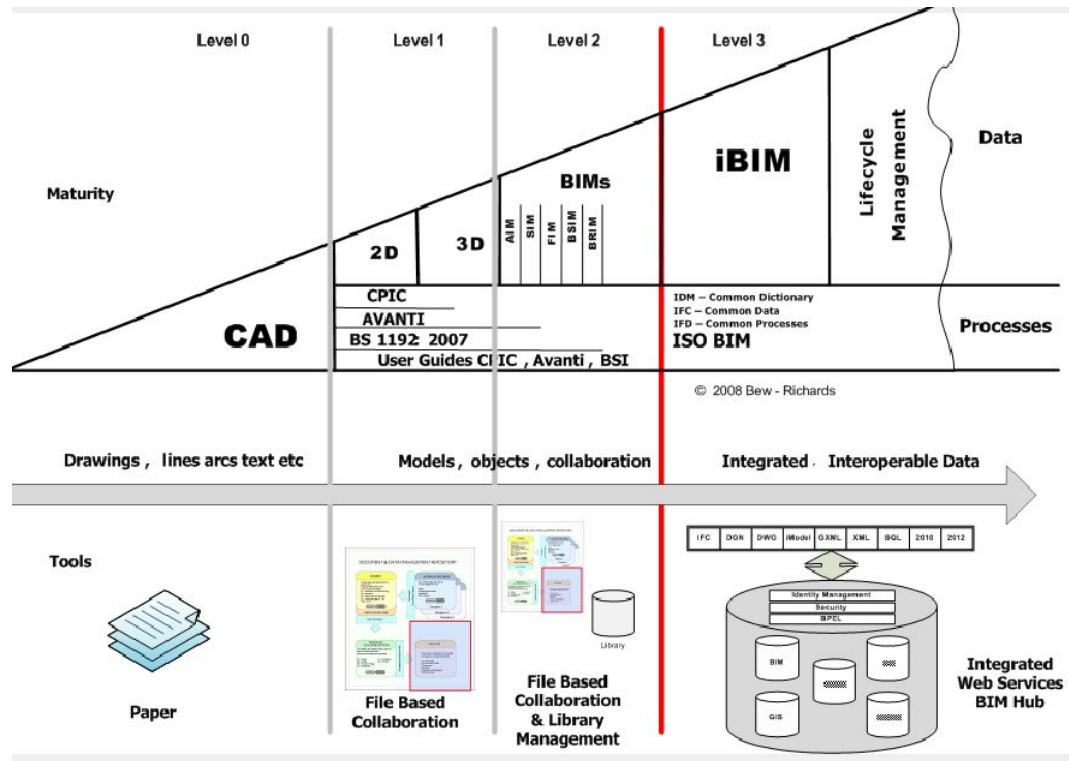


Figure 2.1: The maturity levels model for BIM (Bew and Richard, BIMTaskGroup, (2011))

centric data such as Enterprise Resource Planning (ERP). The integration of heterogeneous (i.e. building and related) data at level 2 is based on the concept of “properties” or “interfaces”, as denoted by the label “iBIM” in Figure 2.1. Examples of related data can be time taken for construction stages (e.g. 4D) and cost of construction elements (e.g. 5D).

- **Level 3:** At this level, the process is based on open widely accepted standards and enables building data integration using Web services, as emerged with the BuildingSmart Standards, e.g. Industry Foundation Classes (IFC), managed in a collaborative model in the form of a server. This level could be referred to as iBIM (or integrated BIM), and it has the potential to employ concurrent engineering processes.

The level of BIM adoption’s construction industry is approximately between level 1 and 2, evidence of which can be found in the literature (buildingSMARTUK, 2014). However, to move forwards toward adopting BIM at level 3, socio-organisational, legal, technical and contractual aspects need to be developed further.

2.2.3 BIM applications and BIM products

There is a difference between BIM and CAD. For example, people who are critical of CAD design state that it is a time-consuming process, involving boring, inaccurate or inconsistent information, with the attendant difficulty of collaboration among professionals such as designers, engineers etc. Often it is very expensive to address any conflicts detected during construction. However, according to BIM advocates, BIM averts the majority of CAD problems, since it does not involve designs based on geometric concepts. Furthermore, it delivers a means to understand the relationship between the components of building design, making it possible to view the BIM model not only in 2D or 3D, but by allowing the enhancement or elimination of inconsistent design or engineering concepts (Rosenberg, 2006). Many BIM products are available, such as Autodesk Revit packages, Bentley systems packages, and Graphisoft packages. Each of these provides a different building models from which to propose a building design (Rosenberg, 2006). CAD transformed the design landscape, and BIM is now seen to have a huge impact on the design landscape.

However, BIM enabled software offer a diverse range of applications, including but not limited to: low-cost 3D visualisation; fabrication or shop drawings; code reviews, such as used by fire departments for their review of building projects; forensic analysis; facilities management; cost estimating; construction sequencing; or conflict, interference and collision detection (Azhar et al., 2007). Nonetheless, the following areas are the main areas of BIM application and usage:

- **Modelling and design:** Despite the potential for enhancing process efficiency in collaborative setting, BIM models can assist the conventional design process. BIM software helps to reduce the cost of preparing 2D drawings for a traditional project, especially when designs are constantly subject to alteration. Working with data rich elements, rather than drawn objects, accelerates the production of contract drawings. BIM modelling ensures that the parties working from a model share the same source. Under existing practice, few individuals are working directly from a model. However, where team members are employing BIM based software, the partial elements of a BIM model can be transferred, imported, or exported from a source model (Ashcraft, 2008).
- **Visualisation:** Since it is primarily a 3D process, BIM models are schemes for assessing different approaches e.g. capability to assess how alterations affect essential attributes, energy use, enhance the model's usability as a thinking tool. Nevertheless, the software interface can interfere with the innovating design process (Kivits

and Furneaux, 2013).

- **Clash detection:** Construction projects are inherently complex projects, conflict recognition and resolution is an extremely expensive, as well as a daunting task. Designers usually do not have resource (time and money) to discover and fix all conflicts. Clash detection and conflict identification is done manually, as follows. Thus, in a complete project, total coordination cannot be achieved throughout the design stage, because the contractor would probably subsequently amend crucial systems; for instance, Heating, Ventilation, & Air Conditioning (HVAC) might not be incorporated into design drawings. Thereafter, construction details and layouts may require information about equipment that might be installed on-site. These missing details are normally resolved by warning contractors that the design is ‘diagrammatic’, and coordination is needed (Ashcraft, 2008). Normally, the contractor manually coordinates paper-based drawings from different disciplines, laying them on light tables to determine if various drawings can actually be constructed in the allocated spaces. Here, the drawings for each discipline are merged and printed as colour-coded overlapping drawings. This process will allow the team to identify clashes and conflicts, and bring them to the designer’s attention to request solutions and clarifications (Ashcraft, 2008). However, applying a 2D process to 3D problems creates a potential for human error. Therefore, conflicts are the main source of contractor claims (Khoshnava et al., 2012). The use of BIM modelling tools, e.g. Autodesk Revit and NavisWorks have significantly minimised clashes and conflict, by integrating all the major systems (architectural, structural, and MEP) into a single model. BIM authoring tools have the functionality to detect internal conflicts in a BIM model, and to highlight conflicts between the models and view relevant information allowing the user to propose a solution. This is an effective mechanism, especially in projects (Ashcraft, 2008).
- **Team Collaboration:** Another aspect of BIM involves facilitating team collaboration by allowing a collaboration process based on integrated models. BIM improves the design and engineering collaborative process, and provides coordinated information, via integrated databases, to all actors involved in the process of designing and engineering buildings (Kivits and Furneaux, 2013). In addition to graphically visualising a project, BIM provides key information about the building, which can be used to analyse its performance. Thus, utilising coordinated, consistent, computable information and results in a reliable, digital representation of a building, which can be used throughout the design decision making process, ensuring the creation of contract documents, planning, and building performance. Moreover, BIM

allows information to be kept up to date, and accessed by Architecture, Engineering and Construction (AEC) professionals among others (Barlish and Sullivan, 2012).

- **Facility management (FM):** Facility managers need to provide consistent and reliable data on the operational aspects of a building or facility for administrative management and planning. There is an identified gap in the quality of information available for facility management. Evidence suggests that adopting BIM can enhance the quality of information through standardisation (Sabol, 2008). Although data systems and services with a wide range exist, targeting needs in the facilities area, no one fits all FM applications, because FM practices differ widely in their requirements (Sabol, 2008). To support its tasks and assets, FM mainly relies on data-centric applications for information. Thus, because the information is not graphical, FM applications are not smooth facilitators of change management, requiring large and tedious synchronisation process when building configurations, and associated data attribute changes (Sabol, 2008). However, BIM as an emerging technology is poised to offer a new level of functionality for the FM of buildings. It provides an integrated digital repository for building components; as well as offering an integrated 3D model it has the ability to clearly display views typically not shown in standard 2D building drawings (Sabol, 2008).
- **Cost estimation:** Using BIM during a construction project enables prediction of the total cost of each stage in the planned project phase, as it makes it possible to establish the budget areas, especially in the early phases of a project (Mohandesa et al., 2014). BIM models contain the necessary information to generate bills with respect to: quantity, size and area estimates, productivity, materials cost, and other cost categories. They eliminate the manual calculation of initial material, thus reducing human error and misunderstanding (Ashcraft, 2008). The ability to use BIM information to directly create drawings for fabrication avoids problems and eliminates errors that effect the traditional workflow of the construction project process (Kivits and Furneaux, 2013).

However, with the amount of information delivered, the importance of different formats is growing, because BIM aims to provide integrated documentation for the entire project. This means that it might not be sufficient for a single vendor to develop BIM tools with the capability of supporting the various requirements from collaborating disciplines. Thus, BIM tools and applications need to have the capability to support the data generated for the sake of facilitating BIM technology adoption in the AEC industry (Hooper and Ekholm, 2010). Although a variety of BIM applications already exist, there are still major shortcomings for potential users. The majority of the developed systems are re-

search prototypes and demonstrator-based, and have only been evaluated in small field trials with a limited scope for usage (Fathi et al., 2012).

Primarily, two types of software products are used in the construction industry; design and management. Different disciplines expect BIM to function as an extension of their software. For example; design disciplines expect BIM to be an extension of Computer Aided Design (CAD), while project managers and contractors expect BIM to function as an intelligent Data Management System (DMS) capable of extracting data from CAD Designs to perform analyses, time sequencing and cash flow modelling, as well as planning risk scenarios (Gu and London, 2010). Although there is a clear overlap, BIM application vendors are striving to integrate two separate requirements. According to Gu and London (2010) current BIM applications are not sufficiently mature to fit either purpose. Practitioners, such as designers with CAD backgrounds, expect BIM to assist in navigation, offering an integrated visualisation of the current applications they use. On the other hand, project managers and contractors, with a DMS background, are expecting BIM to be a more intelligent DMS that can extract data straight from CAD packages for analysis, time sequence and cash flow modelling & simulation as well as risk scenario planning. It is interesting that the majority of current studies have emphasised BIM as an improvement to CAD, downplaying the document management aspects (Gu and London, 2010).

2.2.4 BIM benefits and barriers to adoption

Although, the use of BIM has significant benefits, which have been reported in several construction projects, the possibility of its adoption and implementation in the construction industry faces several issues and barriers.

Benefit of BIM

It is possible to achieve benefits by adopting BIM in the AEC industry. It is possible to gain full support for the production of construction documents, so that another drafting application need not be used. It uses smart objects, maintaining associativity, connectivity, and relationships with other objectives. Several benefits of BIM identified by Azhar et al. (2007) are: (a) the availability of a BIM objects library; (b) the ability to support distributed work processes, with multiple team members working on the same project; (c) quality of help and supporting documentation, tutorials, and other learning resources; (d) ability to work on large projects; (e) multi-disciplinary capability serving as architecture, structural engineering, and MEP; (f) an ability to support preliminary conceptual design

modelling; (g) direct integration with energy analysis, structural analysis and project management applications; and (h) compatibility with industry foundation classes (IFC). Furthermore, there are other advantages of BIM, as highlighted by Ashcraft (2008), including: (a) multiple use for single data entry; (b) efficiency in design; (c) design bases consistency; (d) conflict resolution and 3D modelling; (e) estimating and takes-offs; (f) fabrication and shop drawing; (g) identification of conflicts; (h) alternative solutions and option visualisation; (i) energy optimisation; (J) 4D simulations and constructability reviews; (k) costing errors and fabrication reduction; (l) facility management; and (m) functional simulation.

Hooper and Ekholm (2010) revealed that some BIM benefits can be summarised as follows: BIM, in a given project, allows integration of all related documents and data generated and required by different disciplines. It also allows immediate control and distributed access to data, simplifying the updating, maintenance and retrieval of data over the course of long-term programming. It simplifies utilisation of resources by reducing the need for repeated work and avoiding duplication. At any stage of the project development, it permits automatic extraction and processing of data involving dedicated efforts, such as cost, area, etc. Moreover, it allows for an easier transition for different representations of the same data improving visualisation and build ability. It reduces and facilitates conflicts and coordination errors, and offers the ability to analyse and visualise product performance over a building's lifecycle, with potential to facilitate the legal and regulatory processes. Finally, it allows the development of content for electronic building objects, by linking them to manufacturers' websites.

In addition, the current research and development in BIM for the integration and visualisation of information reduces the duplication of work and interface complexity, saving both time and cost. Nowadays, BIM capabilities for information integration, visualisation and parametric design aids reduces the duplication of work and interface integration complexity, which has a positive effect on the construction project, saving on both time and cost (Chuang et al., 2011).

BIM adoption issues and barriers

Although the construction industry is moving towards the adoption of BIM, because of its many features and most specifically implications for cost reduction, there remain many barriers and challenges that are slowing the adoption of BIM in the construction industry. The fragmented nature of the AEC industry is the main challenge to BIM adoption in the construction industry (Johnson et al., 2003, Eastman et al., 2011).

A recent study into the adoption of BIM has revealed that the architects by 43% are the group most aware of the importance of BIM (Hill 2010). Only a fifth 20% of engineers or contractors are as well informed as architects. Notwithstanding, there is a general feeling that BIM adoption is much slower than anticipated because of both technical and management issues (Azhar et al., 2007). Gu and London (2010) reported that several factors affect BIM adoption and noted that these can be categorised into two main areas: (i) technical tools and functional requirements and needs, and (ii) non-technical strategic issues. There is a need for guidance on where to start, what tools are available, and, how to work through legal, procurement and cultural challenges. These challenges were evidenced in an exploratory study conducted by Gu and London (2010). As they have subsequently developed and presented their collaborative BIM decision framework based upon industry concerns. However, limitations to this collaborative BIM decision framework research study are acknowledged here, most particularly as a consequence of the need to test any decision framework via case studies of projects (Singh et al., 2011).

Barriers to BIM adoption include: technical problems (compatibility and reliability), fragmentation of project teams, change resistance, shortage in training, and issues related the business processes (Howard and Bjrk, 2008). In addition, the legal, contractual and overall organisational implications of BIM can be problematic (Chao-Duivis, 2009). Furthermore, Ashcraft (2008) classifies the barriers to BIM adoption into three main categories: (i) Commercial, i.e. immediate benefits do not accrue to the key adopter (Designer) and there is an absence of standard BIM contract documents, (ii) Legal concerns, i.e. issues inherent with BIM (CAD on steroids) and issues arising from How BIM Is Used, BIM as a Collaborative Framework, and (iii) technical issues i.e. standards, interoperability, and archiving. Azhar et al. (2007) classifies the issues as: technical issues, BIM usage and implementation management issues, and BIM risks.

There is an agreement that technical and socio-organisational aspects should accompany BIM development efforts (Rezgui and Miles, 2011). However, there is no general agreement about the owners of BIM models, or regarding who should take responsibility for the financing and the maintenance of models over the project lifecycle (Eastman et al., 2011, Rezgui et al., 2013). There are also socio-organisational, legal and technical issues (Rezgui Y et al., 2012) affecting BIM, and solving them is crucial, to ensure widespread and successful adoption of BIM and related technologies in the industry. These issues will be explained in more detail in the following paragraphs.

In terms of socio-organisational issues, in the construction industry there is a strong culture of reliance on paper-based legally binding documents (including technical drawings) (Grilo and Jardim-Goncalves, 2010). The integration of a building lifecycle in BIM has been hindered by the separation between design and construction activities along with some procurement pathways. The hegemony of small and medium-sized companies in different parts of the lifecycle, especially during the construction phase involves a limited process, technical maturity and abilities. Investment limitations in ICT because of tight margins on project financials (Rezgui et al., 2013). Rethinking and mapping of project authorities, responsibilities and financial arrangements is linked to virtual buildings, and should be involved in BIM rather than frozen paper-based documents. Traditional procurement routes delay cooperative work across the supply chain from the design concept stage, preventing early stakeholder involvement in the design process because of financial arrangement, for example, the assessment of contractors when selecting products and materials (Grilo and Jardim-Goncalves, 2011). The additional costs when adopting a BIM approach are variously covered by clients or shared across stakeholders (Bryde et al., 2013).

With regard to legal issues, it is often unclear who owns and has responsibility for BIM (Das et al., 2015). Both IFC data and IFC-based servers carry no contractual or legal obligations. Most importantly they are lack of specification documents and contractual drawings (Rezgui et al., 2013). The current BIM approach does not involve legal responsibilities in the case of incomplete or wrong information, when it comes to dispute resolution (Kim et al., 2013). At present, procurement routes are not adopted by BIM, nor are main issues relating to intellectual property rights. Stakeholders' roles, responsibilities and authorities are not embedded in BIM, but can be reflected in the rigorous access controls on data, which opens the way to accidental and unwanted changes (Beach et al., 2013).

Finally, technical issues are among the most significant barriers, as various IFC products lack compatibility (Kiviniemi et al., 2008). During the import/export of IFC, there was a loss of semantics between different IFC-based packages (Sacks, 2010). BIM experiences data fragmentation across the design and engineering teams, and contractors and facility managers. Information is continuously at risk of being lost because of company mergers, and bankruptcy, as well as being poorly sustained across a project's lifecycle (Wu, 2013). Commercial and proprietary solutions address the access controls to data. Such solutions are incompatible and fail to embed the process dimension and project procurement pathway (Beach et al., 2013). BIM data security is an issue even when BIM data is stored on

a BIM server, because it is controlled and managed by a single company (or possibly in a best case scenario, outsourced to a datacentre) (Jiang et al.). There are cost/overheads affecting networks and communications when using virtualised storage (i.e. internally virtualised) for hosting big sizes of BIM models. Privacy restrictions relate to using virtualised storage to store sensitive data, and are classified as data integrity support, user authentication support, data security support and access control support (Redmond et al., 2012).

BIM model ownership challenges have been addressed by the American Institute of Architects (AIA, 2007), and additional legal measures and agreements can ensure data security and confidence in the partnering-team that is applicable to varied industry needs. However, recent research shows the presence of challenges inhibiting BIM implementation in UK construction practice (Mihindu and Arayici, 2008, Eastman et al., 2011). These challenges include: getting people to understand the value of BIM in order to overcome their resistance to change; taking on new workflow processes applying lean oriented processes; finding people who understand BIM; training people in BIM; understanding hardware infrastructure and networking facilities, to effectively run BIM applications and tools; understanding and facilitating collaboration, integration and interoperability across the supply-chain; construction lawyers and insurers needing a clear understanding of the different responsibilities of stakeholders introduced through new processes.

Azhar et al. (2007) have suggested some potential solutions to these issues. Firstly, they propose that technical issues can refer to data interoperability issues, digital data design requirements, integration and exchange of information among BIM model elements. In order to eliminate data interoperability issues, there is a need for well-defined transactional construction process models. This sets out suitable requirements to compute digital data design. It is crucial to develop practical strategies to successfully exchange and integrate information across BIM model elements. Secondly, BIM usage and implementation management issues, which exist because there is no clear agreement on how best to implement or use BIM, because the whole process is not formally defined, means there is a need to standardise the BIM process and its implementation (Azhar et al., 2007). The current research aims to resolve these issues, potentially leading to an increase in BIM usage in the AEC industry. Formerly, managers were very limited participants in the process of planning buildings; but BIM can now allow facilities managers to become involved in the earlier stages of the building design process. BIM may also allow all stakeholders, including service agents, tenants and maintenance companies, to receive important information prior to the completion of building projects (Porwal and Hewage, 2013).

The third and final risk concerns legal issues, including the ownership of BIM data, licensing issues, and determination of who will control the entry of data into the model, and be responsible for inaccuracies, and who will take responsibility for updating BIM data and ensuring its accuracy (Howard and Bjrk, 2008). This can create a need for more time spent inputting and reviewing BIM data, which represents a new cost to the design and project administration process. The following table 2.1 provides a summary of, and categorises the barriers explored to BIM adoption. These barriers were obtained by critically reviewing the content of the most recently published of the relevant journal papers.

Table 2.1: Barriers to BIM adoption

Category	Issues	Relevant articles						
Socio-organisational	People's resistance to change	(Isikdag et al., 2007)	(Howard and Björk, 2008)	(Eastman et al., 2011)	(Singh et al., 2011)	(Barlish and Sullivan, 2012)	(Rezgui Y et al., 2012)	(Azhar et al., 2012)
	Natural fragmentation of ACE							
	Lack of education and training				X		X	
	Recognition and enforcement by owners					X		
	Immature BIM technologies						X	
Legal	Legal disputes		X		X			X
	Ownership issues		X			X		
	Business related issues				X			X
	Intellectual property related issues		X					X
	Organisational issues						X	
Financial	Data misuse		X					
	Lack of financial support							X
	Expensive cost						X	
	Document centric of data							X
Technical	Technical issues				X		X	
	Loss of data		X					
	Absence of standard BIM		X					
	Issues with contractual documents		X					
	Data translation/Interoperability issues	X	X	X	X		X	X
	Data versioning problems	X		X				
	IFC-based technologies and exchange methods are not mature	X		X			X	
	Unknown responsibility of a BIM model						X	
Process	Inconsistence data/Information	X					X	
	Workflow and process management issues	X			X			X
	Conflict management problems	X						
	Data management issues	X			X			
	Communication issues			X				X
	Coordination issues							X
	Collaboration issues				X			X

2.3 BIM Collaboration

Construction projects are intensively dependent on team collaboration (Wilkinson, 2005). Team collaboration starts with first meeting at the beginning of the construction project (Eadie et al., 2013). However, since construction involves multiple actors from multiple-disciplines during a building's lifecycle, many issues arise regarding team collaboration (Poerschke et al., 2010, Singh et al., 2011). Therefore, many efforts have targeted the collaborative aspects of the construction industry sector (Singh et al., 2011). These efforts, with the support of ICT, offer many and diverse solutions that can solve collaborative issues generated during the team collaboration process (Amarnath et al., 2011). Such issues include: ownership and IPR disputes, data loss, and data inconsistency (Wong et al., 2014). In the UK, the Government requires fully collaborative BIMs for all its public sector projects, involving all project and asset information, with documentation and data being integrated into the model as a minimum by 2016 (BIMTaskGroup, 2011). Current ICT and collaborative practices in the construction industry are heavily reliant on documents, either paper-based or electronic-based; hence, the increasing need for transformation and transition towards an integrated model centric collaboration to accomplish BIM collaboration requirements (Shafiq et al., 2013).

The general-purpose collaboration systems available (e.g. project extranets) have significantly improved documentary collaboration. Nonetheless, their abilities for BIM-based model collaboration are limited because of: (a) immaturity of collaborative technologies based on multi-model environments, (b) unstable users requirements for collaborative BIM solutions, (c) lack of users awareness regarding collaborative BIM solutions, and (d) shortage in evaluation the performance and functionalities of collaborative BIM solutions in real construction projects. Hence, they do not fully support the complex requirements of collaborative BIM (Shafiq et al., 2013). Currently, many BIM applications are available to create smart building information models, these applications have improved the quality of visualisation, coordination, and the management of project life-cycle data in the construction industry (Cerovsek, 2011). Construction practitioners use BIM tools to create BIM models for specific disciplines, e.g. architectural, structural models, etc. so, coordination is limited to visualisation and clash detection. This is no longer the case, because of the emergence of BIM collaboration systems, such as BIM model servers, with the ability to exploit and reuse straightforward information from BIM models, to move from intra-disciplinary collaboration towards multi-disciplinary collaboration (Shafiq et al., 2013).

2.3.1 Collaborative BIM frameworks

In order to facilitate BIM adoption in the construction industry, a collaborative BIM framework was raised and established (Gu and London, 2010). There were efforts made to develop several frameworks to ease implementation and adoption of collaborative BIM. (Cerovsek, 2011, Leon and Laing, 2013, Poerschke et al., 2010, Shafiq et al., 2013, Singh et al., 2011, Wu and Issa, 2013b). The following are examples of the most significant related works to this study.

Succar (2009) conducted a research and delivery foundation for industry stakeholders, using the BIM framework. It offered research in the form of a delivery foundation that maps domain dynamics and allows AECO stakeholders to understand the underlying knowledge structures to negotiate BIM implementation requirements accordingly. It is a multi-dimensional framework, and can be represented by a tri-axial knowledge model, encompassing: (a) BIM fields: represents technology, process, and technology; (b) BIM stages: delineating implementation maturity levels; (c) BIM lenses: providing the depth and breadth of enquiry necessary to identify, assess and qualify BIM fields and BIM stages.

Moreover, a collaborative BIM decision framework was initiated in Australia by Gu and London (2010), to facilitate the BIM adoption in the AEC industry. Their research resulted in a development of a collaborative BIM decision framework. The main aim of this framework was to enable industry players to relate their familiar experiences with existing collaboration tools use in their current practice to their BIM adoption. One of their framework outcomes highlighted the importance of developing methodologies and techniques that would lead to a user-centred, adaptive software system, in close cooperation with construction industry stakeholders. Industry experts stress that IT should work more closely with practitioners when developing and proposing IT solutions for the construction industry. They identified a gap between practitioners and the research community, which demotes a lack of communication and shared understanding among them. Practitioners focus on the early stages of a project, but their framework efforts extend beyond that, attempting to map users' concerns, and those of the producers and owners of models, working within an online collaborative environment that is fully integrated with a particular focus on the challenges of implementing a supporting model server (Gu and London, 2010).

Gu and London (2010) analysed the industry's readiness to adopt BIM with respect to product, processes and people; as well as, in terms of current status and expectations

across disciplines. The findings from their study indicate there is a need to consider both technical issues (e.g. interoperability issues across different commercial software) and non-technical issues (e.g. roles and responsibilities) when adopting BIM. The findings also showed there is a varying levels of BIM adoption, and therefore, that there is a need for a specific tool to facilitate BIM adoption. Gu and London (2010)'s framework comprised of four interrelated key elements. However, their framework has not been validated; in addition their work pertained to the Australian construction environment that differs from that in the UK. Moreover, understanding and facilitating the adoption of BIM in the AEC industry requires further extensive analysis to ensure ratification of BIM arguments.

Another BIM framework intended for practical implementation, was that developed by Jung and Joo (2011). Their framework incorporated BIM technologies in terms of property, relation, standards, and utilisation of practical BIM implementation across different construction business functions throughout a real-world project, and managing organisational and industry perspectives. They have identified comprehensive list of variables from their BIM framework, and discusses these according to three dimensions (BIM technology, perspective, and construction business functions), and six categories (data property, relation, standards, utilisation, perspective, and construction business function). Beside underscoring several issues for practical BIM implementation, their framework also provides a solid basis for evaluating promising areas and identifying the driving factors for practical BIM implementation effectiveness (Jung and Joo, 2011).

Porwal and Hewage (2013) proposed an approach that facilitates BIM adoption through a BIM-partnering framework, and establishes the development of a collaborative BIM model for the construction process in Canada. They described different approaches, which might help project teams to overcome technical, procedural, and organisational challenges. They claimed that BIM adoption would require changes to existing work practices, observing that a different approach to collaborative BIM development is needed in public procurement settings where owners are bound to work within procedural and legal frameworks. Organisations should also find ways to incorporate existing defined processes and protocols at different phases of their projects. In addition, they should assign responsibilities for design reviews and validations appropriately (Porwal and Hewage, 2013).

2.3.2 Requirement for BIM collaboration solutions

Main users of BIM collaboration solutions are construction practitioners, whose requirements need to be fulfilled in a new system. A number of studies have presented target

requirements for the development of collaborative BIM solutions, as follows:

Singh et al. (2011) conducted a theoretical study, with the aim of identifying requirements for developing a BIM-based multi-disciplinary collaboration platform. Their study resulted in several requirements: technical requirements for suitable collaboration on a BIM Server are as identified by Singh et al. (2011): a central model repository linked to other federated data repositories, variety of spaces for public and private models, Global Unique Identifier (GUID) for objects identification, Information Delivery Manuals (IDM)-based specifications, securing access to the model, a hierarchical structure of the model based on the requirements of the user, securely checking uploaded, downloaded, and transferred models, user interface customisation, real time collaboration via web (viewing and printing), ease of checking the properties of objects, different levels of detailed objects and sub-models.

Two years later, another study was conducted by (Shafiq et al., 2013), aiming to explore BIM collaboration requirements and the available features of existing model collaboration systems. They identified a number of functional requirements for multi-disciplinary collaboration in models, using a Common Data Environments (CDE) categorised according to following domains: model content management, model content creation, viewing & reporting, and system administration. (i) model content management requirements includes: model upload / download, support multiple data model formats, partial model exchange, model versioning, model merging, data locking, clash detection, conflict resolution, audit trail, data publishing, and workflow management. (ii) model content creation requirements include: Model modifications, 2D data modelling, data querying, reference data linking, product libraries support, model checking, rule-based modelling, model comparison, and change management. (iii) viewing and reporting requirements include: remote model viewing, 3D navigation, Mark-up, collaborative communication, report generation, FM data support, colour customisation, workflow reporting, mobile computing support. (iv) system administration domain: User profiling, access control, data handling, interface customisation, security, disaster protection, and data archiving.

To date, the majority of BIM collaboration vendors have yet to fully address practitioners' requirements, as their solutions were developed for commercial purposes where the customers' business values are the most important aspect. Moreover, this study focuses on BIM governance, and so the aforementioned requirements might not be applicable to the development of a BIM governance platform. Hence, an objective of this study is to identify relevant requirements to establish and develop an applicable Cloud-based BIM

governance solution.

2.3.3 BIM collaboration technologies and tools

A number of software products have appeared in the marketplace, with a focus on BIM collaboration. These solutions can be divided into two main categories; open source and proprietary (vendor-specific) software products. An example of an open source BIM collaboration solution is the BIM Server (Beetz et al., 2010) and EDMmodelServer (Jotne, 2015). Examples of several proprietary BIM collaboration solutions include, the Onuma system (OPS, 2014), Revit Server (Autodesk, 2011), ProjectWise (ProjectWise, 2015), and ArchiCAD BIM Server (Graphisoft, 2015). These BIM servers tend to use proprietary governance data structures, adopting either; central servers for data storage and management, accessed by all team members over WAN or local servers for data storage, and management accessed by all team members over LAN (Rezgui et al., 2011). Although there are many BIM collaboration solutions, Table 2.2 summarises the major BIM collaboration solutions currently used in the construction industry, highlighting their main features and limitations.

Broadly, nearly all major vendors for BIM collaboration solutions tend to emphasise features and functionalities due to the lack of studies concerning BIM-based collaboration solutions with a specific focus on aspects of governance. However, interoperability across multi-vendor systems, such as Bentley architecture and Autodesk Revit, is enabled by interoperability tools. This is done by supporting a 3D viewer able to render a BIM model for visualisation, alongside Industry Foundation Classes (IFC). In addition, Open Source BIM servers enable the integration of user specific schemas using the XML Schema Translation mechanism (XSLT). BIM model versioning is enabled by nearly all systems, which allow access to the current BIM model version through end user systems. In terms of data sharing, all products support IFC, and enable other data model integration, e.g. specialist XML schemas (GBXML), Comma Separated Value (CSV) and KML (Google maps/Earth). However, nearly all collaboration solutions support multi-user collaboration over hosted BIM data, as it supports a large number of users. Not all collaboration BIM servers can import/export from/to other formats, such as Google Sketchup and Autodesk. This is because most of these solutions utilise IFC-based servers, such as BIMServer (Beetz et al., 2010).

In a Horizontal Glue System (HGS) (Newton, 2011), which is web-based technology that manages the exchange of a various BIM data types with aim of eliminating compatibility issues between BIM products. In HGS, data integration is enabled using a “Glue Server”.

Table 2.2: Collaborative BIM solution overview

Collaborative BIM environment	Software Licence/ Code	Main features	Link with Cloud	Limitations	References
RevitServer (AutoDesk)	Proprietary	<ul style="list-style-type: none"> • Real-time multi-team collaboration. • Adopt local/central model concept. • Model synchronisation. • Clash detection. 	Yes	<ul style="list-style-type: none"> – High cost. – Requires IT infrastructure. – Poor workflow management. – Lack of 2D data modelling. – Poor in remote model viewing. – Poor in mobile computing support. 	(Autodesk, 2011, Shafiq et al., 2013)
BIM 360 (AutoDesk)	Proprietary	<ul style="list-style-type: none"> • Design development. • Value engineering. • Constructability reviews. • Multidisciplinary coordination. • Job site visualisation. • Collaborative project reviews. • Construction layout. 	Yes	<ul style="list-style-type: none"> – High cost. – Do not archive data. 	(AutoDesk, 2015, Shafiq et al., 2013)
ProjectWise	Proprietary	<ul style="list-style-type: none"> • Interdisciplinary teams collaboration. • Support different applications and file formats. • Data synched to the most up-to-date project information. • Facilitates access to large and interrelated files distributed geographically. 	Yes	<ul style="list-style-type: none"> – High cost. – Poor data archiving mechanisms. 	(ProjectWise, 2015, Shafiq et al., 2013)
BIM Storm (Onuma systems)	Proprietary	<ul style="list-style-type: none"> • Real time cost and area calculation. • Multiple users collaborating in real time. • Support decisions-making in real-time. • Share and exchanges data based on open standards. • Support different communication many tools e.g. City GML, Google Docs, Go To Meeting, and Skype. 	Yes	<ul style="list-style-type: none"> – High cost. – Controlled and managed by the company. 	(OPS, 2014, OPS, 2015)
BimXtra (Clearbox)	Proprietary	<ul style="list-style-type: none"> • Data management • Team collaboration • View, edit and enhance BIM models • Data revision control 	Yes	<ul style="list-style-type: none"> – High cost – Provide collaboration support up to level 2 BIM. 	(Clearbox, 2015)
UNIT4 Business Collaborator (Business Collaborator Ltd)	Proprietary	<ul style="list-style-type: none"> • Support open standards for 3D models and data. • View an IFC file. • Large file support. • View IFC data. • Core security model. • Search model for objects by associated data. • Version control. 	Yes	<ul style="list-style-type: none"> – High costs 	(BCL, 2014)
cBIM Manager (Asite Solutions Ltd.)	Proprietary	<ul style="list-style-type: none"> • Model server & viewer. • Merge multiple models. • Cloud storage. • Publish and subscribe BIM models. • Integration with other BIM tools. • Provide multi-level versioning and audit trail. 	Yes	<ul style="list-style-type: none"> – Poor partial model exchange. – Data locking – Conflict resolution. – Audit trail. – 2D data modelling – Reference data linking. – Model checking. – Product libraries support. – Rule-based modeling. – Change management. 	(Asite, 2015)
4Projects (4Projects Ltd.)	Proprietary	<ul style="list-style-type: none"> • Provide Common Data Environment (CDE). • BS1192 & PAS1192 compliant. • API allows integration with BIM Eco system solutions. • BIM in a browser SaaS based so no technology requirements. • Unlimited users. • Supports openBIM standards. 	Yes	<ul style="list-style-type: none"> – Controlled and managed by the company. 	(4Projects, 2015, AECMagazine, 2013)

ArchiCAD (Graphisoft)	Proprietary	<ul style="list-style-type: none"> • Edit multiple BIM models simultaneously. • Team collaboration. • Support Workflow and Collaborative Environment. • Support IFC standard. • Generate PDF-based workflow and. 	Yes	<ul style="list-style-type: none"> - Multiple data model formats. - Rule-based modelling. - Remote model viewing. - Poor Interface customization. 	(Graphisoft, 2015, Shafiq et al., 2013)
BIMServer (BIMServer.org)	Open-source	<ul style="list-style-type: none"> • IFC-based server. • Multi-user collaboration • Revisioning. • Check-in/check-out/ merge BIM models. 	Not yet	<ul style="list-style-type: none"> - Under development. - Do not support other BIM file formats apart from IFC. - Poor workflow management. 	(Beetz et al., 2010, BIMServer.org, 2015, Shafiq et al., 2013)
EDMModelServer (Jotne IT)	Open-source	<ul style="list-style-type: none"> • Check-in/check-out/ merge BIM models. • Validate BIM Models according to schema and exchange requirements. • Execute methods. • Rule validations. 	Not yet	<ul style="list-style-type: none"> - Poor remote model viewing. - Poor mobile computing support. - Under development. 	(Jotne, 2015, Rangnes, 2004, Shafiq et al., 2013)

The Glue Server makes it possible to combine multiple data models, detect conflicts between those data models, and make it possible to stamp users' data with a time stamp when it is submitted. The latter capability is helpful when a number of different users are collaborating on the same project. Nonetheless, the majority of former open source software products allowed users to upload and store their data to their own data centres, because most of these systems supported remote data hosting. The benefit of this is that it supports team collaboration on the same projects. However, although most BIM collaboration solutions offer Cloud-based services, it is not clear to end-users where the Cloud IT infrastructures are located.

In order to adopt collaborative BIM, according to Gu and London (2010) it is essential to apply changes to existing work practice such as: (i) Improve collaboration and communication across disciplines to suit integrated model development ; (ii) develop different solutions targeting approaches to implement a collaborative setting that allows multiple parties to access a single shared model; (iii) agree a protocols and standards process that will make it necessary to assign responsibilities and conduct design reviews and validations; (iv) utilise DBMS (Database management Systems) to organise and manage data. However, there is a need to develop a specific data management system using practices that suit the team structure and project requirements; (v) address different business models and associated legal issues (e.g. ownership and IPR challenges); and (f) maintain a BIM model that can be produced in-house or outsourced to service providers. In cases where service providers maintain the BIM model, there would be additional legal measures and agreements put in place, to ensure user confidentiality and data security. Many papers have discussed the implications for lifecycle management within BIM models. Although the Royal Institute of British Architects (RIBA) (RIBA, 2013b) workflow is considered the most widely used in the modern construction industry, other lifecycles can

also be used to construct, buildings such as Construction Industry Council (CIC) project lifecycle. These lifecycles need to be agreed upon and revised prior to final release. The difficulty using a particular lifecycle to develop a BIM governance solution is associated with the following reasons: (i) Building lifecycles differ from one place to another, due to the inherent differences between building sites and local conditions, and (ii) lifecycles must change to accommodate the new requirements of collaborative BIM.

Commercial BIM collaboration solutions are rapidly developing. Moreover, there are many solutions available; however, most collaborative tools are owned by software providers. This makes it difficult to expose internal data management and governance approaches, as well as their developmental approach. Furthermore, the majority of collaboration solutions tend to focus on the technical aspects of collaborative BIM, socio-organisational, legal and contractual aspects take less interest in the development process. Although, multi-model collaborative technology is available in different capacities, there is a need for a comprehensive custom built solution that will fit the specific characteristics and work practices of the construction industry (Shafiq et al., 2013). The majority of collaborative BIM solutions vendors recognise the value of utilising Cloud in their solutions. Accessibility and massive storage are the two main features prompting use of Cloud-based BIM collaboration solutions. Many of these solutions require a complex hardware infrastructure, involving offering collaborative solution software as a service reduces investment in IT infrastructure for providers and clients. Since the main aim of this study is explore BIM collaboration and develop a BIM governance platform to facilitate team collaboration across BIM-based projects lifecycles, there is a need for intensive investigation with regard to: (a) team ICT and collaborative processes and practices, (b) the internal process of the aforementioned collaboration solutions.

2.4 BIM Governance

Research and development in IT governance is more advanced than research in data governance, this is due to its 25-year history (Brown, 1997). IT governance follows a more flexible approach to assigning accountabilities. Early research distinguished two types of IT governance models: centralised and decentralised. With decentralised models units' IT departments perform all IT tasks, whereas in the case of centralised models, corporate IT companies perform all IT functions (e.g. (Ein-Dor and Segev, 1982)), and (Wende, 2007)). Follow-up research in the field of IT governance specified more IT models, allowing several IT functions (Sambamurthy and Zmud, 1999), and others involving more than one organisational level (Brown, 1997). Lastly, Weill (2004) proposed five IT functions

(IT investment, architecture, principles, application needs, and infrastructure); three of which related to organisational units, underlining the distinction between decision and input rights.

By adopting IT and data governance models, organizations can implement corporate-wide accountabilities for Data Quality Management (DQM), involving professionals from both business and IT departments (Wende, 2007). A data governance model helps companies to structure their data quality accountabilities (Weber et al., 2009, Wende, 2007). It defines roles, and assigns responsibilities for decision-making areas to these roles. The research also suggested the implementation of company-wide guidelines and standards for DQM. Moreover, DQM assures compliance with corporate strategy, and laws governing data (Weber et al., 2009). Friedman (2006) recommended that in order to address data quality issues, organisations should adopt a holistic approach focused on people, processes and technology, as well as constantly measuring and quantifying their data quality, which implies that data needs to be governed in order to address quality issues.

There is a lack of overall data governance within current construction projects; therefore, a generic data governance model is essential, in order to facilitate the adoption of BIM for collaborative projects, such as the building industry, which draws on expertise from multiple disciplines, and multiple actors during a building's lifecycle (Rezgui et al., 2013). According to Thomas (2005) *"data needs to be governed as it has neither will nor intent of its own. Tools and people shape the data and tell it where to go. Therefore, data governance is the governance of people and technology"*. However, it is important to highlight the difference between governance and management. Data governance complements data management, but cannot replace it. Governance refers to decisions that must be made to ensure effective management and use of IT (decision domains), focusing on who makes the decisions (locus of accountability for decision making). Whereas, management involves implementing and making decisions. For example, governance includes establishing who in an organisation holds decision-making rights to determine standards of data quality. Management involves determining the actual metrics employed for data quality. This research focuses on the former (Khatri and Brown, 2010). Gartner defines information governance as:

"[T]he specification of decision rights and an accountability framework to encourage desirable behaviour in the valuation, creation, storage, use, archival and deletion of information. It includes the processes, roles, standards and metrics that ensure the effective and efficient use of information in enabling an organisation to achieve its goals."(Logan, 2015)

There are several definitions of data governance. Cohen as cited in (Cheong and Chang, 2007) defines it as,

“[T]he process by which a company manages the quantity, consistency, usability, security and availability of data.”

Newman and Logan (2006) define it as

“[T]he collection of decision rights, processes, standards, policies and technologies required to manage, maintain and exploit information as an enterprise resource.”

Thomas (2006) states that data governance

“[R]efers to the organisational bodies, rules, decision rights, and accountabilities of people and information systems as they perform information-related processes.”

Whereas (Wende, 2007) states that

“[D]ata governance sets the rules of engagement that management will follow as the organisation uses data.”

In light of the above definitions, (Cheong and Chang, 2007) stated that “data governance is important because it defines policies and procedures to ensure proactive and effective data management”. Adopting a data governance framework would allow collaboration at different levels of an organisation to manage enterprise-wide data, and to provide an ability to align data programs with corporate objectives (Thomas, 2006). Further, Guo (Guo et al., 2010) define Governance in Cloud as:

“Controlling access to service using policies, tracking Services using repositories, and logging and monitoring the execution of those Services. The master repository tracks the enterprises records and the slave repository tracks the records in the Cloud.”

In order to overcome the aforementioned issues associated with BIM, it is important to develop protocols and organise responsibilities across disciplines, which can be shared via a common model stored in a central or outsourced location (Singh et al., 2011). Improving communication between disciplines is also an important element in this process (Eastman et al., 2011). It helps to raise awareness, support intensive training, and share formal responsibility among stakeholders across a discipline’s entire lifecycle (Smith et al., 2005, Rezgui et al., 1998). There is a strong need for a balanced framework to implement

BIM, taking into account both monetary and managerial outcomes (Succar, 2009). In terms of achieving effective collaboration, the best approach to achieving effective collaboration is to coordinate information through process, and by improving communication between all the stakeholders involved in a project (Barlish, 2011). Considering people and their processes is key to successful implementation of a governance model (Linthicum, 2009). Critical success factors for implementing data governance models were identified by Marinos (2004) as cited in (Cheong and Chang, 2007), and include: accountability and strategic accountability, standards, managerial blind spot, embracing complexity, cross divisional issues, metrics, partnership, choosing strategic points of control, compliance monitoring, and training and awareness.

There is a general data governance model for use with the Cloud, published by (Guo et al., 2010) which could be used to combine the BIM governance model with a Cloud governance model. As first step towards the development of IT governance in the construction industry, Rezgui et al. (2012) initialised a governance model to manage and to outsource BIM during a building's lifecycle, and across the supply-chain. However, this governance model is not sufficiently mature, as there is a need for a further development and enhancement to make full use of it.

A building information model can be viewed at a very simple level as complete information about a building, offering a phaseless workflow (Succar, 2009). Data related to BIM could be accessed and manipulated using "Lenses and Filters" (Succar, 2009); where lenses highlight selected objects that meet particular criteria, and filters remove objects that do not meet a selected criteria (Succar, 2009). Rezgui et al. (2013) argued that this perfected view of BIM data does not match current industry requirements. Therefore, a study is required to investigate BIM professionals' requirements for developing BIM governance solutions in more detail.

However, in order to successfully implement Cloud Computing as a hosting environment for a BIM governance solution, it is important to know what to govern. An overview of an outlined model for Cloud governance is provided by (Guo et al., 2010). This model is based on underlying requirements needed for services' life-cycle management, policy and process management, visibility and contextualisation. When application services are moved to the cloud, several new risks arise; e.g. availability of the Cloud, security of Cloud, data integrity erosion, etc. When an enterprise requires visibility, trust and control over Cloud-based services, there must be an approach, processes, procedures and technology for managing and controlling massive data, services and processing elements

in the Cloud environment in the form of a Cloud governance model, to avoid the risks associated with Cloud-based implementations (Guo et al., 2010).

2.4.1 Existing data governance models/frameworks

There are several data governance models/frameworks that have been investigated in relation to different areas ((Koooper et al., 2011, Khatri and Brown, 2010, Thomas, 2006, Wende, 2007, Young and McConkey, 2012). This section provides an overview of these models.

A. The DGI governance framework

The DGI Data Governance Framework was developed by (Thomas, 2006), and is a logical structure for classifying, organising, and communicating complex, activities involved in taking decisions about, and acting on enterprise data. It was designed to assist a variety of data stakeholders from Business, IT, Data Management, Compliance and other disciplines (Thomas, 2006).

B. Data governance model

A data governance defined by (Wende, 2007), comprised data quality roles, decision making areas and responsibilities. The fundamental decision making areas, and primary activities of Wende's model can be categorised according to (i) strategic, (ii) organisational, and (ii) technical aspects. Moreover, this model includes a proposed RACI chart to document and structure people's roles, their type of interaction with the governance model activities, and to explain how they make a decision concerning activities. This model helped structure data quality accountability in companies. Based on proposed roles and decision making areas, companies can structure their individual data governance configurations in the form of a RACI chart. They can also use a data governance model as a company-wide communication device for DQM roles and as a type of interaction to guide specific activities and decisions (Wende, 2007).

C. Data governance framework

Khatri and Brown (2010) presented a data governance framework for Cloud, to be used by professionals to develop a data governance strategy and approach to managing data at the organisational level. They identified and presented five decision based domains: (i) data principles, (ii) data quality, (iii) metadata, (iv) data access, and (v) data life-cycle. This was followed by a description of some key decisions made for each domain,

and some examples of organisational positions accorded accountability in that data governance framework. In addition, they proposed different levels of centralised, decentralised, and shared decision rights that might be appropriate to the different decision domains within an organisation. Moreover, they suggested that a “one page” design matrix might be useful for communicating a given organisation’s data governance approach. Their framework provided a common terminology useful to researchers.

2.4.2 Existing Cloud governance models

This section briefly discusses relevant Cloud governance models identified.

A. Cloud governance model

The Cloud governance model introduced by Guo et al. (2010) discussed aspects of Cloud Computing in general. Their governance model outlines the underlying requirements or objectives of governance via the Cloud. Based on the requirements of Cloud governance the model identifies and emphasises four areas of Cloud Computing namely: service, policy, risk, and compliance. A number of requirements are identifiable within each area (Alam, 2012). The model presents important components for Cloud governance and focuses on policy modelling, operational modelling and other management activities, such as service, risk, security, and policy. Compared with previous models, this model was not initiated by business strategies, thus it neglects organisational alignments, roles and responsibilities for adjustment (Alam, 2012).

B. Lifecycle process model for Cloud governance

Similar to Guo et al. (2010) Cloud governance model, He (2011)’s model identifies five areas of interest for Cloud governance; namely: strategic planning (vision), organisational alignment (define), service lifecycle management (build), policy management (deliver) and SLA management (operate). However, He (2011)’s model follows a lifecycle approach, wherein each of the lifecycle components address an area of Cloud governance, which follows Schepers et al. (2008)’s Service Oriented Architecture (SOA) governance framework. This means it differs from Guo et al. (2010) model, which only outlines governance domains and areas (Alam, 2012).

C. Governance lifecycle framework for managing security in public Cloud

Ahmad and Janczewski (2011) framework addresses data security issues as they affect any public Cloud deployment model. It defines an approach for managing user data security concerns, in the public Cloud via incorporating of both the domains of Cloud user

and Cloud Service Provider (CSP). The region between these two domains is covered by incorporation of the Joint Governance Board (JGB). This JGB acts as a bridge among users, Cloud service providers, and authorities for approving various Cloud governance issues. These approval related issues fall into the following categories: risk management, asset management, security policy, monitoring, audit and compliance. The framework also addresses governance functions in a balanced manner so that management and responsibility is shared in a controlled environment (Alam, 2012).

D. Lifecycle governance approach to SOA governance

Schepers et al. (2008) have developed a governance model that addresses the lifecycle approach to SOA governance. They identify 6 phases of SOA and place them into defined phases for the SOA governance lifecycle. These aspects are: (a) vision: defining a SOA strategy, (b) Plan: aligning an organisation to SOA, (c) design: managing a service portfolio, (d) build: controlling the lifecycle of the service, (e) deliver: policy enforcement, and (f) operate: managing service levels. Moreover, their model proposes several processes in each phase (Alam, 2012).

2.4.3 Existing governance models for AEC

The governance frameworks discussed above are considered general, and were not specifically developed for use by the construction industry. Therefore, this section discusses several examples of industry specific governance models.

A. Tracking decision-making during architectural design (ADS)

Cooper et al. (2005) conducted a study with the aim of developing a conceptual framework combined with a developed software environment to support decision-making (ADS) to support building projects. Thus, generating reports on work carried out to assist in the application of the approach at the architectural design stage. The developed system provided a software layer, on top of established electronic information management services used by construction projects. The system keeps track of meta-information to support decision-making during a construction project lifecycle. Further, it is designed to track a wide range of mixed data types across a project, rather than just a single data format i.e. CAD data (Cooper et al., 2005).

B. Relational cooperation model for AEC

Kubicki et al. (2006b) developed a relational cooperation model with a view to conceptualising relationships and interactions between actors on a project, through the activities,

tools, and artefacts (BIM documents) that they produced; thereby facilitating the coordination of construction activities. The development of their model passed through several stages:

- (i) Identify organisational forms and coordination mechanisms in building construction projects based on a theoretical study;
- (ii) Suggest hypotheses about coordination assistance tool requirements;
- (iii) Present the methodological framework;
- (iv) Suggest and describe two assistance tools: (1) meeting report tool, and (2) a multi-view interface representing the project's context in multiple interlinked views (i.e. "Bati'Views")

However, their theoretical approach supported an association between organisational forms based on coordination mechanisms. Thus, it supported coordination, via the two tools proposed and resulting from the cooperation meta-model based on a Model-Driven-Engineering (MDE) approach (Kubicki et al., 2006b).

C. BIM governance model

Rezgui et al. (2013) conducted an industry wide consultation that resulted in the development of a BIM governance model for managing multi-actor, multi-discipline, and total lifecycle data. Their study identified a number of barriers to BIM adoption and team related issues, their BIM governance model offered a solution to overcome those barriers. However, the first step towards creating their model was to identify key characteristics of BIMs taking into account users, and the process dimension. In order to create their governance model, they first identified key characteristics to establish a focus on BIM users and the process dimension. They highlighted these characteristics in five key areas: (i) building lifecycle, (ii) multi-disciplinary users' actions impacting the BIM model at different stages of the construction project's lifecycle, (iii) building a data conceptualisation within a BIM model, (iv) building data relationships within a BIM model, and (vi) access rights and controls of BIM artefacts.

Their developed BIM governance model delivered a conceptualisation of BIM in a simplified and pragmatic form, taking into account stakeholders' capabilities and information delivery for projects. Their BIM governance model targeted BIM adoption at level 2, on the basis of "mixed-approach", i.e. handling different forms of information delivery associated with a variety of files formats, e.g. paper-based, structured, unstructured,

object-based files. Thus, the developed governance model aimed to manage BIM data as one, open, standardised and logical approach. It interesting to note that work conducted by (Kubicki et al., 2006b) aimed to facilitate coordination of construction activities, Whereas, the BIM governance model suggested by Rezgui et al. (2013) focused on: (i) enabling the modelling and capturing of complex data access requirements within a collaborative working environment prevalent within the AEC industry; (ii) facilitating the adoption of BIM in industry; and (iii) helping to alleviate concerns about security, responsibility, ownership, and Intellectual Property Rights (IPR), as held by many in the AEC industry.

2.5 Cloud Computing

Cloud Computing has recently become a phenomena in the IT revolution as it grows quickly and sharply (Kumar et al., 2012). The use of Cloud is not restricted to a certain business domain. It has been implemented and used to underpin and support various software applications and platforms. It has the potential to transfer IT industry making software even more effective, attractive and cost less than traditional software (Armbrust et al., 2010). Therefore, it is the most demanded advanced technology throughout the world. As a business paradigm and new technology, it became dominant and taken commercial computing to another level. Cloud offers easy access to a Cloud provider's highperformance and storage infrastructure over the Internet. One of the significant benefits of the Cloud is to hide the complexity of IT infrastructure management for Cloud users (Jiyi et al., 2010). Lately, there is a noticeable development and use of Cloud services by general users and also by governments, In spite of positive results, there is a challenge in both theory and practice to find a proper Cloud provider that meet individual requirements of an organisation or a government (Repschlaeger et al., 2012).

This section explore Cloud Computing definition and its important concepts, Cloud infrastructure, providing an overview on famous Cloud Service Providers (CSPs), highlighting benefits and drawbacks of utilising Cloud in BIM technologies development, highlighting significant efforts of adopting Cloud technologies in BIM research and development.

2.5.1 Cloud definition

Due to its status as a new concept and become widely popular concept in the latest years (Kolodner et al., 2011), there are many definitions of the term Cloud Computing

reported in (Arsanjani, 2004, Leung et al., 2003). However, the majority of researchers have agreed upon the NIST definition (Mell and Grance, 2009) whereby

“Cloud Computing is a model for enabling 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”.

Although, term Cloud pertains to sharing resources to enhance efficiency. Akintoye et al. (2000) define Cloud Computing as:

“[N]ew computing paradigm which offers a huge amount of computational and storage resources to the masses”

However, Cloud can be seen as a high virtualisation for datacentres infrastructure that are distributed geographically and linked via high bandwidth network cables which provides variety of virtualised services ranging from providing whole infrastructures to small software applications as well as different types of services such as high performance computing and massive scalable storage services based on a pay-per-use model.

2.5.2 Cloud infrastructure

In general, Cloud infrastructure can be divided into four main layers: hardware layer, infrastructure layer, platform layer and application layer.

- **Hardware layer:** responsibility of the hardware layer is to manage the Cloud’s physical resources. Those resources include physical servers, cooling systems and physical network equipment. This layer is naturally implemented at datacentres which contain thousands of servers networked together (Zhang et al., 2010).
- **Infrastructure layer:** infrastructure layer is also called the virtualisation layer. It layer creates a pool of computing resources and storage solutions, achieved via the process of partitioning physical resources for the use of virtualisation technology, e.g. Xen and VMware and is considered to be an essential part of the Cloud. Hence, it almost impossible to dynamically assign resources without using virtualisation technologies (Zhang et al., 2010).
- **Platform layer:** platform is built on top of infrastructure layer, and consists of applications frameworks and operating systems. The idea of this layer is to lower the burden of directly deploying an application into VM containers; e.g. the Google App Engine platform (Zhang et al., 2010).

- **Application layer:** this layer exists at the top level of the Cloud hierarchy. It consists of different Cloud-based applications and traditional applications (Zhang et al., 2010).

Figure 2.2, which follows, shows Cloud architecture; it highlights the fact that each layer is loosely coupled with the layers above or below, enabling each layer to separately evolve. It is very similar to the Open Standard Interface Model (OSI) for network protocols. However, the modularity of Cloud architecture supports a different range of application requirements, whilst at the same time it reduces management and management overheads (Zhang et al., 2010).

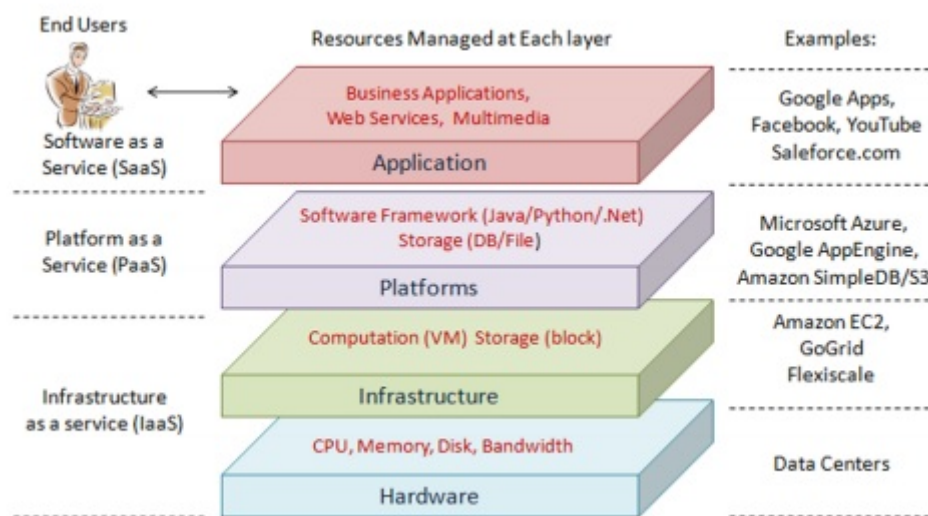


Figure 2.2: Cloud architecture (Adopted from (Zhang, Cheng et al., 2010))

2.5.3 Cloud service delivery models

In general Cloud services delivery can be divided into three different models: Infrastructure-as-a-Service “IaaS”, Platform-as-a-Service “PaaS” and Software-as-a-Service “SaaS”. Figure 3 shows these delivery models that can be seen in a hierarchic context. To the normal end user only can use SaaS, while PaaS and IaaS tend to be more for developers use to deploy their applications (Chorny et al., 2010). The three models are introduced individually as follows in figure 2.3:

- **IaaS:** is the delivery of complete computing infrastructure Over Internet. Delivered services include machine instances that behave similar to dedicated servers. These instances are completely controlled by developers whom are fully responsible of its operation and manually handle Scalability process. IaaS is mainly for developers

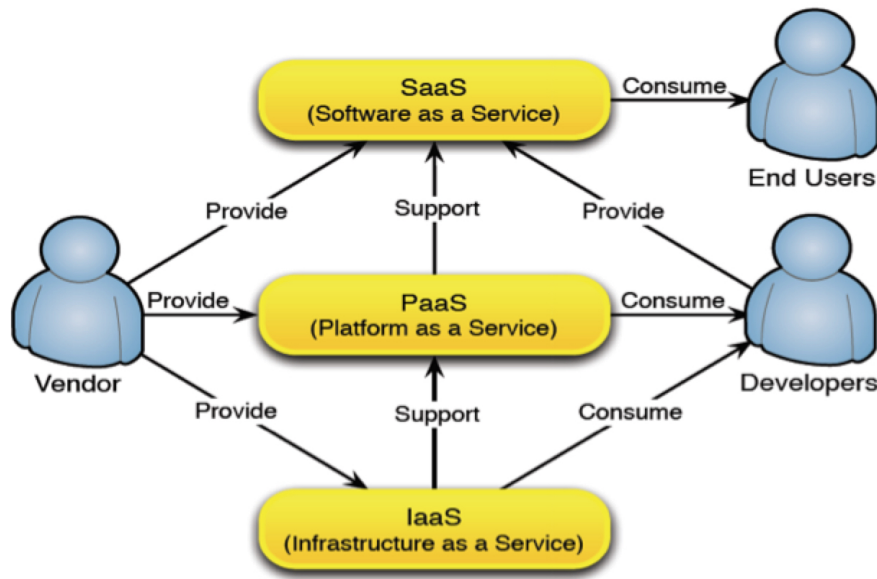


Figure 2.3: Cloud delivery models (adopted from (Marinos and Briscoe, 2009))

whom wants to develop their solutions on the top of the infrastructure and do not want to use any other of CSPs tools or (Application Program Interface) APIs (Marinos and Briscoe, 2009).

- **PaaS:** is higher level than IaaS as it provide a full/partial application development environment under an abstraction of machine instances. The developed application/solutions run on anonymous data centres. Moreover, developers must handle some of constraints that development environment enforces on their solution design (Marinos and Briscoe, 2009).
- **SaaS:** are well-developed applications that offer to users customised and scalable software resources and storage. Thus, this differentiates SaaS from traditional web applications (Marinos and Briscoe, 2009). Although there are several Cloud Services Providers for example Amazon, Dropbox, Salesforce and many others, Google infrastructure is the most applicable development environment due to its massive functionalities and offered services as well as the huge technical support.

2.5.4 Common Cloud Service Providers (CSPs)

Due to the popularity of the Cloud Computing concept as a possible new business model, developed based on distributed processing, parallel processing and grid computing, many giant IT companies, such as Amazon, Google, Microsoft, etc. have been seeking to develop Cloud computing technologies and products (Kolodner et al., 2011). This sec-

tion highlights several examples of famous CSPs, offering a general overview, and cross-comparative analysis between them.

A. Amazon Web Services (AWS)

AWS is a group of Cloud services that offers Cloud-based storage, Cloud-based computation, and other useful functionalities that enable Cloud users to set up applications and services based on on-demand protocols at service linked prices. AWS offers can be accessed over HTTP, using REST and SOAP protocols (Zhang et al., 2010, AWS, 2015).

B. Microsoft Windows Azure platform

There are three principle components of Microsoft’s Azure platform, and each one offers a precise set of services to Cloud users. These components are: (i) The Windows-based environment that is used to run applications and store data in data centres; (ii) SQL Azure offers Cloud-based data services based on the SQL Server; (iii) .NET Services that provide distributed services as infrastructure to both local applications and Cloud-based applications, which can be run on the Windows Azure platform (Zhang et al., 2010, Azure, 2015).

C. Google Cloud Platform (GCP)

GCP is Google’s hosting service for web applications. It uses a pre-defined runtime environment to allow the development and deployment of Cloud-based applications. It offers different Cloud-based hosting services from other Cloud providers such as Amazon Web Services that operate on an IaaS level. GCP provides an application infrastructure based on PaaS level. In other words, GCP provides the deployed application with a set of application-oriented services due to the abstraction from the underneath hardware and operating system layers. This approach is appropriate for such a Cloud-based applications developers. The main driver behind the GCP is its focus on three aspects: scalability, usage-based infrastructure, payment (Chorny et al., 2010, GCP, 2015).

D. Rackspace

Rackspace has delivered enterprise-level hosting services to businesses of all sizes and types worldwide, since 1998. Rackspace is the global leader in hybrid cloud and the founder of OpenStack, the open-source operating system for the cloud. It operates across four continents and integrates the best technologies to meet specific customers’ needs by delivering best-fit solutions and leveraging the public cloud portfolio, private cloud, dedicated servers, and a combination of platforms (Rackspace, 2015).

E. OpenStack

In 2010, a joint collaboration between Rackspace Hosting and NASA resulted in the launch of an open-source environment to create OpenStack (Ohlhorst, 2012). According to (Piatt, 2011) OpenStack’s mission is to offer a universal Open Source cloud computing platform to meet the requirements of public and private cloud providers, taking into account simplicity of implementation and massive scalability. OpenStack operates on four core principles: open source, open design, open development, and open community. OpenStack is a Cloud operating system developed by datacentres. Furthermore, it is also seen as at the core of Cloud operations, enabling vendors to build diverse software to run in the Cloud. OpenStack consists of three main modules: Nova, for computing; Swift, for object storage; and Glance, an image service module (Ohlhorst, 2012).

2.5.5 Comparisons between Cloud Services Providers (CSPs)

Several comparative reports and white papers exist with which to assess Cloud providers. Authors of these are either interested in Clouds options used via blogs, company websites, or are professional academics in the field. A number of comparisons have been provided. For example, (Rodrigues T, 2012) aimed to offer a starting point for those who were new to Cloud, or wanted to understand the options and services offered by Cloud providers. In order to facilitate the comparison among Cloud providers, he created dimensions to reflect important aspects of Cloud computing, including: cost reduction; economic benefits of scaling; service levels for the customers; ease of use and flexibility when configuring servers; security; compliance; and technical support. He established fourteen criteria: (i) The price plan; (ii) The average monthly price; (iii) the Service Level Agreement (SLA); (iv) data centre numbers; (v) certification and scale up (when paying more money was it possible to have extra storage and CPU etc.; (vi) scale out (if it was possible to quickly deploy new server instances); (vii) support and monitoring; (viii) APIs (was there an existing API which helped development); (ix) free trial (what did the customer get during a free trial); (x) operating systems support; (xi) instance type numbers; (xii) different server configurations available; (xiii) outbound data transfer costs; and (xiv) inbound data transfer cost. However, since this study does not intend to undertake an in depth technical comparison of different CSPs, the following section compares CPSs from a documentation perspective. It considers the following parameters (infrastructure and computing services, networking technologies, storage technologies, developers’ environment and support, security, and price):

- **Infrastructure and Computing services.** First, Amazon Elastic Compute Cloud (EC2, 2015) allows Cloud users to initiate and manage server instances at

data centres, using APIs, tools and utilities. EC2 uses a Xen virtualisation engine, which runs on the top of this, and EC2 instances as a virtual machine. Users can upload and edit software after creating and initiating a new instance. When changes are complete, software is then packed to deliver a new machine image. Therefore, with this tool it is possible to launch an identical copy at any time. Thus, almost all users have the feature of full control over the entire software stack on EC2 instances. EC2 supports place instances in multiple locations consisting of regions and availability zones. Regions are distributed geographically and comprise one or more availability zones, which are distinctive locations engineered to be immune from failure in other availability zones. They also provide network connectivity to other availability zones in the same region at low cost. EC2 stores and retrieves machine images using Amazon S3 (Zhang et al., 2010).

Nonetheless, Google Cloud Platform (GCP) in the Google App Engine (GAE) runtime environment presents areas in which deployed applications are executed. These application do not run constantly if no invocation process has been made; they only run once an HTTP request is processed to the GCP through a web browser or other interface. When an HTTP request is made, the request handler forwards it to the GCP, which selects a server from the many servers running on the Google infrastructure; the application is then instantly deployed and executed during a limited time. The application Cloud then performs computing codes and returns results to the Request Handler, which forwards an HTTP response to the client (Google, 2014). It is crucial to highlight that the deployed application is embedded and runs entirely in a secured sandbox environment, assuming requests are still coming in and that the application is working on processing codes. Applications should only compute and run when there is a need, otherwise precious computing power and memory are being allocated unnecessarily. This paradigm shows the potential scalability of GCP. The ability to run independent multiple instances of a deployed application on different servers guarantees good levels of scalability (Google, 2014). Nevertheless, there are some limitations to this highly flexible application execution paradigm; e.g. requests are processed within a timeframe that is shorter than 30 seconds, after which the response has to be returned to the client before the application is again removed from the GCP. The application is deployed and started each time a request is processed; hence, additional time is needed to ensure the application is up and running in the GCP. However, the GCP aims to resolve this problem by caching the application in the server memory for as long as possible, adjusting to allow several subsequent requests in the same application (Chorny et

al., 2010). Moreover, the GCP offers many services and links to all Google services APIs, e.g. Google Mail, Maps, and Google search engine, etc. The following are examples of services offered most directly to the developed prototype: Memcache, Url fetch, Mail, XMPP, Images, Users, OAtuh, administration console (Google, 2014).

Rackspace provides Cloud Servers that are flexible and scalable and allow users to spin up to hundreds of servers in minutes. It can be scaled up when users need power, and down when they do not. These Cloud servers were built entirely with RAID 10-protected, data-centre-grade SSDs, Powerful Intel Xeon processors, and 40 Gigabits per second of highly available network throughput to every host machine. Users deliver Rackspace's Cloud servers in minutes, to quickly scale capacity up and down (Rackspace, 2015). OpenStack provides two computing modules: (a) Image Service model called (Glance): this provides a catalogue and repository for virtual disk images. These disk images are most commonly used in OpenStack Compute. While this service is technically optional, any sizable cloud will require it; (b) Compute model called (Nova) provides virtual servers on demand (Ohlhorst, 2012).

- **Storage technologies.** First we consider Amazon Simple Storage Service (S3, 2015), which stores data in the form of objects grouped in buckets. The size of each object ranges from 1byte to 5 GB of data. URI pathnames are essential to determining object names and must be explicitly created before using buckets. Buckets can be stored in one or several regions. The user should decide whether to choose these regions to enhance latency, reduce costs or address regulatory requirements (Zhang et al., 2010). Conversely, Windows Azure stores data in blobs, tables and queues. This data can be accessed over the internet via HTTP/HTTPS and the RESTful protocol. The Azure database uses the Microsoft SQL Server to provide a Database Management System (DBMS) inside the Cloud. This data can be accessed using ADO.NET and different data access interfaces compatible with Windows. It is also possible for users to use on-premises software to work with Cloud information. "Huron" Data Sync is used to synchronise relational data across different on-premise DBMSs (Zhang et al., 2010).

Second, GCP Storage technologies. Google Cloud provide three types of storage solutions over its infrastructure: (a) Datastore: GCP uses a storage approach, called Bigtable (Chang et al., 2008), for data persistence. This storage approach differs from the Relational database approach. Data is stored in entities instead of the

rows found in the relational database approach. Entities are always associated with a certain type. These entities have properties, that act in a manner similar to columns in the relational database scheme (Chorny et al., 2010). (b) Google Cloud SQL: This data storage solution was developed to form the MySQL database in the Google Cloud. It does not require installation of software or maintenance, thus it is easy to use and ideal for small-medium applications. In addition to having full capabilities and functionalities, it has additional functionalities. The creation and management of these instances can be done via Google Developer Console. The user can choose their hosting datacentres (Google, 2014). (c) Blobstore: The Blobstore storage API allows deployed application to assist large data objects that are much larger than the object size allows in the Datastore. These “Blobs” are valuable when serving large data files such as videos, images or in this case BIM models. They allow users to upload large files through an HTTP request (Google, 2014).

Rackspace offers four storage technologies: (a) Cloud backup: this technology works on a file-level backup and restores capabilities to help safeguard customers’ businesses. Users have the option to encrypt files using AES-256 encryption, and can automatically compress and de-duplicate files; (b) Cloud Block Storage: this technology provides a consistent and reliable storage performance. Customers can create and delete volumes in high performance standards; (c) Cloud Files: offer unlimited, on-demand storage for users’ files and media, serving customer content around the world at rapid speeds via the Akamai Content Delivery Network (CDN). Access to this technology is via Control Panel or API; (d) Cloud Databases: This technology delivers faster applications with Cloud databases, offering high-performance MySQL databases, with built-in redundancy and automated configurations included (Rackspace, 2015). However, According to Ohlhorst (2012), OpenStack storage implements two storage technologies: (a) Object Storage (Swift): allowing users to store or retrieve files, but not mount directories like a file server; (b) Block Storage (Cinder): providing persistent block storage to guest Virtual Machines (VMs). This project was developed using code originally in Nova. It offers block storage or volumes, not file systems, like Network File System (NFS).

- **Developers’ environments and support.** Most Cloud Providers offer on-demand access to a wide range of cloud infrastructure services, charging only for the resources used. By only providing resources throughout the duration of development phases or test runs, researchers can achieve important savings, as compared to in-

vesting upfront in traditional hardware. Developers primarily use local laptops or desktops to run development environments. This is typically the case where Interactive Development Environment (IDE) is installed, where unit tests are run, and where source code is checked in, etc. However, there are several cases where on-demand development environments are hosted in Cloud.

With Amazon Web Services (AWS), a developer can access a variety of different instance types, some with very specific hardware configurations. In the case of more complex working environments, AWS CloudFormation makes it easy to arrange collections of AWS resources. The developer can code against and control IT infrastructure, whether the target platform for his/her project is AWS, or if the project involves orchestrating resources in AWS. In such cases, the developer can use various AWS SDKs to integrate their applications with AWS APIs easily, thereby removing the coding complexity relating to authentication, retries, error handling, etc. AWS SDK Tools are available for multiple languages: Java, .Net, PHP, Ruby, and for mobile platforms: Android and iOS. AWS also offers tools such as the AWS Toolkit for Visual Studio, and the AWS Toolkit for Eclipse, which makes it easier to interact with AWS from within the developer's IDEs (Carlos and Attila, 2012). For example, Windows Azure supports the following development environments: .NET framework built applications, Visual basic, C++, C#, etc. and general purpose programs (Zhang et al., 2010). Alternatively, developers can use ASP.NET and the Windows Communication Foundation (WCF) to create Cloud applications, and to manage independent background process applications as a companion for both applications.

The GAE environment was established over Google servers according to the programming language selected and used for developing and deploying Cloud applications. For instance, a Java Virtual Machine (JVM) was provided when using Java or other languages that support Java-based compilers (JRuby, Rhino and Groovy). A framework for rich web applications is also offered through Google Web Toolkit (GWT), and a Python-based environment is provided when using Python and related framework (Chorny et al., 2010). Nevertheless, Rackspace offers "Rackspace Templates" supporting developers who seek simplicity. The Rackspace Cloud Control Panel can be used to spin a pre-built, pre-validated stack in minutes. A developer simply clicks a few buttons and provides some basic information to get started. Rackspace builds standard stacks using industry best practices, and has a growing catalogue that includes WordPress, LAMP, Drupal, PHP, Ruby on Rails, MySQL,

MongoDB, Cassandra, and more (Rackspace, 2015). Finally, OpenStack provides a modular form called “Dashboard (Horizon)”. This is a Web-based user interface for all OpenStack services. With this Web GUI, it is possible to perform most cloud operations; i.e. launching an instance, assigning IP addresses, and setting access controls (Ohlhorst, 2012).

- **Security.** In terms of security aspects, the Amazon Virtual Private Cloud (VPC, 2015) provides a secure bridge between AWS Clouds, and an enterprise’s IT infrastructure. It allows connection between an enterprises’ infrastructure and a set of isolated AWS computer resources via a Virtual Private Network (VPN), as well as allowing extension to management capabilities. These management capabilities can either be security services or firewalls. Amazon also has a management tool, known as “CloudWatch”, which is very useful for collecting raw data from connected AWS services, e.g. Amazon EC2. After collecting raw data, it is processed into readable real-time metrics. These metrics refer to EC2, and contain CPU utilisations and network in/out bytes disk read/write operations, etc. (Zhang et al., 2010). According to Arredondo (2013), Rackspace adopts a security management model comprised of four main stages: Plan, Do, Check, Act, as recommended by the ISO 27001 standard. Their Customer Security Program, is built on the foundation of this model, and combines Rackspace expertise with technology and services. Whereas in Openstack, “Keystone” is a security model providing authentication and authorization for all OpenStack services. It also delivers a catalogue of services within a particular OpenStack Cloud (Ohlhorst, 2012). Finally, security aspects associated with the majority of commercial CSPs must be complied with, as stated in the ISO 27001 standard (ISO, 2013).
- **Price and payment plans.** Rodrigues T (2012) determined some interesting points. First, that there was a large variation in Cloud providers’ prices ranging from 40\$ to 274\$. The second point was that most of Cloud providers claimed 100% uptime SLA, which might reduce fear when moving towards the Cloud. The third point was that many Cloud companies did not provide customers with a free trial to experiment with its Cloud platforms. However, it was possible to trial the platform for a small amount of money on a “pay-as-you-go” basis. The fourth point he made, was that certain tools were useful when comparing Cloud services providers, such as CloudSleuth (Tajudeen, 2012).

Moreover, Li et al. (2010) conducted a piece of research named “CloudCmp”, which aimed to compare different Cloud providers. CloudCmp sought to provide

a systematic comparison of the cost and performance of selected Cloud Providers. It measured computing flexibility, storage persistence, and network services side by side with direct reflection metrics that impacted customer application performance. They applied CloudCmp to the four most popular Cloud providers, namely: C1 Amazon, C2 Microsoft Azure, C3 Google App Engine and C4 Rackspace. They claimed that CloudCmp could assist customers to make the right choice of Cloud provider in order to host their applications. Li et al. (2010) determined that the performance and price of the four Cloud providers' varied considerably, with no Cloud provider standing out, e.g. although Amazon's virtual instances were not the most cost-effective it had the highest intra-Cloud bandwidth. Even though Microsoft Azure's network bandwidth was somewhat limited, it had the most powerful virtual instances. Google App Engine storage services were slower than the other options, and had the lowest wide-area network. These were interesting findings as outlined: (i) In terms of cost effectiveness, Cloud instances were not cost effective. For instance, although it was only 30% more expensive, Rackspace's Cloud instances rose twice as fast as Amazon; (ii) Microsoft Azure was able to fully utilise the physical machine when there was no competition for local resources. Thus, at low cost, an instance could achieve high performance; (iii) there was a significant diversity across the Cloud providers in terms of storage services, e.g. Amazon's table query operations were faster than those of the others; and (iv) although the intra-data centre traffic was free of charge, all the Cloud providers compared offered different intra-data centre bandwidth, e.g. The bandwidth of Microsoft Azure was three times lower on average than Amazon's bandwidth. They argued that the time has now arrived for computing-as-a-utility, and that CloudCmp could be extended to measure other Cloud providers. However, Openstack provides open services that are free of charge (Ohlhorst, 2012).

Table 2.3 summarises comparisons among several CSPs highlighting the most frequently offered technologies

2.5.6 Choosing CSP's criteria

According to (Stadtmueller, 2012), five main criteria are worthy of consideration when choosing a Cloud provider: (i) interoperability across the working environment, (ii) flexibility in supporting different workloads, (iii) security, (iv) SLA, (v) help and support, in particular of major enterprise applications.

Table 2.3: Comparison among widely used CSPs

Cloud Service Providers	Amazon	Windows Azure	Google	Rackspace	OpenStack
Infrastructure and Computing services	<ul style="list-style-type: none"> • Xen • Virtual Servers • Containers • Event-driven compute Functions • Autoscalling • Load Balancing 	<ul style="list-style-type: none"> • Virtual Machines • Cloud Services • Batch • RemoteApp 	<ul style="list-style-type: none"> • App Engine • Compute Engine • Container Engine 	<ul style="list-style-type: none"> • Cloud Servers • VMware virtual servers • Rapid development servers • Dedicated servers 	<ul style="list-style-type: none"> • Nova computing model • Glance computing model
Networking	<ul style="list-style-type: none"> • Virtual Private Cloud • Direct Connections • Load Balancing • DNS 	<ul style="list-style-type: none"> • Virtual Network • ExpressRoute • Traffic Manager • Load Balancer • DNS • VPN Gateway • Application Gateway 	<ul style="list-style-type: none"> • Load balancing • Carrier interconnect • Direct Peering • Cloud VPN • Cloud DNS 	<ul style="list-style-type: none"> • Cloud Network • Cloud Load balancers • Cloud DNS • RackConnect • Custom networking 	<ul style="list-style-type: none"> • Neutron networking model
Storage technologies	<ul style="list-style-type: none"> • Object Storage • Block Storage • File system storage • Amazon Relational database • Amazon DynamoDB 	<ul style="list-style-type: none"> • SQL database • DocumentDB • Storage: Blobs, Tables, Queues, Files and Disks. • StorSimple 	<ul style="list-style-type: none"> • Cloud Storage • Cloud Datastore • Cloud SQL • Cloud bigtable 	<ul style="list-style-type: none"> • Cloud Block Storage • Cloud Backup • Custom storage • Cloud Files • ObjectRocket NoSQL • Cloud database 	<ul style="list-style-type: none"> • Swift storage model • Cinder storage model
Developers' environment and support	<ul style="list-style-type: none"> • AWS CodeCommit • AWS CodeDeploy • AWS CodePipeline 	<ul style="list-style-type: none"> • Visual studio Online • Visual Studio Application Insights • API Apps 	<ul style="list-style-type: none"> • Google Developers Console • Eclipse IDE • Google API 	<ul style="list-style-type: none"> • Cloud Orchestration • Auto Scale • Cloud monitor 	<ul style="list-style-type: none"> • Horizon dashboard
Security	<ul style="list-style-type: none"> • AWS Identity & Access Management (IAM) • AWS Directory Service • Amazon Inspector • AWS Key Management Service • AWS Malicious Web Traffic Filter (WAF) • ISO 27001 (ISO, 2013) compliance 	<ul style="list-style-type: none"> • Azure Active Directory • Azure Active Directory B2C • Azure AD Domain Services • Multi-Factor Authentication • ISO 27001 (ISO, 2013) compliance 	<ul style="list-style-type: none"> • Google security model • Secured Service APIs and Authenticated Access • Secure logging • 256-bit Advanced Encryption Standard • Cloud Security Scanner • ISO 27001 (ISO, 2013) compliance 	<ul style="list-style-type: none"> • Rackspace security manager • PDCA cycle • ISO 27001 (ISO, 2013) compliance 	<ul style="list-style-type: none"> • Keystone security model
Price	<ul style="list-style-type: none"> • Pay-as-you-go • AWS free-tier for 12 months 	<ul style="list-style-type: none"> • Pay-as-you-go • Free trail with limited resource 	<ul style="list-style-type: none"> • Pay-as-you-go • Free trail with limited resource 	<ul style="list-style-type: none"> • Pay-as-you-go • Free trail with limited resource 	<ul style="list-style-type: none"> • Open-source
References	(AWS, 2015b)	(Azure, 2015a)	(Google, 2015)	(Rackspace, 2015)	(OpenStack, 2015)

2.5.7 Benefits of Cloud in BIM development

There are a number of case studies that are trying to show the benefits of using Cloud technology in BIM. The current trend in the construction industry is to efficiently integrate and manage building information by applying building information modelling (Chuang et al., 2011). However, there are general benefits that can be achieved via the use of Cloud Computing technology in any technical development at any area and most specifically in the terms of BIM collaboration development in construction industry. The

following benefits can be significantly seen throughout the use of Cloud Computing.

Accessibility (Beach et al., 2013, Redmond et al., 2012), as it is possible to access stored data or to data files from anywhere anytime as long as there is an Internet connection. Scalability is another substantial need when working with BIM data due to the massive amount of data that is generated during the construction project. Beach et al. (2011) stated that Cloud has ability to decrease and increase the space and resources according to the needs of the user or organisation. Another advantage is advance interoperability for BIM applications (Redmond et al., 2012). Security is an argumentative issue, whether it is an advantage or disadvantage. Some argue it is an advantage because of the location of the stored data is unknown therefore; no one such as hackers can harm stored data. Whereas, others consider Cloud unsafe to be used as long as it is connected to the Internet. Automatic backup in real time that will solve data lost issues. Costs is another argumentative issue, some see Cloud is cost effective compared to buying hardware infrastructure for a company but others see it might be costly when there is no need for services or storage for long times. Some researchers consider Cloud as a Green technology. It helps to reduce hardware costs, use of electronics, as well as cooling systems for the data centres. According to Stadtmueller (2012) Report there are 5 main advantages when adopting Cloud in an enterprise: reducing investment in hardware; taking full advantage of scalability; reducing time when launching new applications and quality and consistency improvement.

2.5.8 Disadvantages of Cloud in BIM development

Although Cloud has many benefits, yet still there are some drawbacks especially when adopting Cloud in an enterprise e.g. security, performance, reliability and control. Jiyi et al. (2010) emphasis that Cloud platforms provide massive scalability, reliability by 99.999%, high performance and specifiable configurability at relatively low cost when it compared to dedicated infrastructure. According to Armbrust et al. (2010) these obstacles are: availability, data Lock-in, data confidentiality and auditability, data transfer hinders, performance (unpredictability), scalable storage, bugs in large distributed systems, scaling quickly, reputation fate sharing, and software licensing. Further in (Kumar et al., 2012). Security on both levels cyber and data is still a major issue. However, there are major concerns related to using Cloud in BIM collaboration as Redmond et al. (2012) raised three issues: security, privacy, and Internet connection dependency. There is always a need for a network connection to reach the stored data. Sometimes it might costs more when is needed for long time. Data ownership and control are considered an argumentative obstacle because nearly no one knows who owns the data hosted by a CSP.

Cloud is still a new technology therefore it is under research and development.

2.5.9 Research and development of Cloud in BIM

In terms of research and development in computer science, Cloud Computing is an increasingly pertinent topic, having been widely adopted despite its relative freshness. Cloud can be defined as a model for enabling on-demand network access to a shared pool of configurable IT capabilities or resources, allowing them to be rapidly provisioned and released with minimal management effort or service provider interaction. This enables users to access technology-based services from the network Cloud without knowledge of, expertise with, or control over the technology infrastructure that supports them. Cloud both delivers applications as services over the Internet, and its systems and hardware are also located in the data centres of the service providers (Richmond, 2012).

Due to its many advantages Cloud Computing technology has been posited as an interesting solution for BIM researchers and developers. Therefore, a number of research studies have been conducted using Cloud for BIM. This section will provide a short summary of two such studies. Adopting Cloud technologies can positively overcome the mobility, and data-intensive nature of construction projects, and issues associated with unstructured and dynamic data (Fathi et al., 2012).

A. CommtCloud

Beach et al. (2011) devised a BIM governance model for the management of multi-actor, multi-discipline, and total lifecycle data, informed by an industry wide consultation in the UK, and its associated Cloud environment implementation. The CLOUDBIM approach adopted by (Rezgui Y et al., 2012) shared a similar philosophy to this system. It provides an IFC support to guarantee interoperability with other commercial software products. Although the above mentioned software systems only support the function of data/document versioning, Rezgui's approach supported other functions: optioning, concurrency, composition and derivation. Availability of these functions permitted a version of a subset of a BIM data set, without versioning the entire model. (Rezgui Y et al., 2012) found, based on industry consultation, that additional levels and additional details were of much greater benefit than the approved capacity of current systems.

Moreover, their Cloud implementation can only support data storage and data management; although, it also uses the specialist "worker" process to support computational capability. This can be done by mapping each worker to one or more virtual/physical machines that will integrate simulation software in the same way as data. This access management capability depends on the user role, and access requirements that restrict

access to particular BIM data. Therefore, it enables multi-party collaboration that is more coherent. Many of the previously mentioned systems do not support access capability; most suppose there is just one type of user accessing their software product system without any distinction between different user roles (Rezgui Y et al., 2012). To address this, they created a Cloud-based model that offers a unique opportunity to solve the AEC industry wide data sharing, access, and processing requirements. However, at the present time, their research is still under investigation and development.

B. Enhancing information exchange through Cloud BIM

Redmond et al. (2012) sought to address the issue of developing a simple format for compiling and exchanging building information more effectively and efficiently through a building's lifecycle. They suggested a solution to this issue involving heterogeneously binding applications through a central repository platform (i.e. Cloud Computing). They examined Cloud Computing capabilities and found benefits to using shared platforms, as such an approach provides an integration service with other web-based applications, thereby reducing investment in infrastructure. Security and privacy are the biggest drawbacks of Cloud computing. They also considered BIM software interoperability, claiming that use of Cloud Computing resolves multiple different issues in working environments, by introducing different technologies and hardware/software; arguing that this could be done in the early stages of a project's design to advance interoperability. In addition, the current application has become more readable, as the internet is furthering the development of new standards for application interoperability.

Cloud and BIM contractual issues involve different parties with different interests within the supply chain, as this is the only way to benefit the construction industry. However, issues will arise from open standards being used to improve the interoperability of Cloud BIM, although most specifically, issues related to contractual terms were recognised in the early design stage. Redmond et al. (2012) illustrate business process characteristics using Cloud BIM. Drivers from Cloud BIM stress that efficiency can be gained through cost reduction, sharing information via interoperability, and unlimited access. There is a need to promote exchange standards, as these would probably improve integration with other companies, although a basic standard should be sufficient. There is also a need for both business pull and technology push to ensure successful industry adoption.

In terms of information exchange, the core aim is to develop a Cloud platform capable of hosting web-based BIM applications, with flat structured XML being created to obtain full interoperability. However, the current preferred industry solution is to have an

agreement regarding familiar vocabulary for document exchange, e.g. Using IDM (Information Delivery Models) when defining MVD (Model View Definition), which are a standard based subset of IFCs. It is emphasised that the design stage is a key stage for information exchange, with design and operate as the preferred procurement path for implementing a standard exchange mechanism (Redmond et al., 2012).

Based on the previous figure, web services features are a basic standard for information exchange. The expected process for using Cloud BIM would be enable web services to evolve with open standards exchange mechanisms hosted at a central repository (Cloud platform), and use of a web service to define needs to be exchanged between various applications at specific stages of the construction process (Redmond et al., 2012).

Regarding the BIM lifecycle, based on Cloud services, one of the respondents in their questionnaire stated “it would be of benefit to any project to undertake an analysis of the building before you build it as one can eliminate problems that would have originally being unforeseeable in the traditional way”. Under this system, the American Integrated Project Delivery model and the NEC were cited as preferred contracts.

Redmond et al. (2012) concluded that there is a need to find a solution to the problem that ensure different BIM applications do not communicate with each other. IFC, which is the main standard file exchange format, was not intentionally designed to carry all relevant data, and so the solution is to create a super schema with the ability to read various formats and combine them into a single format. Issues ranging from privacy and security (also whether such a platform is technically possible) have arisen from the prospect of developing a BIM central repository based on an integrated platform via the internet. There are potential issues related to the industry’s lack of motivation when using new technology, that mean it is not being influenced contractually. The need to develop a Cloud BIM information exchange mechanism is emphasised by various disciplines only using the information they require, in combination with the business process results.

C. Applying Cloud computing technology to BIM visualisation and manipulation

Chuang et al. (2011) stated that the current trend in the construction sector is toward developing a BIM application for efficient integration and management of information engineering. The current BIM desktop applications, e.g. Autodesk, and Bentley can visualise and integrate BIM information on-site; however, the situation is complicated when it comes to obtaining and updating information from remote sites, which cause communication and information distribution restrictions. An increasing improvement

in both hardware capabilities and visualisation efficiencies that operates side by side with the development of applications frameworks means moving from a “client-server” to a “host-based” server, in other words, “Cloud Computing” technology (Chuang et al., 2011). Therefore, they utilise the concept of (SaaS) with Cloud Computing, in order to develop a visualisation and manipulation system for BIM. The system is not only capable of visualising 3D BIM Models, but goes beyond that to manipulate these through the web without time or distance limitations. The developed system has the ability to effectively and efficiently manage projects by facilitating information distribution and communication among a project participants e.g. building owners, and companies (Chuang et al., 2011).

The Cloud-BIM system developed by (Chuang et al., 2011) was developed according to five User Interface (UI) design principles: visibility, feedback, ease of remembering, mapping and consistency. Therefore, their Cloud-BIM system has four major characteristics: (i) enable users to visualise and manipulate BIM information anytime and anywhere, through the use of Cloud computing applications; (ii) develop an effective and efficient GUI based on UI design principles, to facilitate information distribution and communication among related participants to result in effective and efficient project management; (iii) create an easy to use system using GUI as a substitution for the traditional text-based UI; and (iv) enabling the project manager to quickly grasp the current state of an on-going project because of visual representation of project information. However, CLOUD-BIM architecture, according to (Chuang et al., 2011), is more concerned with visualising and manipulating BIM models, extending beyond this to assist in controlling and monitoring construction projects (Chuang et al., 2011). One issue with their Cloud-BIM system is that they are not utilising any standards when assessing the process, nor are they concerned with different levels of authorisation for access.

D. Context-Aware Cloud Computing Information System (CACCIS)

CACCIS was a project initiated in Malaysia by Fathi et al. (2012). The aim of this project is to develop a Cloud-based system to provide an awareness of a user’s place within the environment context (such as location, roles and responsibilities, etc.). According to (Fathi et al., 2012), this offers the most efficient and valuable information and services, which are relevant to a particular context; thus, it might enhance the effectiveness of the construction industry. CACCIS architecture consists of: (i) front-end representing end-users’ computers (e.g. desktops, netbooks, laptops, tablets, mobiles and smartphones) and a web-based application for accessing the Cloud service; (ii) a back-end, i.e. the Cloud environment selected for the system; and (iii) a network connection to provide on

overlay for the sending/receiving of data. CACCIS allows integration with web-based services, such as web-based e-mail and storage programs, such as Gmail, Yahoo Mail, Hotmail and Dropbox.

E. Integrating BIMs and SNS

Jiao et al. (2012) developed a Cloud based approach to unified lifecycle data management in architecture, engineering, construction and facilities management. Their developed solution targeted the problem of data integration throughout the lifecycle of a construction project, addressing the demands of multiple collaborative enterprises, which is typical of the fragmented nature of the construction industry. However, the developed novel Cloud-based solution focuses on China's unique construction requirements. Their approach proposes a series of as-built BIM tools, and a self-organised application model linking "project engineering data" and "project management data" through a federal seamless BIM and BSNS (business social networking services). A unified data model is constructed by integrating two types of databases through the adoption of handlers, to achieve a logical centralised single-source data structure. Several critical technical mechanisms were considered to successfully manage large amounts of proposed and implemented data, including: grant permissions, data manipulation and file version control. The proposed Cloud solution has been successfully used in China for real-world applications allowing data sharing on the individual and team level, at the enterprise level, by allowing data management in a consistent and sustainable way throughout the life of a construction project (Jiao et al., 2012).

F. Linking Building Data in the Cloud

Curry et al. (2013) conducted research to link building data in the Cloud, in order to integrate cross-domain building data using a "linked data" approach (linkeddata.org, 2015). They applied their work to building performance monitoring. They proposed a viewpoint for a high-level multi-domain collaboration using "linked data", in conjunction with a supporting service layer. Their use of "linked data" is considered a smart and relatively easy approach to managing distributed data from multiple domains; thus, it makes collaboration at different stages achievable (Li et al., 2013).

J. Supporting communication and cooperation in distributed representation of adaptive design

Kotulski and Strug (2013) carried out research under the title of supportive communication and cooperation as a means of distributed representation for adaptive design.

They explained an innovative concept, suggesting an entire building could be formally characterised as a hyper-graph. They identified relevant means for modelling multi-agent systems, based on hyper-graph transformations, together with replicated complementary hyper-graphs to demonstrate the design at different stages of the design process.

2.6 Summary

The critical review of the current contexts of BIM has assisted us in gaining a broader knowledge with respect to on-going developments in the field of BIM. It has highlighted BIM adoption levels worldwide, BIM applications in construction projects, BIM adoption benefits, and barriers. It has investigated the concepts informing the collaborative BIM approach, underlined the notion of BIM governance, and critically reviewed existing data governance frameworks, existing Cloud governance models, and previous efforts to develop data governance models/frameworks to serve the AEC industry. Furthermore, it investigated the Cloud computing paradigm and related concepts; exploring different CSPs, identifying the benefits and drawbacks of using the Cloud to support BIM technology development, critically reviewing existing research and the efforts expended when utilising Cloud technologies in BIM research and development. It is believed that, overall, this governance system will be more efficient and effective than other similar systems, models and approaches.

3

Methodology

3.1 Introduction

The aim of this chapter is to describe and justify the methodology research and design upon which this research is based. This chapter links the literature review with the findings to achieve the outlined thesis objectives. The chapter first gives an overview of philosophical approaches in research with a view of positioning the research approach and justifying the choices of research design and data collection processes. The different stages of this research combining theoretical and empirical studies are also presented in this chapter. The research instruments employed at each stage are explained in detail. Followed by an overview on tools are used for data collection, analysing, modelling, and developing proposed solution. The outcomes of each instrument will be presented in the following chapters.

3.2 Philosophical research paradigms

Research is defined as a systematic inquiry that uses disciplined methods to answer questions and solve problems (Saunders et al., 2011, Polit and Beck, 2004). The ultimate goal of research is to develop, refine, and expand the body of knowledge (Polit & Beck, 2004). However, Lee and Lings (2008) states that research is about generating knowledge about what the authors believe the world is. However, Oates (2005) have highlighted several reasons for a researcher to conduct a research: (a) find out what happens in order to solve a problem; (b) find the evidence to inform practice; (c) develop greater understanding of people and their world; (d) contribute to personal needs; (e) test or disprove a theory (f) come up with a better way of solving a problem; (j) understand other person's point of view; (k) create more interest in the research field.

A particular research paradigm establishes itself in the researcher's point of view and the epistemological position that the researcher will take (Saunders et al., 2011). As a result, it is extremely important that the researcher has a crystal clear understanding of research paradigm underpinning their research (Hines, 2000). Several research paradigms can be used in Information systems and construction research to deliver new insights into real-life challenges and problems. According to Weaver and Olson (2006) research paradigms are "patterns of beliefs and practices that regulate inquiry within a discipline by providing lenses, frames and processes through which investigation is accomplished. Due to the existence of many research paradigms, positivism and interpretivism paradigms have been up-to-date receiving approval from researchers as being highly influential lenses through which to view the world of knowledge within the ICT and built environments research (Oates, 2005, Fellows and Liu, 2009). This because positivism focus on researching the natural world that we live in but have limitation to when it comes to the social world, however, interpretivism in information system research is concerned with social context of an information system. Moreover, majority of researchers in ICT and built environment concentrate on "proof-of-demonstration" that goes beyond designing and creation of information technology artefacts (Oates, 2005).

3.2.1 Positivism paradigm

Positivism was defined by Comte and Spencer (as cited in Corbetta, 2003), the founders of the discipline, as "*the study of social reality utilising the conceptual framework, the techniques of observation and measurement, the instruments of mathematical analysis, and the procedures of inference of the natural sciences*". According to Corbetta (2003) a conceptual framework represents: categories of 'natural law', cause and effect, empirical verification, explanation, etc. The instruments of observation and measurement include the use of quantitative variables, measurement procedures applied according to an ideological orientation, mental abilities, and psychological states. Mathematical analysis is the use of statistical, mathematical models. The procedure of inference in the natural sciences refers to the inductive process; the extrapolation from a research sample to the whole population. Positivism underlines the scientific method' applied in the natural sciences (e.g. physics, chemistry, biology) (Oates, 2005) emphasising statistics (Corbetta, 2003). In positivism, reality (knowledge) is immutable because it is governed. Therefore, the positivism paradigm employs theoretical groundwork as its primary investigative tool. Positivism also assumes that reality is researchable and objective, therefore its epistemology offers a deductive research design (Lincoln et al., 2011).

There are two versions in positivism paradigm: original and post positivism (Corbetta,

2003). In the middle of nineteenth-century researchers took positivism as the mode where Fact is the main focus for the researchers who adopt original philosophy (Bryman and Bell, 2011). The researcher whom adopts original positivism must be independent of the data. Moreover, the research adopting original positivism is undertaken in a value-free approach. (Gray, 2013). Researcher in this paradigm may possibly put together data employing existing theory to develop hypotheses the verification that leads to further development (Remenyi, 1998, Saunders et al., 2011). In contrast, in post positivism, the assumption of social reality is more flexible and relaxed than in original positivism (Alvesson and Skldberg, 2009). Reality continues to be the objective but in some way fallible (Corbetta, 2003). Original positivism appears like the traditional scientific approach, whereas post-positivism is a modern scientific approach which perceives a degree of uncertainty (Bryman and Bell, 2011). As a result, the knowledge is represented in the form of probabilistic law (Della Porta and Keating, 2008). Methodology remains inspired by a detachment between observer and observed object but qualitative methods are acceptable to critic and analyse hypotheses (Corbetta, 2003).

3.2.2 Interpretivism paradigm

According to Oates (2005), interpretivism paradigm defined as *“it is a philosophical stance which uses naturalistic methods and concentrates on holistic understanding of human being experiences in context-specific settings”*. Naturalistic methods involve observation of subjects’ behaviour in their natural environments without intervention. In this paradigm, objective and subjective are interdependent (Bryman and Bell, 2011). Moreover, an absolute reality does not exist it as there are multiple realities that vary in form and content amongst individuals, groups, and cultures (Corbetta, 2003). In other words, it assumes that the world can be investigated and explained, but not in terms of Statistics (Bryman and Bell, 2011). This viewpoint conveys the shared idea that life and the world are made up of different forms of reality recognised differently by different people (Stiles, 2003). The methodology in interpretive research focuses on value, meaning and purpose (Corbetta, 2003). Since this paradigm looks at the world as if through multiple perspectives, a vocal, illustrative, or explanatory definition could be useful and so its understanding should also be from multiple standpoints (Remenyi, 1998). As a result, the research technique would be qualitative and subjective, if the research aim is to understand the meanings that subjects attribute to their own actions (Creswell, 2013). The discovery will differ from case to case depending on the interaction between subjects and researchers (Creswell, 2013). So, understanding the social world of the studied subjects through their point of view is very important to the research (Corbetta, 2003, Saunders et al., 2011).

3.2.3 Pragmatism paradigm

Research paradigms help guiding the process of research. In some situations, however, selecting a single paradigm for application in the whole research can be impractical, due to the different characteristic and multi-dimensional categories of a single research. Paradigms help guiding research; but, in some situations selecting a single position amongst positivism, post positivism and interpretivism is quite impractical (Corbetta, 2003). For this reason, researchers may adopt pragmatism, as this paradigm is more appropriate for answering particular practical questions (Creswell, 2013). Pragmatists argue that the most determinant factor of a research philosophy is the research question (Creswell, 2013). This research paradigm applies a practical approach, integrating various viewpoints to assist in gathering and interpreting data (Saunders et al., 2011). Aforementioned paradigms treat a phenomenon as a collection of facts, whereas pragmatism paradigm provides meaningful knowledge in practice (Johnson et al., 2007). In this paradigm, researchers are free to manipulate their research environment to certain task. This suites the nature of knowledge and its practical dimension (Blosch, 2001). When a framework is developed based on pragmatic basis, it underlines a linkage amongst knowledge, context and practice. Thus, understanding this linkage provides workable plans for both practitioners and researchers to create knowledge-based organisation (Creswell, 2013).

With respect to research in organisational management, a pragmatic paradigm offers insightful context for handling the challenges related to organisational research and practice (Ruwhiu and Cone, 2010). A pragmatic research is not restricted to the question of how knowledge claims are validated, but rather explores alternative orientations (Creswell, 2013). Because of this, pragmatism paradigm provides diversity to organisational research and practice studies such as taking into consideration the consequences of actions (Ruwhiu and Cone, 2010). It is important to emphasise on that those research paradigms on investigating the world are highly significant, since research issues usually require a composite methodology that relies on more than one perspective (Denzin and Lincoln, 2008). According to Remenyi (1998), interpretivism and positivism can be taken as relevant paradigms, rather than two mutually exclusive paradigms. Therefore, this research adopts a composite philosophical approach by incorporating positivism, interpretivism and pragmatism paradigms. Theoretical underpinning this research is situated within interpretivism and positivism. Moreover, the practical work in this research is suited within pragmatism paradigm. Table 3.1 illustrates a comparison among research paradigm.

Table 3.1: Research paradigm characteristics adopted from (Corbetta, 2003, Saunders et al., 2011)

	Positivism	Postpositivism	Interpretivism	Pragmatism
Ontology	<ul style="list-style-type: none"> • Naïve realism: Social reality is 'real' and knowable (as if it were a 'thing') 	<ul style="list-style-type: none"> • Critical realism: Social reality is 'real' but knowable only in an imperfect and probabilistic manner 	<ul style="list-style-type: none"> • Constructivism: the knowable world is that of meanings attributed by individuals, groups and culture 	<ul style="list-style-type: none"> • Multiple view of reality chosen to best enable answering of research question
Epistemology	<ul style="list-style-type: none"> • Dualism-objectivity • True results • Experimental science in search of laws • Goal: Explanation 	<ul style="list-style-type: none"> • Modified dualism-objectivity • Results probabilistically true • Experimental science in search of laws • Multiplicity of theories for the same fact • Goal: Explanation 	<ul style="list-style-type: none"> • Non-dualism; non-objectivity. • Interpreting results • Interpretive science in search of meaning • Goal: Comprehension 	<ul style="list-style-type: none"> • Focus on research question • Dependent upon the research question • Integrating different perspectives to help interpret the data • Goal: answering of research question
Methodology	<ul style="list-style-type: none"> • Experimental-manipulative • Observation (observer-observed detachment) • Quantitative techniques • Analysis 'by variables' 	<ul style="list-style-type: none"> • Modified experimental-manipulative • Observation (observer-observed detachment) • Quantitative techniques with some qualitative • Analysis 'by variables' 	<ul style="list-style-type: none"> • Empathetic interaction between researcher and object studied • Interpretation (observer-observed interaction) • Qualitative techniques • Analysis 'by cases' 	<ul style="list-style-type: none"> • Mixed or multiple method design • Either or both observation and interpretation • Quantitative and qualitative • Either or both variables and cases

3.3 Research typology

Generally research has three main types: explanatory, exploratory, and descriptive (Creswell, 2013). Explanatory type of research has been found to be effective in investigating problems with a certain level of ambiguity in their organisation but have to be examined employing various kinds of expertise; for example the ability of a researcher in observing and then identifying some problems (Ghuri and Grnhaug, 2005). Exploratory research are significant in circumstances that need investigating particular levels of life and attempting to achieve some innovative conclusions regarding an existing phenomenon from a fresh perspective (Saunders et al., 2011). Differently, descriptive research can be very useful in showing up a transparent outline of certain occurring phenomena, therefore, this type of research needs systematic regulators to approach a problem (Saunders et al., 2011). Moreover, descriptive research address structurally organised problems very well (Ghuri and Grnhaug, 2005). Explanatory type research tends to examine causal interactions between various circumstances (Saunders et al., 2011). Henceforth, this re-

search fall within the explanatory and descriptive types of research, since it intends to investigate ICT and collaboration practices of BIM-based projects and the potential for the development of BIM governance solution underpinned by it Cloud Computing infrastructure.

3.4 Research approach

After selecting the research paradigm, the researcher then needs to adopt appropriate research methods, which are of three main kinds: **quantitative** (i.e. positivist research paradigm), **qualitative** (i.e. interpretative research paradigm), and **mixed-method approach** (i.e. combination of quantitative and qualitative) (Fellows and Liu, 2009, Saunders et al., 2011, Panas and Pantouvakis, 2011, Oates, 2005).

Choosing and selecting quantitative approach can be tracked back to the late twentieth-century (Creswell, 2013). Quantitative approach can be defined according to Polit and Beck (2004) as the investigation of phenomena that lend themselves to precise measurement and quantification, often involving a rigorous and controlled design. Further, Creswell (2013) states that quantitative research contains building and testing assumptions deductively. Quantitative is related to positivism and seeks to gather factual data in order to study the relationships between facts and how such facts and relationships accord with theories and the findings of any previous research (Fellows and Liu, 2009). Quantitative data are collected in a quantified (numeric) form which can be measured and analysed using statistical procedures (Polit and Beck, 2004). Results and conclusions are derived from evaluation of the outcomes in lights of the theory and literature (Fellows and Liu, 2009).

On the other hand, qualitative approach seeks to gain insights and gather peoples' perceptions (Fellows and Liu, 2009). This approach is commonly used in interpretivism research. Qualitative research is defined according to Polit and Beck (2013) as the investigation of phenomena, typically in-depth and holistic fashion, through the collection of rich narrative materials using a flexible research design. In qualitative research, peoples beliefs, understandings, opinions and views are investigated as a result the data may be unstructured (raw form) but very detailed and rich in content and scope (Fellows and Liu, 2009). This makes the analysis of data considerably difficult than quantitative, requiring a lot of filtering, sorting and classification to make these data appropriate for reporting (Fellows and Liu, 2009). Since qualitative research is a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem

(Creswell, 2013); therefore, the following instruments are typically used in qualitative research: interviews, observation, document analysis and case studies (Blumberg et al., 2008).

A number of research experts have an opinion that is a mixed-methods approach (triangulation) could be very advantageous thorough investigation (Oates, 2005, Fellows and Liu, 2009). Triangulation means using various research methods for various purposes within the same research investigation (Saunders et al., 2011). According to Bryman and Bell (2011) triangulation employs more than one specific research framework or data collection methods within the same study. Employing both approaches may reduce or eliminate disadvantages of each individual approach while gaining most benefits from using both of them together (Fellows and Liu, 2009). Mixed-method approach is increasingly selected as main research approach in various disciplines research (e.g. Management, Science and Engineering) (Peng and Annansingh, 2012, Azorn and Cameron, 2010). In the area of computing and engineering research, developing technological innovation does not only involve technical aspects but also social, legal and financial perspectives (Lethbridge et al., 2005).

According to Creswell (2013), data collection timing in mixed method may be in form of sequential, concurrent or transformative process. In sequential process, collecting both qualitative and quantitative data is done at the same phase. Either starts collecting qualitative data first followed by quantitative or vice versa. In concurrent process, qualitative and quantitative data are collected and analysed concurrently by the researcher. However, in concurrent form qualitative and quantitative data are concurrently collected and analysis giving equal priority to both data types, whereas, in sequential form the priority is to the collected data type at the first place. This kind of form gives equal priority to both types. Therefore, triangulation is very effective when investigating the research topic adopting several, alternative paradigms or methods (Fellows and Liu, 2009). Table 3.2 illustrates difference among afford-mentioned research approaches.

Table 3.2: Comparison among three research approaches adopted from (Creswell, 2013)

	Quantitative	Qualitative	Mixed-methods
Philosophical assumptions	<ul style="list-style-type: none"> • Postpositivism 	<ul style="list-style-type: none"> • Interpretivism 	<ul style="list-style-type: none"> • Pragmatism
Strategies	<ul style="list-style-type: none"> • Surveys • Experiments 	<ul style="list-style-type: none"> • Phenomenology • Case study • Narrative research 	<ul style="list-style-type: none"> • Sequential • Concurrent • Transformative
Data collection	<ul style="list-style-type: none"> • Closed-ended question • Predetermined approaches 	<ul style="list-style-type: none"> • Open-ended questions • Emerging approaches 	<ul style="list-style-type: none"> • Both open-and closed-ended question • Both emerging and predetermined approaches
Nature of data	<ul style="list-style-type: none"> • Performance data • Attitude data • Observational data • Census data 	<ul style="list-style-type: none"> • Interview data • Observation data • Document data • Audio-visual data 	<ul style="list-style-type: none"> • Multiple forms of data drawing on all possibilities
Data analysis	<ul style="list-style-type: none"> • Statistical analysis • Statistical interpretation 	<ul style="list-style-type: none"> • Test and image analysis • Theme, patterns interpretation 	<ul style="list-style-type: none"> • Statistic and text analysis • Across databases interpretation

3.5 Research instruments

This section will provide an overview of instruments used in this research. Followed by a detailed description regarding the research design.

3.5.1 Questionnaires

A questionnaire is a pre-defined set of questions (items), assembled in a pre-determined order prepared for respondents to answer the questions, thus providing the researcher with data that can be analysed and interpreted (Oates, 2005). They are frequently associated with the survey research strategy often questionnaire is sent out by post to a sample of people, who are asked to complete it and return it to the researcher or sometimes it is developed using web-based survey websites (Blumberg et al., 2008). Questionnaire can be used within other research strategies such as a interviews, case studies, action research or design and creation (Oates, 2005). This research instrument is widely used in research because they provide an efficient way of collecting data from a large number of respondents in geographically diverse locations (Lethbridge et al., 2005). Questionnaires obtain the same kind of data from a large group of people in a standardised and systematic way

(Fellows and Liu, 2009). It can be used with interpretive and critical research (Bryman, 2012). Questionnaires are widely accepted and used in the IS field as it has been used in many IS journals (Oates, 2005). In computing, a common use of a survey is in the user evaluation of a software system, although it must be said that many such surveys appear to have been tagged on at the end of system development since they are poorly designed and executed (Oates, 2005).

However, there are many advantages for using questionnaires in research reported in (Oates, 2005) that are: (a) to obtain data from a large group of people; (b) to obtain relatively brief and uncontroversial information from people; (c) needs to obtain standardised data, by posing identical questions to each respondent and pre-defining the answers; (d) can expect respondents to be able to read and understand questions and possible answers; (e) time and cost effective especially when using web-based questionnaires; (f) results of the questionnaires can usually quickly and easily be quantified by the researcher or through the use of an analytical software package; (g) results can be analysed more scientifically and objectively than other forms of research; (h) the quantified data can be used to compare and contrast other research and may be used to measure changes; (j) Positivists believe that quantitative data can be used to create new theories and/or test existing hypotheses.

On the other hand, according to (Lethbridge et al., 2005, Popper, 2005) questionnaires have some drawbacks: (a) ambiguous and poorly-worded questions could be problematic especially when the researcher is not there to clarify; (b) the targeted respondents may have no time to fully complete the questionnaire; (c) it is argued to be not suitable to understand some information forms (e.g. emotions, behaviour, feelings, etc.); (d) it lacks validity and is difficult to tell how truthful a respondent is being; (e) respondents might interpret each question differently and then reply based on their own understanding of that question, hence, does not acknowledge the level of subjectivity.

Several researchers have used questionnaires in BIM research for example: Khosrowshahi and Arayici (2012) have used mixed method including a questionnaire in order to establish a BIM implementation guidance at strategic and operational levels. Furthermore, they developed a roadmap for BIM implementation in the UK. Another example is the work done by Tsai et al. (2014) targeting Taiwan's AEC industry, where they proposed an approach for developing critical success factors (CSFs) that can be further extended to develop assessment of BIM adoption at organisational level in the AEC industry. Recent example can be seen through the work of Cao et al. (2015) where they examine current BIM practices in China, and assess how various practices alter their effectiveness. The

designed questionnaire has been hosted in SurveyMonkey (SurveyMonkey, 2014). It is a Cloud-based website that provides customisable surveys with data collection, analysis, reporting, and publishing features. Hence, the use of SurveyMonkey in this research has aid creating comprehensive questionnaire for GovernBIM platform, distributing questionnaire among BIM experts, and gather their responses to be analysed and interpreted.

3.5.2 Semi-structured interviews

An interview in research perspective is a particular kind of conversation between people but has a set of unspoken assumptions that do not apply to normal conversations (Oates, 2005). Usually, the researcher has a purpose for undertaking the interview, as s/he wants to gain information from targeted group of people (Oates, 2005). This means that the discussion does not occur by chance, but has been plan in some way by the researcher (Oates, 2005). There are three types of interviews: (a) structured interviews, contains pre-determined, standardised, identical questions for every interviews; (b) semi-structured interviews, a researcher have a list of themes to be covered and questions to be asked; (c) unstructured interviews, the research has less control over the conversation, as it start with introducing the topic and let the interviews develop their ideas (Oates, 2005, Fellows and Liu, 2009). Interviews are much used in case studies and ethnographies as well as with questionnaire as it used to obtain more detail about some questionnaire responses from BIM experts (Oates, 2005).

Oates (2005) stated that interviews are suitable data generation methods when the researcher wants to: (a) obtain detailed information; (b) ask questions that are complex, or open-ended, or whose order and logic might need to be different for different people; (c) explore emotions, experiences or feelings that cannot easily be observed or described via pre-defined questionnaire responses; (d) investigate sensitive issues or privileged information, respondents might not willing to write about on paper for a researcher that they have not met.

Furthermore, it has several advantages as reported by (Oppenheim, 1992, Remenyi, 1998, Bryman and Bell, 2011) that are: (a) it offers a freedom for interviewees to answer in their own way in their familiar language so they provide a natural response; (b) it encourages the interviewee to take time in giving detailed responses to questions and probes hence add more contribution to the discussion; (c) it allow the interviewee to share their own particular viewpoints; (d) it gives the researcher chance to bring fresh inquiries within the same interview based on the interviewee's replies; (e) it provides massive and rich data in the form of detailed responses.

On other hand, semi-structured interview is not devoid of drawbacks. According to (Brewerton and Millward, 2001) these drawbacks are: (a) it essentials that a well-trained researcher conduct these interviews; (b) it can take very long time in forming the discussion and data analysis; (c) many bias factors could effects its reliability. A semi-structured interview is the type used in this research to determine a set of questions to be investigated with regard to Cloud-based BIM governance platform development. This set of questions comprises major themes, topics, and areas related to the BIM governance research. Semi-structured interviews are chosen in particular for the following reasons: (a) there are not enough resources with respect to BIM governance solution; (b) the required information and knowledge are exists with the BIM experts; (c) the researcher is willing to change the questions order depending on the flow of the conversation, it is possible to ask additional questions if BIM expert brings up issues that has no prepared questions for; (d) allow the BIM experts to speak in more details on the issues that the research rise as well as introduce new issues that are relevant to the research theme (Oates, 2005).

Several researchers have adopted semi-structured in their research investigations. For example (Redmond et al., 2012) conducted a semi-structured interviews with 11 BIM experts to explore how information exchanges can be enhanced through Cloud BIM solutions. Also, Ren and Kumaraswamy (2013) conduct as study to Explore the conflicts between BIM and existing project processes in Hong Kong. Their work contributes to a proposal for developing measures to accelerate progress towards more collaborative processes for BIM implementation. Moreover, Ahmad Latiffi et al. (2014) conducted semi-structured interviews with BIM and Project consultants to explore BIM roles in the Malaysian construction industry. The results showed a positive effects using of BIM in construction projects and potential improvement in implementing BIM in construction projects in Malaysia. After conducting the interview, a transcription to the interview record must be made, because it is much easier to search and code through and analyse the data once it is in written form (Oates, 2005). The responses of interviews might be affected by the researcher role and identity e.g. the interviewees' answers might be different depending on what they think of the researcher. The researcher must aim to be professional, polite, punctual, receptive and neutral (Oates, 2005).

3.5.3 Case Study

Case studies are used as a tool for intensive description and analysis of a single individual or group with the aim of exploration and understanding of complex issues within their real world context (Zainal, 2007). It is a proper research method especially when

a holistic, in-depth investigation is needed (Zainal, 2007). Case study defined by (Yin, 2011) as An empirical inquiry about a contemporary phenomenon (e.g., a case), set within its real-world context especially when the boundaries between phenomenon and context are not clearly evident. As said by (Yin, 2011), there are three main reasons for choosing case study as a research methods: (a) if the research contains descriptive questions or explanatory questions; (b) the case study method favours other research methods in collecting data in natural settings by emphasising the study of a phenomenon within its real-world context; (c) when a researcher wants to conduct an evaluation study.

There are several advantages for using case studies in research reported in (Yin, 2011) that are: (a) it simplifies complex concepts by exposing the researcher to real life situations which can be sometimes difficult; (c) helps in add new knowledge to the researcher through discussion on concrete subjects; (d) aid the development of analytical thinking, communication, tolerance for difficult views on the same problem; (e) it offers the researcher an opportunity to innovate; (g) it might contain biases in data collection and interpretation.

On other hand, there are several drawbacks for case study reported in (Yin, 2011) that are: (a) it might be difficult to find an appropriate case study to suit all subjects; (b) Cases studies contains the study observation and perception of one person, thus, there are chance that the person presenting the case study may completely present it in one manner missing other aspects completely; (c) Case studies generally consume more time when compared to other instruments; (D) since there is no right answer, the problem arise in validation of the solution because there are more than one way to look at things; (e) it depends on the level of maturity of participants.

There are number of researchers whom adopted case study approaches within their investigation. For example, Barlish and Sullivan (2012) have adopted use cases in order to develop a BIM benefit measurement model via empirically measure data from Non-BIM and BIM projects and determine if the utilisation of BIM can be beneficial in construction projects. However, (Leon and Laing, 2013) investigated early design stages team collaboration with the support of Cloud Computing. Their case study focused on virtual collaboration and face-to-face conceptual design by utilising tactile and Tangible User Interfaces (TUIs). Information about the conceptual design stages is presented, together with the importance of those stages, and the analogue early design processes are translated into digital and Cloud based platforms, with the eventual application as a conceptual design plug-in tool for BIM. Another example can be seen through Chong et

al. (2014)’s explanatory case study where they reviewed and identified forty two Cloud Computing applications that are suitable in the built environment and. Based on their outcomes they built a decision-making model to assist interested parties in the built environment to select an appropriate and suitable Cloud-based application that best fits their needs.

Due to the lack in existing studies regarding ICT and collaboration practices especially with regard to managing collaborative environments. This research used case study method in order to model Cloud-based GovernBIM platform lifecycle using BPMN and UML.

3.5.4 Modelling

Modelling is process of designing software applications before coding (OMG, 2015). Henceforth, Modelling is a vital part of large software projects and very beneficial for medium and small projects. A model plays an independent role in software development that draft the software plans by software developers. By using a model, developers can make sure that the business functionality of their software system is complete, correct, and end-user requirements are met. Hence, programmed software design supports requirements for scalability, robustness, security, extendibility, and other characteristics, before coding stage. This helps to avoid expensive errors, difficult changes during the implementation stage (OMG, 2015). According to (List and Korherr, 2006) there are many modelling languages, however, the following are the most domain in modelling field: Unified Modelling Language (UML) (OMG, 2015), Business Process Definition Meta Modelling (BPDM) (OMG, 2008a), Business Process Modelling Notation (BPMN) (OMG, 2008b), Event Driven Process Chain (EPC) (Mendling, 2008), Integrated DEFinition Method 3 (IDEF3) (Mayer et al., 1995), Petri Net (Peterson, 1977), and Role Activity Diagram (RAD) (Ould and Ould, 1995). Table 3.3 provides a comparison among common modelling languages.

Several studies show that large software projects have massive probability to fail, because most of these projects failed to meet all of its requirements within the agreed time and budget (Lehtinen et al., 2014). However, modelling and visualising the design of the software project and checking it against its requirements before coding will minimise the risk of failure as well as it aids the project development by allow working on higher level of abstraction (Voightmann, 2004). This can be achieved by hiding smaller details and focus on the big picture or highlighting on unique aspects of the prototype (OMG, 2015).

There are many researchers whom have used BPMN and UML in Cloud Computing and

Table 3.3: Comparison among different modelling languages (adopted from (List and Korherr, 2006))

	Modelling languages					
	UML	BPMN	IDEF3	EPC	Petri Nets	RAD
Purpose	Description, Enactment	Description, Enactment	Description	Description, Analysis	Enactment	Description
Source domain	Software Engineering	Process Engineering	Software Engineering	Process Engineering	System Engineering	Software Engineering
Execution language	BPEL4WS	BPEL4WS and BPML	None	EPML, academic proposal	PNML, academic proposal	None

built environment research. For example, the work conducted by Schmidt (2012) used UML to create a conceptualisation for Cloud-based information systems' lifecycle. Their work aimed to provide (a) static view on Cloud-based information systems' lifecycle, and (b) dynamic view on Cloud-based information systems' lifecycle. Another example can be seen through the work conducted by Zhang et al. (2013) where they used BPMN-based process map to represent the project stakeholders, project phases, and information exchange between them i.e. process map for construction safety planning and operation. However, the study conducted by Lopez-Campos et al. (2013) used a combination of both BPMN and UML in proposing an e-maintenance integration platform that combines the features of the three main systems that are: (a) Computerised Maintenance Management Systems (CMMSs), (b) Condition Based Maintenance (CBM) systems and (c) the application of Reliability Centred Maintenance (RCM) system. However, since the development of Cloud-based GovernBIM platform involve process and software modelling, BPMN and UML will be both chosen as the main modelling approaches used in this research. Therefore, BPMN and UML are discussed in more details as follows:

A. Business Process Modelling Notation (BPMN)

Object Management Group (OMG) is founder and the developer of BPMN, it initial developed by a consortium of process modelling vendors in 2003 and further developed until in 2006, when it finally released as an OMG standard (White, 2004). The main purpose of using BPMN is to help businesses understand their internal processes by allowing business decision makers see their processes without regard to how a particular solution constrains the problem domain (OMG, 2008b, Chinosi and Trombetta, 2012). The power of using BPMN in the system development context is it has the ability to capture business process information without an existing information system initiative as well as it support such an initiative by providing rich contextual information about

the targeted domain (Flowers and Edeki, 2013). However, BPMN diagrams have several elements that are classified into four main categories. The following table 3.4 provide on an overview over main BPMN elements:

Beside the use of BPMN, UML is used in this study to model the internal and external structure of Cloud-based BIM governance platform in more details.















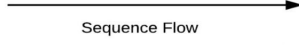
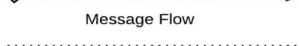
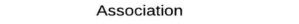





B. UML 2.0

UML has been embraced as the standard modelling language for modelling software systems (Bendraou et al., 2010). It helps to specify, visualise, and document models of software systems, including internal and external structure and design, in a way that meets all of system requirements. It was defined to model the architecture of software systems. However, it also can be used for business modelling and modelling of other non-software systems (OMG, 2015). Although software systems and business are similar, there are some differences; Business systems have several concepts that are never intended to be executed in a software program (e.g. people, production machines, rules and gaols). However, since UML initially was designed to describe characteristics of a software system, it needs to be extended to clarify and cover more concepts of process, goals, resources, and rules of business systems (Eriksson and Penker, 2000) therefore BPMN is used for that reason. Modelling by using UML allows the researcher to zoom out from a detailed view of an application to the hosting environment where it executed, providing a visualisation of application's connections to other applications. Moreover, the researcher can focus on different aspects of the application, e.g. its automotive business process, or viewing its business rules. According to (OMG, 2015), UML 2.0 there are nearly thirteen types of UML diagrams. It is divided into three following categories:

- **Structure Diagrams:** include the following diagrams: class diagram, object diagram, component diagram, composite structure diagram, package diagram, and deployment diagram.
- **Behaviour Diagrams:** include the Use Case diagram (used by some methodologies during requirements gathering), activity diagram, and state machine diagram.
- **Interaction Diagrams:** It is derived from the general Behaviour Diagram, include the sequence diagram, communication diagram, timing diagram, and interaction overview diagram.

There have been several efforts that have adopted Object-oriented modelling using UML in their investigation e.g. (Lucas et al., 2013, Clune et al., 2012). However, the use of UML in this Ph.D. research is to describe the internal design and functionalities of

Table 3.4: Detailed description of BPMN elements

BPMN elements	Sub-elements	Description	Shape
Flow Objects (These are the chief graphical elements that define the behaviour of the processes)	<i>Events</i>	It represents an event happens in the during the business process. It affects the process flow and usually has a cause and a result. BPMN contains many ways of starting or ending the process; hence, there are different types of starting events, end events and intermediate events.	 Start  Intermediate  End
	<i>Activities</i>	It represents the work that is carried out as part of a business process. Sometimes activities could be complex, and multiple, therefore, there exists two types of activity: Task, Sub-processes	 Task  Sub-Process  Transaction  Call Activity
	<i>Gateways</i>	It represents elements are used to control the divergence and convergence of the flow. There are 5 main types of gateways: Exclusive Gateway, Gateway Based on events, Parallel Gateway, Inclusive Gateway and Complex Gateway.	 Exclusive  Event Based  Parallel  Inclusive  Exclusive Event Based  Complex  Parallel Event Based
Connecting Objects		It represent elements that are used to connect two objects in the process flow. There are 3 types of connection objects: Sequence Lines, Association, and Message lines.	 Sequence Flow  Message Flow  Association
Swim Lanes	<i>Pool</i>	It represents a participant in a process. It is also acts as a graphical container for partitioning a set of activities from other pools.	
	<i>Lane</i>	It represents a sub-partition within a Pool and will extend the entire length of the Pool, either vertically or horizontally. It is used to organise and categorise activities.	
Artefacts		It represents elements that provide additional information about the process. There are three types in general: data objects, group, and annotations.	 Data  Annotation  Group

GovernBIM platform in greater details. Several use cases will be modelled via the use of UML use case diagram. Moreover, Class diagram is used to describe the internal structure of GovernBIM platform.

C. Visual Paradigm

Visual Paradigm for UML (VP-UML) is a modelling software support creating and developing BPMN, and UML diagrams. In addition to modelling support, it provides report generation and code engineering capabilities including code generation. It can reverse engineer diagrams from code, and provide round-trip engineering for various programming languages. As a modelling tool consider the best modelling tool that has capability to develop model various software solutions. It has been several editions, starting from community version for free to enterprises level with high cost. Higher price editions provide more features. Visual Paradigm is the main tool used to create GovernBIM platform BPMN and UML diagrams in the requirements and specifications stage. There are many modelling approaches used for data modelling.

3.5.5 Prototyping

Prototyping is the activity of creating software prototype that represents an incomplete version of the developed software platform as it typically simulates a few functionalities the final software product and in some cases a complete version of the product (Pomberger and Weinreich, 1994). Kordon (2002) defines prototyping as an executable model of a system that accurately reflects a chosen subset of its properties, such as display formats, computed results, or response times. Prototypes are useful for formulating and validating requirements, resolving technical design issues, and supporting computer-aided design of both software and hardware components of proposed systems.

According to Sommerville (2007), prototype process involve four main stages: (a) Establish prototype objectives: Determine basic objective for developing a prototype as the same prototype cannot meet all objectives. If the objectives are left unstated, management or end-users may misunderstand the function of the prototype: (b) Define prototype functionality: include decisions on what functions to put into and what to leave out of the prototype system. To reduce prototyping costs and speed delivery of final product, the researcher should leave some non-functional requirements (e.g. response time and memory utilisation). As well as ignore error handling and management may be ignored or kept simple unless the objective of the prototype is to establish a user interface. (c) Develop initial prototype: initial prototype includes user interfaces and implements selected func-

tions; (c) Evaluate and enhance the prototype: In this step the end-users examines the prototype and provide feedback on additions or changes in order to improve the prototype.

According to Sommerville (2007), there are several advantages of using prototyping in IS research. These advantages are: (a) development team can receive valuable feedback from end- users early phases of software project which leads to a better solution; (b) end-users can check whether the developed software matches their needs and requirements; (c) it allows the developer to detect errors much earlier; (d) difficult or missing functionality can be identified easily; (e) it assists in validating end-users requirements via a quick implementation of incomplete but functional software.

According to Sommerville (2007), there are several drawbacks of prototyping: (a) it leads to implementing and then repairing systems thus this methodology may increase the complexity of the system as scope of the system may expand beyond original plans; (b) Incomplete or inadequate problem analysis as this leads to a partial software solution; (c) It can be time consuming if end-users continuously test prototype after another one, or if developers seeks perfection as they will spend too much time in fixing small details in a prototype that will might be thrown away.

In this research, the use of prototyping is for testing and validating the results obtained from other previous stages e.g. requirement analysis, BPMN and UML diagrams, etc. Goolge Cloud infrastructure is chosen to form the development environment for Govern-BIM platform prototype.

3.5.6 Software development lifecycle (SDL)

SDL used in developing computer-based systems. Both SDL and research are concerned with create something new (Oates, 2005). SDL is defined by Ruparelia (2010) as a conceptual framework or process that considers the structure of the stages involved in the development of an application from its initial feasibility study through to its deployment in the field and maintenance. Mainly, SDL has four main stages: analysis, design, implementation, and testing. Analysis stage involves analysis of current systems, if it exists, if not analysis of proposed system and produce requirements and specification documents based on the clients briefs. Normally, this document includes objectives of the proposed system. The design stage, include planning and designing the proposed system initially on high level, then moving to more detailed levels of the system. The implementation stage follows the design stage, which involve the development of the software i.e. writing API codes and interfaces as webpages. This stage is followed by testing stage involving

evaluating the produced system to check whether it met the initial requirements and specifications or need further development (Oates, 2005). Nonetheless, there are several software development models: waterfall model, spiral model, incremental model, iterative model and others (Ruparelia, 2010). Table 3.5 compares main SDL models and shows advantages and disadvantages of each one of them.

Reflecting on previous comparison, this research adopted an iterative approach for developing Cloud-based BIM governance platform in combination of a prototype development. This due to the major requirements must be defined; however, some functionalities or requested enhancements may evolve with time. There is a time constraint to complete the first prototype. Moreover, developing Cloud platform is as new technology being used and is being learnt by GovernBIM development team while working on the project. Further, there is a lack in BIM governance aspects' resources and needed skill set are not available and are planned to be used on contract basis for specific iterations.

3.6 Research ethics

The nature of any conducted research involves some ethical principles that guide the research from its conceptual stages, fieldwork until final interpretation and analysis of the outcomes (Marshall and Rossman, 2010). According to Fellows and Liu (2009), several ethical need to be considered while carrying out research such as, quality and integrity, confidentiality of collected data; participation be informed about the purposes of the research and their participation should be voluntary; and their anonymity should be respected. The researcher (I) was totally aware of these research principles; therefore in this Ph.D. research study I have complied with the ethical guidelines. In other words, Cardiff University has a Research Ethics Committee that deals with the ethical issues of any given research. In compliance with the requirements of this committee, this study has submitted detailed methodological information to the Research Ethics Committee of the Cardiff School of Engineering. Then Ethical approval has been obtained from Cardiff University.

At the beginning of this study, a pre-investigation with a leading construction company has been made. This investigation emphasised on the urgent need for developing a BIM governance solution. The results obtained from initial investigation alongside theoretical study led to the development of a comprehensive questionnaire targeting BIM Experts. This stage provided potential participants with detailed information about their role in this work and helped the researcher to identify the most motivated participants who are

Table 3.5: Comparison between different SDL models (Adopted from (Sommerville, 2007))

SDL Model	Application,(when to use)	Advantages	Disadvantages
Waterfall model	<ul style="list-style-type: none"> Requirements are clear, fixed, well documented Requirements are not ambiguous Final project has stable definition The development technology is not dynamic and is understood by developing team Sufficient resources with required expertise are available to support the project development Development time is short 	<ul style="list-style-type: none"> Ease to understand and to use. Easy to manage due to the inflexibility of the model – each phase has particular deliverables and a certain review process. Each phase is clearly defined. Each phase is processed and completed before next one. Convenient for small projects where requirements are well understood Tasks are easy to arrange Development process and results are well documented 	<ul style="list-style-type: none"> Extreme amounts of risk and uncertainty Not suitable for complex and object-oriented projects. Insufficient model for long and on-going projects. Not appropriate for projects moderate requirements or have high risk of changing. It is hard to measure progress within phases. Changing requirements cannot be accommodated. Scope adjustment during the life cycle cloud end the project
Spiral model	<ul style="list-style-type: none"> Suitable for medium to high-risk projects Suitable for long-term projects due to potential changes to budget and as requirements with time Suitable for new products, which should be released in phases to get enough feedback form customers Budget has constraint and evaluating risk is important Client is not certain of their requirements Requirements are complex and need further evaluation to get clarify Substantial changes to final product are expected during the development cycle 	<ul style="list-style-type: none"> Can accommodate changing requirements Extensive use of prototypes Accurate capture of the requirements Final product cloud be seen in early phases. Development process cloud be divided into smaller parts. Better in risk management through 	<ul style="list-style-type: none"> Managing development process is more complex Development process is complex End of project cloud not be set in earlier phases Can be expensive for small projects Not appropriate for small and low risk projects Spiral may be indefinitely A number of intermediate phases between main phases are required that needs intensive documentation
Iterative model Or (Incremental model)	<ul style="list-style-type: none"> Requirements of the complete system are understood and clearly defined however, major requirements must be defined More functionalities or requested enhancements cloud evolve during the development time. There is time constraint When a there is a need to learn new technology by developing team during the project lifecycle. There is lack of resources and skills that are needed for specific iterations There are some high-risks with regards to feature and goals that might change in the future 	<ul style="list-style-type: none"> Some fully working functionality can be developed quickly in early phases. Results can be obtained earlier and periodically during lifecycle Accommodate planning for parallel development Development progress can be measured Cost less when scope or requirement are changed Ease to test and debug product during small iteration Easily identify, mange, resolve risks during iterations Easy to manage development process A product is delivered at the end of each iteration. Problems, challenges and risks are identified from each iteration cloud be resolved in the next iteration Appropriate for changing requirements Suitable for large and critical projects 	<ul style="list-style-type: none"> It requires more resources It requires more attention to management aspects Issues with regard to system architecture and design might arise because all requirements are gathered at the beginning of the entire lifecycle Definition of iterations might require a definition of the complete system Not appropriate for small projects Complexity management is very difficult There is a risk of not knowing when the project is finished High skilled developing team is required. High risk analysis should be performed Development progress dependents on risk analysis phase.
V-Model	<ul style="list-style-type: none"> Requirements are clear, fixed, well documented Requirements are not ambiguous Final project has stable definition The development technology is not dynamic and is understood by developing team The development time is short 	<ul style="list-style-type: none"> Highly disciplined model and each phase is processed and completed before next one. Suitable for smaller projects that have well understood requirements Ease to understand and to use. Easy to manage due to the inflexibility of the model – each phase has particular deliverables and a certain review process. 	<ul style="list-style-type: none"> Extreme amounts of risk and uncertainty Not suitable for complex and object-oriented projects. Insufficient model for long and on-going projects. Not appropriate for projects moderate requirements or have high risk of changing. It is difficult to go back and change final product functionalities once it reach testing stage Final product is not produced until late stages of development lifecycle

voluntarily interested and willing to contribute positively to this work. During the data collection stage, questionnaires were sent to the experts who had previously accepted the invitation and who had agreed to participate. An adequate period of time were given

to the participants to receive back their responses. Both consultation stages included: (a) the purpose of the study; (b) examples of how to complete the questions; and (c) a guarantee of anonymity and confidentiality. More importantly, the choice of BIM experts is done based on several criteria: sufficient practical experience of BIM; adequate knowledge of data management; and willingness to participate, common construction culture. The collected data were analysed using Analytical Statistical programs such as MS Excel and SPSS in order to achieve reliable results.

As questionnaire instrument assisted us with quantitative data with regard to BIM governance solution, there is a need for further investigation to obtain more detailed information concerning some of the questions. Thus, a qualitative instrument i.e. semi-structured interviews used. The same criteria for choosing BIM experts in questionnaire are used in choosing them in the interview but with more focus on getting the same participated Experts in the questionnaire. The interpretation and analysis of the collected data involves is done based on code pattern analysis.

The overall results consisting of: (a) BIM governance solution requirements, (b) G-BIM framework, and (c) the analysis process of collaborative environments in three selected companies that adopt BIM as a collaborative approach, supported the development of the underlying BPMN and UML diagrams of Cloud-based BIM governance platform. The use of modelling tool i.e. Visual paradigm added more reliability to the developed diagrams though its quality checking function making sure that the modelling rules are correctly applied. Moreover, a review of the existing software oriented architectures and software design patterns facilitated building the software architecture for practical implementation of the GovernBIM platform. Eventually, the proposed BIM governance solution was subjected to a validation process which involves technical implementation of GovernBIM platform prototype underpinned by Cloud infrastructure i.e. Google. Further, a proper validation stage is conducted with several BIM experts, company representatives, and computer scientists in order validate the final outcomes of BIM governance research.

3.7 Research methodology adopted in this study

This research uses a combination of a software engineering iterative approach and prototyping to investigate and develop theoretical and practical parts of Cloud-based BIM governance platform. Thus, this research consists of seven stages as earlier shown in Chapter 1 Figure 1.1. These stages are interrelated and are not sequentially as at some points a revisit to previous stages is required in order to be updated and corrected.

However, these are explained below in more details:

- **Stage 0:** This stage includes conducting a literature review, initial investigation on the existing solutions, brainstorming as well as identifying and agreeing on the suitable research instruments for this research. As well as identifying potential research instruments to be used during the investigation process. The finding of this stage contributes to the following stage
- **Stage 1:** In order to collect primary data for developing Cloud-based BIM governance solution, this stage includes development of a comprehensive questionnaire followed by semi-structured interviews targeting UK construction practitioners and BIM experts. Moreover, one of outcomes of this stage is the factors scheme for successful BIM governance.
- **Stage 2:** The outputs of previous stages will form input into this stage. This stage includes definition of specifications for Cloud-based BIM governance platform via converting the collected data from the three cases studies into several visualised BPMN and UML diagrams i.e. (Use cases and Class diagrams) using VisualParadigm modelling software (VisualParadigm, 2014).
- **Stage 3:** The gathered requirements are then analysed by using a requirements engineering approach (Sommerville, 2007). This stage involve specifying a solution for BIM governance model i.e. Cloud-based BIM governance conceptual model and BIM governance solution implementation architecture. However, a review of existing Software-as-service architecture and design patterns is conducted before designing and agreeing by the researcher on the best architecture for developed solution.
- **Stage 4:** This stage involves a prototype implementation for BIM governance solution based on the selected Cloud Computing technology. In this stage the researcher have adopted Google Cloud infrastructure in order to develop and test GovernBIM platform.
- **Stage 5:** This stage involves an evaluation of outcomes as well as the developed prototype for the Cloud-based GovernBIM platform through varies testing and evaluation techniques.
- **Stage 6:** This stage involves taking follow up actions based on the outcomes and results from the previous stages. Also, in this stage documentation is done in order to keep a record and track changes made to the platform. This includes future work necessary to improve the outcomes as well as the developed platform functionalities.

3.8 Summary

As developing Cloud-based BIM governance platform consist of complex social-organisational interactions, understanding ICT and collaboration practice of team during a construction project, there is a need for a research approach that is flexible enough to compromise workable methods. Therefore, the mixed-method could be an appropriate approach. Furthermore, a mixed-method approach is underpinned by pragmatism philosophy, which holds that research always occurs in social and other contexts. The questions asked by pragmatists are not about reality and the law of nature aspects, but they look to different aspects mixing between quantitative and qualitative approaches in order to gain the best understanding of research problem (Creswell, 2013).

Furthermore, since this research involves the study of BIM governance, ICT and collaboration practices in construction industry, and Cloud Computing technologies, the major techniques employed are: comprehensive questionnaire, semi-structured interviews, and examination of relevant documentation and software packages to determine the details of the system and to investigate the need for the development of a Cloud-based BIM governance solution; therefore, the present research study will employ both qualitative and quantitative research techniques as a mixed-methods approach. The very reason for choosing these techniques for this research is to explore and understand the BIM understanding, its adoption barriers, ICT and team collaboration practices and identifying the potential of BIM governance model development. Moreover, in order to develop Cloud-based BIM governance platform, the researcher will pursue the general overview of construction projects and how the team are collaborating from the beginning of a construction project up until the team is disseminated. This will include examine existing collaboration software and management data practice such as documents describing policies, and rules and regulations for the management of construction project team, will be considered.

Research methodology is a very vital element to the research study, as it assists a plan and a guide for the researcher to achieve his research aims and objectives. This chapter presented the underpinning methodology to this research that contains a discussion on the following: research philosophy, research questions, research design, method of research and research strategies. The whole methodology can be summarised as follows: (a) research philosophy: interpretive and pragmatism, (b) research approach: inductive, (c) research strategy: analysis, process modelling, and prototyping strategies (d) type or research: explanatory and descriptive, (e) method of research: mixed-methods, (f)

techniques and procedures: data collection, analysis and modelling, (g) Underpinning software development lifecycle: An iterative approach supported by prototyping. Table 3.6 provides a summary of overall methodology used in this Ph.D. study.

Table 3.6: Summary of adopted research philosophies and approaches in this study

The current adopted approach	
Research philosophy	Interpretive and Pragmatic
Research approach	Inductive
Strategies	Analysis and modelling process strategies
Type of research	Descriptive and explanatory
Research methods	Mixed-methods, software development lifecycle (SDL)
Techniques and procedures	Data collection, analysis and modelling using BPMN & UML, prototyping
Software development lifecycle	Iterative approach, prototyping

BIM experts' consultation for developing BIM governance solution

4.1 Introduction

The aim of this chapter is to contextualise the current ICT and collaboration of team members during construction projects, besides it investigate the need for a BIM governance model as well as identifying its requirements. Specifically, it also investigate further the case for developing a BIM governance model for that purpose, by (a) exploring the current ICT and collaboration practices of construction team members, (b) discovering the barriers to BIM adoption in the construction industry, (c) highlighting common collaboration problems in BIM-based projects, (d) identifying BIM experts' successful factors for developing a BIM governance model, and (e) exploring the potential role of Cloud in underpinning that model.

A comprehensive questionnaire followed by semi-structured interviews with informed BIM experts in the UK were conducted. Firstly, the purpose of the questionnaire is to: (a) identifying socio-organisational, legal, financial, and technical barriers to BIM adoption; (b) exploring current practices of ICT and collaboration, communication and coordination during construction projects; (c) highlighting issues with generated data during a construction project with the role of cloud technology towards addressing such issues, and; (d) identifying the need for developing a BIM governance model and exploring its requirements for developing such a model. Secondly, it argues that the development of the BIM governance model with its cloud infrastructure will minimise such concerns and thus facilitate team collaboration during a construction project. Therefore, semi-structured interviews with informed BIM experts in the UK was the followed stage, aiming at: (a) discovering the current status of ICT and team collaboration during a construction

projects; (b) exploring BIM adoption barriers with with respect to team collaboration; (c) exploring BIM-related standards roles; (d) examining the need for a BIM governance approach to tackle team collaboration on BIM-based projects; and (e) investigating the role of using cloud in supporting BIM governance model development.

This chapter has been organised to include the presentation of findings of both two stages questionnaire and semi-structured interviews supported by a detailed discussion on BIM adoption, ICT and collaboration practices, BIM related standard and the major requirements and aspects of developing BIM governance solution.

4.2 Demographic information of participated BIM experts

This section shows information of participated BIM experts in this study. It first shows information of BIM experts whom participated in the questionnaire, followed by information of BIM experts whom took place in the semi-structured interviews.

4.2.1 BIM experts' background participated in questionnaire

Practitioners in the construction industry in the UK were the main contributors to the resulting questionnaire. Demographic and work related characteristics of the respondents are given in Table 4.1. Among 118 respondents, 107 (93.04%) were male and (8%) were female. At the time of the questionnaire, the majority of respondents have been working in the construction industry for more than 20 years 29.57%. The majorities of respondents have graduated from college and have higher qualifications 72.5%. Nearly 58.5% of respondents works in companies aged more than 30 years, while others work in companies aged less than 30 years. At least 1.1% of each discipline has participated in this study. However, BIM managers and architects are the heavy contributors with 33.7% and 32% respectively.

Table 4.1: BIM experts background

Variable	Scale/Category	N	%
Age (yr)	18–21	2	1.7
	22–25	15	13.04
	26–30	20	17.39
	31–35	16	13.91
	36–40	17	14.68
	41–45	17	14.68
	46–50	15	13.04
	>51	13	11.30
Gender	Male	107	93.04
	Female	8	6.96
Work experience (yr)	<1	8	6.96
	1–5	18	15.65
	6–10	30	26.09
	11–15	15	13.04
	16–20	10	8.70
	>20	34	29.57
Qualification	College/Pre-university	12	10.62
	Vocational/Technical	27	23.89
	Undergraduate	44	38.9
	Postgraduate taught	34	30.1
	Postgraduate taught	4	3.5
Company age (yr)	1–10	19	17.9
	11–30	25	23.6
	>30	62	58.5
Occupation	Architect	29	32.6
	Building Surveyor	1	1.1
	BIM Manager	30	33.7
	Civil Engineer	6	6.7
	Client	1	1.1
	Client Advisor	2	2.2
	Contractor	5	5.6
	Electrical Engineer	1	1.1
	Facility Manager	1	1.1
	Non-Disciplinary	1	1.1
	Geographical & Land Surveyor	1	1.1
	Health & Safety Consultant	1	1.1
	Heating & Ventilation Designer	3	3.4
	Information Manager	6	6.7
	Interior Design	2	2.2
	IT Technician	5	5.6
	Mechanical Engineer	6	6.7
	Project Manager	8	9
	Public Health Engineer	1	1.1
	Quantity Surveyor	4	4.5
	Specialist Designer	3	3.4
	Structural Engineer	3	3.4
	Others	33	27.9

4.2.2 BIM experts participated in semi-structured interviews

The initial investigation of related studies as well as the questionnaire outcomes emphasised on conducting an in-depth investigation with BIM experts. The interviews were designed to target BIM experts, including BIM academics, BIM practitioners and BIM technicians. The expert panel were chosen based on the following the criteria: willingness to participate, background and experiences in the construction industry (specifically

with BIM), and their tangible efforts using BIM (e.g. BIM-based projects and BIM publications). The BIM experts were interviewed according to individual preference, using: face-to-face, and via an online communication tool i.e. Skype. The interviews were held in different locations in the UK including: London, Leeds, Birmingham, Liverpool, Cardiff and Loughborough. Table 4.2 displays the BIM experts' backgrounds.

Table 4.2: BIM experts' demographic information

	No.	BIM Expert	Position	Experience in construction/BIM (years)	Place of the interview	Interview approach
BIM Academics / Researchers/Clients	1	Academic	Professor of architectural design	More than 40	Cardiff	Face-to-face
	2	Academic	Professor of sustainability, client, contractor	More than 40	Cardiff	Face-to-face
	3	Academic	BIM researcher	More than 20	Loughborough	Face-to-face
	4	Academic	BIM researcher	More than 10	Loughborough	Face-to-face
BIM Professionals / Construction Practitioners	5	Practitioner	Architect & CAD/BIM manager, consultant	More than 15	Cardiff	Face-to-face
	6	Practitioner	BIM manager, structural engineer	More than 17	Birmingham	Face-to-face
	7	Practitioner	UKMEA BIM implementation manager	More than 15	Leeds	Face-to-face
	8	Practitioner	Structural technician, BIM co-ordinator	More than 13	London	Face-to-face
	9	Practitioner	Architect, BIM manager	More than 8	London	Face-to-face
	10	Practitioner	Building Physics/Environmental Engineer	More than 22	Glasgow	Skype
	11	Practitioner	Environmental design of buildings, building simulation & optimisation	More than 10	London	Skype
	12	Practitioner	Civil engineer	More than 10	Birmingham	Skype
Technicians/IT Managers /Software Developers	13	Technician	Chartered engineer, software specialist	More than 20	Leeds	Face-to-face
	14	Technician	Technical director	More than 23	Liverpool	Skype
	15	Technician	BIM developer, collaboration software solution	More than 4	London	Face-to-face
	16	Technician	Technical manager	More than 27	London	Skype
	17	Technician	SaaS IT specialist	More than 27	London	Skype
	18	Technician	Projects' document manager	More than 7	Cardiff	Face-to-face

4.3 Findings and discussion

This section highlights the most significant findings from the conducted questionnaire and semi-structured interviews. It presents the combined findings in the following order: (a) collaboration and ICT practices during typical construction projects; (b) BIM adoption barriers and teams' data management issues; (c) role of collaborative BIM related standards in BIM governance; (d) experts' functional, non-functional, and domain specific requirements in developing BIM governance solution (i.e. GovernBIM platform); (e) role of Cloud technologies in supporting BIM governance solution; and finally (f) factors for effective BIM governance solution framework (G-BIM).

4.3.1 Collaboration and ICT practices during typical construction project

As construction projects involve multi-discipline, multi-actor collaboration during the project lifecycle, results from the questionnaire also explored the current ICT and collaboration practices among the team on typical construction industry projects. The following subsections demonstrates these practices during a typical construction project:

A. Responsibility of maintaining collaborative environment

Setting up, maintaining a team collaboration environment is a very important task on collaborative construction projects. Figure 4.1 shows that most respondents agreed that project managers are responsible for preparing the construction project's collaborative environment 46%. However, nearly same percentage 45% agreed that the responsibility of this is varies from one project to another. Only a small percentage agreed that setting up the project environment is an IT manager's responsibility. With the adoption of BIM in construction projects, the need for a dedicated BIM manager becomes crucial, as the majority of construction respondents agreed by 80%.

B. Used software for project management & planning

Management and planning software are critical tools for planning and managing construction projects. Figure 4.2 shows that the majority of respondents are using Autodesk Navisworks for managing their construction projects 71.3%, followed by Microsoft packages (MS Word, MS Excel) by 55%. However, the use of Primavera and Solibri is almost the same. Small percentages 2.5% of respondents only use Sage Masterbuilder. The high percentage of using Navisworks compared to others is due to its up-to-date functions that support BIM implementation and review.

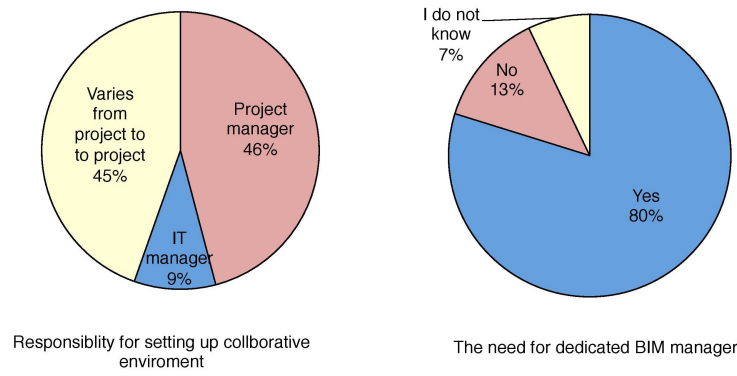


Figure 4.1: Responsibility of maintaining a project's collaborative environment

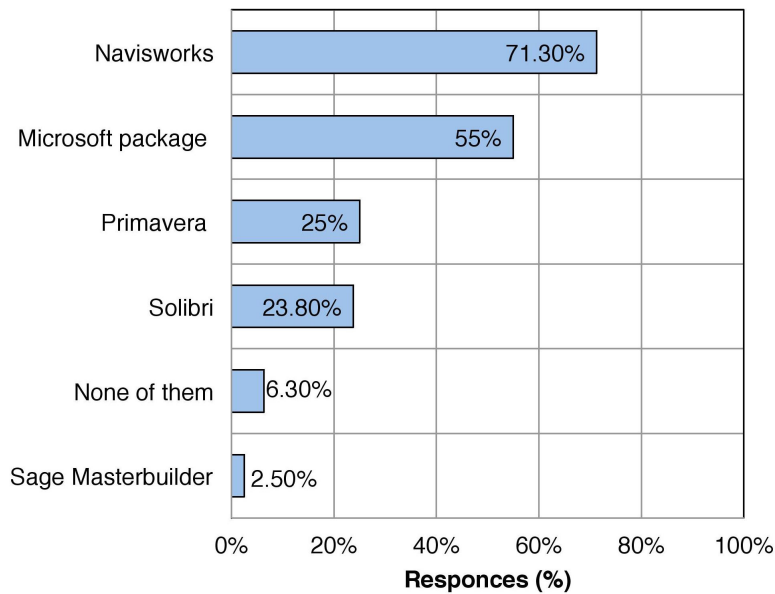


Figure 4.2: Used software for project management & planning

C. Used models for design & construction process

Most construction companies adopt a process models to facilitate work on the project. However, due to the UK governments' aim of using BIM as a fully collaborative delivery system, many organisations such as Royal Institute of British Architects (RIBA) and Construction Industry Council (CIC) are working towards this goal by improving their models of work plans. Figure 4.3 shows the used model for design and construction on typical UK construction projects. It demonstrates that the RIBA plans of work with its different versions (Outline Plan of Work (RIBA, 2007), BIM Overlay (Sinclair, 2012), and Plan of Work 2013 (RIBA, 2013b)) are used more than (CIC, 2013). In addition, the figure illustrates that some construction companies are still using RIBA Plan of Work 2007, there is a rapid adoption of newly released project lifecycles, such as RIBA's Plan of Work 2013.

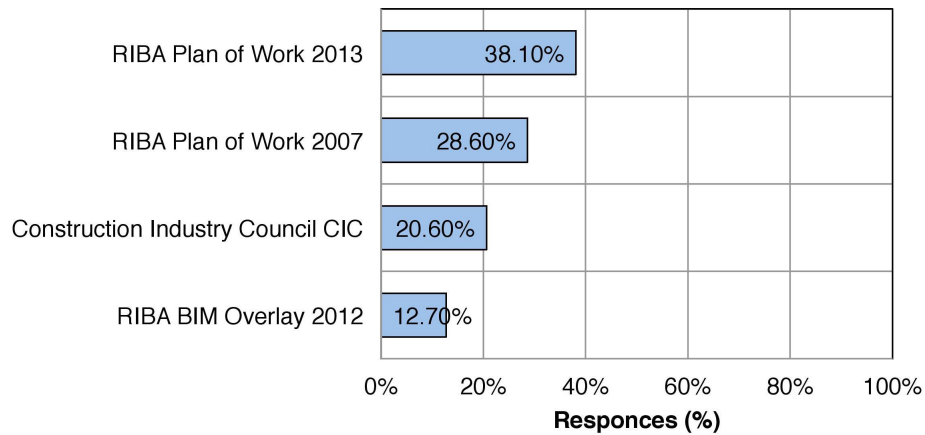


Figure 4.3: Used model for design and construction process

D. Procurement methods

With the rapid development of the construction industry, new procurement methods in construction projects have emerged, such as prime contracting, framework agreement, etc. Table 4.3 illustrates the procurement methods more likely to be used during construction projects. It shows that the design and build is the most commonly used procurement method, followed by the traditional method. The Framework agreements procurement method was the third most commonly used method, along with the two-stage tendering method. However, the private finance initiative and prime contracting methods are rarely used. This indicates that the current construction industry still rely on old procurements methods that do not fully support BIM collaborative approach. Thus, procurement methods should be developed or updated to include the collaborative side of BIM.

Table 4.3: Used procurement methods

Methods	Responses ^a					Mean	SD
	1	2	3	4	5		
Traditional	4	7	21	38	12	3.26	1.403
Design and build	3	4	17	48	12	3.38	1.398
Two stage tendering	5	7	24	36	6	3.01	1.426
Public private partnerships	10	14	21	22	9	2.75	1.495
Private finance initiative	12	10	25	19	6	2.50	1.532
Management contracting	10	18	19	24	2	2.40	1.466
Framework agreements	7	7	21	37	10	3.03	1.514
Prime contracting	14	12	15	19	6	2.28	1.640

^a 1:Never; 2:Rarely; 3:Sometimes; 4:Often; 5:Always.

E. BIM collaboration solutions usage

When construction team members collaborate together on the same BIM model many issues arise, due to the usage of different software and tools. This has led to the development of collaboration solutions that aim to bring a construction team together. Figure 4.4 illustrates the level of the selected respondents' usage of BIM servers to facilitate team collaboration. It shows that the use of commercial BIM collaboration servers is at a higher level than the use of open-source BIM collaboration servers among the selected respondents. RevitServer is the dominant collaboration tool 33%, followed by AutoDesk Buzzsaw 31.9% and Bentley ProjectWise 27.8%, whereas the level of Bentley AssetWise usage is very low 2.8%. Interestingly, the level of Onuma systems "BIM Storm" usage is 0%. The level of use of open-source BIM servers such as BIMServer and EDMmodelServer is also very low, only 2.86% and 0% of the selected respondents having used or experienced it. The majority of the selected respondents 34.7% who did not use any of the above-mentioned collaboration solutions are using other collaborative solutions such as BimXtra (Clearbox, 2015), UNIT4 Business Collaborator (BCL, 2014), Asite (Asite, 2015), 4Projects (4Projects, 2015) or Citrix servers (Citrix, 2014).

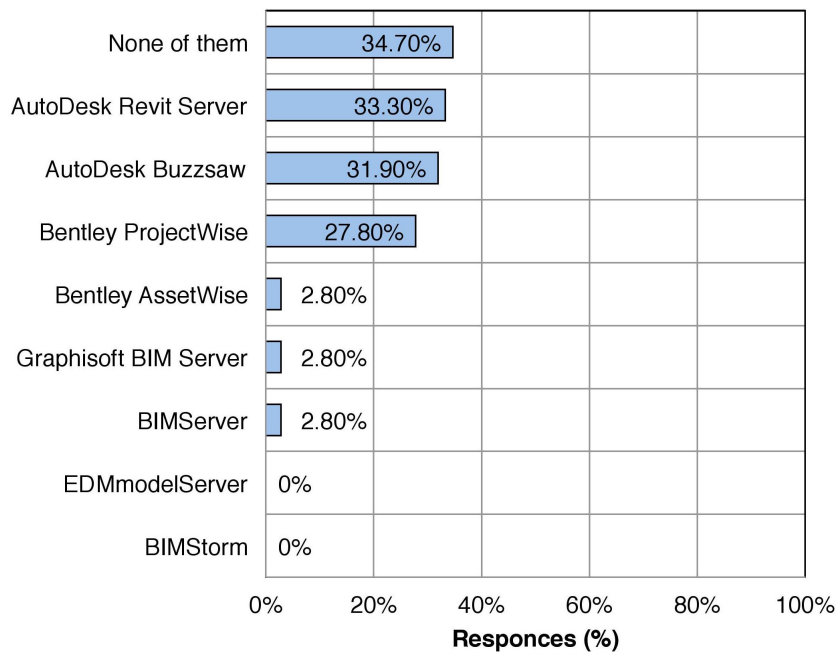


Figure 4.4: The level of using BIM collaboration servers

F. Communication technologies/tools

Communication between construction project team members is important for effectively and efficiently completing construction project tasks. Table 4.4 shows the communication

tools/software used for facilitating collaboration across the team. It demonstrates that emails are the communication tool used most often, followed by face-to-face meetings. Next most popular are mobile phones and landlines, in that order. According to the same table, the use of teleconferencing and online meeting tools is low compared to that of earlier technologies and tools; there is a rare use of online meeting tools. The separation between communication tools and collaboration solutions bring many issues to the team during a construction project such as loss of important data with regard to made decision during the communication process.

Table 4.4: Used communication tools between the team's members

Technologies/Tools	Responses ^a					Mean	SD
	1	2	3	4	5		
Landlines	3	5	13	34	24	3.90	1.033
Mobile phone/SMS	3	4	12	36	25	3.95	1.005
Email	1	2	0	23	55	4.59	0.738
Teleconference	8	15	19	27	9	3.18	1.181
Online voice/video meeting software	11	19	19	21	9	2.97	1.240
Face-to-face meeting	1	1	4	42	29	4.26	0.732

^a 1:Never; 2:Rarely; 3:Sometimes; 4:Often; 5:Always.

J. Data storing methods

Construction data must be stored in a suitable place for archiving and reuse purposes. Table 4.5 shows the methods currently used by construction respondents for storing and archiving their data. It shows that the most favoured method is the network drive hosted by the practitioner's company. The use of paper is the second most commonly used method of storing data. The levels of use of flash storage and Cloud solutions are almost the same. However, the level of using personal PCs/laptops to store data is higher than the use of optical media. Finally, the use of a portable external hard drive is less popular among respondents. The use of company hosted hard drive rises many issues and concerns to the majority of practitioners such as the limited space of storage, access rights to data is restricted and limited by company IT department. Therefore, they maintain a printed copy on paper for their data to preserve them from loss. Significantly, the use of Cloud storage solution is more popular than other traditional storage methods.

H. Project's data sharing & exchanging methods

Sharing and exchanging data with other team members during the project lifecycle is essential on any typical construction project. Table 4.6 shows current methods of sharing and exchanging data among the project team. It shows that there is a strong dependency

Table 4.5: Respondents' methods for storing their data

Technologies/Tools	Responses ^a					Mean	SD
	1	2	3	4	5		
Paper	5	21	15	24	11	3.20	1.189
Optical media	6	22	24	16	5	2.89	1.061
Flash storage	7	14	26	22	7	3.11	1.102
Networked drive hosted by the company	2	5	7	20	44	4.27	1.040
Portable external hard drive	17	19	19	15	5	2.63	1.228
Cloud storage	8	16	29	18	7	3.00	1.105
On pc/laptop	13	18	17	15	13	2.96	1.350

^a 1:Never; 2:Rarely; 3:Sometimes; 4:Often; 5:Always.

on using email for sharing/exchanging project's data, followed by use of a shared storage drive hosted over a company network. It also reveals considerable reliance on paper for sharing and exchanging data. However, there is very little use of external hard drives for sharing/exchanging project's data. Surprisingly, the use of Cloud storage solutions such as Dropbox (Dropbox, 2014) for this purpose is greater than the use of paper, optical media and flash storage devices. The use of emails is very bad practice for sharing/exchanging the project's data because it creates many issues such as different versions, data inconsistency, etc. This finding makes it clear that the use of Cloud storage solutions has become popular for sharing and exchanging construction project data.

Table 4.6: Practitioners' methods for sharing & exchanging

Technologies/Tools	Responses ^a					Mean	SD
	1	2	3	4	5		
Paper	4	22	18	25	10	3.19	1.133
Optical media	12	21	21	17	7	2.82	1.203
Flash storage	8	22	24	20	3	2.84	1.052
Email	0	0	4	47	29	4.31	0.565
Networked drive by the company	9	4	15	27	23	3.65	1.277
Portable external hard drive	26	25	13	7	6	2.25	1.237
Cloud storage solution	9	15	17	24	15	3.26	1.280

^a 1:Never; 2:Rarely; 3:Sometimes; 4:Often; 5:Always.

I. Common data formats used during a project

Although sharing and exchanging project data is very important, it is also essential to know what the typical data formats are that are being shared/exchanged. Table 4.7 shows different types of data format used during a typical construction project. It shows that there is strong reliance on the Portable Document Format (PDF) file format. It also demonstrates that Microsoft packages data formats are used more frequently, specifically Word and Excel file formats. In addition, the figure shows that the AutoDESK file format

is used more than the AutoCAD file format for generating design data. Remarkably, the use of various image formats is very high. Working with diverse data formats during a construction project presents both compatibility and governance risks: regarding, for example, IP, ownership, access rights, data inconsistency and liability. Moreover, the use of uneditable data formats such as PDFs makes it difficult to track changes that have been made to the data file. Thus, makes the possibility to lose the track of change occurs to a specific data.

Table 4.7: Most commonly used file format when sharing/exchanging data

Item	Responses ^a					Mean	SD
	1	2	3	4	5		
Microsoft Word (e.g. .docx,.doc, etc.)	2	7	15	33	25	3.88	1.023
Microsoft Powerpoint (e.g. .pptx, .ppt, etc.)	6	17	18	24	15	3.31	1.217
Microsoft Excel (e.g. .xlsx, .xls, etc.)	2	4	16	35	22	3.90	0.955
Portable Document Format (.pdf)	0	0	3	32	43	4.51	0.575
Autodesk (.dwg)	0	6	14	37	22	3.95	0.875
AutoCAD (.dxf)	6	25	21	16	8	2.93	1.135
Bentley Microstation (.dgn)	34	21	7	10	5	2.10	1.283
Industry Foundation Classes(.ifc)	21	20	15	18	2	2.47	1.205
Comma-Separated Values(.csv)	28	24	14	9	2	2.13	1.116
Extensible Markup Language(.xml)	28	22	17	9	1	2.13	1.080
Green Building XML Schema(.gbxml)	34	24	12	4	1	1.85	0.968
Simple Text Format (.txt)	28	31	10	7	3	2.06	1.090
Image Format (e.g. .jpeg,.png, .gif, etc.)	1	11	24	30	12	3.53	0.963

^a 1:Never; 2:Rarely; 3:Sometimes; 4:Often; 5:Always.

To sum up, the findings of this study shows that the majority of respondents agreed on the need to introduce new roles when adopting collaborative BIM approach such as BIM manager. Due to the strong collaborative relationship among team members during work on construction projects, many collaboration issues arise such as data errors and inconsistency that lead to legal disputes. This indicates that a successful collaboration strategy must take account of the actors' collaboration concerns such as access rights, ownership, IPRs. A number of communication tools are used in construction projects that should raise the concerns of not effectively recording made decisions. This study shows that there is strong reliance on email for communication, even where the company has its own BIM server solutions for communication and collaboration. Although respondents use ICT technologies for communication, face-to-face meetings always take place during the project. In collaborative projects on which multiple actors within multi-disciplines work together, various methods are used for sharing/exchanging project's data. The results from the questionnaire, again, show a strong reliance on emails for sharing and exchanging construction projects' data with other team members. Some construction respondents use the following tools for sharing and exchanging data: Business Collabo-

rator (BC) and Project Extranets such as UNIT4 (BCL, 2014), EDMS such as Buzzsaw (AutoDesk, 2014), Conject (Conject, 2015), Asite (Asite, 2015), etc. However, even with the existence of these collaborative solutions, construction practitioners still use emails for sharing/exchanging their data.

During a construction project, the team produce and work with different file formats; thus the construction industry faces the challenge of adopting a single file format with the ability to host all the data generated during the project. Collaboration through the use of these different file formats by different actors leads to an increase in IPRs, ownership and data responsibility concerns. Practitioners use software of varied design in their organisations when producing building designs. Although some respondents use well-known design software such as AutoDESK packages, Bentley packages, etc., others use alternative software solutions, including BimXtra, RhinoBIM, Tekla products, Vectorworks, and Oasys products. One of the respondents stated, *“I have 25 years’ experience in BIM software. In principle AutoCAD provides dumb data. Revit provides information. Bentley provides similar. But none of the above are true BIM”*. In order to successfully manage their data and files, many organisations adopt shared place technology to accommodate all their files and data from different sources. For that reason, commercial BIM collaboration solutions have been used more often than open-source BIM collaboration solutions.

The use of various traditional procurements, design & construction process, communication tools, storage methods, sharing/exchanging methods, different file formats leads to many issues during the collaboration process during the project. Hence, developing a governance model with the ability to control and manage these different, and possibly unrelated, file formats can be very beneficial. To sum up, results from semi-structured interviews highlighted that ICT has a long history of adoption and use in the construction industry. ICT has a positive impact on the possible adoption of BIM. This section describes ICT and the collaborative practices adopted on BIM-based projects.

- **ICT tools and practices:** Many practitioners continue to rely on email, e.g. Outlook and Gmail, as their main tools of communication. They request advice via emails and using print screens showing errors in their BIM models. Most of the BIM experts interviewed reported this, one interviewee stated: *“we use email with written words and screenshots”*. In addition, they use Skype for face-to-face interaction with a remote team, in order to clarify aspects of project design or BIM models. They also use communication tools built-in to the collaboration tools. Some teams explore other options, such as SMS, Skype, Go-to-Meeting, and other web teleconferencing sessions. They also arrange regular face-to-face meetings to discuss

project progress and receive clear updates on goals and milestones to organise and track their objectives. Nonetheless, there are problems recording actions during informal communication processes or meetings. One academic stated: *“the best communication practice during a construction project should be via project management environment e.g. ProjectWise which contains: (a) built-in communication tools/channels, (b) a good data structure so that it is easy to keep track of it, (c) find who/when and why a decision is made”*. This emphasises that a good collaborative BIM solution would include a well-structured data governance framework and built-in communication tools to keep track of information.

- **Collaboration tools and practices:** Email is used for communication and for sharing BIM models. However, most companies use proprietary web-based collaboration tools and Electronic Document Management Systems (EDMS) to manage the sharing of project data among team members, because of reliability and technical support (e.g. Conject (Conject, 2015), ProjectWise (ProjectWise, 2015), Asite (Asite, 2015), and Autodesk RevitServer (Autodesk, 2011)). However, teams combine the use of RevitServer with ProjectWise at the local level inside the company, whereas at the global level the team might use more advanced collaborative technologies, such as 4Project (4Projects, 2015). Although most web-based BIM collaborative tools enable access to stored data according to each actor’s role, the process of defining roles and responsibilities tended to be unclear and overseen by the organisation. In terms of BIM data storage practices, some practitioners use personal hard drives to retain copies of their files/models, but the majority use online-shared networked storage solutions due to the easy-to-use storage and access mechanisms provided. When adopting BIM as a collaborative approach, it is necessary to change management and re-engineer the traditional collaboration process. *“Educate people more about BIM”*. one practitioner stated, *“having the tools is one thing but knowing what to do with the tools is another thing”*. ICT technologies can facilitate communication between team members, but it is up to people to engage in effective collaboration.

4.3.2 BIM adoption barriers

There are several barriers to BIM adoption in the UK construction industry, consisting of socio-organisational, legal, financial and technical aspects. Exploring these barriers is an essential step towards the development of a BIM governance model. Therefore, this section sheds light on the major BIM adoption barriers.

A. Socio-organisational barriers

Addressing socio-organisational barriers is crucial for the development of a BIM governance model. Hence, Figure 4.5 presents these barriers to BIM adoption in the UK construction industry. It shows that the most significant barrier is team resistance to change 70%, and then generational gaps in BIM skills and understanding between junior and senior respondents 63.6%, followed by the barrier to collaboration, e.g. trust within a team, and the barrier of adopting a single management process for multiple disciplines, across the lifecycle and supply chain by 54.5% and 45.5% respectively. However, The barrier of organisational cultural, values and believes that are shared within an organisation 42% is more higher than the barrier of the team structure and relationship of the team project 39.8%. The final barrier, at the lowest level, is undefined roles and responsibilities of team members 43.1%.

The updated BIM socio-organisational barriers include such significant aspects as team resistance to change, leading to generational gaps in BIM skills and understanding between junior and senior practitioners. This breakdown shows that team members know their roles and responsibilities but are resistant to change. It is also important to note that working with teams of a different culture and different traditions, in which responsibilities and roles are also unclear, leads to collaboration issues e.g. trust (Holzer, 2007, Thomas, 2013). These collaboration issues might produce difficulties in dealing with the generated data. Overall, key respondents have stated that various people/groups are trying to define too many things related to BIM, those things are not yet well defined, incorporating only “*guidance*” but not legislation. This, in turn, has created reluctance to work toward an undefined goal.

B. Legal barriers

Six potential legal barriers have been identified that may hinder BIM adoption. Figure 4.6 shows that lack of defined liability for wrong or incomplete information input is the greatest barrier 65.4%, followed by the second barrier, which is the lack of intellectual proprietary rights and fair practice standards for electronic information and documentation 53.1%. The lack of clear regulations related to practitioners’ roles, responsibilities and authority, is the third strongest barrier 45.7%. The fourth strongest legal barrier is presented by the lack of collaboration standards 44.4%. The fifth greatest barrier is the lack of personal indemnity insurance coverage and maintenance, due to unknown liabilities associated with shared projects. The final and least significant, legal barrier’ consist of

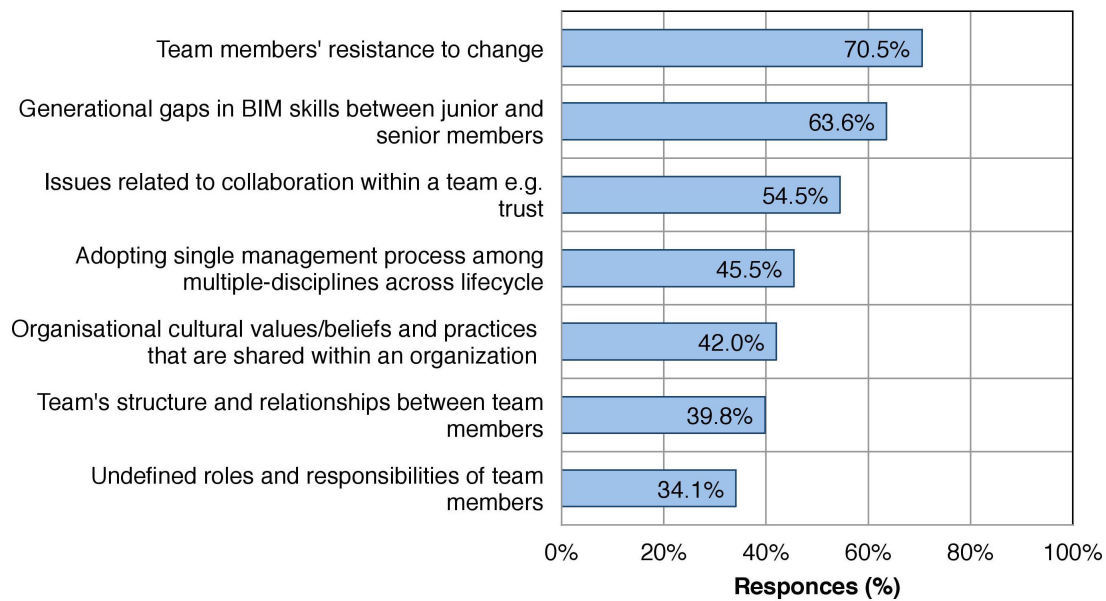


Figure 4.5: Socio-organisational barriers to BIM adoption

historic government regulations that do not meet the industry's current and future needs.

Legal barriers have been another major concern when work is being done in a collaborative environment (Wickersham, 2009, McAdam, 2010). When adopting BIM in collaborative projects, many collaboration issues related to legal concerns such as IPRs, or ownership of the model can appear. As one of the respondents commented, "*Ownership to answer the question of who take responsibility of what is done in the model*". The results from the questionnaire strongly confirm the legal barriers to BIM adoption mentioned in the literature. However, this research strongly emphasises that lack of defined liability for wrong or incomplete information input is the major barrier. The reason is that there is no clear regulation related to participant roles, responsibilities and authority, to intellectual proprietary rights, or to fair practice for electronic information and documentation.

In addition, there is a need to develop government regulations because the existing ones do not meet the current and future needs of the industry. In fact, the government is moving towards developing its regulations so as to meet current developments in the construction industry. As one practitioner stated, "*Standards are now catching up e.g. PAS 1192-2:2013*". However, another practitioner added, "*Standards progressing but everything else is moving too slowly. Technologies leading push but focus is in the wrong areas i.e. software developers should not be the determinant for BIM*". This strongly highlights the role of the UK government in the development of BIM regulations, standards and legislation. Moreover, working on shared projects increases the risk of unknown liabilities,

which makes it difficult for insurance companies to cover and maintain Personal Indemnity Insurance without increasing the cost.

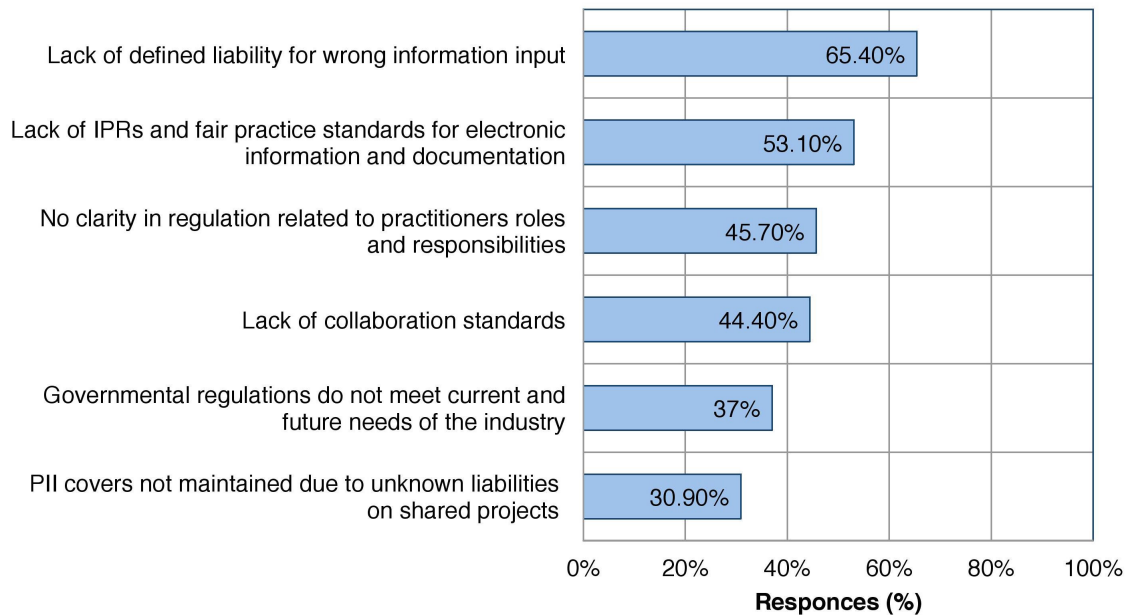


Figure 4.6: Legal barriers to BIM adoption

C. Financial barriers to BIM adoption

It is clear from Figure 4.7 that the training cost is the main financial barrier to BIM adoption by 68.2%, followed by the cost of initial software setup by 68.1%. Tight budget and existing small profits margins on projects became thirdly by 64.7%. More than half of the respondents agreed that the cost of initial hardware setup is a very common financial barrier. Interestingly, the increment of Personal Indemnity Insurance (PII) due to shared liability policies is less of a barrier than software maintenance and update costs.

However, these financial barriers have more effect on small organisations than large organisations. Many respondents agreed that the major financial barrier is the cost of the initial software setup, followed by the cost of initial hardware and software, together with maintenance and updates. Because BIM represents new technology, training in its use is required, and many respondents point out that training costs are very high, especially for contractors and FM teams. The use of BIM might face budgetary limits and small profit margins on construction projects. In that respect, one practitioner revealed that BIM is cost effective compared to traditional methods, but another argued that SMEs struggle to see its benefits due to the above-mentioned factors, especially the cost of software, in addition to the uncertainty of obtaining constant work. Therefore, the efficiency of BIM

usage is limited. However, one practitioner argued that, because UK industry focuses on cost rather than on added value from investment, the current business models do not support collaboration. Overall, there is a general increase in time and cost implications, as the increase in coordination leads to increased information and associated teething problems.

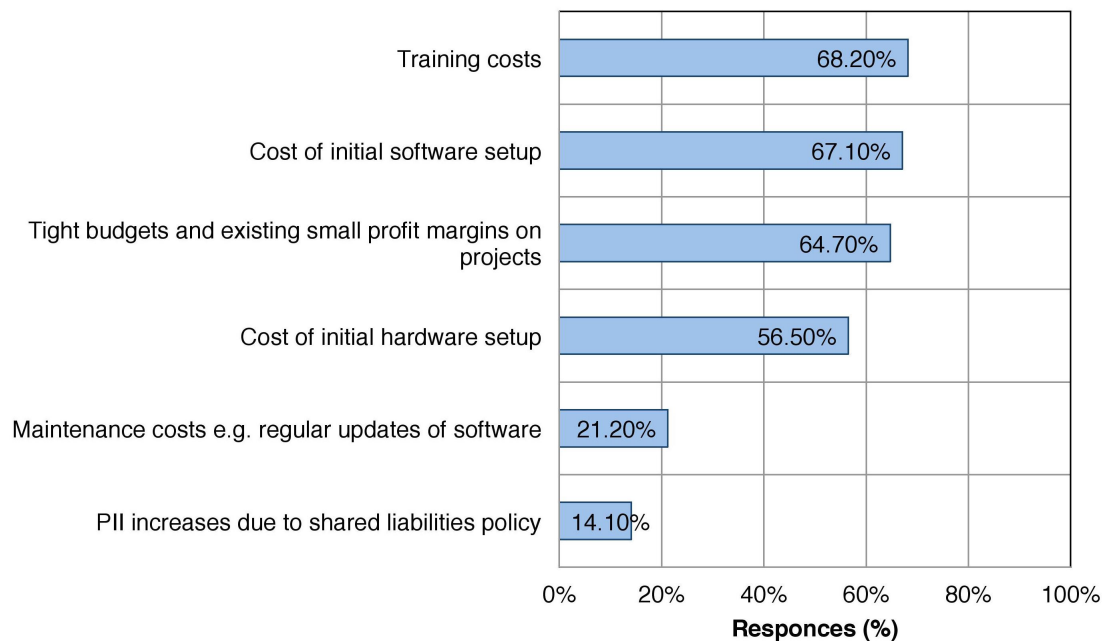


Figure 4.7: Financial barriers to BIM adoption

D. Technical barriers to BIM adoption

Identifying technical barriers to BIM adoption is a very important to the development of a BIM governance model. Figure 4.8 shows the technical barriers to BIM adoption in the UK construction industry. It demonstrates that lack of technical training is the highest barrier 69%. The second greatest technical barrier is the lack of compatibility between various standards-based e.g. IFC products across the lifecycle and supply chains 59.8%. Nearly 55.2% of respondents are found for the lack of compatibility in software and lack of data integration between stakeholders during the lifecycle. Surprisingly, the results show that, as agreed by a third of respondents, lack of support for data integrity, user authentication, data security and access control is the fourth technical barrier to BIM adoption. In addition, almost quarter of respondents 23% agreed that the barrier of privacy constraints associated with externally sourced virtualised storage e.g. Cloud, and the barrier of lack of compatibility between existing and new hardware, occupied the same level of significance.

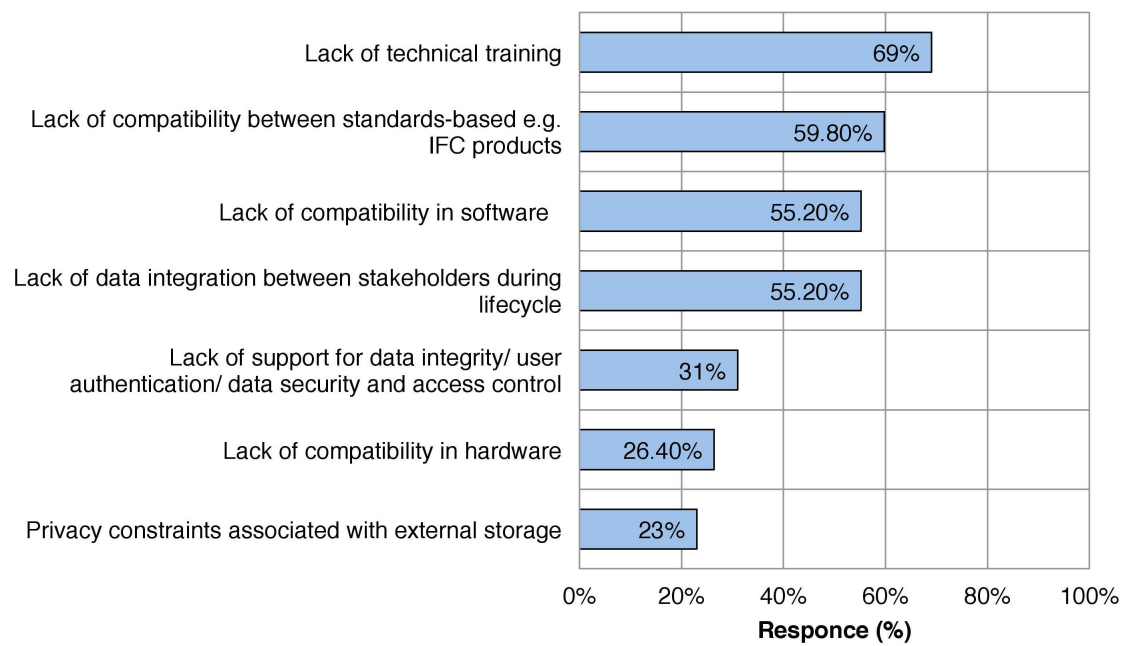


Figure 4.8: Technical barriers to BIM adoption

Barriers related to technical factors are another major concern in BIM adoption. Lack of compatibility between existing and new software is considered the highest technical barrier, as compared with the barrier of lack of compatibility between existing and new hardware. Although there are software packages that support the export/import of open standards, e.g. IFC, the findings indicate that there is a lack of compatibility between various standards-based e.g. IFC products. As one practitioner stated, *“Currently the software is designed one-way translation, thus BIM will not work on any current design software”*. Another practitioner supported his colleague, commenting, *“Software developer vested interests in their proprietary software is a big blocker to open BIM and collaboration”*.

There is general agreement on the lack of technical training among construction practitioners. A further major technical barrier to BIM adoption is the lack of support for data integrity, user authentication, data security and access control as well as for privacy constraints associated with externally sourced virtualised storage (e.g. Cloud), leading to a lack of data integration among stakeholders across the lifecycle and supply chains. Once these technical barriers are tackled, adopting BIM effectively would be achievable.

E. BIM adoption barriers resulting from semi-structured interviews

Further investigation with respect to BIM adoption barriers is conducted using the semi-structured interviews. The findings from the semi-structured interview regarding BIM

adoption barriers endorsed the findings of previous research (Arayici et al., 2011, Bernstein and Pittman, 2004, Won et al., 2013, Rezgui et al., 2013). However, BIM adoption barriers were expanded upon in this study, to include socio-organisational, financial, contractual, technical, and legal barriers. Table 4.8 summarises the most significant BIM adoption barriers.

Table 4.8: BIM adoption barriers

Theme/category	Related barriers
Social-organisational	<ul style="list-style-type: none"> • Resistance to change • Lack of trust in and apprehension towards new technology • Lack of BIM understanding • Variations in practitioners' skills • Lack of BIM training • Lack of motivation • Clients' awareness • Adoption of traditional practices and standards • Avoiding/hiding potential risks and liability for mistakes
Financial	<ul style="list-style-type: none"> • BIM adoption cost • Personal Indemnity Insurance (PII) is not covered • BIM training cost • Limited budget • Expensive human-based services costs
Technical	<ul style="list-style-type: none"> • Maturity of BIM-based technologies • Interoperability issues • Issues with existing BIM modelling and collaboration tools • Massive data inputs/outputs • Massive data and limited data storage • Limited accessibility and access rights • Lack of data sharing mechanisms • Lack of data tracking, checking and versioning control mechanisms • Difficulties coordinating large BIM models • Lack of notification mechanisms
Contractual	<ul style="list-style-type: none"> • Contractors benefit from confusion • BIM contracts are not yet mature • Lack of BIM-related aspects in current contracts • Failure to address BIM legal concerns in current contracts • Contracts need to accommodate changes in BIM collaborative environment
Legal	<ul style="list-style-type: none"> • BIM models ownership: intellectual property and copyright concerns • Liability for wrong or incomplete data • Lack of legal considerations in existing BIM contracts • Lack of legal framework for adopting collaborative BIM • PII does not cover legal aspects of collaborative work

To sum up, several barriers need to be addressed when adopting BIM as a new collabo-

relative approach. While recent research in BIM development has investigated barriers to BIM adoption (Eastman et al., 2011, Mihindu and Arayici, 2008, Gu and London, 2010), the present study has focused on a potential solution consisting of a governance model supported by a sustainable data storage infrastructure. There is a general lack of understanding of BIM, especially among client bodies, as well as a lack of the skills required to adopt BIM. Moreover, there are contractual issues that might hinder the adoption of BIM in the UK construction industry. As one practitioner stated, *“Contractual relationships and adversarial forms of contract are more important than technologies”*. However, another practitioner argued that the barriers cited are problems already present and in effect without BIM, and thus do not provide adequate reasons for rejecting it. This view is supported by the practitioner who observed: *“All above issues are obstacles, but some of them are rather perceptions than reality and based on people’s unwillingness to find out what really exist. On a global level e.g. in Nordic countries most of the issues have been resolved”*. Moreover, (Rezgui et al., 2013) maintained that developing and implementing the BIM governance model would successfully overcome such barriers.

4.3.3 The role of BIM-related standards in promoting collaborative BIM

Existing BIM-related standards provide a good starting point for developing a collaborative BIM approach. These are paper-based standards (e.g. BS1192: 2007 and PAS 1192-1, 2 and 3), and technical-data exchange standards (e.g. COBie and IFC). The question posed to BIM experts concerned how far existing BIM-related standards promote BIM integration and collaboration. Most BIM experts agreed that the standards promote the integration and collaboration of BIM. However, it was agreed that the standards are only guidelines; they do not necessarily facilitate the collaboration process. Paper-based standards have the following limitations:

- They define collaboration processes in a form that is difficult to integrate with technical solutions;
- Individuals tend not to use or adopt the standards unless forced to do so by their managers to satisfy clients’ requirements;
- They offer advice, not rules, and people only implement rules;
- They lack aspects of governance;
- They were developed by large companies, not by SMEs; thus, it might not be suitable for implementation in SMEs practices.

- They reflect the desires, issues and concerns of specific groups excluding others; and
- Research and development is ongoing.

Thus far, technical-data exchange standards have partially solved some of these limitations. For example, COBie offers a practical method for sharing/exchanging BIM data. However, it is an Excel spreadsheet requiring massive input from practitioners, imposing a heavy burden on them (cost and time consuming). Furthermore, COBie datasets differ from one country to another based on governmental policies and requirements. An additional option is IFC, which handles interoperability between BIM authoring packages. One expert suggested, it might become the de facto standard. However, IFC still does not work as it should, because it lacks semantic definitions and sufficient intelligence. Moreover, massive amounts of semantic data are lost when transferring BIM models to IFC.

4.3.4 Specific collaboration issues with the shared data

This section of the findings (a) shows the impacts of insufficient data management solutions; (b) highlights most common issues related to the data generated during construction projects; and (c) explores the role of Cloud Computing in addressing them.

A. Collaboration issues during BIM-based projects

BIM is still a new technology, and people have different understandings and interpretations of what it is. These differences create conflict in a BIM collaborative environment. Table 4.9 summarises issues obtained from semi-structured interviews that arise during team collaboration on BIM-based projects.

B. Impact of insufficient data management solutions

The use of insufficient data management solutions may affect the construction project as shown by the results presented on the following figure. Figure 4.9 demonstrates that data errors and inconsistency are the main results of using insufficient data management solutions during construction projects 82.8%, in addition to other negative impacts such as project delays 74.7%, and poor documentation 67.8%, and negative effects on costs 64.4%. These raise the point of even though that there are data management solutions, there is a need for more accurate solution such as data governance to be incorporated into the existing data management solutions. During a construction project, massive amounts of data are generated.

Table 4.9: Collaboration issues during BIM-based projects

Theme/ Category	Issues
People	<ul style="list-style-type: none"> • BIM maturity and understanding • People's behaviour • Team trust • Collaboration issues
Process	<ul style="list-style-type: none"> • Lack of agreed objectives for the use of BIM • No clear procedure for BIM • Information delivery process related issues • Different team skills • Sharing issues in collaborative process
Data	<ul style="list-style-type: none"> • Data ownership • Copyrights • Intellectual Property (IP) • Interoperability • Big data volumes • Data inconsistency • Data compatibility • Data transportation • Data storage • Data loss

Besides the lack of interoperability between systems, with several standards competing to manage data (Shen et al., 2010), the use of inadequate data management software raises many data-related issues during construction projects. These issues include data inconsistency, resulting in poor documents that lead to project delay. One practitioner noted that this problem might also lead to “*legal disputes*”. Data inconsistency issues, e.g. different versions, and data loss, are the main concerns for the respondents. These issues are likely to arise when people are working within a collaborative environment, which in turn affect decision-making. Accessing data files is another major issue, Shen et al. (2010) pointed to the difficulty of accessing accurate data, information and knowledge at the right time at each stage of the construction project lifecycle. Moreover, it can be clearly seen that data liability-related issues, such as the security, confidentiality, and privacy of data files, are of greater concern than before to the respondents, due to the nature of the BIM collaborative working environment.

C. Common data issues within construction projects

Many issues regarding generated data arise during the project lifecycle. Figure 4.10 shows the most common issues occurs during the project lifecycle. It demonstrates that data

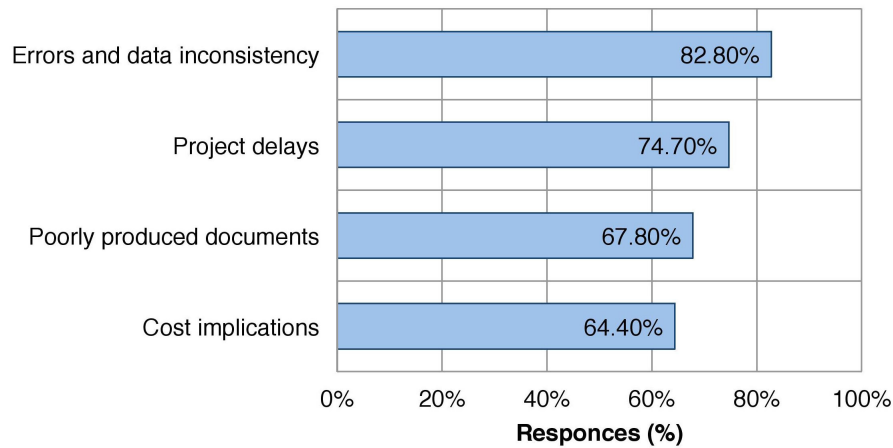


Figure 4.9: Impact of insufficient data management solutions

inconsistency, e.g. different versions or loss of data, is the most prominent data-related issue arising during work in the construction industry 81.2%. The second most common issue is data compatibility when data are shared/exchanged among respondents 54.1%. Another major issue is the big size of data when sharing and storing documents 51.8%. Access to data files of this size is a further issue, as nearly third the respondents agreed 34.1%. However, data security, confidentiality and privacy as well as data liability-related concerns are considered less important than previously mentioned issues. Nonetheless, data privacy is very big issue as reported by a BIM practitioner *“No privacy, all work within a BIM/Revit model becomes public - issues with companies copying our hard work”*.

Although some companies use different asset management solution, there is a problem with data accuracy as reported by a BIM practitioner *“The accuracy of existing data, we have five different asset management systems”*. One practitioner strongly emphasised the need for data filtering, due to the massive amount of generated data. Another respondent added that one big problem is the lack of focus on levels of detail and fit-for-purpose information. However, infrastructure is the key when working globally; in other words, it is necessary to enforce and track data from one practitioner to another to make sure that everyone is working on the correct data at a given time. One respondent argued that *“All the above issues are traditional problems in construction projects, i.e. they have nothing to do with BIM except that there are many success stories where BIM has removed or radically reduced the data management problems”*. This observation suggests that nearly the majority of previously mentioned issues have been partly solved via the use of BIM in the construction industry. Thus, having a governance model to support BIM implementation during construction projects would also help to reduce these issues.

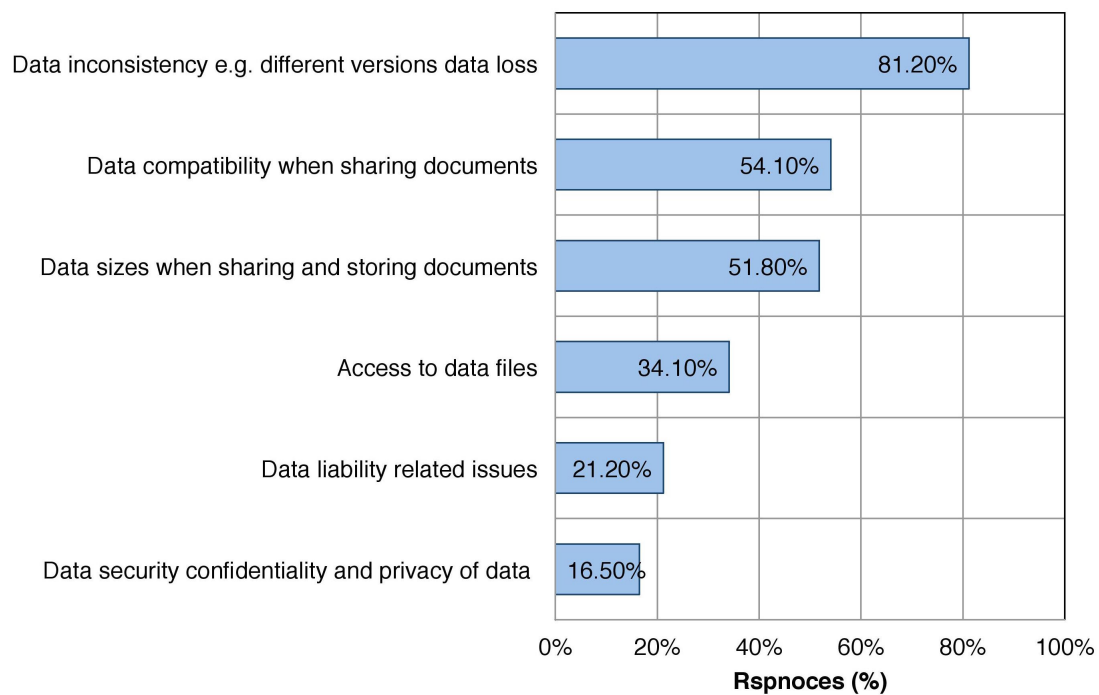


Figure 4.10: Most common data issues within construction projects

4.3.5 Role of Cloud in BIM governance R&D

Recently, many organisations, including construction companies, have moved towards utilising Cloud services to host data, due to its many benefits (Wong et al., 2014). It provides an ideal environment for hosting massive data files, such as those used in BIM governance models (Kumar et al., 2010). Using Cloud technology in developing BIM governance model might solve many problems related to the vast amount of generated data. Figure 4.11, the majority of respondents agreed that the use of Cloud Computing would facilitate access to data files 83.3%. Another problem that might be solved by the use of BIM governance model development with the support of Cloud Computing is data inconsistency e.g. different versions and data loss, due to putting all data in one place. In addition, the use of Cloud Computing plays an important role in solving issues of data file size when sharing and exchanging data files as nearly half respondents agreed 53%. There was less agreement by respondents that the use of Cloud Computing might solve issues related to data liability, security, privacy and confidentiality. However, nearly third the respondents agreed that the use of Cloud Computing would solve problems related to data compatibility.

Further investigation was conducted in order to discover advantages and disadvantages of using Cloud as a solution in supporting BIM governance research and development.

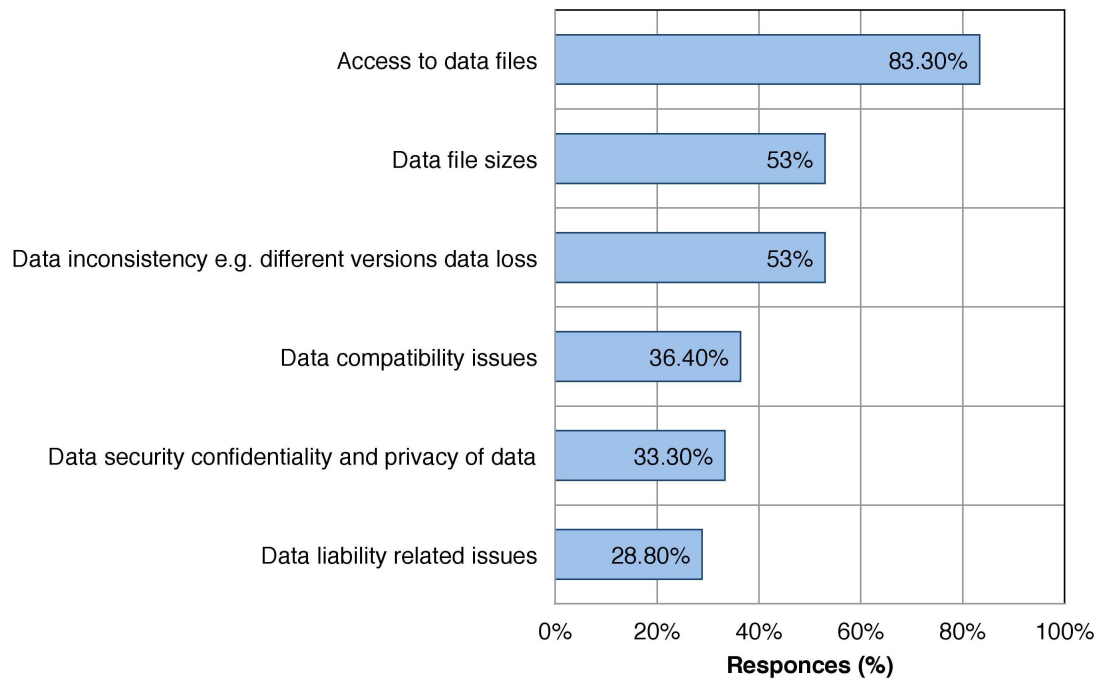


Figure 4.11: Role of Cloud towards solving construction data-related issues

These advantages and disadvantages are listed in Table 4.10:

Table 4.10: Potential role of the Cloud in BIM R&D

Advantages	Disadvantages
<ul style="list-style-type: none"> • Data availability • Data accessibility • Cost effectiveness • Massive storage and backup capabilities • Easy to use • Interoperable • High computing capabilities • Positive environmental effects 	<ul style="list-style-type: none"> • Data security • Cyber security • Network dependency • Initial set-up cost • Concerns about physical location of infrastructure • Lack of legal assurances • Control concerns • Physical data storage issues • Privacy concerns • Negative environmental effects • Ownership concerns

Our consultation also revealed several advantages to using Cloud as BIM governance solution:

- **Data availability and accessibility.** Cloud renders the hosted data available at all times in all places. Moreover, access to hosted BIM data would be password-protected. Wherever there is an Internet connection, there is immediate access to

the stored data. The Cloud allow users to share data with other users permitted to access it.

- **Cost-effectiveness.** Cloud technologies can reduce the cost of a construction company's infrastructure, which is particularly beneficial for SMEs with limited resources and budgets. Working on the "Software-as-a-Service" paradigm allows construction companies to rent the services they need from the Cloud Service Provider (CSP) for short periods, only paying for what they use. In addition, there is no extra cost for software updates and IT infrastructure upgrades, because the Cloud Service Provider (CSP) oversees these.
- **Scalable storage.** Scalable storage spaces and robust backup services are ideal when hosting large BIM models, overcoming the limitations of physical hard drives. The amount of shared data during a collaborative BIM process gradually increases; thus, a flexible and scalable storage solution is desirable. Using the CSP's storage and backup services to host big data volume files enables the user to retain sufficient local disk space.
- **Powerful computing capabilities.** Cloud can improve the computing performance of the hosted solution; for instance, by increasing the number of processors and the temporary storage; e.g. Random Access Memory (RAM) is easy to facilitate and integrate into the CSP's services. Having BIM tools and processes in the Cloud can facilitate the use of complicated BIM tools for data analysis and reporting. The use of the Cloud for hosting BIM data makes it easy for practitioners to synchronise all their data on more than one device, enabling users to work on two PCs with different computing capabilities.
- **Effective use of data.** The CSP infrastructure will allow BIM users to utilise powerful processing capabilities to carry out complex analytical tasks. Moreover, addressing interoperability issues can be a major advantage of Cloud. This is because Cloud environments can host any type of data at any level. Moreover, a Cloud-based BIM solution would allow multiple BIM practitioners to work on the same BIM data versions.
- **Positive environmental effects.** Hosting data management solutions on the Cloud will reduce the energy consumption generated by the construction company's IT infrastructure. Therefore, Cloud Computing technologies can effectively reduce the IT resources held by construction companies.

Conversely, several disadvantages to using Cloud Computing to support a BIM governance solution were identified, as follows:

- **BIM experts' worries.** BIM experts do not always trust Cloud providers with the hosted data. This is not only because of Cloud security, but also because of fears about who might access it. Moreover, because the data is hosted in different, physically remote, places, clients are concerned about their data security. BIM experts and clients are cautious, as Cloud is a new technology that is currently developing. When using Cloud-based BIM solution, team members need to coordinate their activities; this is not yet an option provided by Cloud-based BIM solutions. There should also be firm agreement to update team members, with members of all disciplines updating their models at an agreed time. There is also the problem of data access rights, and limitations; in current Cloud storage solutions and BIM-based solutions, users have basic data sharing permissions i.e. (create, read, write, delete). There are further concerns related to data access rights from the CSP side.
- **Security and privacy.** The security of the hosted data in general is a major concern, which can be subdivided into data security concerns and cyber security concerns. Most BIM experts claim that using the Cloud to host BIM data is unsafe and subject to hacking because the authentication component of the access to data is not good enough. They also query what would happen if the physical location of the data were destroyed by a natural disaster; i.e. all the hosted data would be lost. Moreover, there is no evidence regarding where the data is physically stored and backed up, or whether the provider has access to these data. Thus, privacy concerns arise; e.g. what do CSP do with the hosted data, and who else can access it besides the client.
- **Internet connection dependency.** Cloud is a network-dependent technology. Thus, access to the hosted data depends on the availability of a connection; Therefore, if the Internet connection is lost, the work will be delayed. Additionally, certain variables can reduce network speed; namely, lack of high-speed bandwidth, resulting in time latency when updating the hosted data.
- **Lack of legal considerations.** This drawback mainly relates to the laws implemented in the datacentres' countries. When BIM data is hosted on datacentres located outside the users' country, there are major concerns surrounding the security of the data, especially in the case of sensitive projects. For example, the US government can access digital data stored in the country legally at any time. Therefore, hosting data in datacentres located in the US might not be appropriate for practitioners who are working the UK. This emphasises the legal concerns regarding Cloud usage and the fact that these have not been adequately addressed, in relation to collaboration between global teams.

- **Anonymous control.** Many BIM experts have asked: Who controls the Cloud? And, who is responsible for approving data in the Cloud system? In a Cloud collaborative environment, there must be control over the hosted data via data management and control mechanisms. If the data management process is not transparent, then control might be a problem and not a solution. Moreover, there are numerous coordination problems when working on the same files in a Cloud environment. This highlights the importance of developing a BIM governance model when using Cloud technologies to host and manage BIM data.
- **Physical location of data storage concerns.** There are many concerns related to Cloud data storage technology itself; managing large files can be very difficult, especially when more than one actor is working on the same data file at the same time. Backup concerns also arise due to physical datacentre crashes. The use of gigantic datacentres, which are not that environmentally friendly, has negative environmental effects. Some questions that still need to be answered by CSPs include: Who owns the storage place? Who owns the data hub? Who controls the Cloud environment? Who owns the Cloud environment? If these questions were answered satisfactorily, construction practitioners would be more comfortable about using the Cloud to host their data.
- **Initial set-up cost.** Major financial questions arise when a construction company wants to utilise a private Cloud solution; in particular regarding who should pay for the initial cost of setting up the system. Providing a model-as-you-go service would be a very effective option for SMEs, in terms of reducing the cost of hardware and infrastructure.

One BIM expert suggested that Cloud Computing may or may not solve the problems referred to, while the majority agreed that it may help with access to data files and data file sizes, with the processing of large amounts of data and information, or with analysis, thus reducing the cost of high-powered hardware. However, one of the respondents observed that access to data files depends on project management by teams along with infrastructural support (i.e. the availability of internet connection, etc.), and that only certain “Cloud” software solutions, pertaining to BIM, can act as common-format aggregators. “Cloud Computing” plays no part in liability until it is factored in as one. Moreover, nothing will prevent “data inconsistency” within a Cloud-based EDMS if there is no protocol to govern it. There are also issues related to security with Cloud-based systems a case in point hacking attacks. As for liability, it depends on correct and relevant content, in which Cloud plays no role. Also, compatibility is related to the file format and standards, which, again, are not related to Cloud unless the BIM tool that produces and

handles data is totally re-engineered. File size problems relate to the bandwidth, and a purely Cloud-based solution can, in fact, make these problems much worse; for example, large files require replication to local copies until much greater and more reliable bandwidth is available. There is also strong evidence that development of a governance model with its Cloud infrastructure will facilitate current collaboration and ICT on construction projects (Beach et al., 2013).

4.3.6 BIM governance model requirements

The following subsections will discuss in depth the critical factors that can influence the overall development of a well-built BIM governance model. As this section highlights the findings of the questionnaire, with a focus on the need to develop a BIM governance model as well as the requirements for developing such model.

A. Respondents opinions regarding BIM governance model

One of the aims of this study is to investigate the need for a governance model for facilitating BIM collaboration across the lifecycle and supply chain. Therefore, the finding from this study shows that there are many issues raised during team members' collaboration, which emphasises the need to develop a BIM governance model in order to tackle most of these issues. Table 4.11 shows opinions are used to determine the future implications of BIM usage for the construction industry and the level of agreement on developing a BIM governance model. The majority of respondents agreed that the new BIM management solutions will change the way teams collaborate during a construction project. Also, they agreed that BIM will improve project quality and efficiency in the construction industry. They also agreed that BIM will speed up the supply-chain collaboration during the projects lifecycle.

However, the majority agreed that developing a BIM data governance model would tackle most existing BIM collaboration problems. One practitioner added the following comment: *"The BIM collaboration problems are very complicated. There is no single solution for those, but a good data governance model can improve the situation"*. This statement emphasised the need to tackle issues related to team collaboration by designing a good BIM governance model. Another argued that there could not be a common model, because BIM is consistent and must incorporate several domain models with clear ownership, due to the varying responsibilities and data needs to be dealt with. However, there is an issue related to the way these models are facilitated/federated/linked together. A well-structured model server would be a good solution on the conceptual level of the

model, but not on the level of an integrated model consisting of several sub-models.

Table 4.11: Practitioners' opinions about BIM data governance model development

Technologies/Tools	Responses ^a					Mean	SD
	1	2	3	4	5		
New BIM governance solutions will change teams collaboration methods during projects	1	0	9	32	32	4.27	0.781
BIM governance solution will improve projects' quality and efficiency	2	2	8	36	25	4.10	0.900
BIM governance will speed up supply-chain collaboration during lifecycle	2	2	18	32	19	3.88	0.927
Developing BIM governance solution would tackle existing collaboration problems	1	8	25	27	13	3.58	0.950

^a1:Strongly disagree; 2:Disagree; 3:Neither agree nor disagree; 4:Agree; 5:Strongly agree.

B. Initial practitioners' requirements for developing a BIM governance model

The findings from the questionnaire show that addressing socio-organisational and legal requirements is more important than addressing technical requirements when developing a BIM governance model. Table 4.12 summaries practitioners' requirements ordered according to intensity of importance. It shows strong agreement on the first requirement category, namely, socio-organisational and legal requirements for developing a BIM governance model. This category includes: improving communication among disciplines, developing collaboration protocols, defining clear roles and responsibilities for stakeholders across disciplines through the lifecycle, awareness raising, help and support, standardizing overall data management policy, and provide intensive training.

The same table shows that the level of agreement on the second category, namely, technical requirements, is lower than the level of agreement on the category of socio-organisational requirements. This second category includes: providing a notification system to inform other participants of changes being made on the model, providing a real-time mechanism with which team members can share/exchange information, establishing a central repository for storing data online, viewing and printing models online via the web, providing security checks when uploading, downloading and transferring models, providing a secured log-in with access rights, and allow users to customise their interface.

The respondents also mentioned other requirements, including: facilitating/federating/linking different BIM models together, and taking account of BIM sub-models. One stated that it is crucial to work with live data rather than dumb data because the current systems for planning work do not understand BIM environment. Also, it is important for

Table 4.12: BIM governance model requirements

Requirement	Responses ^a					Mean	SD
	1	2	3	4	5		
<i>First Category: Socio-organisational and Legal requirements</i>							
Improve the communication among disciplines	0	0	7	29	36	4.40	0.664
Development of collaboration protocols	0	0	9	27	36	4.38	0.700
Define clear roles, responsibilities for stakeholders across discipline through lifecycle	0	1	8	30	34	4.33	0.727
Awareness raising	0	0	13	38	22	4.12	0.686
Help and support	0	0	13	41	19	4.08	0.661
Standardised overall data management policy	0	1	13	38	19	4.06	0.715
Intensive training	0	1	16	36	20	4.03	0.745
<i>Second Category: Technical Requirements</i>							
A notification system to inform team members of updated data	0	1	8	35	27	4.24	0.706
Provide real-time mechanism for sharing/exchanging information	1	1	10	34	26	4.15	0.816
Central repository for data storage online	0	2	14	35	21	4.04	0.777
Sharing through a common model	2	0	16	31	23	4.01	0.896
Use web for online viewing and printing models	0	4	16	35	16	3.89	0.820
Security checks for uploaded/ downloaded and transferred models	0	1	25	28	18	3.88	0.803
Secured log-in with access rights	0	3	23	30	16	3.83	0.828
User interface customisation	0	4	25	29	13	3.72	0.831

^a1:Strongly disagree; 2:Disagree; 3:Neither agree nor disagree; 4:Agree; 5:Strongly agree.

data owners to be able to decide when to publish their data. Other important requirements include the ability to coordinate at the same time as modelling, the ability to add additional dimensions to a modelling package, and the ability to incorporate more work in a design stage process that has not yet accommodated this change. Other respondents argue that real-time sharing is not needed because disclosure of on-going work only confuses other team members and can lead to wasted effort if changes are made on the basis of incomplete data.

Moreover, practical evidence (Beach et al., 2013) suggests that utilizing the BIM governance model with the support of Cloud Computing for data processing and storage capabilities will positively minimise BIM collaboration issues. The development of BIM governance model still requires further research, as can be seen by considering the various BIM adoption barriers, current ICT practices and BIM governance requirements. The authors, however, argue that developing a BIM governance model with its Cloud computing infrastructure will play a crucial role in addressing the above BIM adoption barriers and ICT & collaboration issues.

C. Comprehensive BIM experts' requirements

The Cloud-based GovernBIM platform can be utilised as an online collaborative solution, with role-based access rights. There are also specific requirements, obtained from BIM experts (BIM professionals, academics and IT technicians), to be considered, that distinguish it from other online collaboration tools. Although, a number of requirements for online BIM collaboration solutions were identified by (Singh et al., 2011, Shafiq et al., 2013), these requirements have been considered general requirements for collaborative BIM solutions. Meanwhile, this study complements previous work, with a specific focus on identifying requirements when developing a Cloud-based GovernBIM platform. One of the issues encountered during the consultation stage involved construction practitioners with diverse understandings of computer-specific terminologies. This issue was solved by providing further explanation regarding confusing terms.

The objective of the platform requirements capture process is to produce a set of comprehensive requirements to provide a foundation from which to specify a BIM governance solution to enhance the capabilities of construction enterprises, and to act to allow their teams to collaborate effectively on projects. These requirements have been collected, analysed and categorised in accordance with the requirement engineering approach (Sommerville, 2007). This approach includes the following steps: requirement discovery, requirement classification and organisation, prioritisation and negotiation, and documentation of requirements. These requirements are then classified and documented within three main categories; (a) Functional requirements: that describe GovernBIM platform functionality or services; (b) Non-functional requirements: that is constraints on services or functions offered by GovernBIM platform. It includes product, organisational, and external requirements. These requirements include three sub-categories: product requirements, organisational requirements, external requirements; and (c) Domain-specific requirements: New functional requirements that reflect the construction domain need for/when using the BIM Governance platform.

Moreover, in addition to identifying general requirements for a Cloud-based BIM governance platform, emphasis was also placed on specific design requirements for a BIM governance model (e.g. that it should define clear roles and responsibilities for each actor during a construction project, it should define who will produce the BIM data, what it will be, and when it will be produced, it should also inform people what to do and when to do it). Moreover, development of a BIM Governance platform requires unique needs to be met to utilise CSP services. Table 4.13 shows a categorised list of all the requirements explored and collected from consultation stage. Herein it refers to the Cloud-based

GovernBIM platform.

Table 4.13: BIM experts' requirements for developing a Cloud-based GovernBIM platform

Category	Sub-category	Sub-sub-category	BIM experts' requirements
1. Functional requirements			<ul style="list-style-type: none"> ➤ Cloud-based GovernBIM platform should: <ul style="list-style-type: none"> – Provide help and support facilities. – Allow different users to customise their interfaces. – Allow users to view and print models online. – Support a central repository for data storage. – Have a notification system to inform team members about new changes when their data is updated. – Record changes' and transitions when they occur. – Allow multiple-actors to share information through a common storage system. – Provide real-time mechanism for sharing information. – Have built-in communication tools. – Have a mechanism for tracking information throughout the whole project. – Be able to track data during the whole lifecycle of the construction project. – Have an administration user interface with full access rights. – Have a common environment data area/workspace for sharing and exchanging data. – Define who will produce BIM data what and when. – Inform people what to do and when to do it. – Inform people about the information that they need to provide. – Assist with decision-making. – Allow the client to be involved in the early stages of the design. – Define who has access to what and when. – Inform each actor about her/his roles responsibilities and when they should perform them. – Define what the requirements are for each individual stage of the construction project. – Define what needs to be provided at the end of each stage. – Define external gates between each stage of the construction project. – Define internal gates among the same actors within the same disciplines. – Have a mechanism for preserving a project's information for future reusability with new projects.
2. Non-functional requirements	2.1. Product requirements	2.1.1. Accessibility requirements	<ul style="list-style-type: none"> – It should be accessible from anywhere at anytime. – It should have a plug-in for modelling software such as: Autodesk Revit and Google Sketch-up.
		2.1.2. Portability requirements	<ul style="list-style-type: none"> – It should be hosted on online-shared storage with clear access rights for each actor. – It should give the option of allowing the actors to host their data on their local machines
		2.1.3 Scalability requirements	<ul style="list-style-type: none"> – It should be hosted on a scalable storage media because of the huge amount of information and bid size of models.
		2.1.4. Reliability requirements	<ul style="list-style-type: none"> – It should have and provide backup facilities. – It should be hosted by a reliable, dedicated, and known IT infrastructure or CSP.
		2.1.5. Usability requirements	<ul style="list-style-type: none"> – It should be easy for all team members to use. – It should have a simple user interface.
		2.1.6. Efficiency requirements	<ul style="list-style-type: none"> – It should effectively improve coordination among team members.
		2.2. Organisational requirements	<ul style="list-style-type: none"> – It should have clear definitions of actors, their roles and responsibilities within multiple disciplines through the building's lifecycle. – Platform development should be based on a standardised overall lifecycle data management policy. – Platform development should be based on the existing BIM related standards and protocols. – The platform should increase trust between people by recording changes that have been made (by whom and when). – It must have a process framework; i.e. process guidelines and protocols.

			<ul style="list-style-type: none"> – GovernBIM platform must have a technological framework; i.e. BIM tools and API. – Development of the GovernBIM platform should be aligned with the UK government's requirements, regulations and standards.
	2.3.1. Legal requirements		<ul style="list-style-type: none"> – It has to have a legal framework. – It should clearly define the ownership of BIM documents. – It should preserve intellectual property rights for each team member.
	2.3.2. Interoperability requirements		<ul style="list-style-type: none"> – It should support different web-browsers. – It should be able to support all types of transfer and collaboration tools. – It should enforce team members to use the same software version, as agreed upon at the beginning of the contract. – It should maintain a consistency of tools during the collaboration process.
2.3. External requirements	2.3.3. Privacy requirements		<ul style="list-style-type: none"> – It should provide access rights to the stored data based on actors' roles and responsibilities.
	2.3.4. Security requirements		<ul style="list-style-type: none"> – It should provide actors with a secure log-in to the system. – It should be hosted on physically secure data centres. – It should provide security checks for uploaded/downloaded and transferred models.
	2.3.5. Financial requirements		<ul style="list-style-type: none"> – It should be affordable to both large companies and small to medium enterprises. – The use of the GovernBIM platform should be time and cost effective.
3.Domain specific requirements	-	-	<ul style="list-style-type: none"> – There should be an intensive training programme for practitioners regarding the GovernBIM platform. – The users of the GovernBIM platform should be able to understand where and how their efforts are contributing towards the entire BIM model. – It should define clear roles and responsibilities for each actor during the construction project. – It should not take decisions away from people during the construction project lifecycle. – It should not change what an actor does but support his work. – It should provide a comprehensive element of consistency. – It has to provide a consistent structure for people during the building lifecycle. – It needs to be connected to the construction professions as well as contractors. – Development of the GovernBIM platform should not only focus on level 2 BIM, but should go further to level 3 BIM. – The GovernBIM platform development process should take into account actors and data structures, which exists in the BIM Execution Plan (PB, BXP, BPE or BIMM) and Responsibility Matrix. – It should define what to govern in terms of: people, information and documents, processes, classifications, and lifecycle. – It should also take into account all the people involved during a construction project, in particular recording all information received and delivered along the supply-chain. – It may act as an intelligent expert system by making use of preserved data, giving it the ability to provide advice on new projects based on experience gained in previous projects.

D. Factors for efficient BIM governance

Several success stories have been reported of BIM experts collaborating effectively and efficiently. This section describes the factors informing efficient BIM governance based on the consultation in interviews (see Table 4.14).

Table 4.14: Factors informing efficient BIM governance

Theme/Category	Factors
ICT factors	<ul style="list-style-type: none"> • Adopt effective communication, collaboration, coordination practices • Use adequate communication, collaboration, coordination tools • Embed trust in BIM technologies • Use effective methods for sharing data • Provide a Common Data Environment (CDE) • Track information
Socio-organisational factors	<ul style="list-style-type: none"> • Client motivation • Early client involvement • Educate practitioners • Provide technical training • Bring all team members together as early as possible • Strong leader who is capable of taking firm actions • Dedicated BIM/information manager • Team engagement • Forward planning • Shared goals and values • Clear roles and responsibilities for each member • Build strong trust links among team members
Practitioner factors	<ul style="list-style-type: none"> • Experience • Ability to use BIM tools • Interpersonal relationships • Ability to accept criticism • Willingness to collaborate • Willingness to share information • Relationship with the client • Solve problems as early as possible • Raise issues as soon as they emerge
BIM process factors	<ul style="list-style-type: none"> • Clear BIM implementation process • Clear and detailed collaboration plan • Having methods for sharing information at the right time • Setting check points during the project's lifecycle • Replacing the traditional delivery method with more integrated methods
Financial and Legal factors	<ul style="list-style-type: none"> • Covering financial resources • Providing business motivation to practitioners • Create business opportunities and possibilities • Create overall legal framework • Clearly define actors' roles and responsibilities • Clarify data ownership and IPRs

4.4 Prerequisites for BIM governance

The interviews revealed that there are, as yet, no formal BIM governance or management policies. Many companies are developing their own strategies and governance models, but they do not share them with other companies for reasons of competition. While, it is very rare to employ complete supply-chain governance/management policies, the larger construction companies have begun to develop their own methods of team collaboration. In addition, most governance is determined on a project-by-project basis, as the company tends to align its data management with the client's requirements for the project. On the other hand, practitioners categorised the existing BIM Execution Plan (BEP) (CPIc, 2013) and Responsibility Matrix (RIBA, 2013a) as BIM governance solutions. However, the issue with these standards is that they are in written format, read only by the practitioners with an interest in them or those forced to read them by their managers. They are also difficult to implement and out-dated, not representing BIM adoption as a new collaborative approach.

These factors underline the need to develop a non-proprietary BIM governance solution to facilitate team collaboration. Such a model should make it easier for all participants to understand their roles and responsibilities; thereby enabling each member involved in the collaboration process to deliver appropriately. Any BIM governance solution should reflect BIM experts' requirements, and the construction domain, as well as including a well-developed legal framework underpinned by ICT technologies. Moreover, the development of a BIM governance solution should incorporate the views and opinions of all construction-related parties, and major software vendors, facilitating team collaboration, and managing access rights to the stored BIM data.

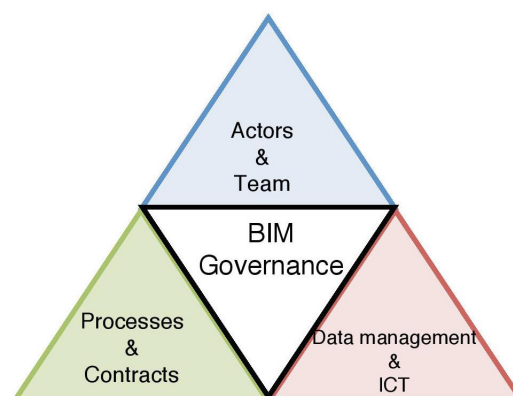


Figure 4.12: Prerequisite components of BIM governance

Figure 4.12 shows the interrelation between the components of a BIM governance solution. The prerequisite components of a BIM governance solution include awareness of:

- i) **Actors and team:** people involved in projects;
- ii) **Data management and ICT:** the technologies used during projects; and
- iii) **Processes and contracts:** the collaboration workflow underpinned by legal frameworks.

Moreover, to successfully govern BIM, we must first focus on the “Actors” sub-component, within a construction project, and their requirements, including those of the Client. “Actors” work within a collaborative “Team” that produces data, because of collaboration. Multiple actors collaborating within a team produce data during the building lifecycle “Process”. They utilise “ICT” to facilitate collaboration during the BIM process. This is supported by “legal contracts and policies agreements and considerations.

4.5 Proposed BIM governance framework (G-BIM)

The results of our intensive consultation led to the development of a G-BIM that presents and summarise the principal factors in successful BIM governance, and supports the future development of Cloud-based BIM governance solutions. The G-BIM comprises three main components: “Actors & Team”, “Data management & ICT”, and “Processes & Contracts”, with sub factors for each.

4.5.1 First component: Actors and Team

- **Actors:** Roles and responsibilities are to be defined and clarified in early meetings, prior to the commencement of the project. Defining access rights over produced and stored data will minimise the risk of unacceptable errors. Knowing who is going to work on which model, when he is going to work on it, and how he is going to work on it, are key factors for effectively governing the BIM collaborative process. In addition, preserving actors’ ownership and IPR is vital to help them more comfortable working in a collaborative environment. Moreover, increasing awareness of the importance of BIM governance will help motivate group work. Training is a crucial aspect of the BIM governance process. Experienced leadership of the team is also essential for motivating the project team towards producing successful outcomes. There is a strong need to involve all team members at the early design stages. The sub-components include: actors’ trust, defining actors’

roles, defining actors' responsibilities, defining access rights, clarify ownership & IPRs, raise awareness and provide relevant training.

- **Team:** Several factors need to be considered when working on a BIM-based project. Team members should adopt and use effective communication, collaboration and coordination practices and tools. They should notify each other of changes as early as possible. Team engagement is vital. These sub-dimensions include trust at the team level, total team engagement, common goals, adopting and using effective communication, and collaboration practices and tools, adopting and using effective coordination practices and tools, leadership, and a common data environment.

4.5.2 Second component: Data Management and ICT

- **Data management practices:** “Data” is the third sub-component of the G-BIM. “Actors”, in collaboration with their “Team”, generate data in various forms during a construction project. Therefore, some data-related factors need to be managed to govern the BIM process productively. Data should be consistent, accurate, available, secured, and stored in a remote and safe place. Data tracking mechanisms, and controlling and managing different data versions, are also important. Governing BIM data flow during a construction project can effectively minimise data errors and inconsistency.
- **ICT:** The fourth sub-component (ICT) represents infrastructure, supporting the BIM governance model. This component should produce several factors in successful BIM governance process: high-performance IT infrastructure, scalable storage volumes, interoperable environment, technical help and support, provision of high security and privacy services, management support for different types of file formats, instant access to data according to each actor's access rights, allowing users to customise their user's graphical interface, provision of and support for online collaboration environments, provision of a clash detection feature (allowing actors to upload and download their documents securely), and provision of servers with large storage volume capabilities for hosting project data remotely. ICT technology plays a crucial role in governing BIM, but its main role is to support and facilitate the governance process during team collaboration.

4.5.3 Third component: BIM Processes and Contracts

- **BIM processes:** “BIM Processes” are the fifth sub-component of the G-BIM. A clear and pre-agreed BIM process on a construction project is crucial for goal

fulfilment, and should be subject to easily followed standards and protocols. A clear, well-designed collaborative BIM process for team members is important and critical to the development of a Cloud-based G-BIM. This dimension includes: a clear BIM-based project lifecycle, a clear business process, clear and easy standards, easy-to-follow protocols, defined requirements for each individual stage of the building lifecycle, detailed processes for sharing information, checking points during the project's lifecycle.

- **Contracts and legal policies:** Contracts and legal considerations form the sixth vital sub-component of a G-BIM. They cover overall written agreements for agreed collaborative processes during a project and are underpinned by governmental rules and regulations. Although the adoption of BIM relies heavily on ICT and socio-organisational dimensions, legal contracts and policies are as important as the other dimensions. Addressing legal and contractual disputes is crucial for removing legal risks when working on collaborative projects. Written forms should include: clients' requirements, early team agreement, overall legal framework for a BIM-based project, collaboration requirements, and governmental rules and regulations; they should enhance information trust, clarify ownership, and address IPR concerns.

Moreover, financial aspects, including cost-effectiveness of BIM adoption, reasonable training costs, feasible infrastructure cost, and realistic software licence cost, should be strongly emphasised. The effective BIM governance factors' framework forms the conceptual framework for effectively governing the BIM collaborative process during team collaboration, establishing the groundwork for future BIM governance research and development. Figure 4.13 summarises and illustrates the six major components of the proposed BIM governance effective factors framework, including important factors for each component.

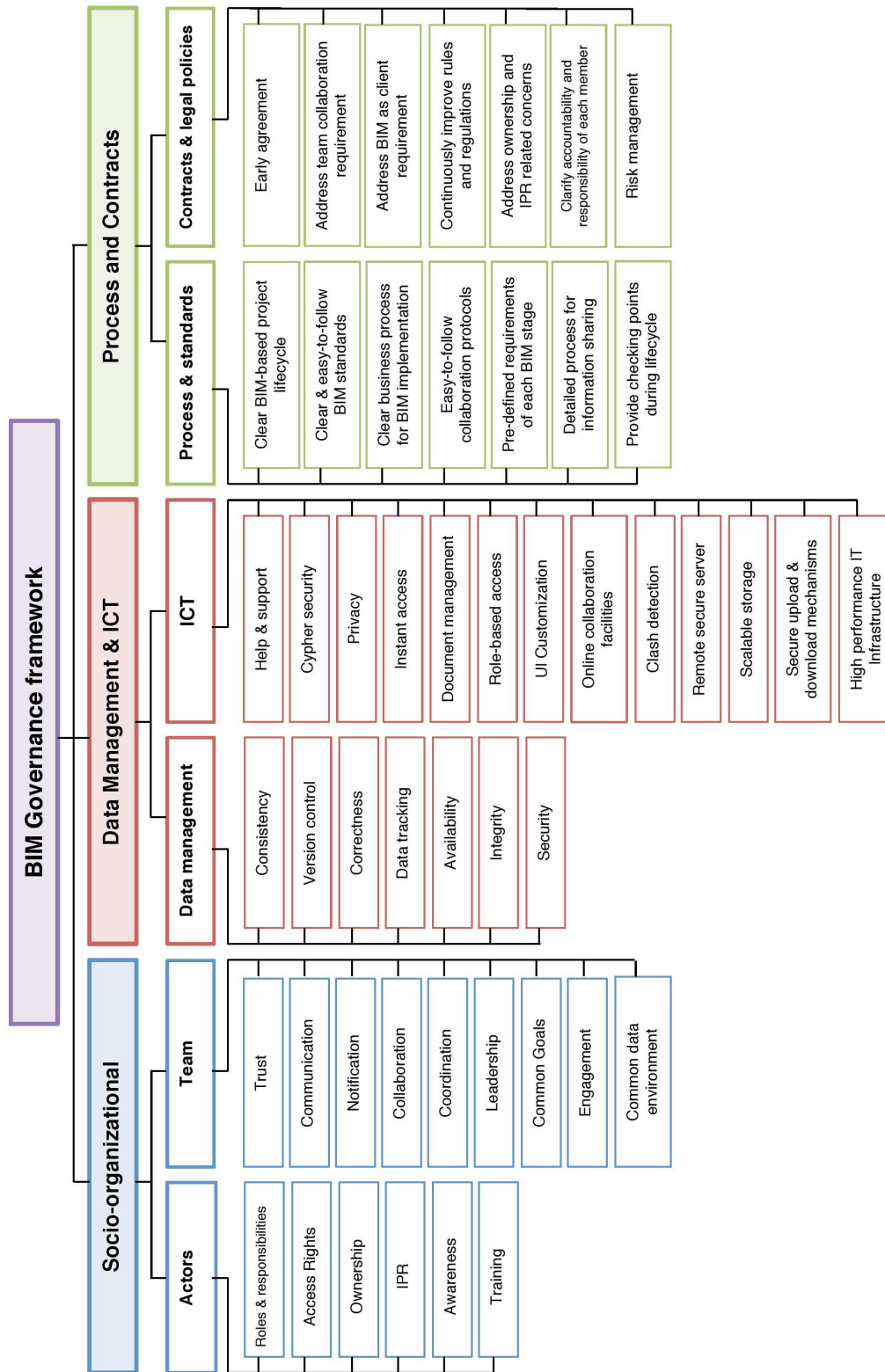


Figure 4.13: Framework of effective BIM governance factors (G-BIM)

4.6 Summary

There is a growing trend towards the adoption of BIM in the construction industry, because of its significant role in addressing several issues related to collaboration during construction projects. However, this adoption of BIM requires the team to accept new collaborative methods. The construction industry is suffering from critical issues regarding BIM adoption, and team collaboration. Although collaborative BIM solutions have been developed, these have largely focused more on the technical dimensions (e.g. socio-organisational, process, and legal). To resolve the identified issues successfully, BIM experts have emphasised the importance of developing governance solutions that can facilitate team collaboration, and enhance the process of decision-making during a construction project.

Consultations with BIM experts for this study, in the form of questionnaire and semi-structured interviews, identified many barriers to BIM adoption and classified many issues associated with team collaboration during construction projects with respect to socio-organisational, legal, financial and technical aspects that leads to negative impacts on team collaboration during the project. Although ICT and collaboration practices exist to a significant extent in construction projects, the current level of ICT and collaboration practices used in the industry does not support the collaborative adoption of BIM. Moreover, the use of inadequate data management solutions results in data errors, inconsistency, and poorly produced documents, which might have negative effects on the progress of construction projects. Further, there are more specific data-related issues include data inconstancy, compatibility, accessibility, security, and data storage problems.

The outcomes from the consultation suggested that a good approach for achieving fully integrated and collaborative BIM would be by governing the collaboration process and data flow, underpinned by Cloud technologies. This can be achieved through automation of BIM-related standards, concealing the complexity of these standards behind a user-friendly graphical interface. Since there is a lack of BIM governance models in the existing research and development, this study has contributed to consolidate key indications of BIM governance requirements. It also has evaluated the intensity of importance of these requirements. Besides expanding on the body of knowledge regarding BIM adoption, team collaboration, and ICT governance, this chapter categorised BIM experts' requirements into functional, non-functional, and domain specific requirements for developing a cloud-based GovernBIM platform. Further, this study contributed toward the development of effective factors for BIM governance framework (G-BIM). The G-BIM framework

comprised three main components: (i) actors & team, (ii) data management & ICT, and (iii) processes & contracts. The G-BIM framework presented a summary of the effective factors ensuring successful governance of a collaborative BIM approach. Moreover, the research supports the future development of a Cloud-based BIM governance solution.

Cloud Computing technology has been expected to address issues related to BIM data management. However, this study argues that Cloud Computing has still not been able to cope fully in dealing with issues related to construction data management. Data governance, for instance, is still an unresolved issue. For this reason, this study suggests that a governance platform should be developed on top of the Cloud infrastructure in order to facilitate handling generated data during construction projects. Moreover, there are many concerns surrounding the use of Cloud, such as security, privacy, and CSP ownership, there are major benefits too; e.g. accessibility, availability, high-performance capabilities and scalable storage. In addition to contributing to the growing body of BIM adoption and collaboration knowledge, this chapter shed light on the importance of BIM governance model laying out the foundation for future research and development.

Exploring the current situation in the construction industry, as well as identifying the requirements of BIM experts, forms the first step towards developing a cloud-based BIM governance solution. Nevertheless, the process of establishing, managing, and operating such a solution remains undisclosed by construction companies; hence, the next chapter (i.e. Chapter 5) will focus more precisely on analysing the outcomes from the wide consultation, as well as analysing the process of the lifecycle of BIM-based collaborative environments within three leading construction companies.

Furthermore, based upon the identified requirements in Chapter 4, the following chapter (i.e. Chapter 5) will focus on the modelling and implementation of the functional requirements and the domain specific requirements. Whereas, Chapter 6 will focus on the technical implementation of the functional and non-functional requirements; more specifically: product requirements and organisational requirements.

Cloud-based BIM governance platform's technical requirements and specification

5.1 Introduction

This chapter introduces findings adapted from the software engineering approach, using Business Process Modelling Notation (BPMN) and Unified Modelling Language (UML), to analyse and model the business process for the collaborative BIM management process at three construction companies: Arup, Mott-MacDonald, and Patel Taylor. This is followed by a section presenting the modelling approach adopted in the modelling business process in collaborative BIM environments. It then shows the analytical results and BPMN diagrams for the collaborative BIM environment, within the three companies. The chief discoveries are presented as follows: (a) set of BPMN diagrams describing the internal and external business procedures of the GovernBIM platform lifecycle, (b) several UML use cases describing the functionalities of the GovernBIM platform, (c) a core BIM governance model (class diagram) presenting the internal structure of the GovernBIM platform, and (d) a well-structured GovernBIM platform architecture for practical implementation, developed based on existing cloud software architecture.

5.2 Modelling business process of collaborative BIM environments

One aim of this study is to establish and develop a Cloud-based GovernBIM platform with requirements and specifications given using Business Process Modelling Notation (BPMN) and Unified Modelling Language (UML). The groundwork of this study was built based on a theoretical study of relevant BIM, collaborative, data governance, and Cloud computing aspects beside the results of wide consultation in the form of a com-

prehensive questionnaire and semi-structured interviews with key BIM experts. Arup, Mott-MacDonald and Patel Taylor are the selected BIM adopting companies with aim of understanding and analysing the lifecycle of their BIM-based collaborative environments. Followed by analysis of current ICT and collaboration practice and BIM collaboration solution, alongside with BIM-related documentation, (e.g. collaboration manuals, BIM standards, etc.) investigation. These afford-mentioned methods were main instruments used to, gather BIM experts' requirements and to build specification using BPMN and UML for Cloud-based BIM governance platform.

Therefore, this stage is structured according to the following tasks: (a) produce a set of BIM experts' requirements comprising their expectations of a Cloud-based GovernBIM platform, as well as a textual description of their collaborative environments, practices and tools; (b) analyse and present a static view (textual descriptions), and a dynamic (sequential) view with BPMN diagrams of GovernBIM platform based on analysis outcomes of the collaborative BIM within the afford-mentioned companies; (c) provide a GovernBIM platform system and UML analysis, with a dynamic model (use cases diagrams) and a static model (class diagrams); and (d) design a Cloud-based GovernBIM platform, based on the platform software architecture and the specifications of its components.

Figure 5.1 illustrates the modelling approaches used to understand end-users companies' business processes, and to capture the requirements of the GovernBIM platform solution. The development of BIM governance model involves working in different levels to provide interconnected activities from the top level to the low level. BPMN is used to define high-level process activity models describing business processes and information management practices (Chinosi and Trombetta, 2012). Therefore, it has been utilised to deliver such objective. However, defining high-level processes can be deemed as generic outcomes. For this case, another modelling tool is required to break down the higher-level process activities. Hence, UML is known for the use at a low-level to specify more activities in lower levels (OMG, 2015). Both BPMN and UML have been used to develop a comprehensive and coherent GovernBIM platform (Lpez-Campos et al., 2013). Hence, this specification phase is divided as follows: BPMN diagrams and UML use cases descriptions (using context diagrams and textual descriptions) address user requirements, Refinement of UML use cases through a class diagram at the level of analysis/conception, Design software architecture to implement a Cloud-based GovernBIM platform.

There are many process modelling techniques and tools such as flow chart technique, data flow diagrams (Yourdon's technique) and Integrated Definition for Function Model

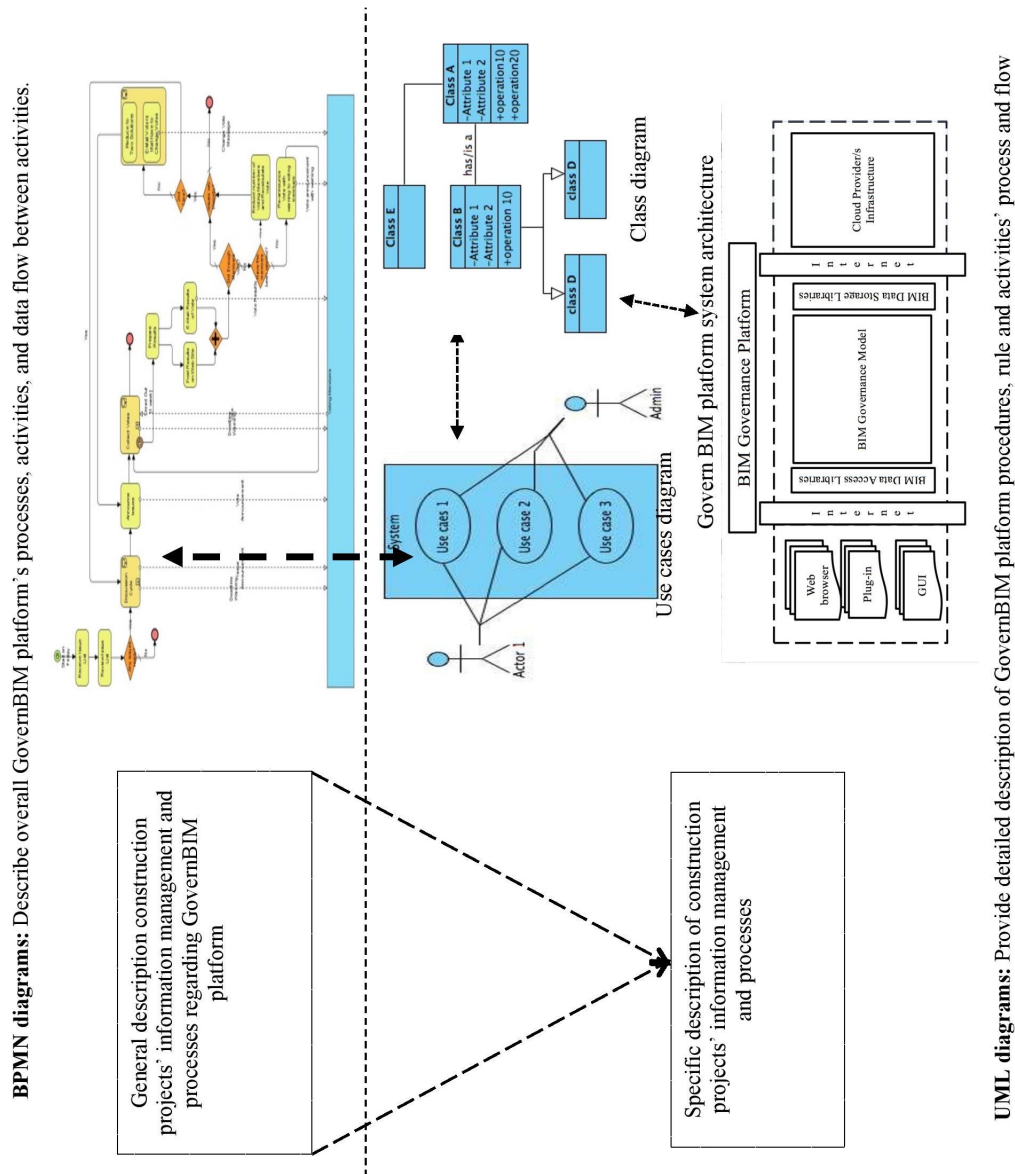


Figure 5.1: BPMN & UML usage in defining GovernBIM platform's requirements & specifications

(IDEF), a discussion on which can be found in (Aguilar-Saven, 2004). These modelling tools are recognised as out dated tools; thus, they do not meet our project scope and requirements (Campos and Mrquez, 2011). On the other hand, Unified Modelling Language (UML) is a relatively recent approach that assists software development processes by providing means to capture software system structure, as well as the behaviour of its components. UML is a language for specifying, visualising and constructing the artefacts of a intensive software system, which was designed to model object-oriented software systems, and has been used successfully in this field for over a decade (Bendraou et al., 2010).

Based on UML, developers have developed the System Modelling Language (SysML), which is a graphical modelling language for systems engineering applications. SysML is built on top of UML and tailored to the needs of system engineers by supporting specification, analysis, design, verification and validation of a broad range of systems and system-of-systems (David et al., 2010). However, SysML is essentially a UML profile that represents a subset of UML with extensions (David et al., 2010). Mastery of SysML requires a substantial learning curve, making it difficult for construction practitioners to understand its diagrams (Liston et al., 2010). Further, SysML reuses and extends most UML diagrams, giving too much freedom and space to the modeller, thereby, increasing the probability of confusion when inexperienced practitioners are interpreting the modelled system (Liston et al., 2010). The outcomes of this study are not specific to software developers but also target construction practitioners; therefore, to support simplicity and to avoid complexity, basic UML diagrams are used in this study.

Nevertheless, UML follows a more object-oriented modelling approach; therefore, in addition to UML, this study also adopts BPMN, which is more process-oriented (Liston et al., 2010). BPMN developed as a standard language for capturing business processes, especially at the level of domain analysis and high-level systems design (Chinosi and Trombetta, 2012). It was developed to help businesses understand their internal processes so that decision makers see their processes without focusing on how a particular solution constrains the problem domain (Flowers and Edeki, 2013). BPMN and UML are two of the most widely used and recognised modelling standards around the world in a variety of fields, from informatics science to management. Furthermore, one advantage of using BPMN and UML is that it is easy to translate their models into software code (LPEZ-CAMPOS et al., 2014).

Although, UML shares some similarities with the BPMN approach, both aim to provide a basis to understand and define the captured requirements of the proposed system (Lpez-Campos et al., 2013). They work differently; UML examines various methods for using a system, as well as for specifying the proposed system use cases (Lpez-Campos et al., 2013). The BPMN provides a detailed top-down description of a business process model, along with messages and information flows between activities. The latter is described using graphical notations to specify business processes in a Business Process Diagram (BPD) (Lpez-Campos et al., 2013). It should be noted that both approaches are complementary, and so can be used in conjunction. VisualParadigm (VisualParadigm, 2014) software is used to analyse, model, and generate BPMN and UML diagrams for the GovernBIM platform in this study.

However, in terms of migration from initial requirements at the capture stage to the internal design and API of the GovernBIM system, the methodological steps are as follow. After enhancing and eliciting the platform requirements obtained for GovernBIM from BIM professionals, there is a generalisation of, and abstraction of findings, leading to the development of the proposed GovernBIM platform's BPMN diagrams. From the BPMN developed for the GovernBIM platform, a set of UML diagrams, including: use cases and class diagrams have been developed and created; these specify and describe the interaction between end-users and the GovernBIM platform. Finally, there is a GovernBIM platform' implementation architecture including a prototype description, user interfaces and data storage design. After defining the use cases for the GovernBIM platform, technical specifications are completed using UML techniques and class diagrams to specify the platform's internal design. Meanwhile, the GovernBIM platform architecture defined, based on the internal specifications, designs and examination of commonly used Cloud-based applications.

5.3 Analysis and result

Results of this chapter are presented according to the following topics: (a) business process analysis of collaboration environments in three BIM-implementing companies, (b) set of BPMN diagrams representing GovernBIM platform lifecycle, (c) set of UML use cases describing GovernBIM platform functionalities combined with class diagram defining the internal structure of the platform, (d) a tailored software architecture for applying GovernBIM platform.

5.3.1 Business process of collaboration environments within three selected companies

This section will describe business process analysis of collaboration environments in three BIM-implementing companies. This section starts with an overview of each selected company followed by their collaboration environment process description alongside a BPMN diagram for their process.

A. Case study 1: Mott MacDonald

Mott MacDonald is a global management, engineering and development company. They use their inventiveness skills to save customers' money and time; reduce risks; increase efficiency; maximise sustainable outcomes, and move ahead using best practice. They

work on various projects regardless of their type, scale or location, creating benefit from their experience of worldwide knowledge and collaborative approaches. Their duty to collaborate is not restricted to their clients, but they have a team that collaborates locally and globally using the latest collaborative technologies to ensure best outcomes.

Mott MacDonald recently adopted BIM environment using various modelling tools such as Revit and Bentley systems. They try to create a workflow so that each software package that they are using is coordinated and is in a live environment. Thus, they have several workflows that are ready to use, which allows them to pick the correct software based on the project. Figure 5.2 present BPMN diagram of their process.

Depending on a construction project, they have a collection of tools/software, and once they understand these tools, they put it into their BIM proposal. Following that, they have their own BIM proposal that will be handed to the client. Then, the client, based on their BIM proposal, will choose what sort of options that they want: If he/she wants the project to be inside the cloud; whether it is going to be used across different continents; if it requires security and Ministry of Defence (MOD) access or any government access; selection of the used software and platform (this includes selecting different parts (services) from the software and the platform which will be used in the project); Sorting out the versioning control system. Once their BIM proposal is accepted, then that forms the set of tools that are going to be used.

They own two management platforms. The first platform is Project Information Management solution (PIMs) that is used for their general management infrastructure. The second one is ProjectWise, which is generally used for their AutoCAD environment, and it can also be transferred to other Bentley platforms and Revit environments. PIMs and ProjectWise are the main tools that are used for managing the documents of the construction company. Their PIMs environment allows them to manage all the information, including modelling costs, procurement, contractor requirements, and client requirements.

Actors' access rights are managed within their (PIMS) environment via access control. Basically, they drop usernames and just give them basic permissions according to the level of access rights inside the project. They have basic NTFS permissions per project. In their Revit environment, they must ask for permission from the main administrator in order to grant them access to the models in the server. Once they are disconnected from the server, their local copies disappear.

When they use a Cloud-based BIM solution, it shows that it has been a complete success

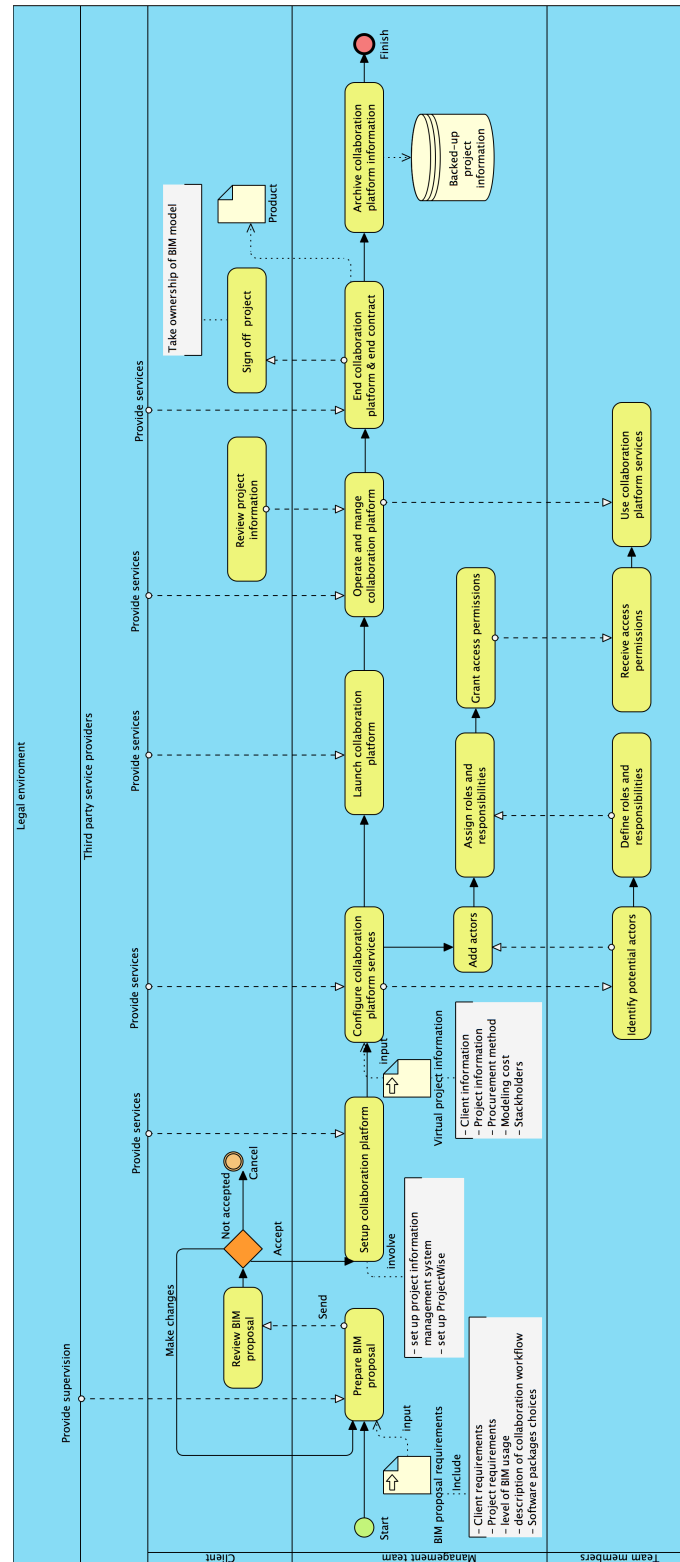


Figure 5.2: Managing collaborative BIM environment at Mott MacDonald

for their project. Mott Macdonald has their own private cloud solution so that people in their organisation do not put their data onto a public cloud. It is maintained within a

secure environment as a private cloud solution within their network. If they work with an external company who does not have this solution, they arrange a plugin into this company so that they can work effectively on their network but inside Mott Macdonald's cloud environment.

At the end of a construction project, they hand-in the BIM model to the client. This includes: (a) signing off the model to the client; (b) providing him or her with ownership of the model. The information produced during the whole virtual construction project is archived via their archiving system based on their standard archiving procedures.

B. Case study 2: Arup

Arup, as a global company, was founded in 1946 with an initial focus on structural engineering. Since then, it has grown into a truly multidisciplinary organisation. The Arup branch in Wales has been established since 1970. It has been working on enhancing the built environment since that date, thus it has become one the most substantial and diverse consultants in the country. Arup has contributed substantially to many projects in Wales, for example the Wales Debating Chamber, Stadium and Millennium Centre, National Waterfront Museum, and delivering and planning major highways in Wales, as well as wind farm programmes.

The process of establishing collaborative BIM environment in Arup as follow: Firstly, they do is to choose the IT infrastructure in order to determine the efficiency of their server. Their infrastructure and services provided by the Citrix software company. They use the server power to drive their models with more efficiency and to benefit from high processing speed, not only giving people access to certain areas. Moreover, their PCs and laptops become out of date quickly, and their local hosting server is over-loaded with many people. After determining their services' provider, they install the required software onto the hosting infrastructure. After that, they set up accessibility options for actors to login to the hosting servers.

In Arup, the process of collaboration is carried out as follows: each team member will have their own model, then they use their models to link to an internet site, for example Asite for managing projects, and then they share their models with each other. Once the models have been uploaded, the information will be checked to see that it is correct, and then the team will continue from that process onwards.

For their communication practices, the team mainly uses emails. Also, based on the

contractual agreements and protocols, the team uses an Internet site for hosting the whole project, and this site will send a notification email to the team to inform them to download the latest version; it is similar to Extranet. This hosting website is also used for storing and sharing project data. They also keep a local copy of the data on their machines. They hardly use paper, as nearly all their files are exchanged and shared electronically in PDF format. However, as for document management in their organisation, they use ProjectWise for managing their documents, besides their internal filing structure. In addition, they also use project Extranets for controlling the document process. Figure 5.3 presents Arup's management process of collaborative environment.

In Arup, the level of management is done on both levels- the file level and objects inside the documents level. The file management in their company is based on the file and where is it stored and how is it stored, as well as them having an internal team that looks at the meta-data assigned. They are still working on level-2 BIM environments. This means that they store their information models (which might be up to 6,7 models). Then they have duplicated models when they upload their models to the central storage area. A link to that model is generated, which allows all other team members to drag that link to their models and make changes.

At the end of a virtual construction project, they backup and archive all information produced on their backup servers. They filter their data for backed-up or archived content. They do not backup all files- they sort out the important reports, drawings, PDFs and other documents that are going to be archived. Nearly all the projects they work on are done so using Extranets, where they have their own local version of the data, and the actual project data that is relevant to the client is stored on the Extranets for the client.

C. Case study 3: Patel Taylor

Patel Taylor is a medium-sized practice based in London. It was established in 1989 to carry out most types of projects while maintaining consistency of quality. The founders have lectured at the RIBA, throughout the UK, in Europe and Japan. The company believes that every project deserves a tailored architectural design when transforming buildings and places. Their collaborative working approach is based on a good relationship between client aspirations, project site and total cost. Their projects range in scale from city planning to leading residential sites.

All parties who are involved in a construction project are gathered around a table, including the attendance of specialists and a decision maker. This group of people decide

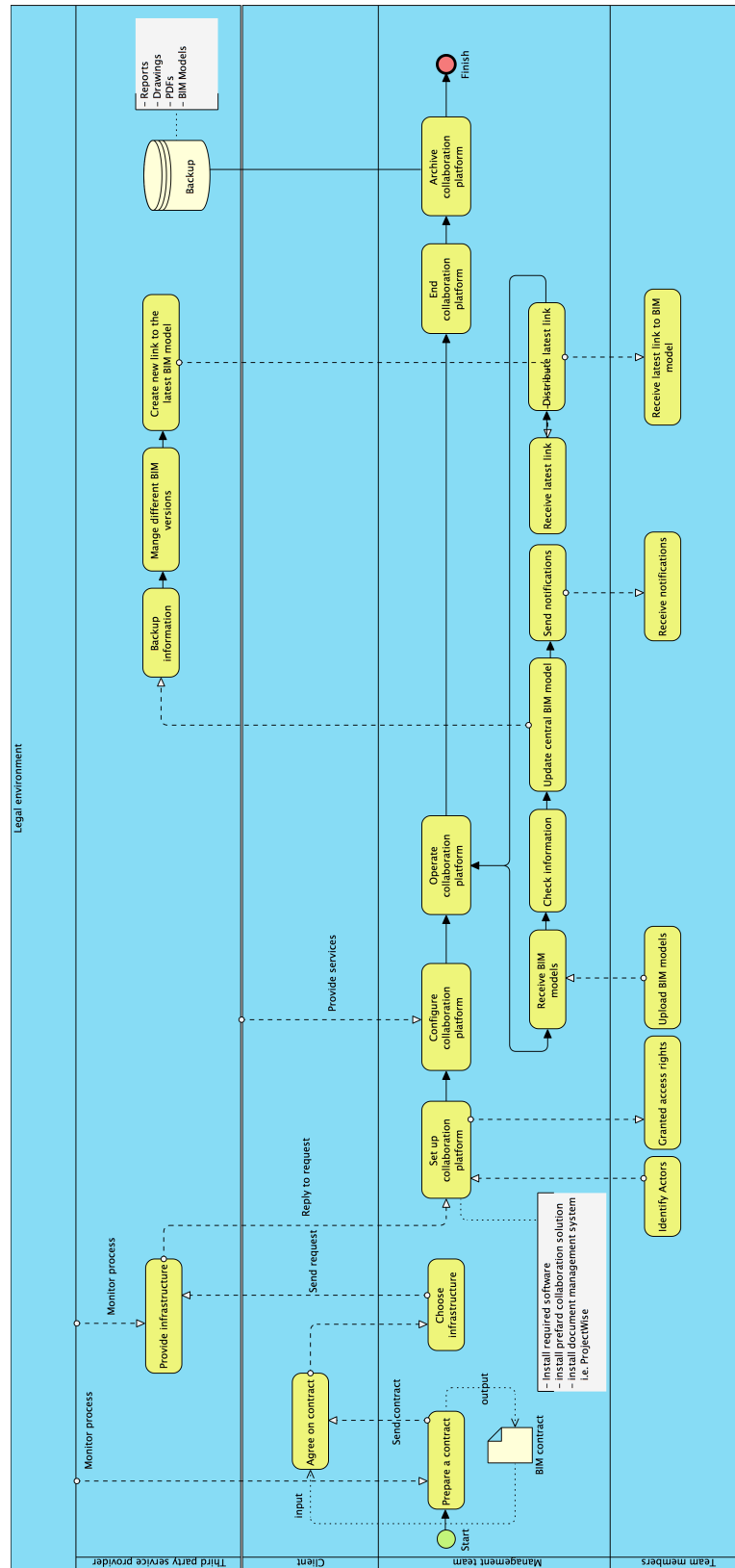


Figure 5.3: Managing collaborative BIM environment at Arup

on the program according to a schedule. The group also identifies client desires, goals, and aspirations, and the local conditions that they need to meet.

At the first meeting, they identify what they can or cannot do. The results are then shown to the client, and it is agreed with the client concerning the process for their construction project including deciding on technical requirements, infrastructure, and required training. Next, the project team sets up checkpoints where they meet regularly every week or two. Then, the team members set out the roles and responsibilities of each member of a given project, and they agree on the budget as well as how they are going to implement the work. They work out the BIM execution plan, but not on the first day, and then they set up and run their Electronic Documents Management Server (EDMS).

The process of ending construction project depends on the type of data. The concept of one big file that holds all the data did not and does not work for them. Thus, all their data is hosted and located on EDMSs where their project lives from the day it is setup until completion of the project. Because of the way their EDMS works, ownership and access rights to stored data will change. At some point of a project, an actor has full access to stored data, but when the project progresses, s/he may no longer have these access rights. The problem with these EDMS and BIM management solutions is that they are owned by developing companies, that is, they are private initiatives and restricted access to code or data governance structure. Figure 5.4 presents BPMN for managing collaboration environment at Patel Taylor.

Large enterprise clients rely on another company as a service provider to host their big data. This brings risks to the hosted data: (a) What will happen if the company goes down or becomes bankrupt?, (b) How can data be accessed if that happens?. Hence, people in Patel Taylor (i.e. small-medium company) are double handling everything as they maintain copies of all data that is issued to them whether they want to or not. They maintain copies of these files and data for six or seven years. In addition, on individual level they always back up their files that are hosted online just in case their Internet connection went offline.

There are many technical issues that need to be addressed for them when they are going to adopt EDMSs. Different actors use different forms of software; therefore their management environment should be able to deal with all different file formats; for example, environmental analysis when assessors are using online resources for their analysis, as well as subcontractors when they are carrying out pricing. Most importantly is that they are still delivering drawings in PDF format on paper or AutoCAD DWS format.

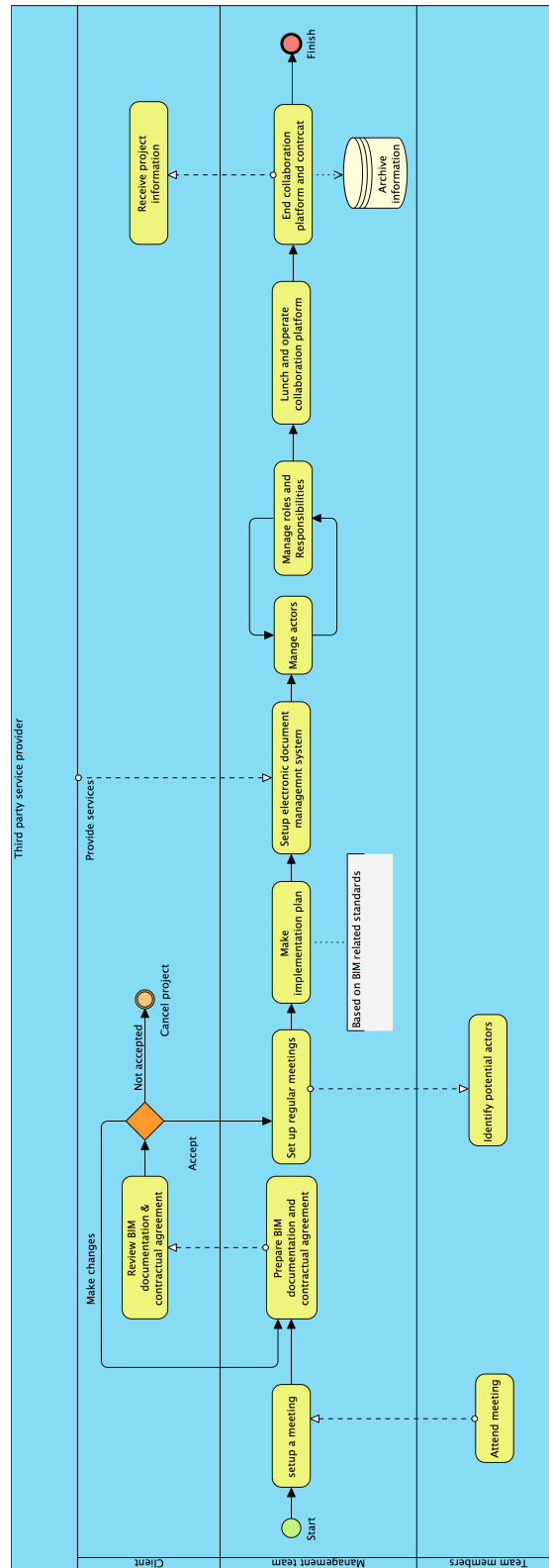


Figure 5.4: Managing collaborative BIM environment at Patel Taylor

5.3.2 Core BPMN diagrams for the GovernBIM platform

Overall inputs into the GovernBIM platform are CSP's services and a set of initial requirements; including, (a) client, (b) construction project, (c) legal, and (d) industry. The legal environment performs a supervisory role over GovernBIM platform activities. The final outputs of GovernBIM platform include: a product/service and all information related to the GovernBIM platform project, in different formats. The GovernBIM management team perform the majority of the GovernBIM platform's activities using GovernBIM tools/APIs and CSP's services.

In this section, we begin with the bigger picture (Core) and BPMN modelling outcomes. Figure 5.5 presents the core BPMN and preliminary GovernBIM platform setup activities. It is considered the source of all BPMN diagrams that follow. The core GovernBIM platform BPMN includes two main activities: (A) provide and manage the GovernBIM platform's services, and (B) provide and manage the GovernBIM platform project.

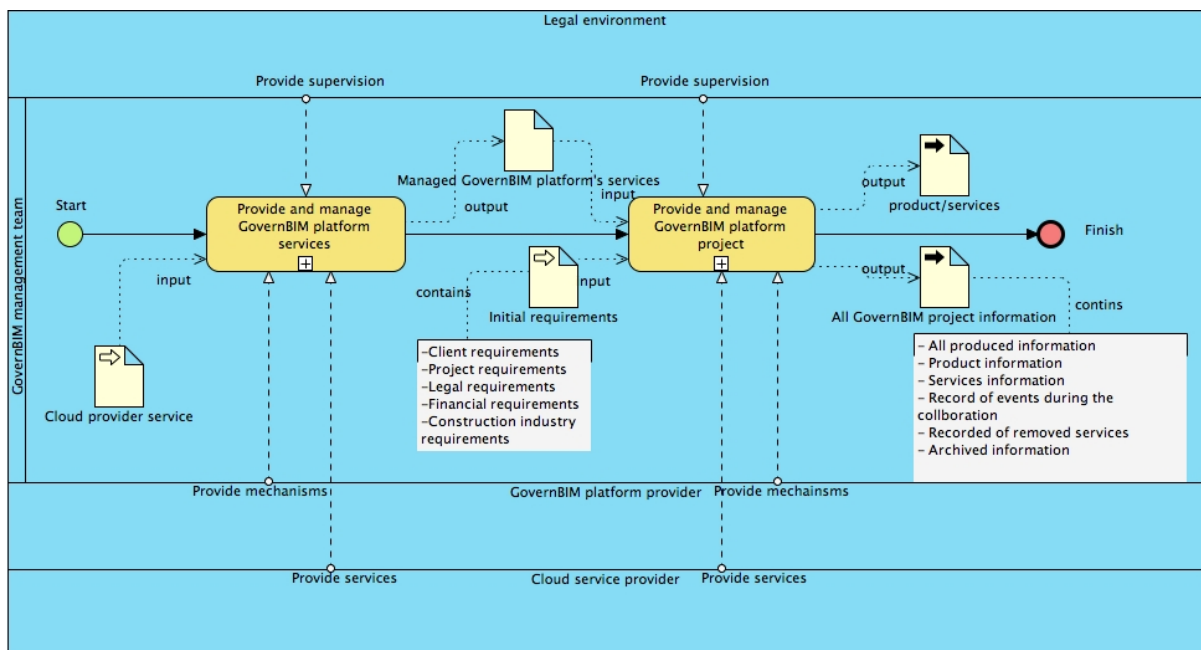


Figure 5.5: BPMN diagram: Preliminary GovernBIM platform setup

A. BPMN activity: GovernBIM platform's services

Providing GovernBIM platform services requires a set of activities to establish the GovernBIM platform's project. Figure 5.6 illustrates the BPMN diagram, used to provide and manage the GovernBIM platform's services. The BPMN activity comprises four main activities:

Register service: this activity encompasses the actions required for registering GovernBIM services that will be made available to clients (end-users). **Provide services:** this activity permits the GovernBIM management team to offer GovernBIM platform services to their clients. **Maintain services:** this activity involves the ability to add, upgrade, and/or remove services as necessary as they become available. **Remove services:** this activity allows the GovernBIM management team and CSP to remove services from the GovernBIM platform. Inputs to activity are maintained and managed as GovernBIM services. For governance and contractual purposes, a record of services removed from the GovernBIM platform is made.

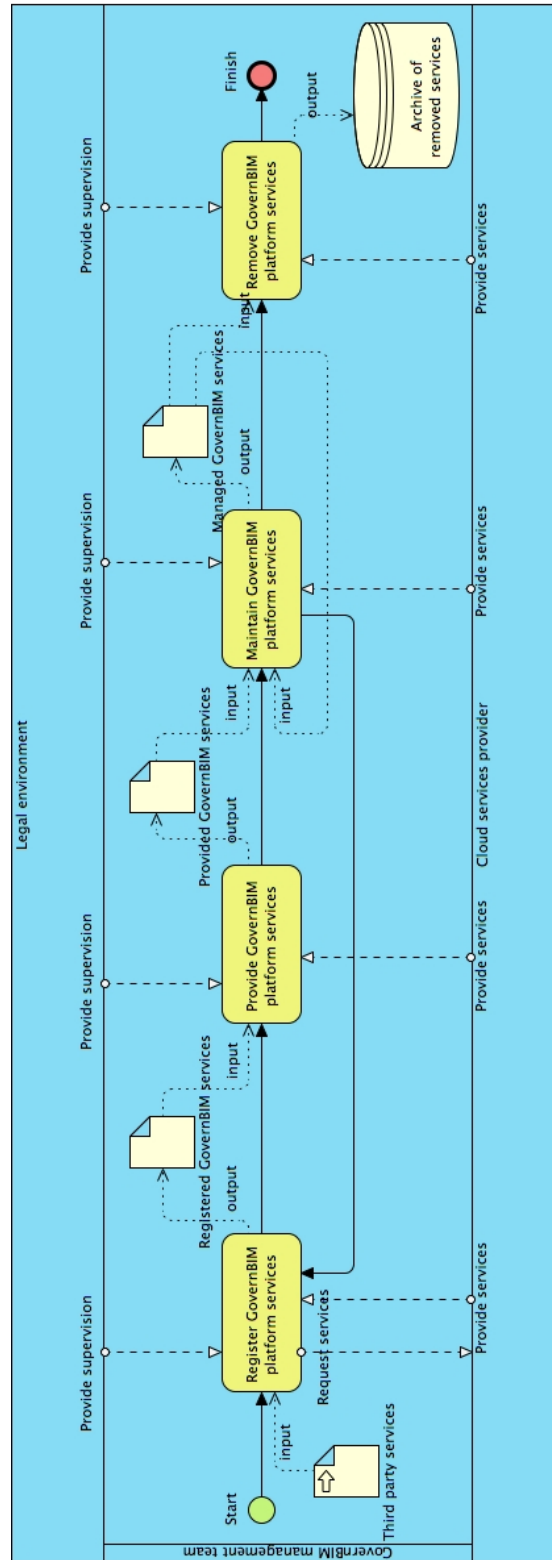


Figure 5.6: BPMN diagram: Provide and manage the GovernBIM platform's services

B. BPMN activity: GovernBIM platform's project

Figure 5.7 shows the BPMN diagram for providing and managing the GovernBIM platform's project. The GovernBIM management team perform activities utilising GovernBIM API/tools and CSP services. Legal environments and contractual agreements (as well as the GovernBIM platform's management team, in the later stages) supervise all activities. These consist of seven activities, as detailed below:

- **Make contractual agreement:** This activity encompasses actions required for the formation of a contractual agreement between the client, GovernBIM management team, and the CSP. The contractual agreement covers the use and operation of an agreed GovernBIM project. Client requirements are inputs for this activity. Outputs are the contractual agreement, which provides supervision of the following five activities.
- **Review contract:** This activity involves negotiation between the GovernBIM management team and the client with regard to the contractual agreement. The client receives a copy of the contractual agreement; they then have the right to cancel, accept after changes, or accept the contract without changes. Inputs for this activity are initial requirements. Based on the client's acceptance of the contractual agreement the following activities will be established. Outputs from this activity will define the agreed contractual agreement, and provide control over the following activities in the BPMN diagram.
- **Set up GovernBIM project workspace:** This activity takes place, as soon as a contractual agreement has been made. The CSP allows the necessary servers, computer resources, logging facilities, and essential services, etc., to establish the GovernBIM platform's project. The inputs to this activity are the GovernBIM project specifications. In addition, during this activity, a GovernBIM project administrator will be registered, and the GovernBIM project will be initialized within the selected service. The outputs from this activity are then registered with the GovernBIM project administrator, and the initialized GovernBIM project for the selected services.
- **Configure GovernBIM project:** This activity contains all the necessary actions for configuring the GovernBIM project, as established under the terms of the contractual agreement. The GovernBIM project requirements; the initialized GovernBIM project with selected services form the input for this activity. A configured GovernBIM project will provide the output from the activity. The GovernBIM

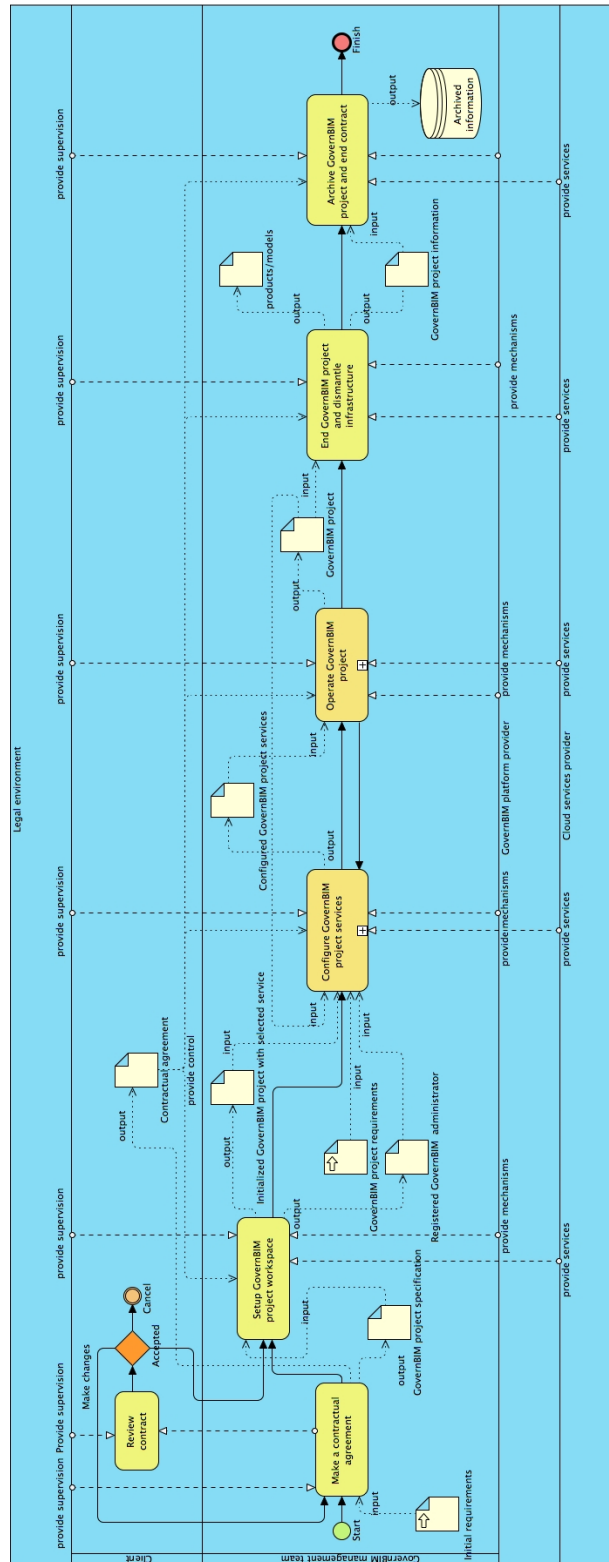


Figure 5.7: BPMN diagram: Provide and manage the GovernBIM platform's project

project Administrator performs the activity using the GovernBIM Tools. This activity is broken down further (see figure 5.8).

- **Operate GovernBIM project:** This activity contains the actions necessary to operate a GovernBIM project, in terms of the management of actors, roles, access rights, BIM objects and GovernBIM platform services. Configuration of the GovernBIM project is achieved from the input for this activity. The output is the GovernBIM project in operational mode. This activity is then broken down into additional detail (See figure 5.9).
- **End GovernBIM project and dismantle infrastructure:** This activity represents the requisite actions to end the current GovernBIM platform's project. The GovernBIM platforms' project in operational mode forms the input to this activity. Outputs include products/services created by the GovernBIM project and GovernBIM project information.
- **Archive GovernBIM project and end agreed contract:** At the end of the GovernBIM project lifecycle, the GovernBIM project's information is archived for future re- distribution and reuse. The input to this activity is all the GovernBIM information to be archived. The output from the activity is the archived GovernBIM project information.

This research focuses on two BPMN activities: B.1. Configure GovernBIM platform's project, and B.2. Operate the GovernBIM platform's project. This is because these selected BPMN activities are considered the key to successfully offering and providing the GovernBIM platform.

B.1. BPMN activity: Configure GovernBIM project

As figure 5.8 illustrates, the activity of configuring the GovernBIM project comprises six activities. These activities are configuring the process for an agreed GovernBIM project, which has been set up under contractual agreement terms and conditions. Both the GovernBIM platform management team and contractual agreements within the legal environment provide supervision over these activities. Both the GovernBIM management team and registered administrator perform these activities utilising GovernBIM Tools/API and the hosting Cloud provider's services.

- **Configure assigned services:** In this activity, the GovernBIM project administrator configures the GovernBIM platform services and other third party services that are assigned to the GovernBIM project to achieve the project requirements.

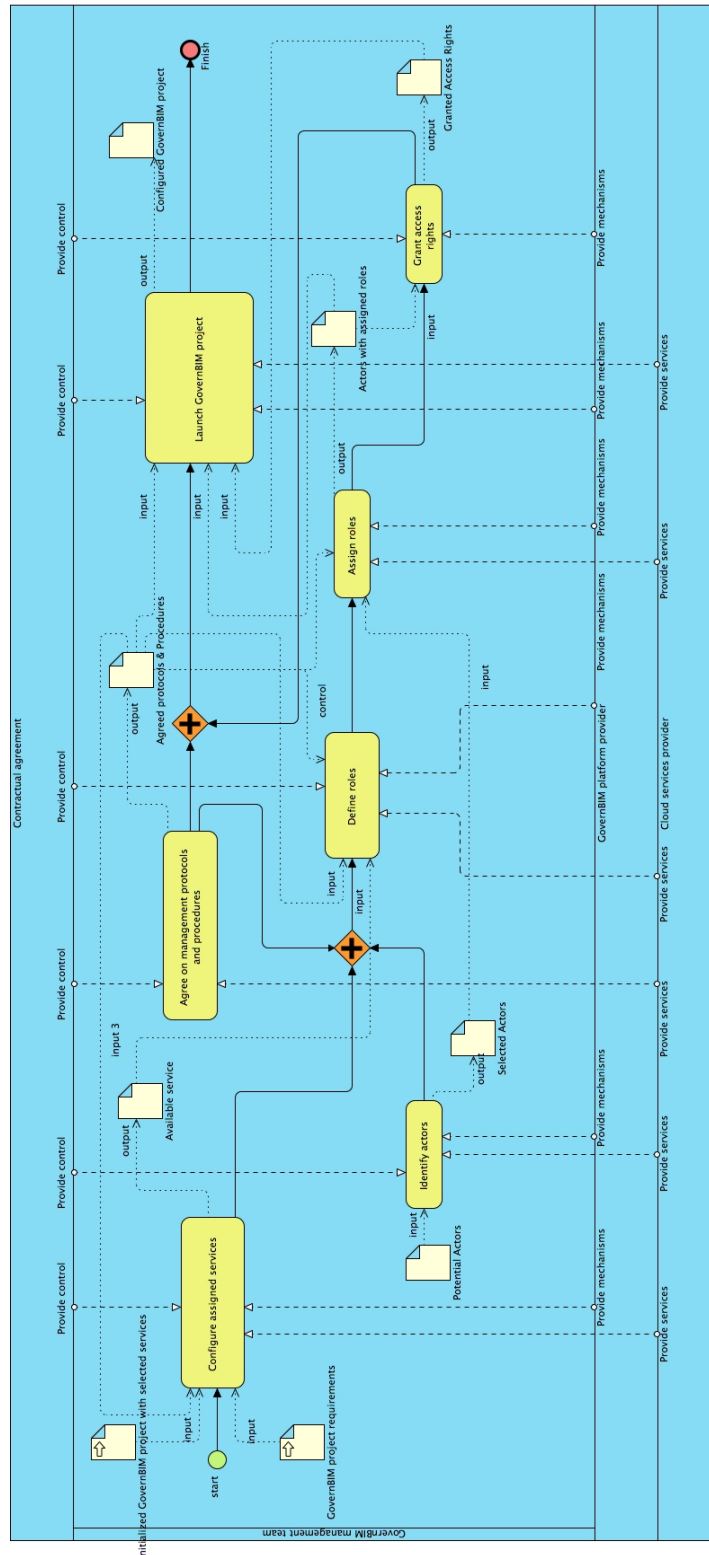


Figure 5.8: BPMN diagram: Configure GovernBIM project

Inputs to this activity contain the initialized GovernBIM project and selected services, GovernBIM project requirements, and agreed GovernBIM management pro-

protocols and procedures from agreed management protocols and procedural activities. Outputs include the configured GovernBIM project services and available service methods.

- **Identify actors:** This activity involves actions required to identify and confirm actors as involved in a GovernBIM project. The inputs to this activity are all identified as potential actors. Outputs are the selected GovernBIM project actors; they will be assigned specific roles and responsibilities subsequently, following on from activities completed during the GovernBIM project.
- **Agree on management protocols and procedures:** This activity includes the actions to be agreed upon during the GovernBIM project (e.g. code of behaviour, responsibilities, plan of action, etc.). The output of this activity is approved GovernBIM management protocols and procedures.
- **Define roles:** This activity includes all the actions required to identify and define potential actors' roles within the specific GovernBIM project. The inputs to this activity are the configured GovernBIM project service, and the agreed management protocols and procedures. The contractual agreement, agreed GovernBIM management protocols and procedures, and project management team control this activity. The outputs are the defined GovernBIM project roles and responsibilities, which will be assigned to relevant actors, with a set of access rights.
- **Assign roles and responsibilities:** This activity includes determining the necessary actions to assign defined roles to the actors identified. The identified actors and the roles and responsibilities for this particular GovernBIM project form the inputs for this activity. The contractual agreement, agreed GovernBIM management protocols and procedures, and the GovernBIM management team provide control over the activity.
- **Launch GovernBIM project:** This activity includes the necessary actions to launch the GovernBIM project. Inputs to this activity include configured GovernBIM services, agreed GovernBIM management protocols and procedures and actors identified within their assigned roles, responsibilities and access rights. The GovernBIM project management team provide control over this activity, and the output from this activity is a configured GovernBIM project.

B.2. BPMN activity: Operating GovernBIM platform's project BPMN

Figure 5.9 below depicts the BPMN diagram for operating the GovernBIM project. It involves six main activities required to operate the project. Both the legal environment

and contractual agreement afford supervision and control over these activities. Primarily, it is the GovernBIM administrator and the end-users that perform activities using GovernBIM API/tools and hosting CSP services. Training of the GovernBIM administrator and end-users might be required if they are to perform activities for this BPMN.

- **Manage actors:** This activity encompasses essential actions for managing selected actors contributing to the current GovernBIM project. The configured GovernBIM project is the input for this activity. The output is managed actors that can also provide control over it.
- **Manage roles:** This activity encompasses the necessary actions to oversee the roles and responsibilities assigned to relevant actors. The configured GovernBIM project forms the input; outputs are managed roles and responsibilities.
- **Manage access rights:** This activity encompasses the actions required to assign access rights to actors who have been assigned as part of the GovernBIM platform's project. Information operations include: sharing, exchange, communication, distribution, archiving, workflow and scheduling, as access rights attached to the assigned roles in the GovernBIM project. Inputs to this activity include the configured GovernBIM project and actors managed with assigned roles and responsibilities. Outputs refer to managed access rights.
- **Manage BIM objects:** This activity encompasses the necessary actions to manage BIM objects uploaded by multiple actors during the GovernBIM project. Inputs to this activity include uploaded BIM objects from GovernBIM platform end-users; outputs are managed BIM objects.
- **Use GovernBIM platform services:** This activity refers to essential actions to allow selected actors to access the GovernBIM platform services and third party Cloud services, made available via the specific GovernBIM project. Inputs for this activity include the configured GovernBIM project, managed actors, managed roles and responsibilities and respective access rights. The output from the activity is the GovernBIM project in operation mode.
- **Manage GovernBIM project services:** This activity involves activities that are central to allowing the GovernBIM platform administrator to guarantee that the services assigned to a specific GovernBIM project are available to all actors involved in that project; hence, enabling continuity of the operational GovernBIM project. Inputs to this activity include the configured GovernBIM project, managed actors, managed roles and responsibilities, and their access rights. The output is the GovernBIM project in operational mode.

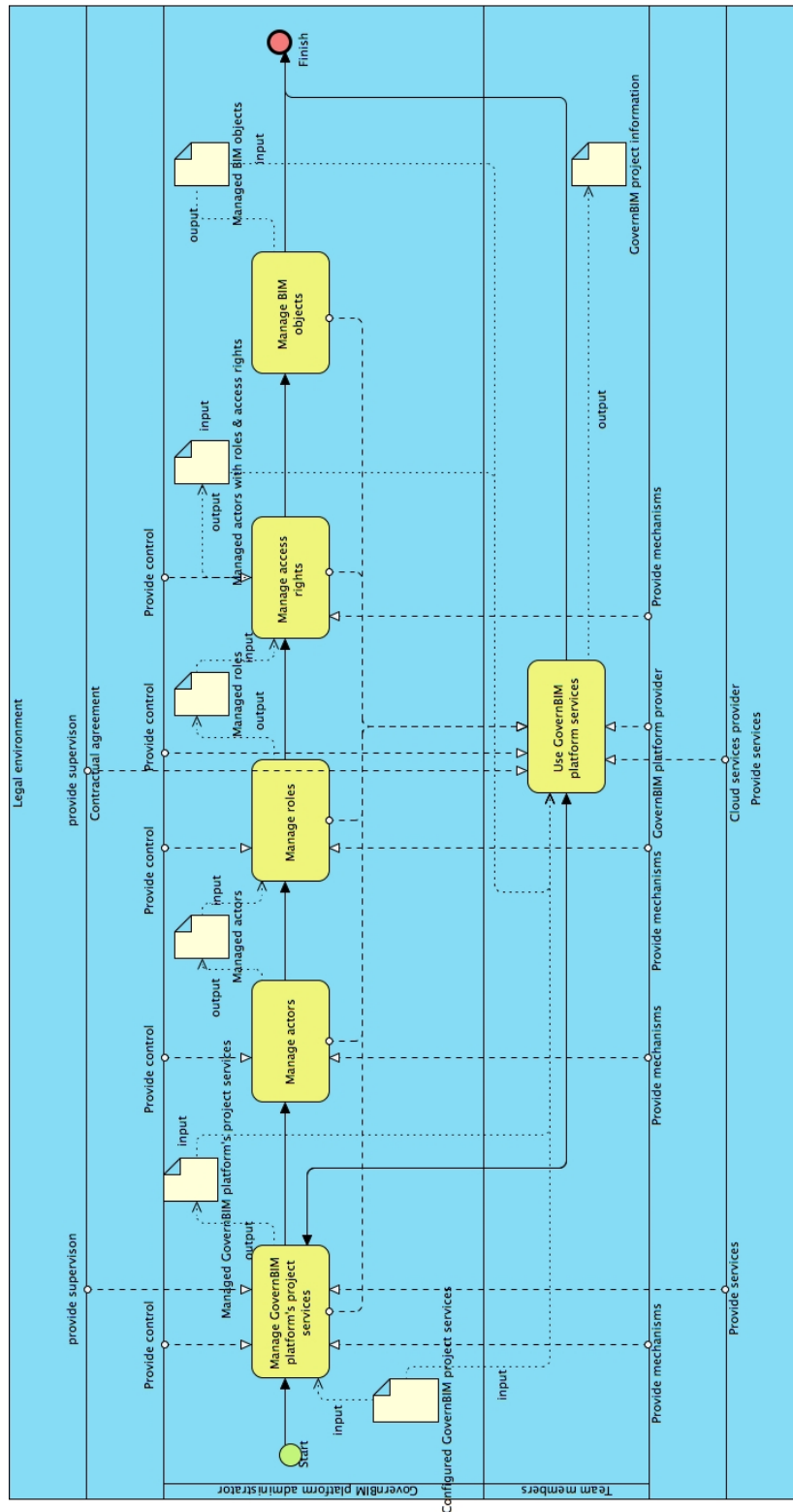


Figure 5.9: Operate GovernBIM platform's project BPMN

5.3.3 Cloud-based GovernBIM platform's UML diagrams

As was identified earlier in the BPMN modelling process, the configuration and operation of BPMN activities diagrams are considered key activities for the development of the GovernBIM platform. This section highlights the most important UML use cases for building and operating a GovernBIM platform. These use cases were extracted from the results obtained and categorised as follows: (A) provide and manage GovernBIM platform services, (B) setup and configure GovernBIM platform project, (C) manage GovernBIM platform's project during operation, (D) use GovernBIM platform's project. In addition, each use case is elaborated in more detail in the following section.

A. Use Cases 1: provide and manage GovernBIM platform services

Provide and manage GovernBIM platform services use cases are the initial use cases for establishing GovernBIM platform, as they are crucial elements to support the platform. They include the following use cases: register, provide, maintain, and remove GovernBIM platform services. Due to the importance of isolating these key use cases between primary stakeholders; i.e. GovernBIM management team and CSP, secondary stakeholders e.g. Internet Service Provider (ISP), are important to the platform but not to this use case diagram. Moreover, this use case diagram assumes that the primary stakeholders are connected to the Internet by default through their choice of ISP. For this reason, illustrations of these use cases exclude secondary stakeholders (e.g. ISP) and focus only on the primary ones: GovernBIM management team and CSP.

The GovernBIM management team and the CSP perform all these use cases. The GovernBIM management team contacts the CSP to register GovernBIM platform services. After an agreement is reached, a second use case, i.e. provide GovernBIM platform service, is performed, which includes: configure a service, and start services. A Maintaining GovernBIM platform services use case is then necessary to maintain the services provided by the CSP that include: start, configure, stop service. Finally, the Remove GovernBIM platform services use case is performed when necessary. This use case includes: stop and remove a service. Figure 5.10 presents the providing and maintaining GovernBIM platform services use case diagram.

B. Use Cases 2: Provide and configure GovernBIM platform project

After providing the GovernBIM platform services and configuring the GovernBIM platform, project use cases are implemented and performed. The GovernBIM management

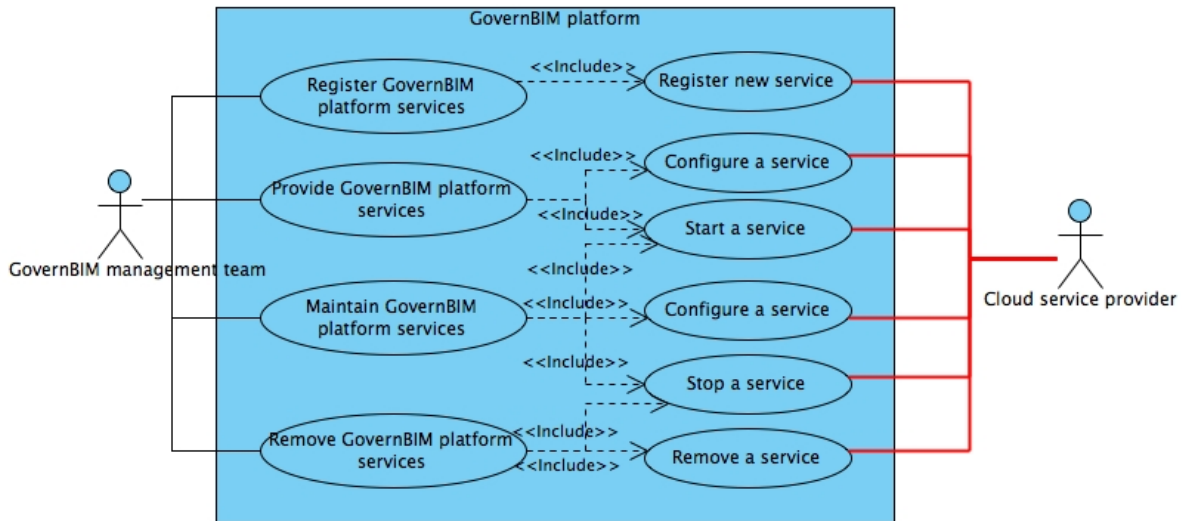


Figure 5.10: Use Cases 1: Provide and configure GovernBIM platform services

team use GovernBIM tools/API provider's mechanisms and CSP services to perform these use cases. Figure 5.11 presents the use case diagram for providing and configuring a GovernBIM platform's project. It includes the following principal use cases:

- **Setup GovernBIM platform's workspace:** The GovernBIM management team first create a GovernBIM project workspace in collaboration with the CSPs and the IT department of a construction company. This use case includes: creation, modification, and deletion of the GovernBIM project's workspace. The result of this use case is a working GovernBIM project workspace ready for utilisation.
- **Define administrators:** After creating the GovernBIM project workspace, the GovernBIM management team register a new administrator, with full permissions over the GovernBIM platform services and tools. The GovernBIM management team, IT department and the CSP perform all the use cases in this use case. This use case includes several use cases: modify, list, and remove administrator. The result of this use case is a list of registered GovernBIM administrators.
- **Configure GovernBIM platform's services:** After establishing the GovernBIM platform project, the GovernBIM platform administrator works with a Cloud services provider to configure GovernBIM platform services utilising CSP services. These services include, for example: communication services, information management services, storage services, notification services, versioning control services, and security services. The results from this use case are a list of configured services that are essential to run and support GovernBIM platform's project.
- **Define BIM project:** The platform administrator then inputs the main necessary

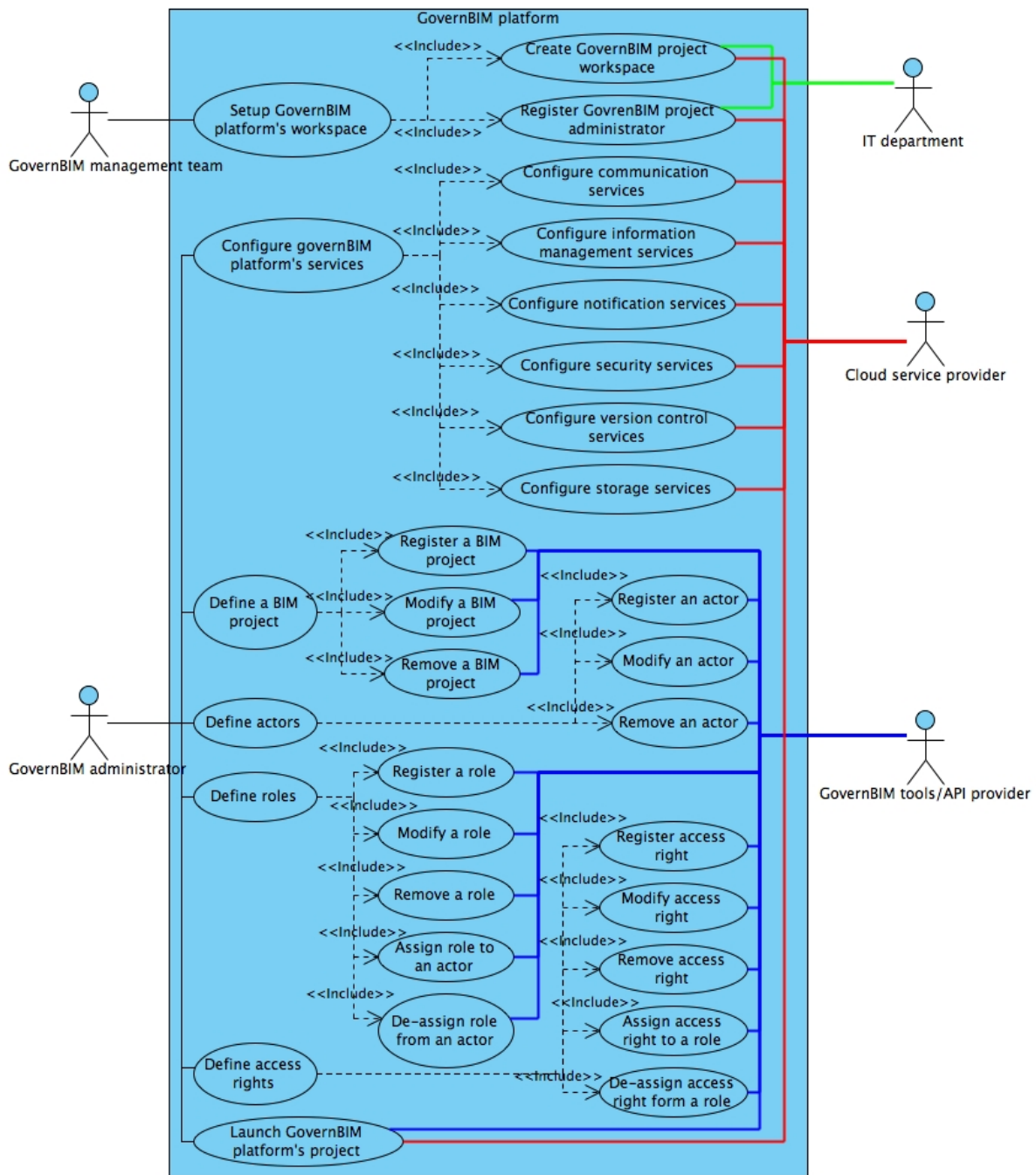


Figure 5.11: Use Cases 2: Provide and configure a GovernBIM project

information for the GovernBIM project. The first step is to register the BIM project information into the GovernBIM platform database. This use case includes the following use cases: modify the BIM project, acquire BIM project information, and remove the BIM project.

- **Define actors:** The administrator then defines those potential actors involved in the GovernBIM project. By registering those actors in the pre-defined GovernBIM

project, the use case introduces the following use cases: register, modify, and/or remove actor. The results from this use case are a list of actors who will collaborate during a GovernBIM platform's project.

- **Define roles:** By defining roles, it is important for the administrator to perform the use case after defining potential actors. This begins by registering all the possible roles for actors during the GovernBIM project then assigning roles to each actor. This use case includes the following use cases: register a role, modify a role, remove a role, assign a role to an actor, and de-assign a role from an actor.
- **Define access rights:** Defining access rights activity follows on from defining activities and roles. Administrators register potential access rights for each role using GovernBIM tools/API mechanisms. This use case includes the following use cases: register, modify, and remove an access right, assign an access right to a role, de-assign an access right from a role. The result from this use case is a list of access rights to be assigned to roles.
- **Launch GovernBIM project:** After accomplishing and completing all previous use cases, the GovernBIM project is now ready to implement. The GovernBIM's administrator launches the configured GovernBIM project, giving permission for actors to use GovernBIM project tools and services.

C. Use Cases 3: Manage GovernBIM's project in operation mode

Management of the GovernBIM platform project use cases was performed while the GovernBIM project is running. The GovernBIM platform administrator utilised GovernBIM tools/API and CSP's services to perform all the use cases presented in this diagram. Figure 5.12 presents use cases diagrams to manage the GovernBIM's project in operational mode. This use case diagram includes the following use cases:

- **Manage actors:** The actors made changes while the GovernBIM project was running; thus, the managing actors use case is required. This abstract use case includes the following use cases: register, update, remove actor, list all actors, and manage actors' roles. The later use case, i.e. manage actors' roles includes the following use cases: assign/de-assign role to/from an actor, list actors with their roles, retrieve an actor's role.
- **Manage roles:** This use case aims to manage actors' roles during the project. It includes the following use cases: registering a new role, modifying an existing role, removing a role, and managing roles' access rights. The later use case includes:

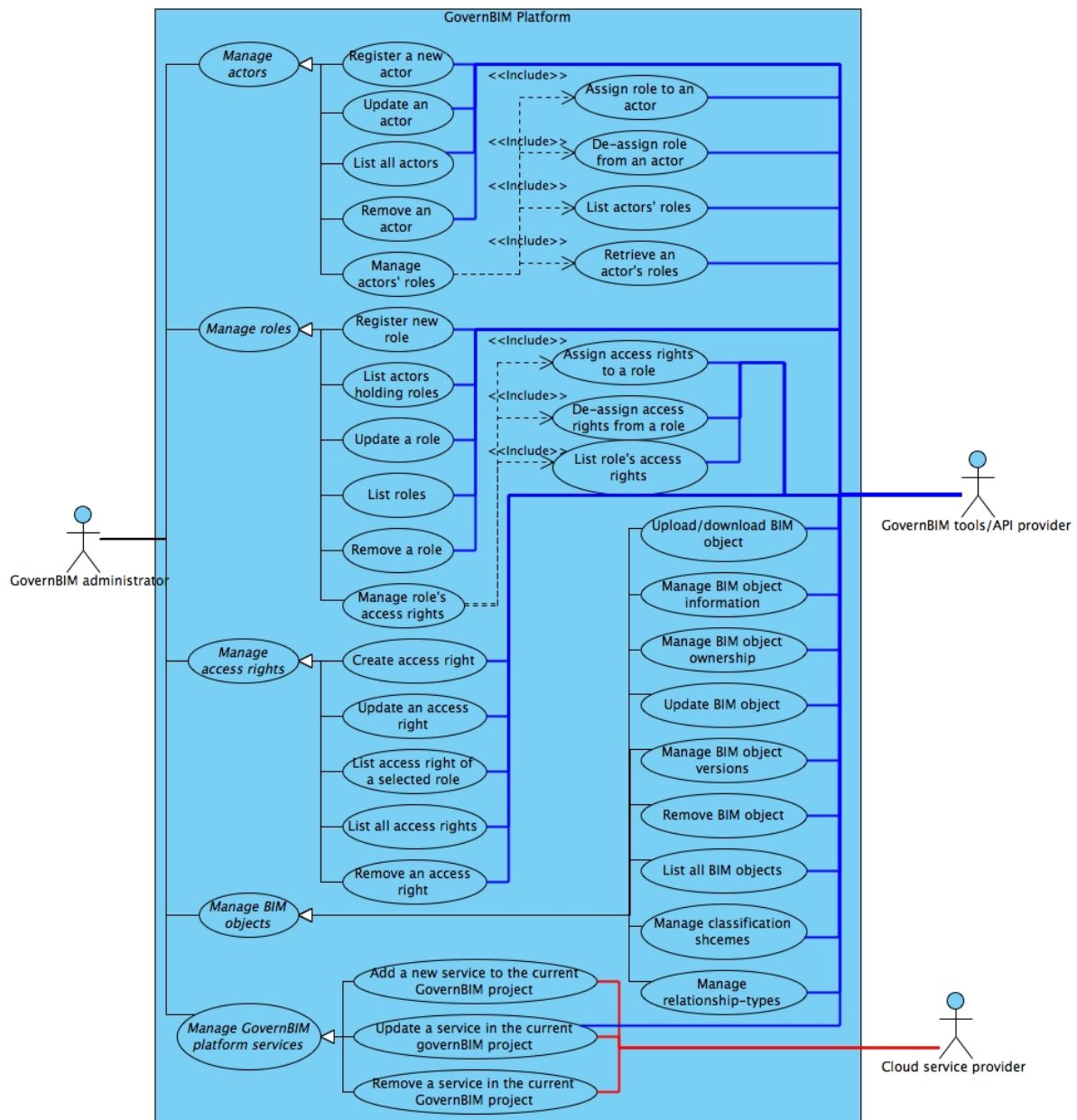


Figure 5.12: Use Cases 3: Manage GovernBIM's project during operation

assigning access rights to a role, de-assigning access rights from a role, listing all the access right of a selected role.

- **Manage access rights:** This use case concerns managing access rights during a project. It includes the following use cases: creating, modifying, and removing existing access rights, listing all access rights, and listing all the access rights of a specific role.
- **Manage BIM objects:** BIM objects refer to all documents shared by actors during a BIM-based project. The use case includes: uploading, downloading object,

managing a BIM object, managing BIM object ownership, managing relationship-types between objects, managing different versions of BIM objects, managing classification schemes, removing BIM objects, and listing all BIM objects. In a collaborative BIM environment, it is rare to treat two objects of BIM as two separate objects. Thus, there must be a relationship between them. Examples of relationship-types between BIM objects would be: no relationship, optioning, versioning, composition, concurrency, and derivation (Rezgui et al., 2013, Beach et al., 2013).

- **Manage GovernBIM project services for the current project:** During a GovernBIM project, there might be a need to add, update or remove services. This use case aims to manage services according to the current GovernBIM platform's project. It includes the following use cases: add a new service to the current GovernBIM project, remove a service from the current GovernBIM project, and update a service within the current GovernBIM project.

D. Use Cases 4: Using GovernBIM's project's environment

When using the GovernBIM's project environment use case diagram, actors and end users perform the use cases mentioned. They interact directly with graphical user interfaces (GUI) that represent GovernBIM tools/API. Figure 5.13 presents use case diagrams for the GovernBIM project's environment. The GovernBIM GUI allows actors to perform the following use cases:

- **Login/logout:** GovernBIM platform actors must login to a platform using their registered information; i.e. (usernames and passwords) to gain access to the platform.
- **Manage BIM objects:** These use cases occur after actors login to the platform. They allow actors to manage their BIM objects within the GovernBIM platform environment. This use case includes several use cases:
- **Upload new BIM object:** Permitting actors to browse their local machines and select files that they want to upload to the GovernBIM environment. When actors upload BIM objects, they can also manage these objects.
- **Classify BIM objects:** Allowing actors to classify BIM objects into schemes of their choices.
- **Update BIM objects without versioning:** Enabling actors to update BIM objects without creating another version of the same object.

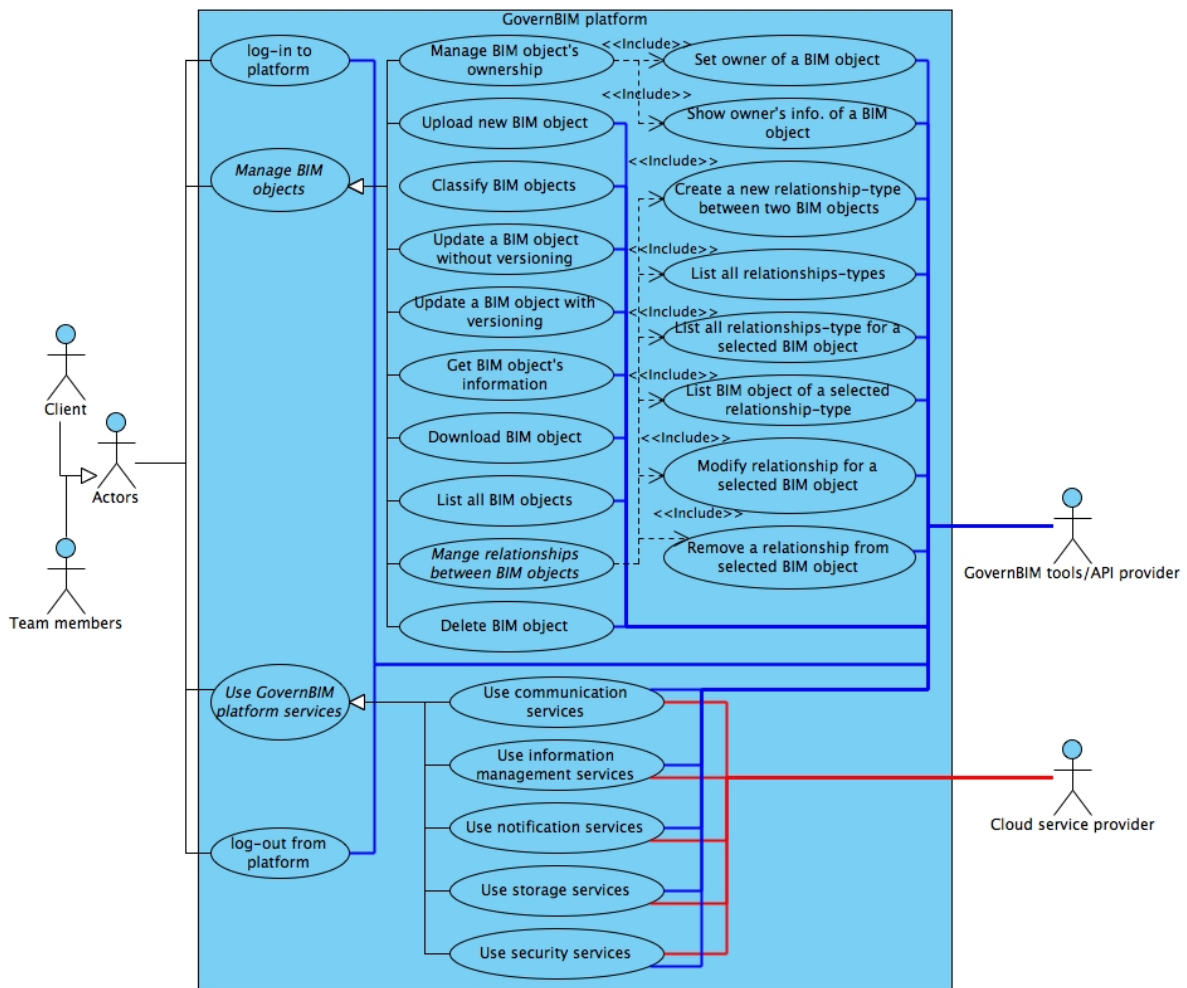


Figure 5.13: Use Cases 4: Using GovernBIM's project's environment

- **Update BIM objects with versioning:** Allowing actors to update their BIM objects by retaining the old version of BIM object and publishing a new version.
- **Manage relationship between BIM objects:** Actors can manage relationships between BIM objects. This use case includes following the use cases: create, edit, and remove a relationship-type from BIM object. In addition, it is possible to list all relationship-types, list all relationship-types of a selected BIM object, and list all BIM objects for a selected relationship-type.
- **Get BIM object's information:** Actors can view all information and the history of a BIM object but cannot edit it.
- **Download BIM object:** Actors can download a BIM object if they want to keep a local copy of that BIM object.
- **List all BIM objects:** Actors have the ability to list all BIM objects, or list

selected lists of BIM objects.

- **Delete BIM object:** Actors can remove BIM objects from the GovernBIM platform's project.
- **Use GovernBIM platform services:** Allowing actors to use services provided by the CSP, for example using communication services, notification services, etc.

5.3.4 Cloud-based BIM governance platform class diagram

The GovernBIM platform class diagram represents a computerised BIM governance model responsible for managing BIM objects from multiple actors, within different disciplines when building a lifecycle. Figure 5.14 presents the class diagram for the Cloud-based GovernBIM platform. This consists of several classes; each class presents a real life object within the GovernBIM platform environment.

The GovernBIM platform class diagram consists of several classes categorised into three main categories: BIM project related classes, actor related classes, BIM objects related classes.

- **BIM project related classes:** Construction projects involve several stages, each stage has a gate. When a stage is completed, a corresponding set of gate requirements are checked and approved, before advancing to the follow-up stage. The BIM project classes are:
 - **BIMProject:** Contains construction project information assisting all actors to collaborate during the projects' lifecycle. It contains all the information regarding the project, e.g. project name, client name, location, etc.
 - **ProjectStages:** This class represents the stages (from, pre-design, facility management) of the construction project.
 - **Gates:** This class represents the gates between different stages. It has two types: internal gates and external gates.
 - **GatesRequirements:** This class represents the gate requirements that are needed when moving from one stage to another stage during the construction project. It has two classes: the optional requirements class, and the mandatory requirements class.
- **Actor related classes:** Actors are the main components of the GovernBIM platform. Their BIM object ownership and IPRs must be reserved during collaboration.



Figure 5.14: GovernBIM platform's class diagram

Moreover, their roles and responsibilities should be maintained during the project's lifecycle. Actor related classes are explained as follows:

- **Actors:** This class contains all information regarding the actors involved in the project. Many actors are involved across many disciplines.
 - **Roles:** This class contains all the information regarding the actors' roles. Each actor performs many roles during the project.
 - **AccessRights:** This class contains all information regarding access rights during the construction project. It has many types: global rights, stages, disciplinary rights, actors' rights, and BIM objects' rights.
 - **Discipline:** This class presents the actors' disciplines and role in the construction project. Each actor is assigned as class according to his discipline.
 - **Workspace:** This class contains all information regarding the common data environment during the project lifecycle. It contains BIM objects shared between multiple actors.
 - **Notification:** This class monitors BIM objects, so that when a flag is raised, this class becomes responsible for notifying other actors.
- **BIM objects related classes:** During team collaboration, actors share BIM objects. Thus, BIM objects are vital components of the BIM governance model class diagram. Classes related to BIM objects are illustrated as follows:
 - **BIM Objects:** This class contains information regarding BIM objects. BIM objects exist in two major types: (a) structured BIM objects, e.g. proprietary vendor files, IFC files, and other semantic BIM files; and (b) unstructured BIM objects, e.g. meeting notes, recorded videos.
 - **BIM Objects Relationships:** This class defines and assigns the different relationships between different BIM objects. Six relationship types, as defined by Rezgui et al. (2013) and Beach et al. (2013), are used in this study; these are: (a) No relationship, (b) Optioning: BIM object as an option of another BIM object, (c) Versioning: BIM object as a version of another BIM object, (d) Composition: new data is added to the BIM object forming part of an existing document, (e) Concurrency: this relationship models a situation where two documents are developed in parallel and illustrates a dependency between the two, and (f) Derivation: BIM object derived from another BIM object.

- **Statuses:** This class contains information regarding the status of a BIM object. Actors use it during the project lifecycle and it is requested to share the BIM object. Suitability involves many types; e.g. private, team, review, finalised, client, archived, etc.
- **Decisions:** This class records all the decisions made about BIM objects by actors during the GovernBIM platform project’s lifecycle.
- **Transactions:** This class records all the transactions being made regarding BIM objects motivated by actors’ decisions.
- **Log:** This class records all operations; e.g. ownership changes, status, decisions, and transaction, and information applied to BIM objects by actors during the project lifecycle. Despite the many classes that exist during the construction project’s lifecycle; the aforementioned classes are key to the initial development of BIM governance model.

5.3.5 Cloud-based GovernBIM platform’s architecture

This section describes the proposed GovernBIM platform architecture, as illustrated in figure 5.15. The architecture of the Cloud-based GovernBIM platform is designed based on multi-tier software architecture, as well as on existing Cloud application architectures, Software-as-a-Service architecture, and MVC pattern (Amies et al., 2012, Lenk et al., 2009, Andrikopoulos et al., 2013, Isikdag, 2012). It is also composed of three main components: User Interface (UI) components, GovernBIM platform components, and CSP’s services and infrastructure components.

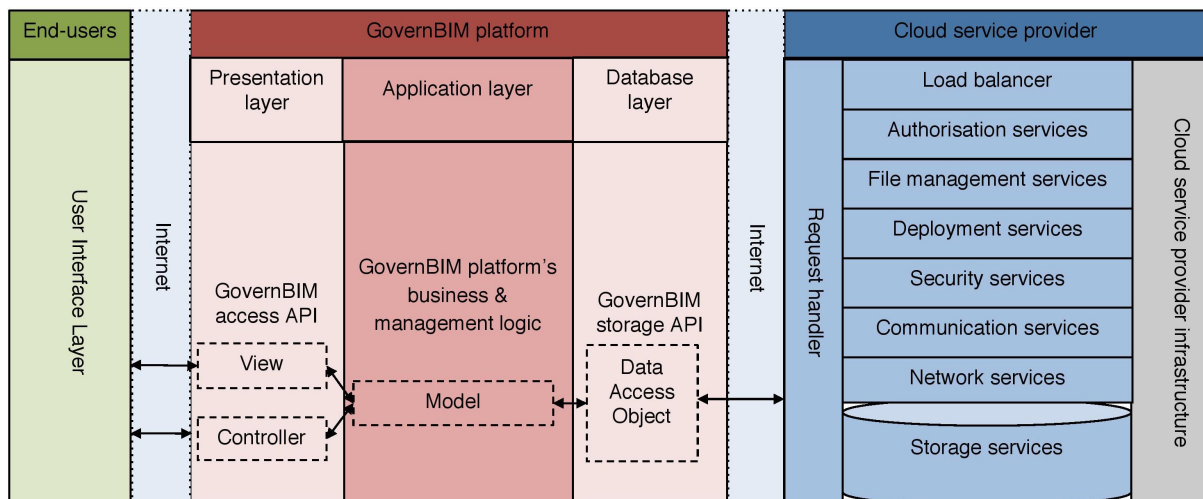


Figure 5.15: Software architecture design for Cloud-based GovernBIM platform

- **1st component: User Interface (UI):** This is a form of web page that can be accessed via a standard web-browser over the Internet. This tier is responsible for interaction between end-users and the GovernBIM platform presentation layers. This UI implements all necessary actions to allow users to insert, edit, retrieve, and remove data to/from the GovernBIM platform. It also should allow users to interact with the GovernBIM platform in a smooth and friendly environment.
- **2nd component: GovernBIM platform:** The GovernBIM platform tier is a core tier in the proposed architecture. It is composed of three main parts:
 - **GovernBIM access API (Presentation Layer):** Responsible for managing end-users' access and usage of the GovernBIM platform's services, comprising the View and Controller. View represents the visualisation of data contained in the GovernBIM model. Whereas, the Controller acts on both the GovernBIM model and view. It controls data flow into the GovernBIM model and updates the view whenever the data changes. It maintains both the view and GovernBIM model separately.
 - **GovernBIM platform business and management logic (Application Layer):** Responsible for providing control over different mechanisms to end-users. This contains the Model, which represents the GovernBIM model data and has the requisite logic to update the controller if the data changes.
 - **GovernBIM storage API (Database Layer):** Responsible for managing the process of storing and retrieving GovernBIM platform data. It contains a Data Access Object (DAO) that can be changed in response to the hosting environment: i.e. Cloud infrastructure, programming language used, and database type.
- **3rd component: CSP's services and infrastructure:** This tier is entirely managed and delivered by the CSP. The GovernBIM platform is linked with the CSP using the GovernBIM platform's APIs and the CSP's API. This link allows the GovernBIM platform to utilise the CSP's services fully or partly. These services include: security services, network services, deployment services, authentication services, file management services, communication services, and storage services.

5.4 Discussion

This aim of this chapter is to develop a set of requirements and specifications using BPMN and UML to develop a Cloud-based BIM governance platform. Since there is a

limited body of research pertaining to this topic, this research presents a foundation for Cloud/BIM developers, to help them to understand and examine the internal/external process of developing a Cloud-based BIM governance platform assuming no knowledge. The study findings are obtained from analysis and modelling of results obtained from different academic resources and techniques. The study uses a software engineering approach (Sommerville, 2007) to develop the GovernBIM platform requirements and specifications. This discussion section will focus on the following four main points: (a) GovernBIM platform lifecycle, discussing the use of BPMN to develop lifecycle processes for the GovernBIM platform; (b) GovernBIM platform UML diagrams, including a discussion about the use of UML for modelling key use cases for the GovernBIM platform; and (c) GovernBIM platform software architecture; providing a discussion regarding its design.

- **GovernBIM platform BPMN:** Many researchers have used BPMN in the BIM field (Saluja, 2009, Wu and Issa, 2013a), focusing on developing BPMN to establish the internal process of team collaboration. However, the scope of this study means using BPMN to develop wider business process diagrams for Cloud-based GovernBIM platforms that allow construction companies to understand the internal and external business procedures of the Cloud-based GovernBIM platform lifecycle. BPMN is a rich language that makes it possible to define a multitude of business scenarios, ranging from internal process choreographies to inter-organisational process orchestrations, service interactions and workflow exceptions (Recker, 2008). Moreover, this study reveals and explores the lifecycle process of Cloud-based BIM governance solutions. Thus, identifiable BPMN diagrams are important for Cloud developers interested in developing Cloud platforms targeting the construction industry.
- **GovernBIM platform UML diagrams:** While employing BPMN to describe higher-level activities of Cloud-based GovernBIM platform, UML can be used to define and describe lower-level activities in detail, i.e. the main functionalities of the GovernBIM platform (Owen and Raj, 2003). This study identified and developed several key use cases for BIM governance to devise a platform aimed at facilitating team collaboration within a construction project. However, there are more use cases to be discovered and modelled, this emphasises the need for more cooperation between construction firms and Cloud researchers; in order to identify and discover more use cases and scenarios. This kind of cooperation would sharpen the functionalities and services offered by the GovernBIM platform. Moreover, this study included a development of the Class diagram; presenting the internal structure of the GovernBIM platform, and describing the interaction between the main class

components. The class diagram was developed based on the work of Kubicki et al. (2006a) and Beach et al. (2013), and from results obtained at the consultation stage. However, the GovernBIM platform class diagram requires additional data, analysis, and modelling before it can fully meet the requirements to govern the process of team collaboration during real BIM projects.

- **GovernBIM platform architecture:** The results of BPMN and UML have led to the creation of an architecture for implementing a GovernBIM platform in a selected CSP's infrastructure. This architecture was developed based on studying several Cloud platform architectures (Amies et al., 2012, Lenk et al., 2009, Andrikopoulos et al., 2013, Arsanjani, 2004) and design patterns (Isikdag, 2012). The conceptual software architecture is the most convenient for organising and executing the APIs developed from the GovernBIM platform. Multi-tier architecture has been used for many years in the development of Cloud-based applications (Rimal et al., 2009); however, a combination of multi-tier architecture and MVC design patterns is highly recommended for developing and implementing Cloud-based solutions for BIM (Isikdag, 2012). Therefore, the GovernBIM platform would be one of the first solutions to adopt proper software architecture for its Cloud prototype implementation. The MVC approach would permit flexibility in terms of integrating future use cases. Separation of the GovernBIM platform into three main components: allows the re-use of business logic across applications, and parallel development of the platform (Isikdag, 2012).

Overall, the GovernBIM platform requirements and specifications are hindrances to the development of a Cloud-Based BIM governance solution to govern the process of team collaboration during construction projects. It is considered a step forward in the move towards facilitating understanding of the internal and external processes/activities required to establish Cloud-based BIM governance solutions. In terms of utilising Cloud rather than alternative solutions, it is put forward that Cloud has many advantages, especially for BIM, as discussed in (Redmond et al., 2012, Zhang and Issa, 2014). For example, Cloud has the ability to provide an advanced heterogeneous environment for hosting various formats of BIM files in one place (Abadi, 2009), physical or virtualised. This heterogeneous environment has the potential to facilitate the integration of different solutions for tackling the interoperability issue in BIM; e.g. IFC and IDM (Redmond et al., 2012, Juan and Zheng, 2014). Furthermore, hosting BIM solutions will allow Cloud developers to utilise the services offered by CSP without the need to invest in a high Cost IT Infrastructure (Beach et al., 2013). However, security remains a major concern when moving towards Cloud hosting (Kandukuri et al., 2009). This issue requires software

developers to offer a technical solution and legal documentation to meet concerns raised (Redmond et al., 2012).

5.5 Summary

With the increasing need for team members to collaborate during BIM-based projects, the use of complex data management systems is increasing as a result. Yet, the used data management solutions have restrictions and the developing company. This established a need for investigating such solutions and thus provides a new understanding of Cloud-based BIM governance platform. The GovernBIM platform proposed in this chapter arises as a direct result of extensive consultation between leading industry stakeholders, BIM experts, their associated organisations and the authors. A requirement engineering approach has been adopted to transform the results obtained from the consultation stage into well-categorised requirements for developing Cloud-based GovernBIM platform.

The use of BPMN provided detailed diagrams of the business process lifecycle for a Cloud-based GovernBIM platform from beginning to end. It also defined several activities and stages for designing, configuring, managing and using a Cloud-based BIM governance platform. This provided a detailed top-down description of the platform business process model, in conjunction with messages and information flows between those activities. Moreover, the use of UML diagrams delivered several detailed GovernBIM platform use cases, and the set of use cases identified forms fundamental to the GovernBIM platform. Furthermore, the UML class diagram developed to represents the core of the GovernBIM platform, describing the internal data governance structure of the platform. GovernBIM platform's architecture provides a solution for implementing the platform over selected CSP's infrastructure. This chapter contributes to the body of knowledge by offering: (a) definitions of functional, non-functional, and domain specific requirements for developing a Cloud-based GovernBIM platform; (b) developing a set of BPMN diagrams for setting, configuration, management, and use of a GovernBIM platform from initial setup until the end of GovernBIM platform's project; (c) several fundamental use cases and scenarios for using a GovernBIM platform, (d) a core BIM governance model (class diagram); and (e) a well-structured Cloud-based architecture to develop a GovernBIM platform for practical implementation.

The outcomes of this chapter tend to reveal the holistic nature of the process of managing collaborative environments during the lifecycle of a construction project. Furthermore, cloud-based architecture in the platform could be considered as a reference point when

developing any cloud-based collaborative solution for BIM. Hence, the next chapter will involve the implementation of a technical prototype based on the technical specifications discussed in this chapter, with the aim of producing GovernBIM tools/APIs and testing the potential role of cloud technologies in GovernBIM platform developments.

Cloud-based BIM governance platform implmentation and vaildation

6.1 Introduction

This Chapter extends BIM governance research and examines different implementation approach of Cloud-based BIM governance platform via utilising Google Infrastructure i.e. Multi-tier software architecture combined with MVP design pattern. Therefore, Chapter 6 examines the opportunity for the development process of a cloud-based BIM governance platform. Initial development of cloud-based GovernBIM platform prototype is mainly built on the basis of requirements and specifications obtained from a wide consultation with BIM experts in the construction field. Followed by a software engineering approach using Business Process Model Notation (BPMN) and Unified Modelling Language (UML) to provide both BPMN and UML diagrams for establishing, configuring, managing, and using obtained platform. Software Oriented Architecture (SOA) and Model-View-Presenters (MVP) were chosen as platform architecture for technical development. Therefore, Cloud-based prototype is developed to: (a) test and validate the proposed results from previous stages of GovernBIM platform; (b) examine potential use of Cloud technologies in BIM governance research and development.

Thus, this chapter embraces successive process including: (a) creation process of Cloud-based BIM governance platform based on requirements and specifications obtained from consulting BIM experts in the construction domain; (b) implementation of the key identified BPMN and UML diagrams developed during consultation stage; (c) testing and validation of the integrated Cloud infrastructure abilities during the development of GovernBIM platform; and (d) delivering a Research and Development (R&D) roadmap for Cloud-based BIM governance platforms. After this introduction, the outcome of this

stage are presented which concerns: GovernBIM platform prototype design, prototype requirements and functionality, prototype implementation, validation and discussion, concluding this chapter with a proposed R&D challenges and opportunities for cloud-based GovernBIM platform.

6.2 Results and findings

This section describes the findings from the development process. These findings include: prototype requirements and functionality, prototype implementation, followed by prototype demonstration.

6.2.1 Prototype requirements and functionality

The main aim of developing GovernBIM platform prototype is to create and implement key theoretical features of the platform; several requirements from the gathered requirements in the consultation stage has been chosen to be designed and tested. However, the platform allows creating new project information to each construction project and assigning actors' to each project. It also creates several roles and access rights and then assigning these to each actor. Moreover, it allows the BIM administrator (Governor) to manage uploaded BIM objects from each user. The platform allows the administrator to perform most of platform functions. However, users (practitioners) have the ability to perform partial functions of GovernBIM Platform (e.g. upload/download their BIM objects, and grant access to these BIM objects based on received requests). The functionality of the prototype reflects the initial identified use cases that are:

- **Setup GovernBIM platform' services:** These are the initial use cases for GovernBIM platform as they are crucial elements for supporting platform development. It includes following use cases: register, provide, maintain, and remove GovernBIM platform services. GovernBIM management team and the CSP perform all these use cases.
- **Provide and configure GovernBIM Platform's project services:** After providing GovernBIM platform services, provide and configure GovernBIM platform project's services use cases are implemented and performed. GovernBIM management team use GovernBIM tools/API and Cloud provider services to perform these use cases.
- **Manage GovernBIM project during operation mode:** These use cases are performed while the GovernBIM project is running. GovernBIM platform admin-

istrator via utilising GovernBIM tools/API and Cloud provider services performs all use cases presented in this diagram.

- **Use GovernBIM platform:** End-users perform most of these use cases that are mentioned in using GovernBIM's platform environment diagram. They directly interact with Graphical User Interfaces (GUI) that represent GovernBIM tools/API.

Prototype implementation at this stage will focus on the basic functionalities of the platform. The platform will be able to: (a) create and edit new BIM construction project; (b) create, edit actors and attaches them to the project; (c) create, edit roles and access rights and then assign them to each actor; (d) Manage BIM objects; (e) Manage the access to BIM objects by different actors. However, future work will include further development and functionalities (e.g. develop communication panels, add IFC viewers and connect to different services offered by CSP).

6.2.2 Prototype implementation

Implementation of GovernBIM platform prototype went through following milestones: environment choice and prototype design, prototype architecture, prototype GUIs interfaces design and creation, prototype database design and creation.

A. Environment choice and prototype design

According to Stadtmueller (2012), there are five main criteria that are worthy of consideration when choosing a CSP, interoperability across the working environment, flexibility in supporting different workloads, security, service Level Agreement (SLA), Help and support, and supporting major enterprise applications. Although there are several other CSPs such as Amazon AWS, and Rackspace, Google Cloud infrastructure and its GAE environment are chosen to underpin GovernBIM platform development. They are not only chosen because of the familiarity with the selected programming languages and the development Eclipse IDE but also for the following reasons:

- GAE provides three different types of Cloud storage solutions: Datastore, Cloud-SQL, and Blobstore. This provides more storage options to be used and tested by platform prototype.
- Flexibility of GCP in terms of supporting different programming languages (e.g. PHP, Go, Python, and Java).

- Availability of APIs to reduce development time. Google developed built-in services with their ready to use APIs (e.g. email API, Maps API) in which the GovernBIM platform can make use of these services when are needed and required.
- Google provides two main tools to develop solutions on their infrastructure: GAE provide the underlying Cloud environment and GWT provides a Java-based framework aiding the development of rich web applications with AJAX-based user interfaces.

To start the deployment we registered as Google developer and then created our platform instance. Then we integrate Eclipse with GAE and GWT in order to develop our prototype. This assisted in developing and testing the platform on the local machine before the deployment to Google Cloud infrastructure using the same tools. The designed GovernBIM platform is hosted over Google Cloud Infrastructure allowing end-users to gain access to its services, as Figure 6.1 illustrates. The use of Google App Engine (GAE) via Eclipse Integrated Development Environment (IDE) has assisted with development and deployment of the platform.

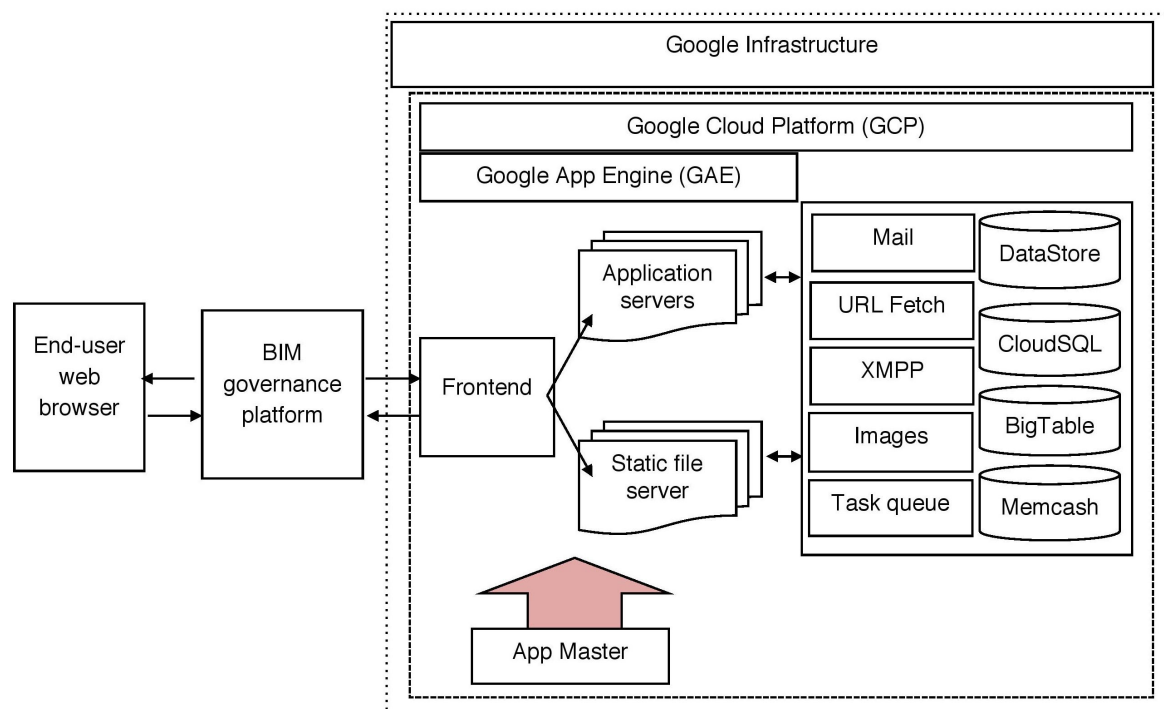


Figure 6.1: Integrating GovernBIM platform in GCP infrastructure

Moreover, the following programming languages are used to develop platform's code: Java, GWT, AJAX, HTML5, CSS, and SQL. More specifically, Java is used as the main

language rather than others because it is more flexible, powerful, and multi-purpose language supporting both client-side and server-side implementation (Reese, 2009). Google Web Toolkit (GWT), which is an asynchronous JavaScript and XML (AJAX) based language, is used to provide rich graphical user interfaces on the client-side as it is highly recommended by the Cloud service provider (Google) in order to develop Cloud-based solutions that suit their infrastructure (Sanderson, 2009). Then, HTML5 is used to host the develop Java and GWT codes and display platform GUIs to the client via web-browser (David, 2013). Moreover, Cascading Style Sheets (CSS) is used due to its efficiency in layout and design of GUI on client-side (David, 2013). Further, Structured Query Language (SQL) is utilised because it is the most applicable language to create, manage and develop relational-databases (Ciurana, 2009). More specifically, the use of Java and GWT are used to program codes that run on server side, whereas the use of HTML, also GWT, and CSS are used to program client-side codes.

In addition, the creation of relational database is done via MySQL on local development mode and then migrated to Google CloudSQL on deployment mode. Moreover, Java database connectivity technology (JDBC) is used to create and run GovernBIM platform queries between platform server's class and SQL-based database. Hosting platform over Google infrastructure provide an ability to utilise several services offered by the CSP such as XMPP, GMAIL, and other types of service APIs. Thus, in this prototype there will be an attempt to link the platform with these services offered by the CSP.

B. Prototype architecture

One of the powerful advantages of our development is the proper use of Object-Oriented Architecture. The Code is well-organised and developed according to the Model-View-Presenter (MVP) concept that has been introduced by Google (Ramsdale, 2010). Separating and organising Java classes in different packages allows us to easily maintain the code. Figure 6.2 illustrates GovernBIM platform implementation architecture.

- **Model:** A model encompasses business objects, and in the case of our GovernBIM platform there are several objects namely: BIM Project, Users, BIM objects, Roles, Access rights, Stages, Decisions and Transactions.
- **View:** Contains all User Interfaces (UI) components that will be presented to the end-users that include any tables, labels, buttons, boxlists, textboxes, etc. It has no notion of the model because its main responsibility is to layout UI components. However, switching between different views is done via History management in the presentation layer.

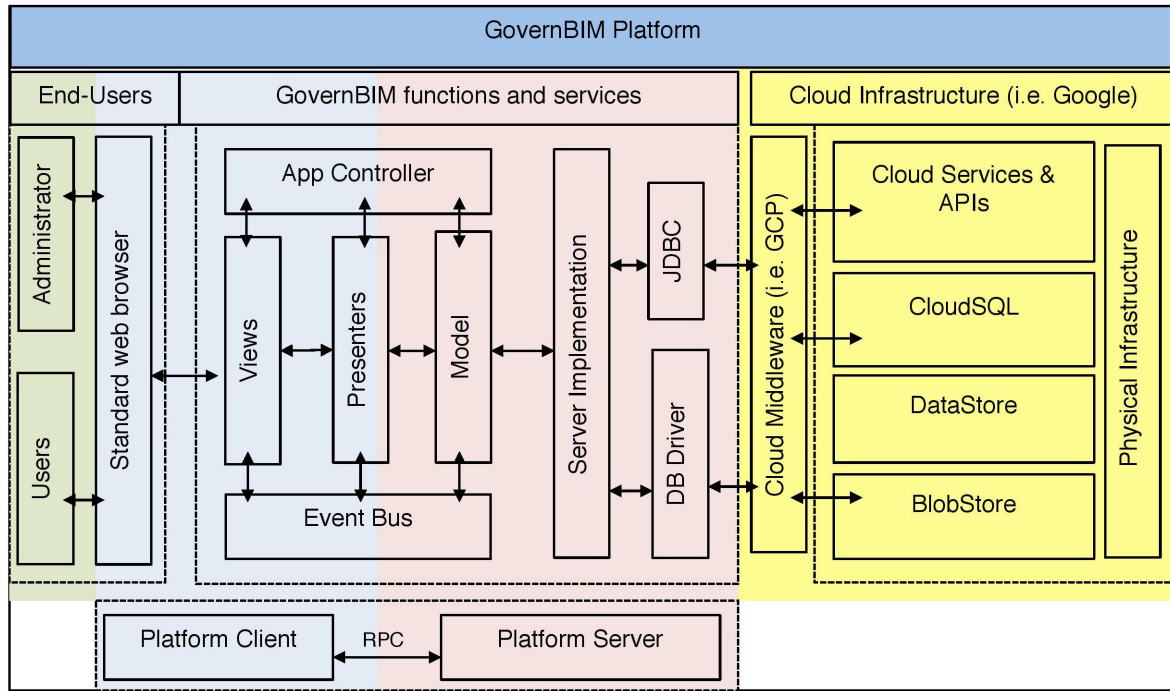


Figure 6.2: GovernBIM platform implementation architecture

- **Presenter:** Contains all of the logic for GovernBIM platform, including History management, viewing transitions and data synchronisation process via Remote Procedure Calls (RPCs) between client and server. For every view, as general rule, there is a presenter that is responsible for that view and handle its events.
- **AppController:** Is responsible for handling all logic that is not specified to any presenter. It lives in the application layer and contains the history management and transactions logic for views. Views transactions logics is directly managed by history management.
- **Events and the Event Bus:** When presenters drop Widgets' events within different views, actions needs to be taken towards these events. Thus, there is a need to rely on EventBus that is built-in on the top of GWT HandlerManager. The main roles of the EventBus are: passing events, register event to be notified of some of their subsets. However, not all events should be included in the EventBus. Only platform-wide events the events that should be passed through the EventBus.
- **History and view transitions:** Handling History Events is very important in web applications. History events are strings tokens representing new states with the platform works as marks for where is user are in the platform. Thus, History Management is added to the AppContoller because it is not specific to any particular to a view.

C. Prototype GUIs

GovernBIM platform accessed via a standard web browser. Therefore, HTML5 and CSS underpinned by GWT are used to create and layout GUIs for the platform. After log-in to the platform, the written code decided whether the user is an Administrator or a User. Based on login process, a selected GUI will be loaded. This force the development of the prototype to create two separate GUI one for the administrator and the other is for ordinary users.

- **Administrator GUI:** This GUI is more complex and has more functions than normal users' GUI. This because administrator has full access to any function within the platform. Figure 6.3 shows administrator GUI.

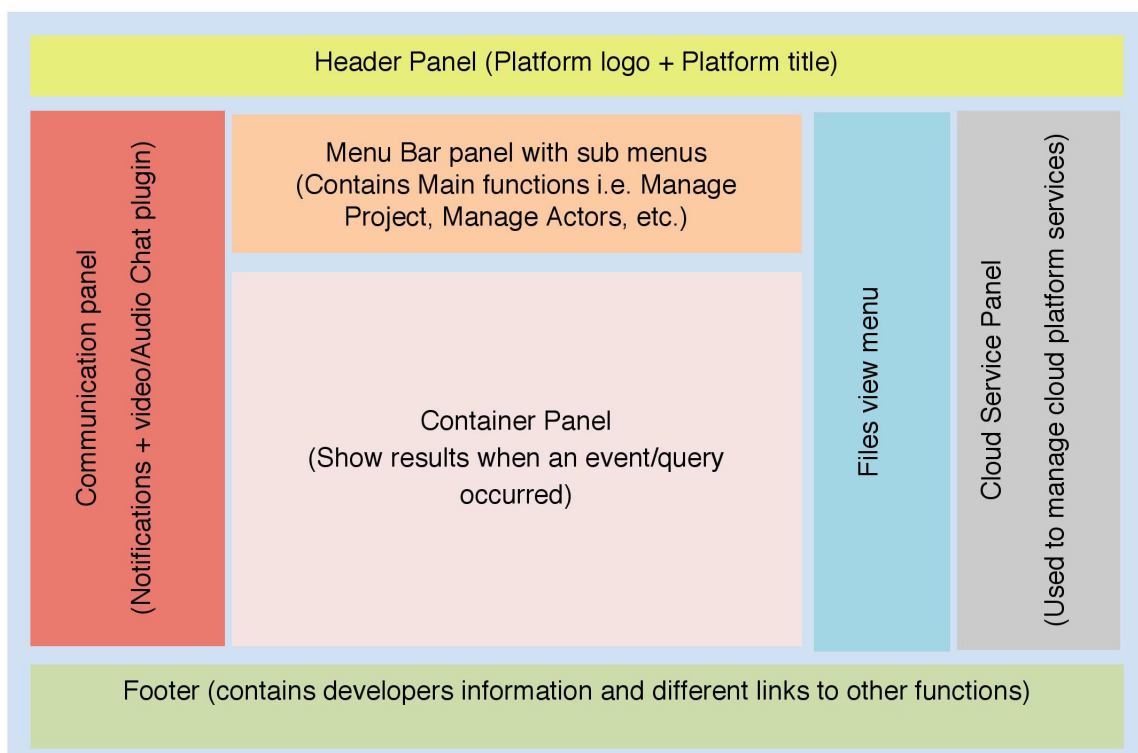


Figure 6.3: GovernBIM platform administrator GUI

- **Practitioners GUI:** Practitioners' GUI design is similar to administrator GUI but slightly different. It has some of necessary functions for them (e.g. grant access rights to the BIM object, upload/download BIM objects, view their BIM objects, edit BIM objects).

D. Prototype databases

Relational database is used for managing socio-organisational aspects of GovernBIM platform. Also, non-relational database will be used to host large BIM objects. Therefore, creation of GovernBIM platform database goes through three main phases:

- **Phase one:** Creation of a local instance of the database using MySQL. This allows testing and modifying database design based on specific test results.
- **Phase two:** Creation of a database instance in Google Cloud and immigrate the local instance to be hosted over Google infrastructure.
- **Phase three:** Creation of NoSQL database in the Google Cloud DataStore for hosting larger BIM files and linking both databases together via Java code within the server-side.

Figure 6.4 shows Enhanced EntityRelationship (EER) diagram of GovernBIM platform relational SQL database. It shows GovernBIM database tables and also relationships between these tables.

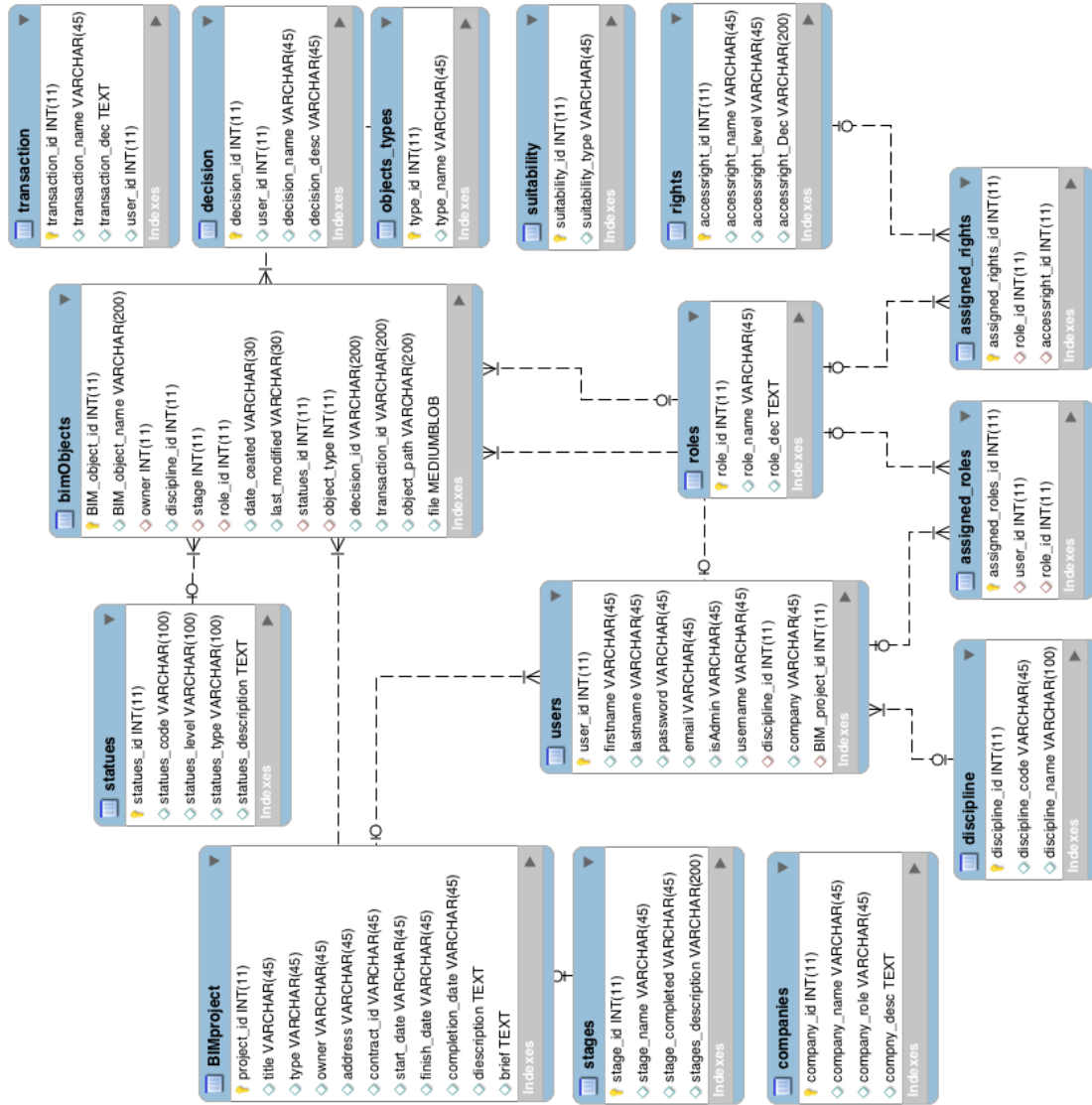


Figure 6.4: GovernBIM platform relational-database design

6.2.3 Prototype demonstration

GovernBIM platform has been successfully deployed to Google infrastructure and can be accessed over the Internet. The relational database is hosted over the Cloud. Figure 6.5 shows screenshots of the hosted GovernBIM platform. Platform administrator sends login information to users via their emails. GovernBIM platform determines which GUI to show, *Administrator GUI* or *Users GUI*, based on the login information.

If administrator is logged-in, then GovernBIM platform will allow following functionalities: Manage BIM Projects, Manage Users, Manage Roles, Manage Access Rights, and Manage BIM Objects.

If user logged-in, then GovernBIM platform will only allow them to view their assigned

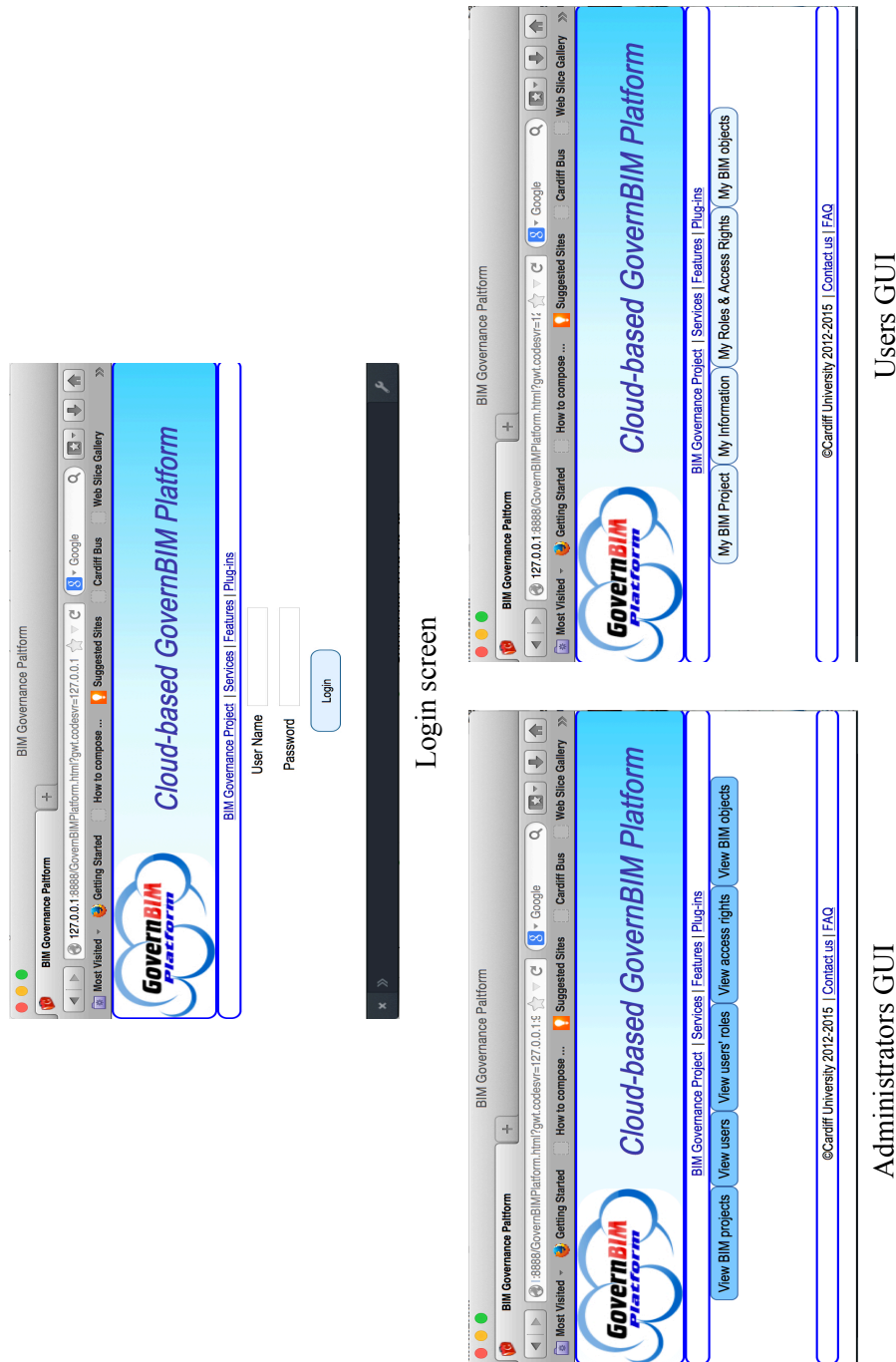
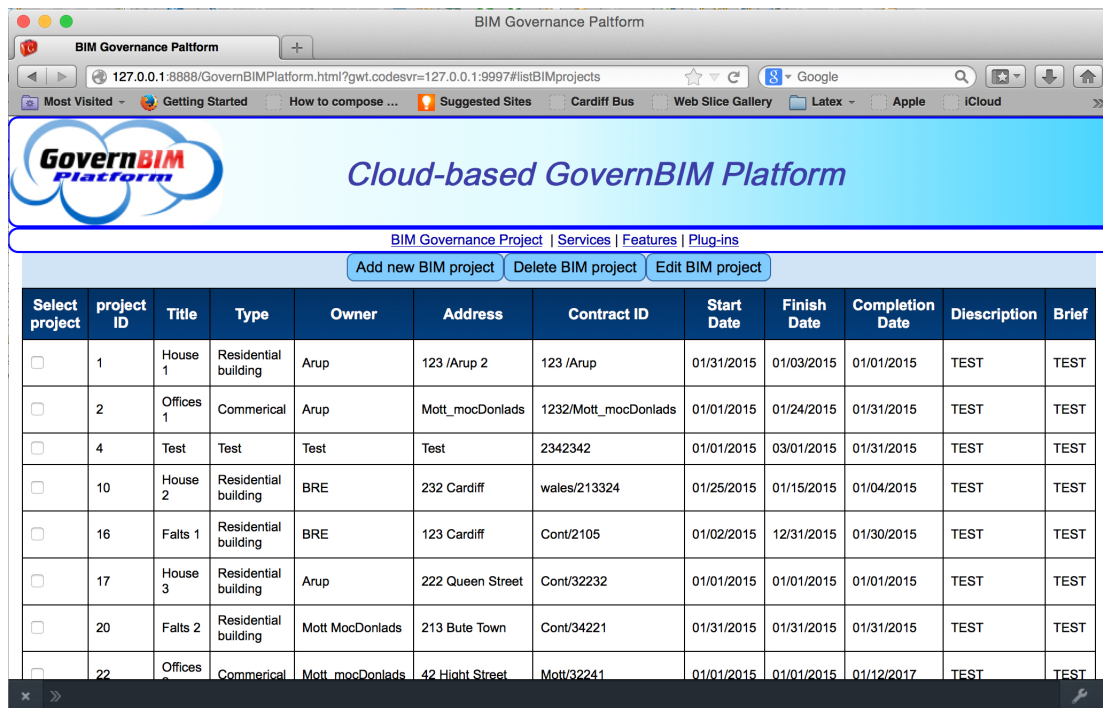


Figure 6.5: GovernBIM platform login, administrator, and user interfaces

BIM projects, their personal information, their assigned roles and rights, their BIM objects. Moreover, they can add, edit and remove their uploaded BIM objects from/to the platform.

Nonetheless, the implementation of the platform covers the following main functionalities:

- **Managing BIM projects:** When the practitioner is logged in as an administrator, the first step is to input all information regarding each construction project. Then s/he inputs the information for the GovernBIM project, such as title, type, owner, location, address, contract number, start date, and finish date. Each project is then given a unique ID in order to distinguish it from other projects. Figure 6.6 shows a screenshot of the management of BIM projects.



The screenshot shows a web browser window titled "BIM Governance Platform". The address bar shows a URL starting with "127.0.0.1:8888/GovernBIMPlatform.html". The page header includes the "GovernBIM Platform" logo and the text "Cloud-based GovernBIM Platform". Below the header, there are navigation links: "BIM Governance Project", "Services", "Features", and "Plug-ins". A sub-header contains three buttons: "Add new BIM project", "Delete BIM project", and "Edit BIM project". The main content area displays a table with 12 columns: "Select project", "project ID", "Title", "Type", "Owner", "Address", "Contract ID", "Start Date", "Finish Date", "Completion Date", "Description", and "Brief". The table contains 8 rows of project data.

Select project	project ID	Title	Type	Owner	Address	Contract ID	Start Date	Finish Date	Completion Date	Description	Brief
<input type="checkbox"/>	1	House 1	Residential building	Arup	123 /Arup 2	123 /Arup	01/31/2015	01/03/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	2	Offices 1	Commercial	Arup	Mott_mocDonlads	1232/Mott_mocDonlads	01/01/2015	01/24/2015	01/31/2015	TEST	TEST
<input type="checkbox"/>	4	Test	Test	Test	Test	2342342	01/01/2015	03/01/2015	01/31/2015	TEST	TEST
<input type="checkbox"/>	10	House 2	Residential building	BRE	232 Cardiff	wales/213324	01/25/2015	01/15/2015	01/04/2015	TEST	TEST
<input type="checkbox"/>	16	Falts 1	Residential building	BRE	123 Cardiff	Cont/2105	01/02/2015	12/31/2015	01/30/2015	TEST	TEST
<input type="checkbox"/>	17	House 3	Residential building	Arup	222 Queen Street	Cont/32232	01/01/2015	01/01/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	20	Falts 2	Residential building	Mott MocDonlads	213 Bute Town	Cont/34221	01/31/2015	01/31/2015	01/31/2015	TEST	TEST
<input type="checkbox"/>	22	Offices	Commercial	Mott_mocDonlads	42 Hight Street	Mott/32241	01/01/2015	01/01/2015	01/12/2017	TEST	TEST

Figure 6.6: Managing BIM projects within the GovernBIM platform

- **Managing actors:** After adding the BIM projects to the platform database as a GovernBIM project, the administrator then completes the information regarding the actors that are going to be involved in the pre-defined BIM project. This information is: username, first name, last name, email, discipline, password, and company information. Then the administrator assigns each actor to his/her pre-registered BIM project. The GovernBIM administrator governs the collaboration process of those actors during the construction project. Each actor will have permissions based on his assigned role. Figure 6.7 shows a screenshot of managing the information relating to the actors.
- **Managing actors' roles:** The GovernBIM platform allows administrators to register new roles, and modify or remove an existing role. Furthermore, the platform

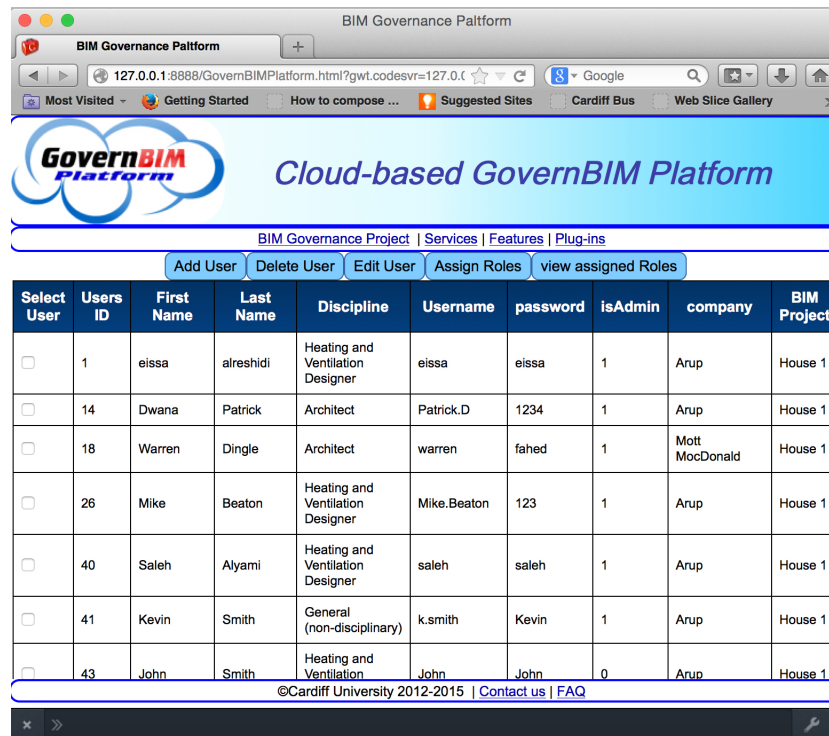


Figure 6.7: Managing actors

is able to manage the access rights of a selected role, including: (1) assigning/de-assigning access rights to a role; (2) listing all access rights of a selected role. The platform contains pre-defined main roles for the actors, such as architect, structural engineer, quantity surveyor, and so forth. Nonetheless, the platform is flexible enough to allow new roles to be added and access rights to be assigned. Figure 6.8 shows a screenshot of managing actors roles.

- **Managing access rights:** This is the main function implemented in the GovernBIM platform. The developed GovernBIM platform enables the administrator to register potential access rights, then assign and de-assign these access rights to/from each role, besides allowing him/her to modify, and remove, an access right. The platform is flexible in terms of not only covering the basic access rights to BIM objects, such as viewing BIM objects or writing to BIM objects, but it also contains further access rights, such as ready for approval, ready for stage 2, and waiting for approval from actor x. Furthermore, the developed prototype will help in terms of capturing other required access rights from BIM experts.
- **BIM object management:** This is an essential function, because BIM objects are the subjects to be shared and exchanged amongst different actors. The developed platform assigns roles and access rights to uploaded BIM objects when the

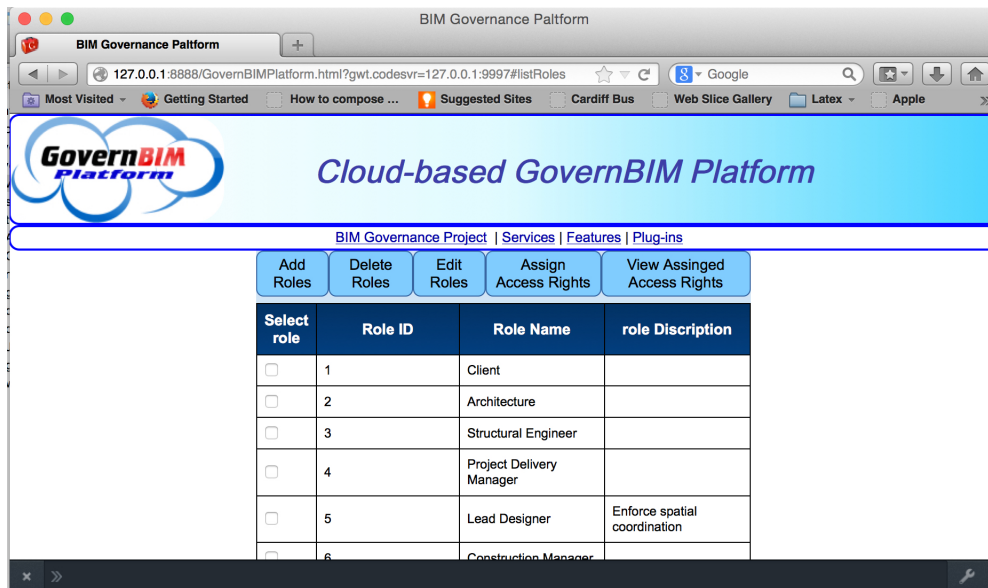


Figure 6.8: Managing actors' roles

actors upload their BIM objects. Hence, access restrictions to BIM objects are based upon the selected role of each BIM object. Thus, access rights assigned to a BIM object differ from one role to another. A Global Identifier (GI) is assigned to each BIM object when it is uploaded in order to distinguish it from others. This GI helps to keep track of the BIM objects when shared amongst different actors. The tracking mechanism for various BIM objects is based upon work discussed in Rezgui, et al. (2013). Furthermore, transactions made on BIM objects are recorded in the database for tracking purposes. Moreover, the GovernBIM prototype offers a collaborative environment in which to share BIM objects with various data formats under the control of a BIM Governor. Figure 6.9 shows screenshots from administrator when manage BIM Objects GUI and figure 6.10 shows a screenshot of upload/manage BIM objects (user GUI).

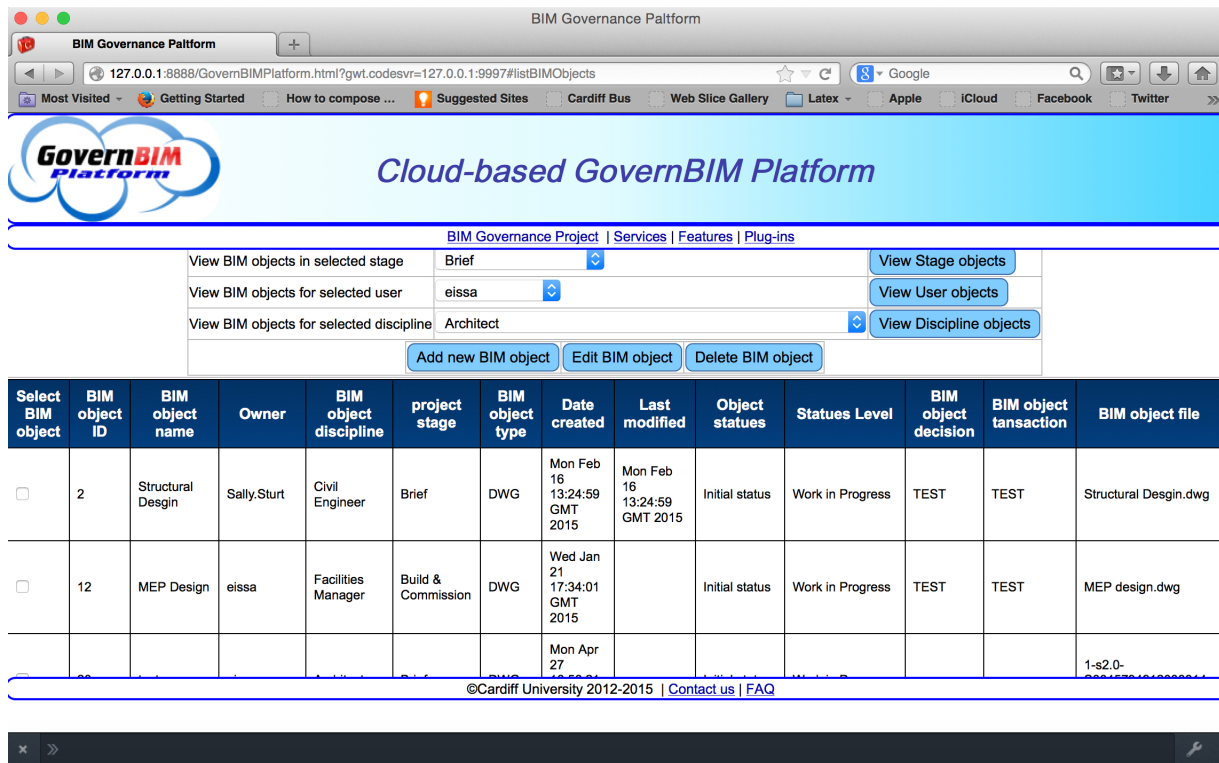


Figure 6.9: Manage BIM Objects (Administrator GUI)

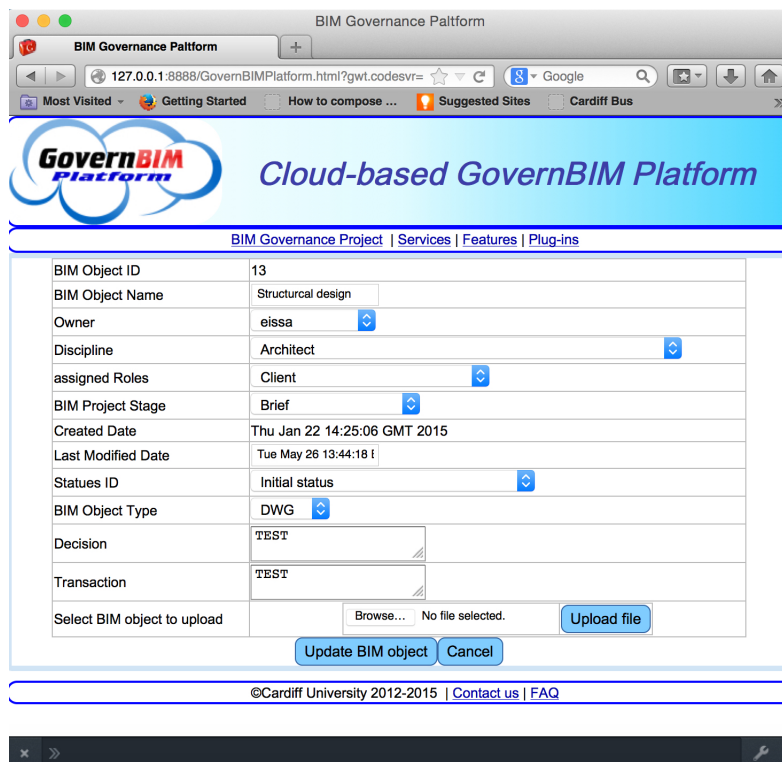


Figure 6.10: Upload/Manage BIM Objects (User GUI)

6.3 Testing and validation

The testing and validation approach adopted for the prototype of the GovernBIM platform is a combination of Black box and White box testing techniques (Williams, 2004). (1) Black box testing (i.e. 'functional testing') overlooks the internal mechanisms of a developed system, focusing exclusively on generated outputs in response to specific inputs and conditions of execution. (2) White box testing (i.e. 'structural testing') takes into account the internal mechanism of the developed system (Williams, 2004).

6.3.1 The validation process

The Whitebox technique was used to test the functionalities of the platform during the development process, and the Blackbox technique was undertaken with several BIM experts who had considerable involvement in the development process of the GovernBIM platform, and who were eager to take part in the validation process. The validation process took the form of a demonstration, presenting the various functionalities of the GovernBIM platform, followed by a trail and hands-on testing by the BIM experts. This was accompanied by an in-depth discussion concerning the achievements, and limitations, of the developed platform. The discussion with the BIM experts was recorded and a transcript was made; this was then analysed and interpreted providing validated results, including: (a) the prototype of the developed GovernBIM platform; (b) the hosting Cloud environment used. Figure 6.11 illustrates the use of the black and white box techniques during the GovernBIM platform validation process.

6.3.2 Results form validating GovernBIMs platform prototype

The following validation points resulted during the demonstration of the developed GovernBIM platform prototype with the BIM expert:

- **Managing BIM projects:** Registering BIM project information is an essential step towards governing BIM objects associated with this project. When the BIM expert logged in as an administrator, he was able to input essential information for the GovernBIM project, as well as being able to: (1) modify an existing BIM project; (2) acquire BIM project information; (3) remove the BIM project. Since information differs from one project to another, it was necessary to adopt collaboration standards, in order to restrict the amount of information entered into certain necessary fields.
- **Managing actors:** Since the administrator is responsible for defining potential

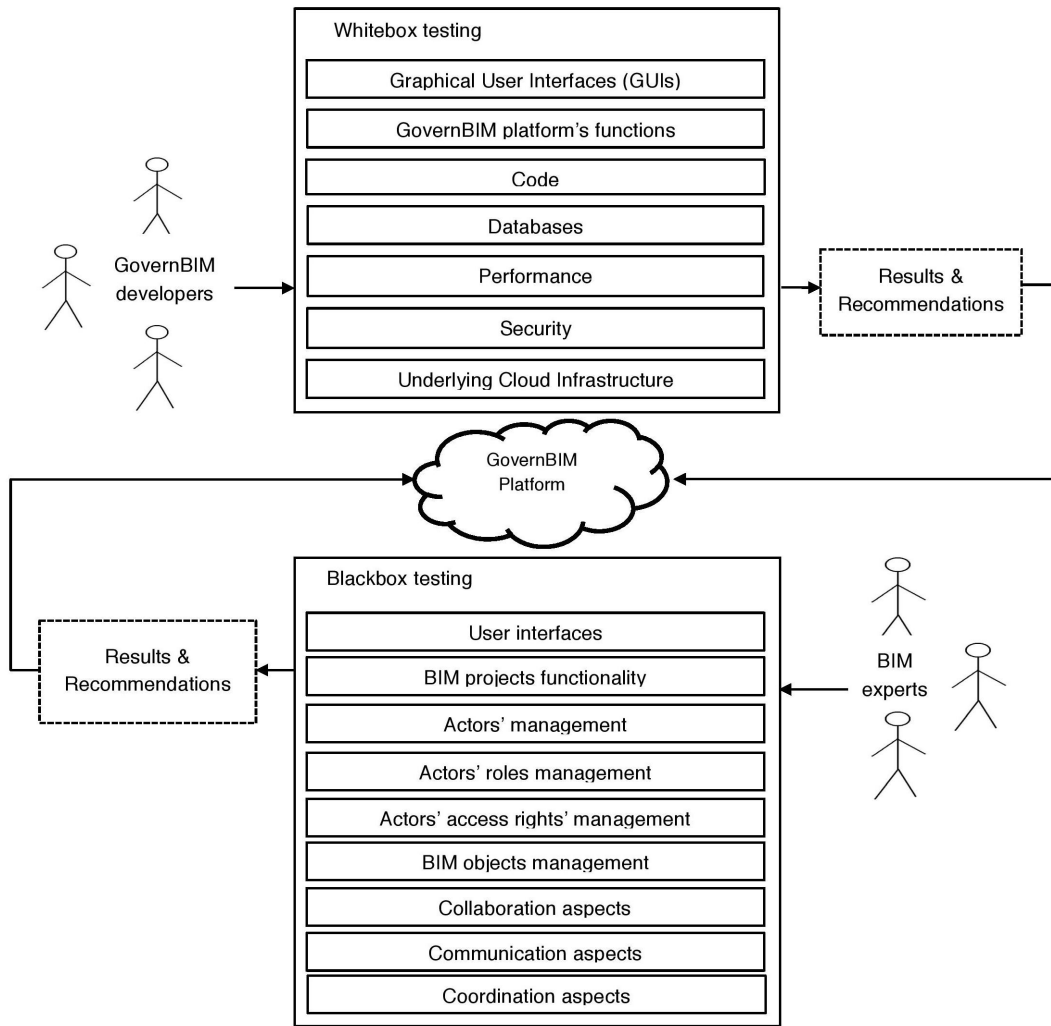


Figure 6.11: Black & white boxes techniques used in GovernBIM testing & validation

actors for involvement in the project, she/he is also responsible for modifying, and/or removing an existing actor. Further, s/he is responsible for assigning actors to pre-registered BIM projects. These assigned actors collaborate with each other via a GovernBIM administrator who is responsible for governing the process of their collaboration during the construction project. A number of BIM experts have suggested increased enhancement of the actors' awareness of management, e.g. (a) improve actors' monitoring screens to allow them track their BIM objects and the decisions that have been made on them; (b) add a function to enable the assembling of similar users into one group; (c) permit actors to modify sensitive information, i.e. personal information. However, none of these are major obstacles to the use of a GovernBIM platform, as it has been agreed that they can be easily integrated into the designed prototype.

- **Managing actors' roles:** Although some roles remain the same for the majority of

construction projects already pre-defined in the GovernBIM platform, there are a number that differ. The GovernBIM platform thus allows administrators to register new roles, and to both modify, and remove, an existing role. Furthermore, the platform is able to manage access rights of a selected role, including: (1) assigning/de-assigning access rights to a role; (2) listing all access rights of a selected role. According to a BIM expert, these functions are of considerable use when assigning roles to actors at the beginning of construction projects, including restricting their roles to those granted to them based on their roles. Moreover, a BIM expert has highlighted the fact that ordinary users have limited control over their own data when they are only able to access material assigned to them by the platform administrator. However, since the main aim of GovernBIM platform is to govern data concerning the built environment during team collaboration, there is a need to develop access priorities of the hosted data that can be accessed by ordinary users. For example, allowing access to insensitive data (e.g. their profile data) and restricting the access to sensitive data (e.g. ownership fields, and data related to other team members).

- **Manage access rights:** It is important to incorporate the function to define access rights into the GovernBIM platform, enabling the GovernBIM administrator to register potential access rights for each role. It also allows him/her to modify, and remove, an access right, as well as assigning and de-assigning an access right to/from a role. A BIM expert has highlighted the fact that granting access rights to an actor working at a distance will reassure him/her that she/he is the only one with access to his/her objects at that specific time, thus, minimising the potential risks of data manipulation, and IPR concerns by other team members.
- **BIM object management:** The managing of BIM objects is a crucial function of the GovernBIM platform prototype, since it is the subject of sharing and exchange among different actors. The GovernBIM platform not only allows actors to upload/download their BIM Objects, but also assigns roles and access rights to uploaded BIM objects. Thus, it restricts access to BIM objects, based on the selected role of each BIM object. Moreover, access rights assigned to a BIM object different from one role to another. Each BIM object has its own Global Identifier (GI), making it easy to find. However, the BIM expert observed a need for further advance search functions, strongly emphasising that when BIM objects are removed from the platform, they should not be completely deleted from the database, but instead re-versioned and archived. Thus, the tracking and versioning mechanism of the GovernBIM platform requires further development.
- **Sharing and exchange practices using the GovernBIM platform:** The Gov-

ernBIM prototype offers a collaborative environment in which to share BIM objects with various data formats under the control of BIM Governor (administrator). This is due to the fact that building involves multi-actor collaboration, requiring different actors at different stages to share data. The platform Governor has full access to the platform, whereas users are granted limited access, according to their roles. The BIM expert noted that the GovernBIM platform still needs to incorporate a creative solution for handling versioning issues, rather than simply overriding the existing BIM object. A second BIM expert pointed out that it would be beneficial for each user to have a unique dashboard, so enabling them to explore and track the lifecycle of his/her BIM objects. Moreover, a tracking mechanism for various BIM objects (e.g. Audit and logging files) can be sufficient for keeping a record of the shared/exchanged BIM objects on the database. One BIM expert emphasised linking the GovernBIM platform with built-in communication tools, in order to facilitate the communication process of team members when sharing their BIM objects. Since the platform is early in its development, one of BIM expert emphasised the development of an advanced query and search functionality, to facilitate accessing large numbers of database records, and thus efficiently retrieving information.

- **Commercial governance models:** BIM collaboration tools are owned by major software companies who (due to competitiveness in their field) refuse to share their codes, data structure and development files. Furthermore, there is a lack of such a BIM governance model apart from research efforts (Rezgui et al., 2013), and a number of BIM experts have stated that commercial companies are slowing down the development of such a collaborative BIM solution. For this reason, the developed GovernBIM platform prototype is proving to be a milestone in contributing towards the development of an open source BIM governance model and platform.
- **Property collaboration process, and solutions:** Due to issues of competition within their industry, the majority of construction companies adopting BIM as a collaborative approach will not share their collaboration process in the absence of a formal agreement not to disclose such information. This is a primary hindrance to the development of BIM governance solutions in the near future. However, in the developed GovernBIM platform prototype, a standards collaboration process (e.g. a BIM Execution Plan) has been adopted. The prototype is designed in such a way that it is sufficiently flexible to cover an increased number of collaboration processes and practices existing in collaboration standards (i.e. PAS 1192:2013). The platform demonstrated an effective use of BIM-based collaboration standards.

However, a BIM expert has stressed that the use of BIM-based standards (e.g. PAS 1192:2007) to underpin the developed GovernBIM platform serves to add additional strength to the developed platform. This is due to the fact that one of the prime objectives of the GovernBIM platform is to hide the complexity of collaborative BIM standards behind a friendly GUI. The development of platforms is undertaken based on PAS 1192:2007, which permits users to practice this standard without knowing that they are integrated automatically into the platform.

- **The availability of GovernBIM platform services and data:** An IT technician has stated that the critical aspect of the GovernBIM platform concerns continuity of hosting, therefore, relying on one CSP risk, in case the provider becomes bankrupt, or their infrastructure critically damaged. However, the most effective solution to addressing this risk is the use of multiple CSPs for hosting the developed GovernBIM platform. Moreover, hosting a GovernBIM platform over one CSP rise carries risks of BIM data being locked-in, i.e. that all operations undertaken on the hosted data follow the hosting provider's policy and procedures. There would be a lower level of risk if all CSPs followed a standardised approach used by all other CPSs, thus enabling the easy migration of a GovernBIM platform from one CSP to another.
- **Confidentiality and auditability of BIM data:** Even when CSP is trustworthy, its information is blurred concerning the location of the hosting servers, and the forms of legislation applied. It has been confirmed that this challenge should be addressed through legal documentation, as well as allowing end-users to choose the location of their hosting servers. Furthermore, IT technicians highly recommend the application of encryption techniques and security operations to the uploaded BIM data through the GovernBIM platform. However, a BIM practitioner has stated that encryption of BIM objects is not recommended, as they do not wish their files to be manipulated by any mechanism. Therefore, the GovernBIM platform should not apply any encryption to the uploaded BIM files, due to the possibility of some sensitive data being altered during the encryption process. Thus, the designed platform offers the choice to the end-user of whether or not to encrypt their files.
- **Bugs:** The architecture of virtualised distributed systems differs from traditional systems, while the majority of debugging technologies are designed for traditional software. Developing Cloud platforms and applications is undertaken with different approaches that adopt tools and APIs designed specifically for the selected CSP. These debugging technologies are still in the development and testing phases, resulting in opportunities for developers to develop and standardise debugging tech-

nologies for highly virtualised distribution systems. During the development of the GovernBIM platform using GAE and Eclipse IDE, the code server encountered a number of bugs and errors that required to use professional fixing tools and techniques listed on the GAE issues webpage.

- **GovernBIM platform licensing:** This is comprised of a combination of legal and business issues, as follows: (1) The provided services should comply with SLAs offered by CSP (i.e. legal issues). (2) There should be an implementation of a business model, and a pay-per-use license should be offered to the users of GovernBIM platform (i.e. business issues). These challenges can be resolved by legal and business collaborations between platform developers and the CSP.

6.3.3 Results form validating the integrated Cloud environment

The hosting Cloud environment is elastic, changeable, and updated regularly. However, certain characteristics are subject to validation (e.g. privacy and security, etc.). Therefore, the following discussion points have been obtained from validating the utilised Cloud environment for integrating the GovernBIM platform prototype:

- **Restrict access to the Cloud's physical infrastructure:** In the case of adopting PaaS paradigm, GAE prevents the development of the GovernBIM platform's operation from accessing the physical infrastructure. This access control includes preventing the developed platform from using sockets and background processes, apart from common jobs and common back-end operations (Roche and Douglas, 2009). This is because CSPs have secured their systems in order to minimise internal security threats, and strengthened their customers' confidence by protecting and restricting access to hardware facilities. This has been achieved through adopting strict accountability and auditing procedures, and minimising the number of workers with access to critical components of the infrastructure (Santos et al., 2009). This restriction assists in increasing the security levels of the developed platform, leading to the developers of Cloud-based BIM solutions having no need to concern themselves with the supportive environment of a physical infrastructure. This is due to the fact that PaaS solutions reduce the effort, time and cost required for building customised Cloud environments, particularly for construction companies having normal (or inefficient) experiences with CSPs.
- **Security:** The Cloud is in constant danger of security risks (Kandukuri et al., 2009), which are more sophisticated and complex than those of traditional computing models. Some BIM objects (e.g. innovative designs) contain sensitive informa-

tion requiring high levels of security when hosted on the developed platform, i.e. security issues such as cyber-attacks, data loss, data damage, and hacker attacks. Such issues have been recognised throughout the development of the GovernBIM platform. However, the solution to such issues might be via a tested encryption scheme to shared storage environment, introducing strict access controls to prevent unauthorised access, and scheduled data backup (Kaufman, 2009).

- **Scalability:** Through its GAE, Google provides a highly effective on-demand scalability feature. GAE was designed to address scalability concerns in its core design, which was based on horizontal scaling, i.e. the developed application is executed on more than one instances, with less powerful hardware, instead of running the application on more powerful hardware (Ciurana, 2009). GAE offers a wide range of built-in services that can be easily integrated into the GovernBIM platform. As the functional development of the GovernBIM platform increases, there is a relative increase in the amount of performed works and resources. Hence, built-in scalability has permitted an increase in the amount of computing resources, along with storage, when it is required. Since BIM objects contain large files, this feature allows the developed platform to be flexible in terms of the size of uploaded BIM objects, thus permitting developers to overcome the need to add restrictions to the uploaded BIM objects. This, in turn, provides the opportunity to host all BIM objects in the same place, thus facilitating the ability to tackle issues of interoperability.
- **Programming languages and techniques:** The programming languages and techniques employed depend on the Cloud infrastructure selected. Each Cloud environment has a set of restrictions for the developer in terms of programming languages used, along with techniques and other functionalities. For example, Amazon Web Services (AWS) offers the developer increased freedom and flexibility, but limited pre-built functions (Abadi, 2009). Compared with AWS, GAE provides additional libraries and functionalities (i.e. pre-built functions) to the developer. This leads to the use of GAE ensuring it is easier, faster, and more convenient to develop GovernBIM platform solutions. Nonetheless, if the pre-built functions are outweighed by GAE restrictions, then the choice of IaaS provider may prove to be a more effective solution. A software engineer has highlighted the fact that the platform architecture is highly flexible when integrated with other open source in Collaborative BIM solutions, but is not sufficiently effective to be integrated into a commercial Collaborative BIM solution.
- **Usability:** Cloud adopts a Utility Computing concept, which implies that users obtain and use the Clouds' platforms as easily as obtaining (and using) traditional

public utility infrastructures (e.g. the electricity network). The same perspective is expected from Cloud-based platform developers when developing a GovernBIM platform, as they are required to provide platform services to users anywhere, at any time, and at a reasonable price. Therefore, it is a cheaper and faster option to adopt a similar concept via delivering the GovernBIM platform as a utility governance service, particularly for small to medium construction companies.

- **Integration of multi-Cloud services providers:** The integration of GovernBIM platform with other CSPs is not yet achievable, due to differences in infrastructure virtualisation techniques (Repschlaeger et al., 2012). This leads to a need to migrate and integrate developed platforms from/to different CSPs, thus raising the need for PaaS/IaaS integration services. GAE does not yet offer such support, although it has the ability to integrate data from external CSPs via GAE tools and services.
- **Availability:** It is difficult to provide a GovernBIM platform that is completely available, unless high availability architecture is adopted, and the platform is fully tested. The level of availability is dependent on the SLAs between CSP and GovernBIM platform developers/operators. In line with SLAs, users may adopt other practices for their data, such as maintaining a backup on other on-premises storage solutions, or on back-up Clouds. However, some CSPs who offer their services based on high virtualisation of the physical infrastructure, claim their services to be 99.9% reliable in their SLA (Bruegge and Dutoit, 2004). Furthermore, BIM data transfer delays have been experienced, during the testing process, due to the low broadband speed offered for transferring data. This highlights the fact that not all countries possess the same quality of Internet infrastructure, which is a major issue that can be addressed through the upgrading of such infrastructure.
- **Support:** Compared to IaaS (where the only services provided are basic hardware and operating systems layers offered in same traditional approach), PaaS should have the capability to provide a complete description of the supported services and features offered. Google provides some documentation on how to use GAE, but at very basic, rather than a professional, level. During the development of the GovernBIM platform, there was a need to contact professional bodies in order to facilitate the use of GAE and GWT, thus aiding the authors to provide a solution for a number of the issues encountered.
- **Privacy:** This it is still a major concern for the majority of the population, and specifically for construction practitioners, who have the ability to sue CSPs if their private information is violated, thus damaging CSP's reputation. CSPs must em-

brace and adopt complex and up-to-date tools and techniques, and work hard towards providing (and achieving) high levels of security and privacy (Google, 2014). However, during the development of the GovernBIM platform, the authors developed the platform in such a way as to minimise the storing of personal and valuable information on the Cloud, applying security techniques to protect uploaded/downloaded and stored data, and provide maximum control over the GovernBIM platform for users. This approach has also followed similar developments (McCammon et al., 2003). It is better to consider privacy aspects in the early stages of development, rather than adding them in later. More meaningful results could be provided by the addition of further tests of privacy.

- **Legal considerations and issues:** Construction practitioners need to provide, and maintain, legal documents to ensure their ownership and their rights in order to fulfil various laws. CSPs should also employ technologies to ensure that they preserve data and meet the expectations of end-users, in order to satisfy their legal documents. This is not a major issue for GAE during the development of the GovernBIM prototype, however, Google as CSP, provides these levels of legal consideration when they provide their services at business level to a construction enterprise. It is vital to take into account the legal documentation needed to use the GovernBIM platform when it is offered to Clients. An effective means of minimising the legal risks of inadequate use of the platform could be achieved through the development of a legal framework, policies, and protocols in addition to the platform's manual.
- **Cost:** CSPs owns and maintains all resources (e.g. servers, software, storage and networks), whereas end-users only plug-in into such resources through the Cloud. Thus, end-users do not need to make a large investment in computing resources, (e.g. staff and administrators supervising these resources, and the electricity and cooling systems required to maintain them). Google has offered a price scheme depending on the usage levels of resources, starting from a free basic account (with limited resources) to a paid version, without limitations (Google, 2014). GAE is considered to be an effective environment in which to develop and test GovernBIM platforms. Google as CSP has a different price rate for large enterprises and individuals. One of the major issues concerns the processing of large chunks of available data being limited to the cost of paid services. This leads to requests for free accounts being subject to a specific time limitation.

6.4 R&D challenges and opportunities for Cloud-based GovernBIM platform

Testing and validation results show that developing comprehensive Cloud-based BIM governance platforms is complex, this due to different architectures and APIs offered by various CPSs. Moreover, there is a lack of experts who have knowledge of both BIM and Cloud who can offer clear understand of governance and collaborative aspects of BIM. Lastly, GovernBIM platform is still under development and testing stages; hence, afford-mentioned limitations are considered in the future development of GovernBIM platform. As new developed technology, Cloud has various obstacles needs to be overcome, especially when developing enterprise platforms. A number of major obstacles of current Cloud, from a business perspective and present corresponding solution opportunities, have been discussed by Armbrust et al. (2009). However, based on results of our conducted prototype so far there are still many research and development challenges ahead of the development of GovernBIM platform. GovernBIM platform prototype developed to form scratch. However, in order to achieve fully function GovernBIM platform, there is a need to address further aspects and functionalities. Figure 6.12 shows R&D opportunities for Cloud-based GovernBIM platform. These will involve the following main objectives:

- Develop GovernBIM governance model to cover more aspects of BIM i.e. governing objects within BIM Structured Files e.g. IFC, and COBie.
- Integrate GovernBIM platform with real-time communication solutions e.g. Go-To-Meetings and edit-on-view solutions.
- Create APIs to link GovernBIM platform with open-source BIM tools e.g. BIM-Server, IFC viewer.
- Develop plugins to link GovernBIM platform with commercial BIM authoring tools e.g. Google Sketch-up, AutoDESK Revit.
- Develop plugin to link GovernBIM with commercial BIM collaboration tools e.g. ProjectWise.

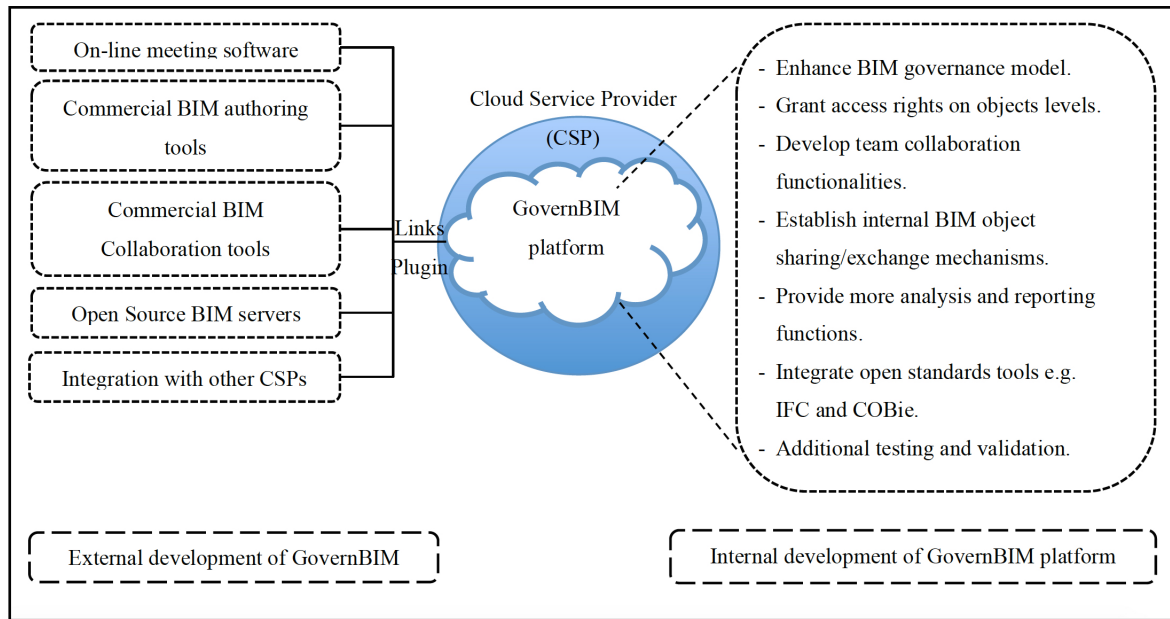


Figure 6.12: R&D opportunities for Cloud-based GovernBIM platform

6.5 Summary

The significance of this prototype development is important stage by which validating the following stages; (a) BIM experts consultation, (b) state-of-are GovernBIM platform's BPMN and UML diagrams, and subsequently offer many suggestion and way of development for robust and fulfilled Cloud-based BIM governance solution. In another words, the investigation during the development of GovernBIM platform prototype, answered the general research question that is to what extends Cloud technologies can offer to BIM governance platform and what can be further deliver". Yet, there is a need for proper tailored governance layer on the top of the Cloud infrastructure for easily govern the hosted BIM data. This research field requires more research and development to fully achieve the ultimate goal that is governing BIM process across multiple actors within different discipline during a project lifecycle. Cloud developer should co-operate with BIM experts and construction practitioners in order to provide solutions that reflect the construction industry needs.

Besides, the contribution to the body of knowledge, this chapter also contributes through outlining the development process of a Cloud-based BIM governance platform. Hosting the developed platform over a Cloud infrastructure has given the ability to inherit built-in services offered by the CSP. Moreover, the developed prototype has the ability to manage BIM projects, including different actors, actors' roles, and actors' access rights, as well

as BIM objects. The validation process demonstrates considerable potential for such a solution towards addressing collaboration issues of team members during a construction project. Further, an effective MVP architecture for developing Cloud platform has been used and tested and which proved to be powerful software architecture for developing Cloud-based platforms, thus allowing future development stages to take place. However, adopting GAE in prototype development has revealed that there are few functionalities and limitations in the Google Platform. The development and deployment process of the platform is straightforward and manageable. The researcher was able to build based on the abstraction provided by the development environment, along with the ability to link to other services and resources (i.e. CloudSQL) with the platform code.

In the next following years, Cloud will emerge and would be a central factor in shaping the development of collaboration solutions in the construction industry as it will change the methods of delivered services (Chun and Maniatis, 2009). This does not mean to remove the existing solutions, but it will allow next generation of developers to invent new features and functions based on mixing old technologies with the new ones (Erdogmus, 2009). Using Cloud in developing BIM applications will positively affect IT solutions within the construction industry. It will change the design of the existing solutions, and also it will create new use-cases because of the new features offered by CSPs. Chun and Maniatis (2009) provide an example of such use-cases that are; overcoming hardware limitations to allow applications perform complex and complicated analysis and calculations, time-saving when it comes to analysing massive data files that might take hours on one PC whereas it might take shorter time when using Cloud computing services. Moreover, it is argued that existing BIM solutions would be more powerful in terms of functionalities and performance (Armbrust et al., 2009).

Conclusion and future work

7.1 Introduction

This chapter concludes the thesis, firstly by highlighting the activities undertaken in this research. Secondly, it answers the overarching research questions based on the findings from the study as a whole. Thirdly, it presents the study achievements and key findings. Fourthly, it points out the limitations of the study, before finally concluding with a set of recommendations for future research.

7.2 Activities undertaken in this research

This study was designed to investigate the requirements, suitability, and industry readiness and perceptions of BIM-based collaborative construction. Thus, it aimed to develop a Cloud-based BIM governance solution to facilitate team management and collaboration across the project lifecycle, and to evaluate the use of a distributed computing environment (e.g. Cloud) for governing and managing BIM data, in the built environment. To fulfil this aim, a review was conducted to identify gaps in BIM governance research, and to further refine the research aim, questions, objectives, and research design. The review was followed by a consultation with BIM professionals' working in the construction industry, in form of: (a) an investigation using a questionnaire into ICT and collaboration practices within construction projects, with a focus on BIM adoption barriers, and issues resulting from team collaboration; and (b) a detailed investigation using semi-structured interviews to explore BIM experts needs and requirements for a solution that addressed collaboration problems. Based on the outcomes of the literature review and the consultation, several BIM standards and collaborative solutions were investigated for their suitability, and measured against the process and lifecycle requirements of collaborative environments.

This extensive consultation identified the need for a BIM governance solution, integrating socio-organisational, legal, technical, and financial aspects to facilitate effective collaboration among team members. Any governance solution should overcome the identified collaboration issues and facilitate the collaborative process among team members. BIM experts' requirements formed the basis for developing a BIM governance solution. The outcomes of the consultation highlighted the importance of hosting team data in scalable, remotely-accessible, secure, and distributed datacentres. Thus, Cloud technologies were selected to underpin the development of a Cloud-based BIM governance platform (GovernBIM).

Existing collaborative BIM processes within construction organisations were investigated with reference to three case studies. The collaboration process at three construction companies already implementing collaborative BIM was observed to identify technical and functional requirements. Two software engineering modelling approaches, BPMN and UML were used to investigate the processes and requirements involved in the collaborative process. Furthermore, a combination of Service Oriented Architecture (SOA) and Model-View-Presenter (MVP) were chosen as the platform architectures for the purpose of technical development.

Before embarking on the prototype's development, existing Cloud Service Providers (CSPs) were reviewed to explore options for hosting the development procedures for GovernBIM platform prototypes, leading to the selection of a Google Cloud Platform (GCP) for prototype implementation. The prototype aimed to test and validate the data obtained in the previous stages, to inform the development process for a cloud-based BIM governance platform and to examine the potential for Cloud technologies in BIM governance research and development. After the prototype implementation, white and black box testing techniques were implemented to test and validate the prototype.

7.3 Addressing research questions

The following section provides answers to the research questions posed at the beginning of thesis.

RQ1: “What is the current status (including barriers and opportunities) of BIM practices and adoption in the construction industry, especially for collaboration between people (e.g. team

members) during construction projects, where data plays a central role?”

The findings from the consultation were based on a questionnaire and semi-structured interviews, and demonstrated tangible evidence of BIM adoption in the construction industry. Nonetheless, the current construction industry is still only at level 2 of BIM adoption, i.e. all practitioners use their own 3D CAD models and do not work on a single, shared BIM model. However, ICT and collaborative practices have long been used within the construction industry, which has the effect of facilitating the adoption of BIM. Although, some construction organisations provide online collaborative tools with built-in communication tools, many practitioners continue to rely on email, not only as their main communication tool but also for sharing BIM models. This practice results in several issues with regard to data; e.g. data loss, multiple versions of BIM models. Furthermore, they set up regular face-to-face meetings to discuss project progress, but use Voice-Over-IP (e.g. Skype) for face-to-face interaction with remote teams in order to clarify aspects of project design or BIM models. This leads to difficulties making critical decisions during meetings; thus, in some cases liabilities and legal disputes arise from errors in BIM models.

The majority of construction organisations use proprietary web-based collaboration tools and Electronic Document Management Systems (EDMS) to manage data sharing, because they are characterised by vendor reliability and technical support. However, the management and governance processes of EDMS solutions tend to be owned by their developers. Although most web-based BIM collaborative solutions can support access to stored data based on each actor's role, the process of defining ownership, and roles and responsibilities relative to these solutions is often unclear. Regarding BIM data storage, the majority of construction professionals rely on standalone storage and archives held on personal computers. However, augmented use of online-networked storage is also evident; especially when sharing large files and accessing them from outside the organisation's Intranet.

A number of barriers to BIM adoption were identified when reviewing the previous literature. However, this research has shown that while the identified issues do exist there are additional barriers to BIM adoption to consider. Known barriers were identified and grouped into five main categories: socio-organisational, financial, contractual, technical, and legal (see chapter 4). Furthermore, a number of issues regarding team collaboration were acknowledged and categorised into three main categories: people, process, and data-related issues (presented in chapter 4). Despite the proliferation of generic data

management solutions, the afore-mentioned collaboration issues remain (e.g. ownership, intellectual property, and data lost and inconsistency).

When adopting BIM as a collaborative approach, there is a need to alter the management and re-engineering of the traditional collaboration process. In addition there is a need to clarify ownership, intellectual property rights, and establish clear roles and responsibilities. Based on these diagnosed and recognised issues, alongside the limitations affecting current collaborative BIM solutions, any new BIM governance solution must overcome these issue to hasten BIM adoption.

RQ2: “How can the identified barriers from RQ1, the ones related to data management and governance, be addressed to enhance collaboration between people and products, and to increase BIM adoption during a construction project’s lifecycle, in particular, using Cloud Computing technologies?”

Industry consultation revealed existing BIM standards offer inadequate support for data management and governance in construction projects. The industry currently relies on ad-hoc governance procedures, often on a project-by-project basis, resulting in barely adequate team management and wasted resources. The majority of BIM experts expressed the need for a BIM governance solution to manage both BIM data and to enforce governance policies concerning collaboration throughout the entire construction team. Further, the project process is managed by whoever has access to the data. Thus, a governance solution would clarify to all participants their roles and responsibilities, so that people can understand what to deliver and when, and feel obliged to complete only their own tasks. In others word, it is essential to conceal the complexity of collaborative BIM standards by offering an automated process that meets those standards in the form of an intelligent, friendly user interface (GovernBIM). Team members adopting collaborative BIM should not need to review any paper-based standards. The development of a BIM governance solution would then be based on requirements collected from BIM experts reflecting the construction domain (elaborated in chapter 4), and offer a well-developed legal framework underpinned by ICT and Cloud technologies.

With regard to the use of Cloud, the results from all the research instruments were important. The consultation revealed the majority of construction organisations deploy collaborative tools on their Intranets, which are hosted by the same organisation. Problems identified as associated with site-specific storage were capacity mismatch, difficulties with remote access and underutilisation of computing resources. Second, new

generation BIM tools were found to be more compute-intensive, requiring more frequent costly infrastructure upgrades. This situation is exacerbated in cases where the compute capacity needs to be increased for short periods. In contrast, CSPs are better equipped for on-demand scalability than typical construction organisations. Moreover, scaling to high-performance computing capabilities saves time and money when performing analysis of large BIM files. Furthermore, consultation findings revealed several advantages to using the Cloud, and more specifically to developing a BIM governance solution; e.g. data availability, accessibility, cost-effectiveness, and scalability of storage and computing. However, respondents raised concerns relating to data and cyber security, network dependency, lack of clarity with legal frameworks and instruments, and physical data storage. Cloud technologies were chosen as the preferred integrating environment for BIM governance solutions.

RQ3: “Can the findings from RQ2 be applied to develop a process-centric governance solution underpinned by Cloud technologies for facilitating collaboration across a building lifecycle that addresses the issues identified in RQ1?”

Findings from RQ2 can be applied to develop a process-centric governance solution that is underpinned by Cloud technology; i.e. a cloud-based BIM governance platform (GovernBIM). To develop such solution, a critical review was conducted to explore existing collaborative BIM solutions, with the aim of investigating their features and functionalities. In addition to conducting a review of existing collaborative BIM-related standards and practices, to understand team’s collaboration process in the construction industry, case studies were undertaken. The process of three firms’ collaborative BIM environment was analysed and then modelled using a software engineering approach employing BPMN and UML modelling techniques. The outcomes from this approach were: (a) the development of a set of BPMN diagrams for setting, configuration, management, and use of a GovernBIM platform from initial setup until the end of the GovernBIM platform project; (b) several fundamental use cases and scenarios for a GovernBIM platform, (c) a core BIM governance model (class diagram); and (d) a well-structured cloud-based architecture of Cloud-based GovernBIM platform for practical implementation (for more details see Chapter 5).

This stage was then followed by conducting a comprehensive review targeting famous CSPs accompanied with an iterative development approach to cloud-based prototypes. This aimed to develop a GovernBIM platform prototype to test and validate outcomes at the consultation and modelling stages (Chapter 4 and 5 outcomes). Since one aim of this

study was to test and validate the developed Cloud-based BIM governance solution and the hosting Cloud environment, Google via (GCP) was used to develop an initial API for a GovernBIM platform prototype. After testing and completing the initial version of the GovernBIM platform prototype, the prototype then underwent a validation process with several BIM experts. This validation process shows the GovernBIM prototype offers an accessible, remote, and scalable collaborative environment permitting BIM objects in different data formats to be shared between multiple actors according to their roles and responsibilities during a project's lifecycle under the control of GovernBIM governor. Furthermore, there are several benefits to using Cloud technologies to underpin R&D in a BIM governance solution. However, many concerns remain with regard to security and privacy (for more details see Chapter 6). In comparison with using a local company infrastructure, using Cloud technologies has the potential to address both construction industry data related issues and governance requirements for hosting BIM governance solutions.

RQ4: “Does the solution developed in response to RQ3 address existing challenges for collaboration?”

The findings after validating the GovernBIM prototype showed great potential for a Cloud-based BIM governance platform to facilitate the collaboration process. The platform has the ability to manage BIM projects better, by involving multi-disciplinary actors in construction projects. Throughout the process of developing the Cloud-based BIM governance platform, the developed prototype was shown to be able to manage BIM projects, including information about actors, their roles and access rights, as well as BIM objects. The GovernBIM prototype supports the management of actors' roles and responsibilities, which is key to tracking changes to BIM objects. This preserves the ownership of BIM objects, and Intellectual Properties (IP) and reduces the liability for wrong/incomplete information. Furthermore, uploaded BIM objects are accessed when managing actors' access rights functions, effecting changes to BIM objects that can be recorded and traced. Moreover, the use of the Cloud for hosting GovernBIM platforms has solved several issues; e.g. data accessibility, availability, and data storage scalability. Although, technical solutions heavily contribute towards addressing collaboration issues, a domain specific legal framework is needed to underpin development. In addition, there should be awareness, training and technical support to enable construction teams to fully tackle BIM adoption barriers and collaboration issues. The developed GovernBIM platform is still in its early stages. Additional investigation and development is needed to comprehensively address most of the collaboration challenges that currently exist. The validation process shows considerable potential for such solutions, emphasising the ability to address collaboration issues established by team members during construction projects.

7.4 Study achievements and key findings

At the beginning of this research, the author established several objectives based on the aforementioned research questions. All the set objectives were accomplished at different stages of the research. The following details what has been achieved:

- **A comprehensive understanding of the barriers to, and opportunities afforded by, BIM adoption, focusing on data management and governance.** The initial stages of the research involved a critical review, leading to understanding in the BIM area with regard to: (a) BIM adoption barriers and opportunities with a specific focus on socio-organisational, contractual, legal, financial, contractual and technical aspects; (b) current BIM collaboration and ICT practices, solutions, and their limitations; (c) existing BIM governance solutions with a specific focus on efforts made in the construction industry; and (d) Cloud technologies, highlighting potential benefits and drawbacks of BIM related research and development. This assisted the researcher to identify the aims and objectives of the study, set the research hypotheses and research questions. It also assisted in the choice of an appropriate research instrument.
- **Identification of current practices, challenges, and requirements related to BIM data governance in construction lifecycle.** Conducting a wide consultation, in the form of a comprehensive questionnaire and semi-structured interviews, with BIM experts, led to: exploring and identifying barriers and opportunities for BIM adoption with a specific focus on team collaboration, taking into account socio-organisational, legal, financial, contractual and technical aspects. As well as exploring data-related issues that arose during team collaboration; for example, trust, ownership and concerns over intellectual property rights (IPRs), miscommunication, data loss, data inconsistency, errors, and liability for wrong or incomplete data (see chapter 4). Furthermore, the discussions with BIM experts, in the form of semi-structured interviews, revealed a need for a BIM governance solution underpinned by Cloud technologies. It is also important to highlight that one of the main achievements of the consultation stage was the clarification of effective BIM governance factors in the form of a summative framework (G-BIM). The G-BIM framework comprises three main components: actors and team; data management and ICT; and, processes and contracts.
- **Modelling data and team management in BIM-based collaborative process between construction team members.** A critical review was conducted to

explore existing collaborative BIM solutions, as well as understanding their capabilities, internal data structure, and interfaces. This investigation enabled understanding of the basic functionalities of collaborative BIM solutions. Furthermore, a review was undertaken regarding existing BIM-related standards and practices aimed at gaining an in-depth understanding of the team collaboration process in the construction industry and the set-up of collaborative environments. A textual description of three case study companies was analysed and modelled using BPMN and UML. The resulting BPMN formed key BPMN activities for the developed GovernBIM platform's lifecycle. All the results collected at previous research stages leveraged the developed BPMN for the GovernBIM platform's lifecycle. Several BPMN diagrams were developed to illustrate key activities representing the entire lifecycle of the developed platform.

Further, the modelling process led to the identification of several key use cases forming the kernel functionalities of the GovernBIM platform. This study identified and developed several key use cases for BIM governance, to devise a platform aimed at facilitating team collaboration within a construction project. Moreover, this study included development of the Class diagram, presenting the internal data governance structure of the GovernBIM platform. The results of BPMN and UML led to the creation of architecture for practical implementation of a GovernBIM platform over a CSP infrastructure. This architecture was developed after studying several Cloud platform architectures, such as SOA and design patterns e.g. MVC.

- **Development, and demonstration of a Cloud-based BIM governance solution based on the identified industry and process requirements.** Based on the requirements identified from the consultation and modelling stages, an investigation was performed regarding existing collaborative Cloud-BIM solutions, as well as widely used Cloud Service Providers (CSPs), to define the Cloud software architecture for implementing and hosting cloud-based BIM governance platform over a selected CSP. This review investigates the infrastructure, internal structures, available services, and payment process, it led to the selection of a Google Cloud Platform (GCP) to underpin the development of a GovernBIM platform prototype. The aim when developing a Cloud-based GovernBIM prototype is to validate the results from all previous stages to explore the potential role of Cloud in hosting a BIM governance solution. Integrating a GovernBIM platform with Google Cloud allows the researcher to fully connect the services of the GovernBIM platform to CSP services based on the pay-per-use Software-as-a-Service (SaaS) paradigm. This integration solved many issues, such as: data availability, accessibility, re-use, and

high-performance capabilities. Furthermore, by migrating the developed GovernBIM platform's database to Google, the Cloud infrastructure made it possible to readily increase storage space to accommodate and store large BIM files. Moreover, delivering a GovernBIM API's as an open-source to developers opened up an opportunity for future development to the platform, e.g. linked to an Open BIM server.

- **Implementation of various testing and validation to GovernBIM platform's prototype and propose recommendations for further development.** The testing and validation approach combined black box and white box techniques. The white box technique was used to test the functionalities of the platform during the development process, and the black box technique was undertaken with several BIM experts who had experience of developing GovernBIM platforms and were enthusiastic about participating in the validation process. The validation took the form of a demonstration, presenting the various functionalities of the GovernBIM platform, followed by a trial and hands-on testing by BIM experts. This was accompanied by an in-depth discussion concerning the achievements, and shortcomings, of the developed platform. The validation process covered, (a) the prototype for the developed GovernBIM platform; and (b) the used hosting Cloud environment (for greater detail see Chapter 6).
- **Documentation of the process for capturing and translating business processes into tangible solutions that can be adopted within and outside the construction industry.** Data governance is an important research domain, not only in the construction industry, but also in other domains; e.g. Banking, Health, and Education. Therefore, regular documentation of outcomes at each stage is done for research and development in other research disciplines. This documentation process includes planning documents, meetings agenda, technical reports, consultation guides, BPMN and UML templates, technical reports, and journal publications.

7.5 Study limitations

Despite the associated effort, planning, and the great support offered by both the researcher's supervisors and scholarship provider, this study encountered several unavoidable difficulties. These limitations are as follows:

- Cloud-based BIM governance research is a novel area within the construction domain. Consequently, BIM experts have different views and understandings of it. Responses gathered concerning the need for, and suitability of Cloud technologies

with respect to the building sector may reflect these different views. However, the study did employ a systematic multi-stages research approach, to minimise the impact of differences in experts opinions on the suitability of Cloud technologies when facilitating team collaboration in the Built Environment via the adoption of a BIM governance solution.

- Constructions companies are reluctant to disclose information about their BIM practices and processes. Therefore, the researcher had to employ a multi-methods approach to extract as much information as possible from construction professionals.
- The analysis of business processes requires detailed observations of the process over a longer period of time, than that permitted by the construction organisations studied. Detailed interviews were used to augment the shorter observation times, to fill in the gaps, and to enable completion of several core BPMN and UML models for key activities when developing the platform.
- The evaluation of the platform has been undertaken based on the white and black box testing techniques, which, to some extent, might not be sufficient enough to fully test the functionality of the platform. Hence, it is strongly recommended to further test the developed platform based on real construction projects.

7.6 Recommendations for future research and development

As highlighted in the section above, there are limitations to this study. These limitations prompt the researcher to recommend future research as follows:

- Conduct further consultation with other key BIM experts worldwide to improve on currently identified requirements, as well as the developed Cloud-based BIM governance solution using Ethnographic research.
- Investigate further the factors for an effective BIM governance factors' framework (G-BIM) using consensus-based approach (e.g. Delphi) combined with a weighting system (e.g. Analytic Hierarchy Process (AHP)).
- Investigate the collaborative BIM process within three case studies to identify key BPMN and UML activities for a GovernBIM platform. It is recommended that further investigations should be carried out to expand and build on core identified

GovernBIM's BPMN and UML activities' diagrams, to cover collaboration activities and processes, involving different collaboration settings (i.e. different kinds of actors, procedures and processes).

- Investigate the potential from integrating the developed GovernBIM platform with open-source BIM servers (e.g. BIMServer) or commercial collaborative BIM solutions (e.g. ProjectWise).
- The prototype was developed on one Cloud service provider only, because of constraints of time and resources. The developed prototype may not be directly applicable to other CSP platforms without modification. Therefore, there is ample opportunity for Cloud-BIM researchers to investigate the process of migrating the GovernBIM platform from Google CPS to another CPS such as Amazon.
- IFC and COBie are considered useful solutions that have been developed to solve interoperability in shared construction data among different software packages; thus, integrating these tools in the developed platform will offer a new approach towards addressing interoperability issues.
- The testing and validation of the GovernBIM platform is based on the white and black box techniques. However, it is recommended that future researchers test the platform within real construction projects in order to ensure that the final outputs from the platform are secure, reliable, and trustworthy.

7.7 Summary

In summary, this study has met its set aim and objectives and provided a methodological framework that can be adapted to other research fields. In addition to contributing to the body of knowledge, it has contributed a new open source Cloud-based BIM governance platform. A formal methodological approach was adopted to achieve this contribution. Furthermore, several key recommendations were presented in the thesis to benefit future research and developments to overcome the limitations of this study.

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Appendix A: Questionnaire invitation letter and design

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Tel: +44 (0) 7577449798
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Title: BIM Governance Solution: Questionnaire participation request

Dear (Expert Name),

My Name is Eissa Alreshidi; I am a PhD Candidate at School of Engineering in Cardiff University.

I am conducting a research on Building Information Modeling (BIM) based collaboration in construction projects. In particular, I am focusing on who governance models can assist in information management as well as the specification of BIM governance model for facilitating BIM collaboration across the supply chain during a building lifecycle.

In that respect, I would like to invite you to take part to a survey with a view of identifying BIM adoption barriers, current practices and BIM governance requirements across the industry. The link to the survey is:

https://www.surveymonkey.com/s/BIM_Survey_Cardiff_University_2014

This questionnaire will take approximately twenty to twenty-five minutes. Your efforts in participating in this questionnaire are voluntarily but highly appreciated.

Your views on BIM-based information management are highly important for this study and are very important for us so your help will be greatly appreciated. The outcomes of which will be widely distributed among practitioners.

Your opinion will be anonymised for reporting and will only be used for academic research. Your participation is entirely voluntary but I would be grateful if you could participate. For research purpose, a recording for the interview is required.

Looking forward to hear from you,

Sincerely yours,

Eissa Alreshidi

Email: alreshidie@cf.ac.uk

Skype: eissa.alreshidi

Supervisors: Dr. Monjur Mourshed, Prof. Yacine Rezgui

Perception of existing BIM solutions/practices in the UK construction

Introduction

Dear BIM Expert,

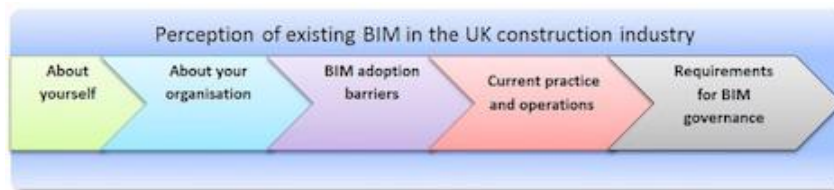
Thank you for your participation.

To date, there has been a strong agreement that construction projects are fragmented and highly regulated, making them challenging to handle. Throughout the lifecycle of a project, data with varying complexities and shapes are generated, which make them difficult to manage and govern in an efficient way. There exists an industry consensus that Building information Modelling (BIM) offers an effective means to deal with the complexity of generated data. Therefore, the community recognizes that there is a lack of a governance approach for governing BIM models throughout the lifecycle stages.

Therefore, I am conducting a research on team collaboration and governance aspects during BIM-based construction projects. In particular, I am focusing on how governance models can assist in information management as well as the specification of BIM governance model for facilitating BIM collaboration across the supply chain during a building lifecycle.

This survey (as illustrated in fig.1) aims to identify the BIM adoption barriers, current practices on typical construction project, and requirements for governance aspects.

Figure 1 survey structure



Participation in this questionnaire is strictly voluntary but strongly advised. We understand that you may not be able to answer all the questions asked here; if you are unsure or do not know the answer or would prefer not to answer, please leave the relevant section blank.

Data collected through this survey will be solely used for purposes described here and will be treated as anonymous and confidential.

Thank you for taking time to complete this survey. Your response will assist us in compiling evidence and based on this we could develop a generic BIM governance model.

For more information, please contact: alreshidi.eissa@gmail.com

Perception of existing BIM solutions/practices in the UK construction

Section 1: About yourself

Please enter your information (optional) :

First name:

Last name:

Please select your gender.

- ☐ Male
- ☐ Female
- ☐ Prefer not say

Please indicate the highest degree/qualification you have completed?

- ☐ College/Pre-university (e.g. High school, O/A level, GCSE, etc.)
- ☐ Vocational/Technical (e.g. HND, HNC, Foundation degree, etc.)
- ☐ Undergraduate (e.g. BA, BSc, etc.)
- ☐ Postgraduate taught (e.g. MSc, MA, etc.)
- ☐ Postgraduate research (MPhil, PhD, etc.)

Other (please specify)

Please select your current job role.

- | | | |
|--|--|---|
| <input type="checkbox"/> Architect | <input type="checkbox"/> Facilities Manager | <input type="checkbox"/> Mechanical Engineer |
| <input type="checkbox"/> Building Surveyor | <input type="checkbox"/> General non-disciplinary | <input type="checkbox"/> Project Manager |
| <input type="checkbox"/> BIM Manager | <input type="checkbox"/> Geographical and Land
Surveyor | <input type="checkbox"/> Public Health Engineer |
| <input type="checkbox"/> Civil Engineer | <input type="checkbox"/> Health & Safety Consultant | <input type="checkbox"/> Quantity Surveyor |
| <input type="checkbox"/> Client | <input type="checkbox"/> Heating and Ventilation
Designer | <input type="checkbox"/> Specialist Designer |
| <input type="checkbox"/> Client Advisor | <input type="checkbox"/> Information Manager | <input type="checkbox"/> Structural Engineer |
| <input type="checkbox"/> Contractor | <input type="checkbox"/> Interior Designer | <input type="checkbox"/> Subcontractor |
| <input type="checkbox"/> Cost Consultant | <input type="checkbox"/> IT Technician | |
| <input type="checkbox"/> Electrical Engineer | <input type="checkbox"/> Landscape Architect | |

Other (please specify)

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Please select your age group.

- ☐ 18 - 21
- ☐ 21 - 25
- ☐ 26 - 30
- ☐ 31 - 35
- ☐ 36 - 40
- ☐ 41 - 45
- ☐ 46 - 50
- ☐ > 51

How long have you been working in the construction industry?

- ☐ < 1 year
- ☐ 1 - 5 years
- ☐ 6 - 10 years
- ☐ 11 - 15 years
- ☐ 16 - 20 years
- ☐ > 20 years

Will you be interested in participating in a follow up interview?

- ☐ Yes
- ☐ No

Please enter your email address below if you want to be contacted on a follow-up interview.

Perception of existing BIM solutions/practices in the UK construction

Section 2: About your organisation

Where is your organisation located: i.e. where do you work?

- | | |
|--|--|
| <input type="radio"/> East Midlands | <input type="radio"/> South East England |
| <input type="radio"/> East England | <input type="radio"/> South West England |
| <input type="radio"/> London | <input type="radio"/> Wales |
| <input type="radio"/> North East England | <input type="radio"/> West Midlands |
| <input type="radio"/> North West England | <input type="radio"/> Yorkshire |
| <input type="radio"/> Northern Ireland | <input type="radio"/> Globally |
| <input type="radio"/> Scotland | <input type="radio"/> Across UK |

How long has your company been established?

- ☐ 1-10 year/years
- ☐ 11-30 years
- ☐ > 30 years

How many employees are there in your organisation?

- ☐ < 10
- ☐ 11-50
- ☐ 51-250
- ☐ > 251

How often does your organization apply the following procurement methods?

	Never	Rarely	Sometimes	Often	Always	Not applicable
Traditional	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Design and build	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Two stage tendering	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public private partnerships	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Private finance initiative	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Management contracting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Framework agreements	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Prime contracting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Perception of existing BIM solutions/practices in the UK construction

Section 3: Barriers to the adoption of BIM in the UK construction industry

This section aims to identify the common barriers that may slow the adoption of BIM in the UK construction industry.

For the purpose of this survey we adopt the definition of BIM as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition"(NBIMS, 2013)

Which of the following factors do you believe may act as socio-organisational barriers in the adoption of BIM in construction projects?

- ☐ Issues related to collaboration within a team (e.g. trust)
- ☐ Generational gaps in BIM skills and understanding between junior and senior members of staff
- ☐ The structure of the team and the relationships between team members (e.g. user/manager)
- ☐ Team members' resistance to change and transition to a knowledge driven organisation
- ☐ Adoption of single management processes with multiple-disciplines; across lifecycle and supply chains
- ☐ Organisational culture- values, beliefs, customs, traditions and practices that are shared within the organisation
- ☐ Undefined roles and responsibilities of team members

Other (please specify)

Which of the following factors do you believe may act as financial barriers in the adoption of BIM in construction projects?

- ☐ Cost of initial hardware setup
- ☐ Cost of initial software setup
- ☐ Training costs
- ☐ Maintenance costs, e.g. regular updates of software
- ☐ Tight budgets and existing small profit margins on projects
- ☐ Personal indemnity insurance (PII) increases due to shared liabilities policy

Other (please specify)

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Which of the following factors do you believe may act as legal barriers in the adoption of BIM in construction projects?

- ☐ Lack of standards
- ☐ Lack of defined liability for wrong or incomplete information input
- ☐ Intellectual property rights and fair practice for electronic information and documentation
- ☐ "Historic" government regulations that do not meet current and future needs of the industry
- ☐ Personal indemnity insurance cover not maintained due to unknown liabilities on shared projects
- ☐ No clarity in regulation related to participant roles, responsibilities and authorities

Other (please specify)

Which of the following factors do you believe may act as technical barriers in slowing down the adoption of BIM in construction projects?

- ☐ Lack of training
- ☐ Lack of compatibility between existing and new hardware
- ☐ Lack of compatibility between existing and new software
- ☐ Lack of compatibility between various standards-based (e.g. IFC) products across lifecycle and supply chains
- ☐ Lack of data integration among stakeholders across lifecycle and supply chains
- ☐ Privacy constraints associated with externally sourced virtualised storage.(e.g. cloud)
- ☐ Lack of support for data integrity, user authentication, data security and access control

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

What are the most common data issues that you face when you are dealing with construction data?

- ☐ Data inconsistency, e.g. different versions, data loss etc
- ☐ Data liability related issues
- ☐ Access to data files
- ☐ Data security - confidentiality and privacy of data and documents
- ☐ Data compatibility issues when sharing and exchanging documents
- ☐ Data file sizes when storing, sharing and exchanging documents

Other (please specify)

What do you believe are the impacts of insufficient data management within a construction project?

- ☐ Project delays
- ☐ Cost implications
- ☐ Poorly produced documents
- ☐ Errors and data inconsistency

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

Section 4: Current practice and operations

This section aims to identify the current construction practices in a typical project within your organisation.

In your organisation, who is responsible for setting up the project working environment ?

- ☐ Project manager ☐ IT manager ☐ Varies from project to to project

Other (please specify)

Do you think there is a need for a dedicated BIM manager for managing BIM data and its associated activities?

- ☐ Yes
☐ No
☐ I do not know

Your comments

Which of the following construction work plans best describes your organization's approach?

- ☐ RIBA Plan of Work 2007
☐ RIBA BIM Overlay 2012
☐ RIBA Plan of Work 2013
☐ Construction Industry Council (CIC)

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

Which stages of construction project are you normally involved with?

(Stages based on RIBA Plan of Work 2013 with corresponding CIC stages in brackets)

- ☐ Stage 1: Preparation (CIC: Brief)
- ☐ Stage 2: Concept design (CIC: Concept)
- ☐ Stage 3: Developed design (CIC: Developed design)
- ☐ Stage 4: Technical design (CIC: Production)
- ☐ Stage 5: Specialist design (CIC: Installation)
- ☐ Stage 6: Construction (CIC: As Constructed)
- ☐ Stage 7: Use & aftercare (CIC: In use)

On a typical BIM-based project that you are currently working on, to what extent is BIM used at each stage?

	0%	1% - 20%	21% - 40%	41% - 60%	61% - 80%	81%-100%
Stage 1: Preparation (CIC: Brief)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stage 2: Concept design (CIC: Concept)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stage 3: Developed design (CIC: Developed design)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stage 4: Technical design (CIC: Production)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stage 5: Specialist design (CIC: Installation)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stage 6: Construction (CIC: As Constructed)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stage 7: Use & aftercare (CIC: In use)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Which of the following design software packages do you use to produce your design data?

	2D CAD only	2D & 3D CAD	3D CAD only	Semantic/Object-based CAD (*)	Not used
Autodesk AutoCAD packages	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Autodesk AutoCAD LT packages	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Autodesk Revit packages	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bentley packages	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Graphisoft packages	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Google Sketchup	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

(*) Semantic/object-based CADs are objects that stores non-graphical data together with the graphical representation of a building in a logical structure as well as carrying information about their relationships with other objects.

Which of the following project management software does your organisation use?

- | | |
|---|--|
| <input type="checkbox"/> Navisworks | <input type="checkbox"/> Primavera |
| <input type="checkbox"/> Solibri | <input type="checkbox"/> Microsoft package |
| <input type="checkbox"/> Master Builder | <input type="checkbox"/> None of them |

Other (please specify)

Which of the following BIM server solutions have you used in previous/current construction projects?

- | | | |
|--|---|--|
| <input type="checkbox"/> AutoDesk Buzzsaw | <input type="checkbox"/> Bentley AssetWise | <input type="checkbox"/> BIMServer |
| <input type="checkbox"/> AutoDesk Revit Server | <input type="checkbox"/> Graphisoft BIM Server | <input type="checkbox"/> EDMmodelServer |
| <input type="checkbox"/> Bentley ProjectWise | <input type="checkbox"/> Onuma systems (BIMStorm) | <input type="checkbox"/> None of the above |

Other (please specify)

Please select the technologies/software/tools that are used for team communication within a construction project?

	Never	Rarely	Sometimes	Often	Always
Landline	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mobile phone, SMS	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Email e.g. Google Mail, Hotmail, Yahoo, company email, etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Teleconference	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Online voice/video meeting software e.g. Skype	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Face-to-face meeting	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

Reflecting on your job role, how often do you collaborate with the following team members?

	Never	Rarely	Sometimes	Often	Always
Architect	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building Surveyor	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BIM Manager	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Civil Engineer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Client	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Client Advisor	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Contractor	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cost Consultant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Electrical Engineer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Facilities manager	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
General Non-disciplinary	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Geographical and Land Surveyor	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Health & Safety Consultant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Heating and Ventilation Designer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Information Manager	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Interior Designer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
IT Technician	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Landscape Architect	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mechanical Engineer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Project Manager	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Public Health Engineer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantity Surveyor	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Specialist Designer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Structural Engineer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

How often do you use the following methods for storing construction project data?

	Never	Rarely	Sometimes	Often	Always
Paper	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Optical media (e.g. CDs, DVDs, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Flash storage (e.g. USB, Memory Card, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Networked drive in the company intranet (e.g. NAS)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Portable external hard drive	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cloud storage solution (e.g. Dropbox, Amazon S3, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
On my pc/laptop drive	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

How often do you use the following methods to share/exchange construction project data/document with other team members?

	Never	Rarely	Sometimes	Often	Always
Paper	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Optical media (e.g. CDs, DVDs, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Flash storage (e.g. USB, Memory Card, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Email	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Networked drive in the company intranet (e.g. NAS)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Portable external hard drive	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cloud storage solution (e.g. Dropbox, Amazon S3, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

Which one of the following data format do you use to share/exchange documents?

	Never	Rarely	Sometimes	Often	Always
Microsoft word (e.g. docx, doc, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Microsoft powerpoint (e.g. pptx, ppt, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Microsoft excel (e.g. xlsx, xls, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Portable document format (pdf)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Autodesk file (dwg)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
AutoCAD file (dxf)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bentley systems' Microstation (dgn)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Industry foundation classes (ifc)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Comma-separated values file (csv)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Extensible markup language file (xml)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Open green building XML schema (gbXML)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Simple text file format (txt)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Image formats (e.g. jpeg, png, gif, etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

*Are you typically involved in the RIBA Preparation stage of a building's lifecycle as shown in figure below?

- ☐ Yes
- ☐ No

RIBA stage 1: Preparation

RIBA Work Stages						
1	2	3	4	5	6	7
Preparation	Concept Design	Developed Design	Technical Design	Specialist Design	Construction	Use & Adaptation
<p>Identify Project Objectives, the client's business aims, requirements, opportunities and other provisions, as necessary and develop the initial Project Brief</p> <p>Generate the Information and other requirements for the project, including necessary inputs</p> <p>Progress the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>	<p>Develop the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>	<p>Develop the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>	<p>Develop the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>	<p>Develop the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>	<p>Develop the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>	<p>Develop the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p> <p>Generate the Project Brief and other requirements of the project, as necessary and develop the initial Project Brief</p>

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 1: Preparation

Which of the following documents do you work on at RIBA Preparation stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Initial project brief	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Feasibility study report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Project programme booklet	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Supplier assessment forms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Procurement strategy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Scope of project team service strategy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Contract agreement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Design responsibility agreement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BIM deployment plan	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Soft landing strategy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Information exchange strategy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

RIBA stage 2: Concept Design

☐ Yes

☐ No

[illegible]

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 2: Concept Design

Which of the following documents do you work on at RIBA Concept Design stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Outline proposal: Structural design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Outline proposal: Building services systems (MEP)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Outline proposal: Site landscape	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Outline proposal: Outline specification	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Outline proposal: Preliminary cost plan	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Project strategies document (e.g. environmental, energy, ecology etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Final project brief	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Procurement strategy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Design responsibility	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Software strategy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BIM execution plan	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Performance specified work	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Construction strategy (e.g. offsite fabrication report, H&S aspect document, site logistic)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 3: Developed Design

***Are you typically involved in the RIBA Developed Design stage of a building's lifecycle as shown in figure below?**

- ☐ Yes
- ☐ No

RIBA stage 3: Developed Design

Description of Key Tasks	RIBA Work Stages						
	1	2	3	4	5	6	7
	Preparation	Concept Design	Developed Design	Technical Design	Specialist Design	Construction	Use & Maintenance
	<ul style="list-style-type: none"> Obtain Project Information, including client brief, and understand the project's context, including the client's brief, the project's context, and the project's context. Obtain the information and data required to develop the project, including the client's brief, the project's context, and the project's context. Obtain the information and data required to develop the project, including the client's brief, the project's context, and the project's context. Obtain the information and data required to develop the project, including the client's brief, the project's context, and the project's context. 	<ul style="list-style-type: none"> Develop the project's concept design, including the client's brief, the project's context, and the project's context. Develop the project's concept design, including the client's brief, the project's context, and the project's context. Develop the project's concept design, including the client's brief, the project's context, and the project's context. Develop the project's concept design, including the client's brief, the project's context, and the project's context. 	<ul style="list-style-type: none"> Develop the project's developed design, including the client's brief, the project's context, and the project's context. Develop the project's developed design, including the client's brief, the project's context, and the project's context. Develop the project's developed design, including the client's brief, the project's context, and the project's context. Develop the project's developed design, including the client's brief, the project's context, and the project's context. 	<ul style="list-style-type: none"> Develop the project's technical design, including the client's brief, the project's context, and the project's context. Develop the project's technical design, including the client's brief, the project's context, and the project's context. Develop the project's technical design, including the client's brief, the project's context, and the project's context. Develop the project's technical design, including the client's brief, the project's context, and the project's context. 	<ul style="list-style-type: none"> Develop the project's specialist design, including the client's brief, the project's context, and the project's context. Develop the project's specialist design, including the client's brief, the project's context, and the project's context. Develop the project's specialist design, including the client's brief, the project's context, and the project's context. Develop the project's specialist design, including the client's brief, the project's context, and the project's context. 	<ul style="list-style-type: none"> Develop the project's construction, including the client's brief, the project's context, and the project's context. Develop the project's construction, including the client's brief, the project's context, and the project's context. Develop the project's construction, including the client's brief, the project's context, and the project's context. Develop the project's construction, including the client's brief, the project's context, and the project's context. 	<ul style="list-style-type: none"> Develop the project's use & maintenance, including the client's brief, the project's context, and the project's context. Develop the project's use & maintenance, including the client's brief, the project's context, and the project's context. Develop the project's use & maintenance, including the client's brief, the project's context, and the project's context. Develop the project's use & maintenance, including the client's brief, the project's context, and the project's context.

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 3: Developed Design

Which of the following documents do you work on at RIBA Developed Design stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Developed design: Structural design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed design: Building services system (MEP)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed design: Site landscape	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed design: Outline specification	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed design: Cost plan	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed design: Project strategies	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Document for planning application	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Change control procedure implementation report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sustainability assessment report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Procurement strategy report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed construction strategy: H&S aspects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

RIBA stage 4: Technical Design

☐ Yes

☐ No

[illegible]

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 4: Technical Design

Which of the following documents do you work on at RIBA Technical Design stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Technical design: Architectural design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Technical design: Structural design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Technical design: Building services systems (MEP)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Technical design: Specifications	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developed performance specified work	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Procurement strategy implementation report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Document for building regulation submission	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Construction strategy (sequencing, programme and H&S report)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

RIBA stage 5: Specialist Design

☐ Yes

☐ No

[illegible]

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 5: Specialist Design

Which of the following documents do you work on at RIBA Specialist Design stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Performance specified work	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Construction strategy report (construction sequence and critical path)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Procurement strategy report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building contract administration	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

RIBA stage 6: Construction stage

☐ Yes

☐ No

[illegible]

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 6: Construction stage

Which of the following documents do you work on at RIBA Construction stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Offsite manufacturing plan	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Onsite construction plan	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Site Inspection report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Administration of building contract report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Soft landing strategy implementation report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

RIBA stage 7: Use & Aftercare

☐ Yes

☐ No

[illegible]

Perception of existing BIM solutions/practices in the UK construction

RIBA stage 7: Use & Aftercare

Which of the following documents do you work on at RIBA Use & Aftercare stage?

	Initiate (owner)	Read/write (Contributor)	Read only (Consultant)	Comment (Approve)	Not Applicable
Soft landing strategy implementation report (e.g. post occupancy evaluation)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Building contract final report	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Project information report (for future project use)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Project Information report (update in response to feedback from asset management and facility management)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

Perception of existing BIM solutions/practices in the UK construction

Section 5: Requirements for BIM governance

This section is aimed to understand your requirements for BIM governance in a distributed collaborative environment (e.g. cloud computing).

By governance in this section we mean “the collection of decision rights, processes, standards, policies and technologies required to manage, maintain and exploit information as an enterprise resource”(Newman and Logan,2006).

To what extent do you agree with the following statements:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
The new BIM solutions will change the way teams collaborate in a construction project	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BIM will improve project quality and efficiency in UK construction industry	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
BIM will speed up the supply-chain collaboration life cycle	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Developing a generic BIM data governance model would tackle most of existing BIM collaboration problems	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Your comments

Perception of existing BIM solutions/practices in the UK construction

To what extent you agree on following functional requirements which are needed for addressing BIM data governance issues?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Help and support	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Intensive training	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Awareness raising	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Development of protocols	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sharing through a common model	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Secured log-in with access rights	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Security checks for uploaded/downloaded and transferred models	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
User interface customisation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Use web for online viewing and printing models	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Central repository for data storage online	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
A notification system to inform team members of updated data	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Define clear roles, responsibilities for stakeholders across discipline through lifecycle.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Standardised overall life cycle data management policy	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Provide real-time mechanism for share/exchange information	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Improve the communication among disciplines	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Other (please specify)

By Cloud Computing in this section we mean "a model for enabling 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." (Mell and Grance, 2009)

Perception of existing BIM solutions/practices in the UK construction

Which of the following data related issues the cloud computing technology may solve ?

- ☐ Data inconsistency, e.g. different versions, data loss etc.
- ☐ Data liability related issues
- ☐ Access to data files
- ☐ Data security - confidentiality and privacy of data and documents
- ☐ Data compatibility issues when sharing and exchanging documents
- ☐ Data file sizes when storing, sharing and exchanging documents

Your comments

Will you be interested in participating in a follow up interview?

- ☐ Yes
- ☐ No

Please enter your email address below if you want to be contacted on a follow-up interview.

Appendix B: Semi-structure interview invitation letter and interview guide

Eissa Alreshidi BSc, MSc
PhD Candidate
School of Engineering
Cardiff University
Cardiff CF14 0PB
United Kingdom



Tel: +44 (0) 7577449798
Email: Alreshidi.eissa@gmail.com

Title: BIM Governance solution: interview request

Dear (Expert Name),

My Name is Eissa Alreshidi; I am a PhD Candidate at School of Engineering in Cardiff University.

I am conducting a research on Building Information Modeling (BIM) based collaboration in construction projects. In particular, I am focusing on who governance models can assist in information management as well as the specification of BIM governance model for facilitating BIM collaboration across the supply chain during a building lifecycle.

As a recognised Expert in BIM, you are invited to be part in this study. This will involve an interview either face-to-face or via Skybe and will take approximately 25-30 minutes.

Your views on BIM-based information management are highly important for this study and are very important for us so your help will be greatly appreciated. The outcomes of which will be widely distributed among practitioners and will be considered by associations such as BRE and BuildingSmart.

Your opinion will be anonymised for reporting and will only be used for academic research. Your participation is entirely voluntary but I would be grateful if you could participate. For research purpose, a recording for the interview is required.

Looking forward to hear from you,

Sincerely yours,

Eissa Alreshidi

Email: alreshidi@cf.ac.uk

Skype: eissa.alreshidi

Supervisors: Dr. Monjur Mourshed, Prof. Yacine Rezgui

**A governance solution for facilitating BIM collaboration across lifecycle
and the supply chain**

“Interview guide”

Start of interview

- Provide a brief overview of the research topic project, taking care to avoid giving information that may prompt or influence the interviewee's responses.
- Tell the interviewee that there will be an opportunity to ask questions at the end of the interview.
- Introduce myself to the interviewee.
- Ask the interviewee to introduce him/herself.

1. Interviewee personal details

1.1. Name:

1.2. Gender:

1.3. Organisation:

1.4. City:

1.5. Qualifications:

1.6. Position:

1.7. Years of experience:

1.8. E-mail:

1.9. Date:

2. ICT and Collaboration practices in the current construction projects (Project Managers – BIM Managers - Construction Practitioners including Architects, Engineers, etc.)

- 2.1. Would you be kind enough to tell me about the context you have been engaged with BIM?
- 2.2. Have you faced any collaboration issues when you collaborate with other team members on construction projects? (related to: data, people or processes)
 - 2.2.1. If yes, would you please briefly explain what they are and how you/your team solved them?
- 2.3. Could you please explain how the sharing/exchange of construction project's data within team members is done?
 - 2.3.1. Have you faced any technical problems when you share/exchange data?
- 2.4. Could you tell us which communication tools and software are used during a construction project for communicating with others? e.g. (Email, Web conferences, etc.)
- 2.5. Could you tell us about the methods are being used for storing/sharing project data during a construction project?
 - 2.5.1. Have you used shared storage before? If yes, would you share your experience with us?
- 2.6. In your organisation's collaboration and storage system, are there any access controls to the stored data based on actors' roles, rights or responsibilities?
- 2.7. Are you familiar with any BIM related standards/protocols?
- 2.8. Do the existing standards promote collaboration and integration of BIM? e.g. COBie, BS 1192: 2007, and PAS1192-2 .etc.
 - 2.8.1. If not, what do you think the solution would be?
- 2.9. Are there any management or governance policies for managing construction project data across supply-chain during a construction project's lifecycle?

3. BIM adoption barriers (Decision Makers – Contractors – Clients - BIM professionals – Project Managers – BIM Managers – Construction Practitioners)

3.1. In your opinion, what are the barriers to BIM adoption in the UK construction industry? In terms of:

- Socio-organisational aspects
- Legal aspects
- Technical aspects
- Contractual aspects

3.2. Do you think the UK government should help the construction industry to embrace and widely use Information and Communication Technologies (ICT) in BIM adoption?

3.3. Are there any potential concerns when team members share/exchange data with each other's? For example :

- Contracts
- BIM model ownership
- Privacy and security
- * Intellectual property
- * Data inconsistency

3.3.1. Are there any other concerns?

4. Requirements of a BIM data governance model (Decision Makers – Contractors – Owners - BIM professionals – Construction Practitioners)

4.1. In your opinion, what are the factors that might lead to a successful collaboration across supply-chain during a construction project's lifecycle?

4.2. Do you think there is a need to develop a BIM data governance model which facilitates collaboration across supply-chain during the building lifecycle?

By BIM Governance I mean "The process of managing BIM data/document during the building lifecycle taken into account stakeholders' rights and responsibilities over the managed BIM data/documents

But more formal BIM governance definition is "the process of establishing a project information management policy across lifecycle and supply chains underpinned by a building information model taking into account stakeholders' rights and responsibilities over project data and information" (Rezgui et al, 2013).

4.3. If yes, would you kindly tell us what you may require for such a model or a system?

4.4. In your opinion, what are the advantages and disadvantages of using distributed environments (cloud computing) as a sustainable storage solution for hosting project data?

5. Current management practices and technical support for virtual construction projects (Technicians - Project managers - BIM managers - Architects)

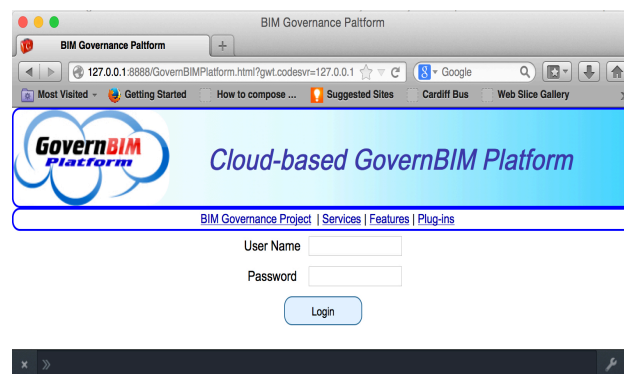
- 5.1. How do you setup the infrastructure for a virtual construction project?
- 5.2. How do you setup/configure the virtual environment for a construction project?
- 5.3. How do you manage (establish and maintain) the virtual environment of a construction project?
- 5.4. How do you manage people's access rights to the stored documents within the virtual environment of a construction project?
- 5.5. What are the tools you use to manage the documents during the lifecycle of the virtual construction project?
- 5.6. Could you tell us what is the level of document management in your organisation? Is it managed at BIM document level or is it managed at the objects/component level within the BIM document?
- 5.7. What is your procedure for ending the virtual environment of a construction project?

End of the interview

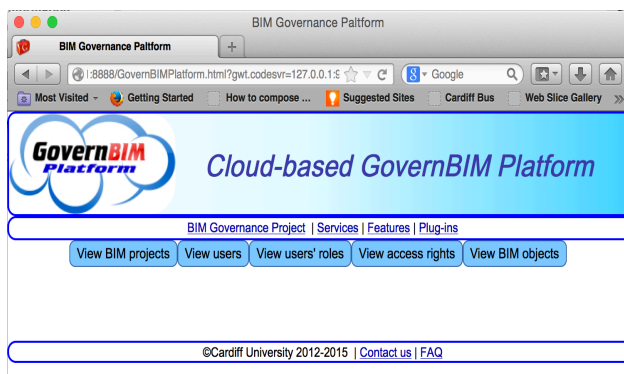
- Ask the interviewee if they have any further information they would like to share.
- Ask the interviewee if s/he has any questions and provide responses.
- Ask the interviewee if s/he is willing to participate in a future work related to the development.
- Thank the interviewee for their time and help.

Appendix C: GovernBIM platform

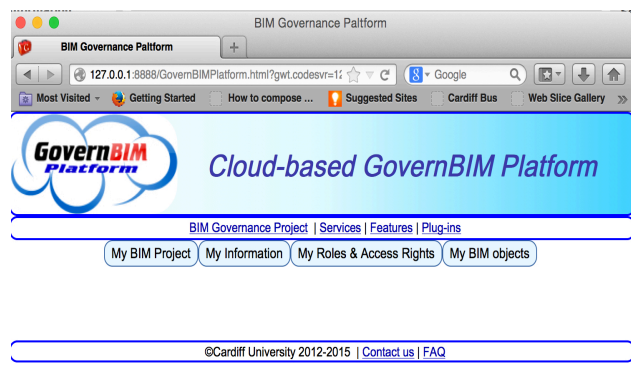
Prototype screenshots and Code sample



Login screen

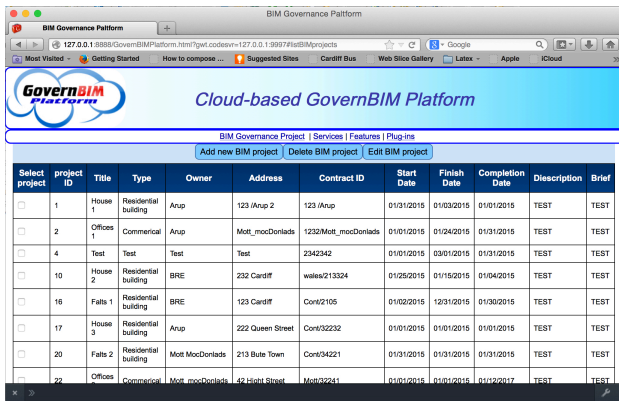


Administrators GUI



Users GUI

Administrator : Manage BIM Projects screenshots



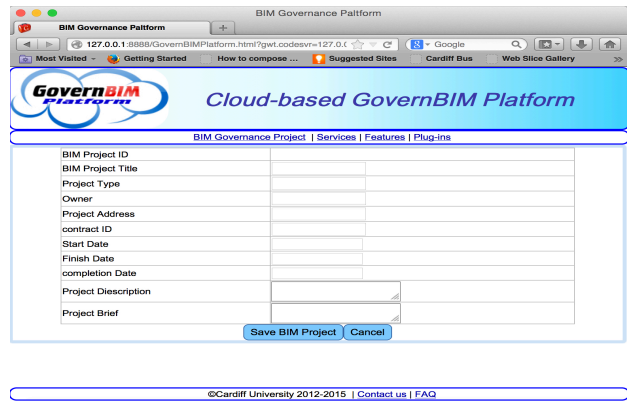
BIM Governance Platform
Cloud-based GovernBIM Platform

BIM Governance Project | Services | Features | Plug-ins

[Add new BIM project](#)
[Delete BIM project](#)
[Edit BIM project](#)

Select project	project ID	Title	Type	Owner	Address	Contract ID	Start Date	Finish Date	Completion Date	Description	Brief
<input type="checkbox"/>	1	House 1	Residential building	Arup	123 Aup 2	123 Aup	01/01/2015	01/03/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	2	Offices 1	Commercial	Arup	Mott_mcdonlads	1232Mott_mcdonlads	01/01/2015	01/24/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	4	Test	Test	Test	Test	2342342	01/01/2015	03/01/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	10	House 2	Residential building	BRE	232 Cardiff	wales/213324	01/25/2015	01/15/2015	01/04/2015	TEST	TEST
<input type="checkbox"/>	16	Falls 1	Residential building	BRE	123 Cardiff	Cont2105	01/02/2015	12/31/2015	01/30/2015	TEST	TEST
<input type="checkbox"/>	17	House 3	Residential building	Arup	222 Queen Street	Cont32232	01/01/2015	01/01/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	20	Falls 2	Residential building	Mott MacDonlads	213 Bute Town	Cont34221	01/01/2015	01/01/2015	01/01/2015	TEST	TEST
<input type="checkbox"/>	22	Offices	Commercial	Mott_mcdonlads	42 Hight Street	Mott/32241	01/01/2015	01/01/2015	01/01/2015	TEST	TEST

View BIM projects



BIM Governance Platform
Cloud-based GovernBIM Platform

BIM Governance Project | Services | Features | Plug-ins

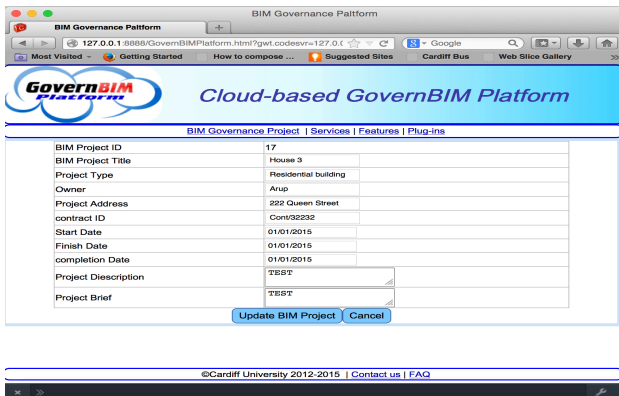
[Add new BIM project](#)
[Delete BIM project](#)
[Edit BIM project](#)

BIM Project ID
 BIM Project Title
 Project Type
 Owner
 Project Address
 contract ID
 Start Date
 Finish Date
 completion Date
 Project Description
 Project Brief

[Save BIM Project](#)
[Cancel](#)

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Add a new BIM Project



BIM Governance Platform
Cloud-based GovernBIM Platform

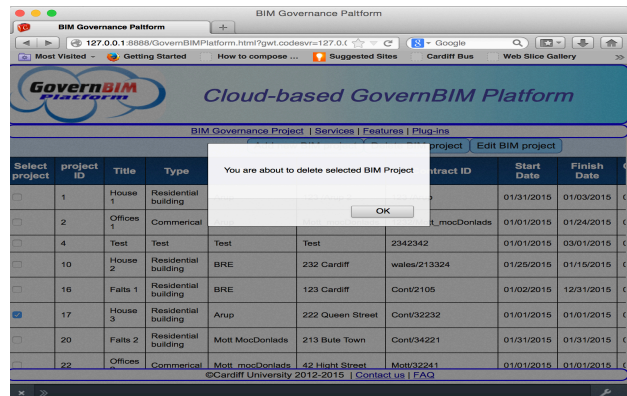
BIM Governance Project | Services | Features | Plug-ins

BIM Project ID: 17
 BIM Project Title: House 3
 Project Type: Residential building
 Owner: Arup
 Project Address: 222 Queen Street
 contract ID: Cont32232
 Start Date: 01/01/2015
 Finish Date: 01/01/2015
 completion Date: 01/01/2015
 Project Description: TEST
 Project Brief: TEST

[Update BIM Project](#)
[Cancel](#)

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Edit an existing BIM project



BIM Governance Platform
Cloud-based GovernBIM Platform

BIM Governance Project | Services | Features | Plug-ins

[Add new BIM project](#)
[Delete BIM project](#)
[Edit BIM project](#)

You are about to delete selected BIM Project

OK

Select project	project ID	Title	Type	Contract ID	Start Date	Finish Date
<input type="checkbox"/>	1	House 1	Residential building		01/01/2015	01/03/2015
<input type="checkbox"/>	2	Offices 1	Commercial	Mott_mcdonlads	01/01/2015	01/24/2015
<input type="checkbox"/>	4	Test	Test	2342342	01/01/2015	03/01/2015
<input type="checkbox"/>	10	House 2	Residential building	BRE	232 Cardiff	01/25/2015
<input type="checkbox"/>	16	Falls 1	Residential building	BRE	123 Cardiff	01/02/2015
<input checked="" type="checkbox"/>	17	House 3	Residential building	Arup	222 Queen Street	01/01/2015
<input type="checkbox"/>	20	Falls 2	Residential building	Mott MacDonlads	213 Bute Town	01/01/2015
<input type="checkbox"/>	22	Offices	Commercial	Mott_mcdonlads	42 Hight Street	01/01/2015

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Remove an existing BIM project

Administrator : Manage Actors screenshots

Select	Users ID	First Name	Last Name	Discipline	Username	password	isAdmin	company	BIM Project
<input type="checkbox"/>	1	eissa	alreshdi	Heating and Ventilation Designer	eissa	eissa	1	Anup	House 1
<input type="checkbox"/>	14	Dwana	Patrick	Architect	Patrick.D	1234	1	Anup	House 1
<input type="checkbox"/>	18	Warren	Dingle	Architect	warren	fahed	1	Mot MacDonald	House 1
<input type="checkbox"/>	26	Mike	Beaton	Heating and Ventilation Designer	Mike.Beaton	123	1	Anup	House 1
<input type="checkbox"/>	40	Saleh	Alyami	Heating and Ventilation Designer	saleh	saleh	1	Anup	House 1
<input type="checkbox"/>	41	Kevin	Smith	General (non-disciplinary)	k.smith	Kevin	1	Anup	House 1
<input type="checkbox"/>	43	John	Smith	Heating and Ventilation	John	John	2	Anup	House 1

View actors

User ID:
 First Name:
 Last Name:
 Email Address:
 Username:
 Password:
 Is Admin: ☐
 Company:
 Assign actor to BIM project:
 Assign disciplines List:
 Save Cancel

Add a new actor

User ID: 42
 First Name: Kevin
 Last Name: Smith
 Email Address: K.smith@co.uk
 Password: 123
 Username: k.smith
 Is Admin: ☐
 Company: Mot MacDonald
 Assign actor to BIM project: House 1
 Assign disciplines List: Architect
 Update user Cancel

Edit an existing actor

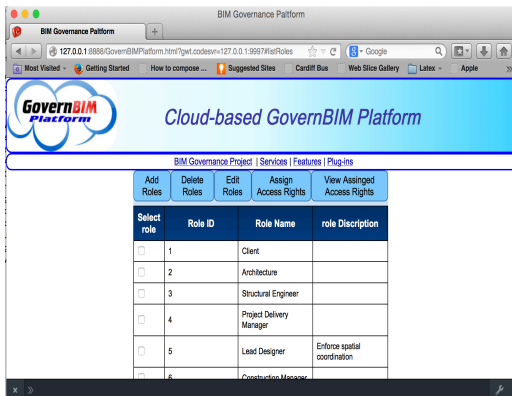
Select role	Role ID	Role Name	Role Description
<input type="checkbox"/>	1	Client	
<input type="checkbox"/>	2	Architecture	
<input checked="" type="checkbox"/>	3	Structural Engineer	
<input type="checkbox"/>	4	Project Delivery Manager	
<input type="checkbox"/>	5	Lead Designer	Enforce spatial coordination
<input type="checkbox"/>	6	Construction Manager	
<input type="checkbox"/>	7	Enforce the Project BIM Standard and	

Assign roles to an existing actor

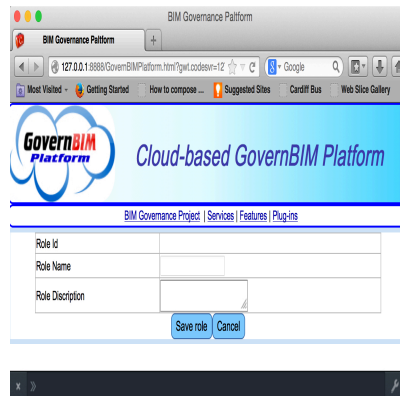
Select role	Role ID	Role Name	Role Description
<input type="checkbox"/>	4	Project Delivery Manager	
<input type="checkbox"/>	11	Task Team BIM Authors	

View & remove roles to an existing actor

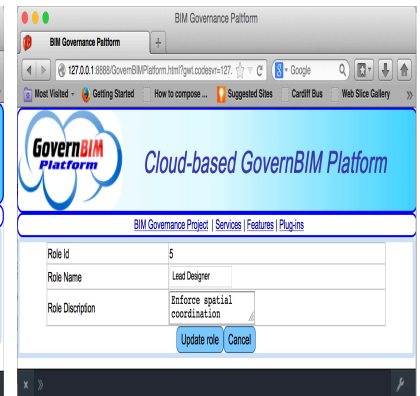
Administrator : Manage Roles screenshots



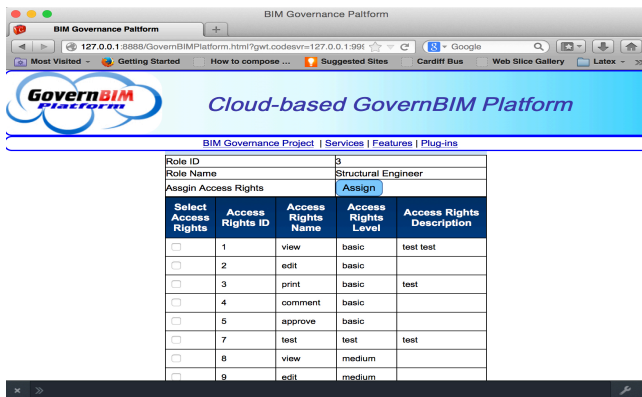
View roles



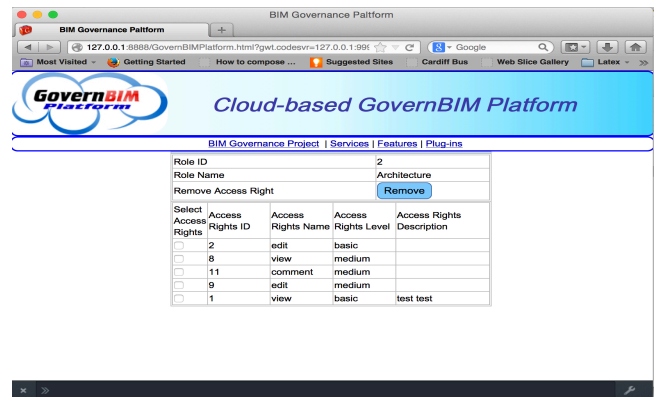
Add a new role



Edit an existing role

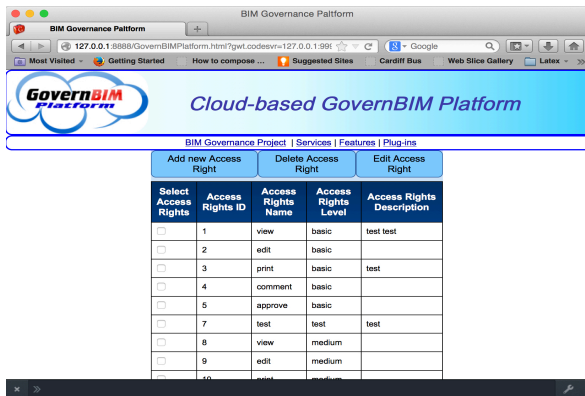


Assign access rights to an existing role

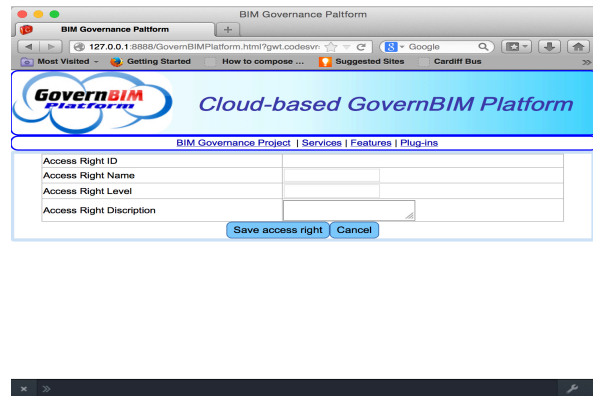


View & remove access rights from an existing role

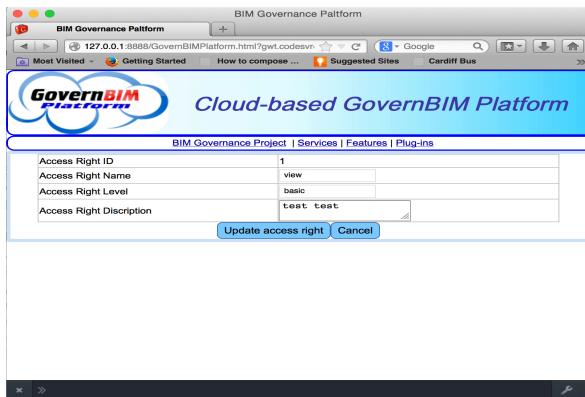
Administrator : Manage Access Rights screenshots



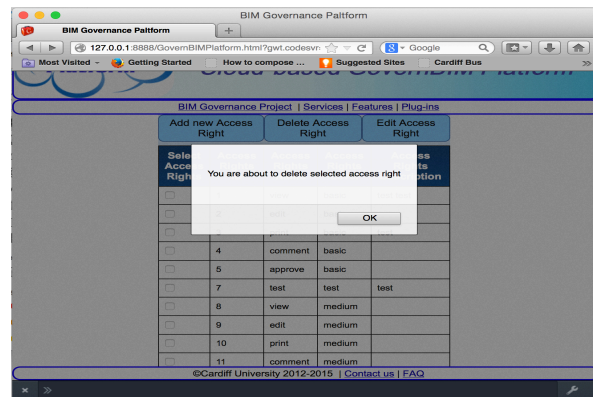
View Access rights



Add new Access Right

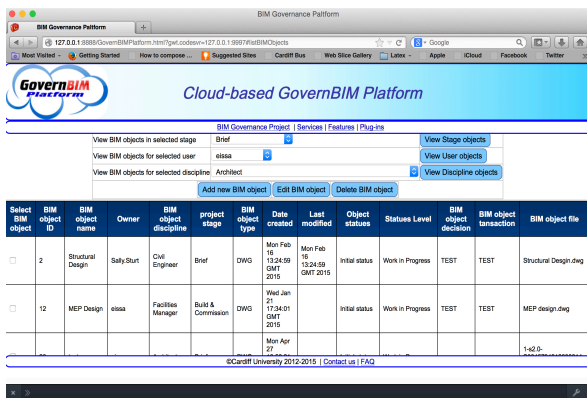


Edit an existing Access Right

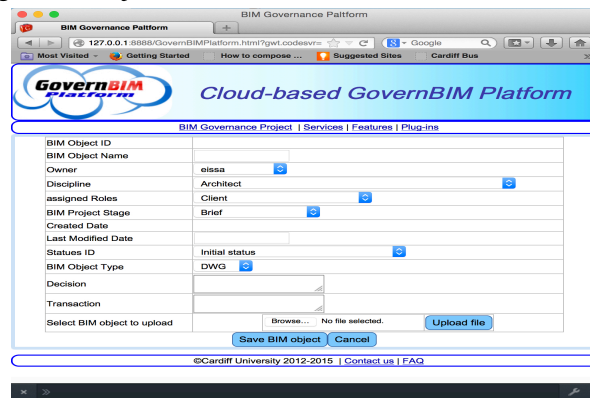


Delete an existing Access Right

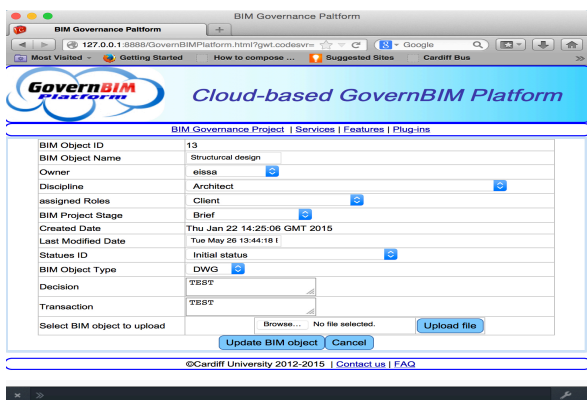
Administrator : Manage BIM Objects screenshots



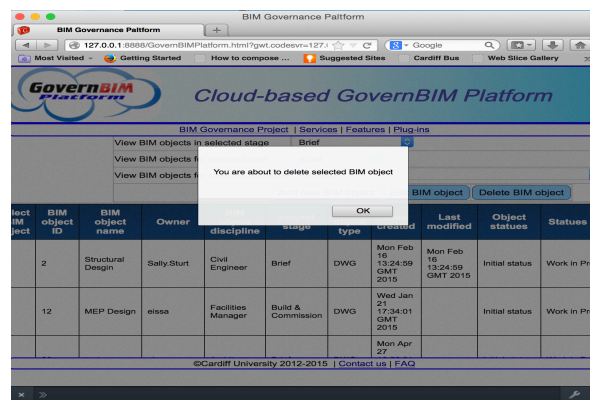
View BIM objects



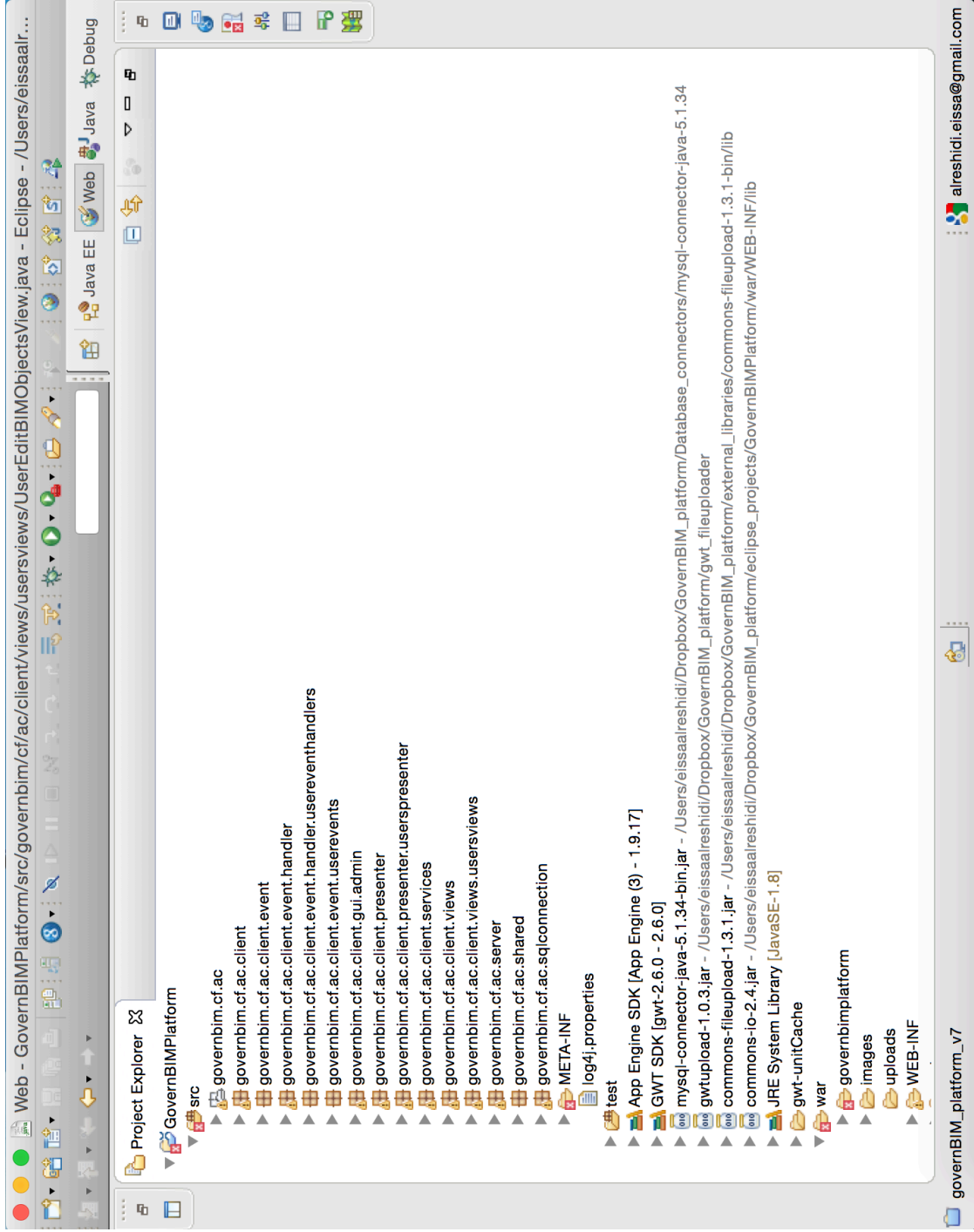
Upload new BIM object



Edit an existing BIM Object



Delete BIM Object



Appendix D: Validation letter and design

Eissa Alreshidi BSc, MSc
PhD Candidate
School of Engineering
Cardiff University
Cardiff CF14 0PB
United Kingdom



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Email: Alreshidi.eissa@gmail.com

Title: Validation of Cloud-based BIM governance research outcomes and platforms

Dear (Expert Name),

As you are aware, construction projects suffer from a lack of integration, comprise complex processes and activities, are heavily regulated, and operate within data intensive project-based industries. When team members collaborate with one another, massive amounts of data are shared and processed, potentially endangering the deliverability of project objectives, with negative implications for the project's success. Project failure has been relatively common in recent years, and is the most significant reason for the lack of effective project team collaboration and integration across the supply chain.

Therefore, the purpose of this PhD research is to investigate the requirements and specifications for an effective BIM governance solution. This will involve developing a Cloud-based BIM governance platform to facilitate team management and collaboration, across the project lifecycle, as well as evaluating the use of a distributed computing environment (e.g. cloud computing) when governing and managing BIM data in the built environment.

Your views on BIM-based information management are of critical importance to this study, and your opinions are of great value to us. Therefore, your help participation will be greatly appreciated. The tool to validate the outcomes of this study will involve **Filling in a Form** and a short **Face-to-Face** interview. The validation stages include:

- a. Reviewing and evaluating the proposed BIM governance successful factors scheme.
- b. Reviewing and evaluating BIM experts' requirements for the development of a BIM governance solution.
- c. Reviewing and evaluating Cloud-based BIM governance platform lifecycle and functionalities.
- d. Demonstrating and validating the developed GovernBIM prototype.

Thank you very much in advance for your anticipated help and support.

Kind Regards,

Eissa Alreshidi

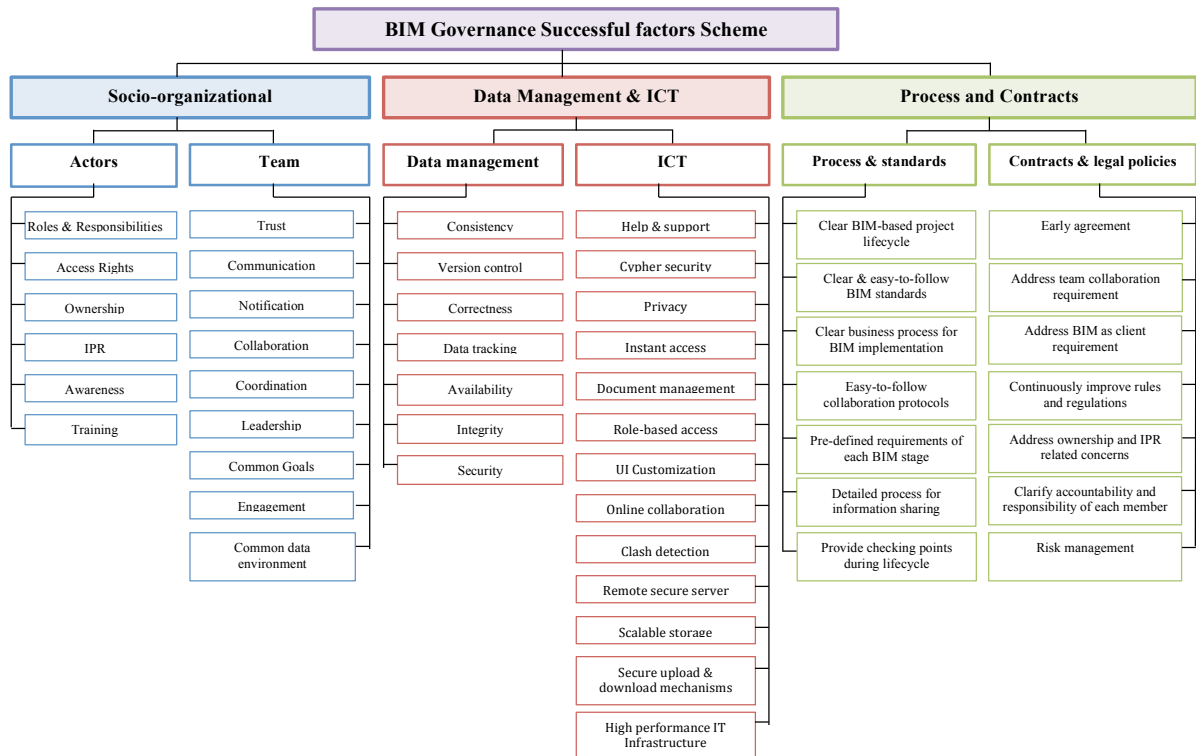
Validation of Cloud-based BIM governance research outcomes and platforms



Cloud-based BIM governance research outcomes and platforms
Validation guide

1 Firstly: BIM governance successful factors scheme

The results of our intensive consultation led to the development of a BIM governance ‘successful factors’ scheme’, which is illustrated in Figure 1. The purposes of this scheme are: (i) to present and summarise the principal factors in successful BIM governance, and (ii) to support the future development of cloud-based BIM governance platforms. BIM governance schemes contain three main components: “Actors & Team”, “Data management & ICT”, and “Processes & Contracts”, with sub factors in each component.



Validation of Cloud-based BIM governance research outcomes and platforms

(Validation statements and questions)

- How would you assess the role of socio-organisational factors in the proposed BIM governance successful factors scheme?

Please type your response here
(You can extend this comment box to add more text)

- How would you assess the role of ICT and data management factors in the proposed BIM governance successful factors scheme?

Please type your response here
(You can extend this comment box to add more text)

- How would you assess the role of process and contractual factors in the proposed BIM governance successful factors scheme?

Please type your response here
(You can extend this comment box to add more text)

- Please enter any further comments with regard to the proposed BIM governance successful factors scheme in the box below?

Please type your response here
(You can extend this comment box to add more text)

2 Secondly: Validating BIM experts' requirements for developing a cloud-based BIM governance platform

The proposed Cloud-based BIM governance platform could be utilised as an online collaborative solution, with role-based access rights. There are also specific requirements, obtained from BIM experts (BIM professionals, academics and IT technicians), to consider, as these distinguish it from other online collaborative tools. The objective of the platform requirements capture process is to produce a set of comprehensive requirements, which will offer a foundation upon which to build specifications for a BIM governance solution that will enhance the capabilities of construction enterprises, and enable their teams to collaborate effectively on projects.

These requirements have been collected, analysed and categorised in accordance with the requisite engineering approach (Sommerville, 2007). The requirements were classified and documented into three main categories: (a) Functional requirements, describing GovernBIM platform functionality or services; (b) Non-functional requirements, describing constraints on the services or functions offered by the GovernBIM platform. These include product, organisational, and external requirements, and can be further subdivided into three sub-categories: product requirements, organisational requirements, external requirements; and (c) Domain specific requirements, which are new functional requirements reflecting the construction domain needs when using the BIM Governance platform. Table 1 shows a categorised list of all the requirements explored and collected at the consultation stage. Herein “it” should be understood to refer to the Cloud-based BIM governance platform.

Validation of Cloud-based BIM governance research outcomes and platforms

Table 1. BIM experts' requirements for developing a cloud-based GovernBIM platform

Categories	BIM experts requirements		
Functional requirements	<ul style="list-style-type: none"> Cloud-based GovernBIM platform should: <ul style="list-style-type: none"> Provide help and support facilities. Allow different users to customise their interfaces. Allow users to view and print models online. Support a central repository for data storage. Have a notification system to inform team members about new changes when their data is updated. Record changes' and transitions when they occur. Allow multiple-actors to share information through a common storage system. Provide real-time mechanism for sharing information. Have built-in communication tools. Have a mechanism for tracking information throughout the whole project. Be able to track data during the whole lifecycle of the construction project. Have an administration user interface with full access rights. Have a common environment data area/workspace for sharing and exchanging data. Define who will produce BIM data what and when. Inform people what to do and when to do it. Inform people about the information that they need to provide. Assist with decision-making. Allow the client to be involved in the early stages of the design. Define who has access to what and when. Inform each actor about her/his roles responsibilities and when they should perform them. Define what the requirements are for each individual stage of the construction project. Define what needs to be provided at the end of each stage. Define external gates between each stage of the construction project. Define internal gates among the same actors within the same disciplines. Have a mechanism for preserving a project's information for future reusability with new projects. 		
Non-functional requirements	Product requirements	Accessibility requirements	<ul style="list-style-type: none"> It should be accessible from anywhere at anytime. It should have a plug-in for modelling software such as: Autodesk Revit and Google Sketch-up.
		Portability requirements	<ul style="list-style-type: none"> It should be hosted on online-shared storage with clear access rights for each actor. It should give the option of allowing the actors to host their data on their local machines
		Scalability requirements	<ul style="list-style-type: none"> It should be hosted on a scalable storage media because of the huge amount of information and bid size of models.
		Reliability requirements	<ul style="list-style-type: none"> It should have and provide backup facilities. It should be hosted by a reliable, dedicated, and known IT infrastructure or CSP.
		Usability requirements	<ul style="list-style-type: none"> It should be easy for all team members to use. It should have a simple user interface.
		Efficiency requirements	<ul style="list-style-type: none"> It should effectively improve coordination among team members.
	Organisational requirements	<ul style="list-style-type: none"> It should have clear definitions of actors, their roles and responsibilities within multiple disciplines through the building's lifecycle. Platform development should be based on a standardised overall lifecycle data management policy. Platform development should be based on the existing BIM related standards and protocols. The platform should increase trust between people by recording changes that have 	

Validation of Cloud-based BIM governance research outcomes and platforms

		<ul style="list-style-type: none"> – been made (by whom and when). – It must have a process framework; i.e. process guidelines and protocols. – GovernBIM platform must have a technological framework; i.e. BIM tools and API. – Development of the GovernBIM platform should be aligned with the UK government's requirements, regulations and standards. 	
	External requirements	Legal requirements	<ul style="list-style-type: none"> – It has to have a legal framework. – It should clearly define the ownership of BIM documents. – It should preserve intellectual property rights for each team member.
		Interoperability requirements	<ul style="list-style-type: none"> – It should support different web-browsers. – It should be able to support all types of transfer and collaboration tools. – It should enforce team members to use the same software version, as agreed upon at the beginning of the contract. – It should maintain a consistency of tools during the collaboration process.
		Privacy requirements	<ul style="list-style-type: none"> – It should provide access rights to the stored data based on actors' roles and responsibilities.
		Security requirements	<ul style="list-style-type: none"> – It should provide actors with a secure log-in to the system. – It should be hosted on physically secure data centres. – It should provide security checks for uploaded/downloaded and transferred models.
		Financial requirements	<ul style="list-style-type: none"> – It should be affordable to both large companies and small to medium enterprises. – The use of the GovernBIM platform should be time and cost effective.
Domain specific requirements	<ul style="list-style-type: none"> – There should be an intensive training programme for practitioners regarding the GovernBIM platform. – The users of the GovernBIM platform should be able to understand where and how their efforts are contributing towards the entire BIM model. – It should define clear roles and responsibilities for each actor during the construction project. – It should not take decisions away from people during the construction project lifecycle. – It should not change what an actor does but support his work. – It should provide a comprehensive element of consistency. – It has to provide a consistent structure for people during the building lifecycle. – It needs to be connected to the construction professions as well as contractors. – Development of the GovernBIM platform should not only focus on level 2 BIM, but should go further to level 3 BIM. – The GovernBIM platform development process should take into account actors and data structures, which exists in the BIM Execution Plan (PB, BXP, BPE or BIMM) and Responsibility Matrix. – It should define what to govern in terms of: people, information and documents, processes, classifications, and lifecycle. – It should also take into account all the people involved during a construction project, in particular recording all information received and delivered along the supply-chain. – It may act as an intelligent expert system by making use of preserved data, giving it the ability to provide advice on new projects based on experience gained in previous projects. 		

Validation of Cloud-based BIM governance research outcomes and platforms

(Validation statements and questions)

- What is your overall opinion and view about the BIM experts' requirements for developing Cloud-based BIM governance platform?

Please type your response here
(You can extend this comment box to add more text)

- Would you like to add any further information?

Please type your response here
(You can extend this comment box to add more text)

3 Validating and testing of the developed Cloud-based BIM governance platform lifecycle and the prototype

The researcher will organise a *Face-to-Face* meeting with the BIM experts to demonstrate the prototype once it has been developed, to elicit valuable comments and feedback from them. The demonstration will be preceded by a short summary explanation of the lifecycle of Cloud-based BIM governance platform using Business Process Modeling Notation (BPMN) diagrams. Followed by a demonstration of the GovernBIM platform prototype itself. The whole demonstration will take approximately 10-15 minutes, after which the BIM experts will be encouraged to engage in an open discussion regarding the validity of the prototype's lifecycle and the prototype itself.

Dear BIM expert, please note that an audio-recording will be made during this interview, and that it is for research and documentation purpose only.

(Validation statements and questions)

- Based on your observations, how could we further improve the Cloud-based BIM governance platform prototype?

Please type your response here
(You can extend this comment box to add more text)

- What limitations did you observe during the prototype demonstration?

Please type your response here
(You can extend this comment box to add more text)

- Would you like to add any further information?

Please type your response here
(You can extend this comment box to add more text)

Appendix E: Conferences, training and skills



Learning Tree International

This is to certify that

Eissa Al-Reshidi

has successfully completed the course

*Cloud Computing Technologies: A Comprehensive Hands-
On Introduction*

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This course qualifies for 1.8 continuing education units.



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David C. Collins, Chief Executive Officer



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*Java Programming: A Comprehensive Hands-On
Introduction*

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This course qualifies for 2.4 continuing education units.



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Richard Chappell, Managing Director

David C. Collins, Chief Executive Officer



Presents this certificate of attendance to:

Eissa Alreshidi

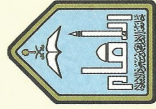
For Completion of the

***15th International Conference on Computing in Civil and
Building Engineering (ICCCBE)***

June 23-25, 2014
Orlando, Florida



مؤتمر الطلبة السعوديين في المملكة المتحدة
Saudi Students Conference - UK



وزارة التعليم العالي
MINISTRY OF HIGHER EDUCATION
المملكة العربية السعودية - لندن
ROYAL EMBASSY OF SAUDI ARABIA - CULTURAL BUREAU - LONDON

Presenter Certificate

*With sincere thanks and appreciation extended for
the valuable contribution of*

Eissa Alreshidi

*In the seventh Saudi Students Conference (SSC2014)
that was held at Edinburgh International Conference Centre (EICC),
Edinburgh, the United Kingdom
1st – 2nd of February 2014*

Mr. Khalid Thamer Althagafy

SSC Scientific Committee Head



Dr. Faisal M. Almohanna Abaalkhail

Saudi Arabian Cultural Attaché in the UK