Title:

Cloud-based BIM governance platform requirements and specifications: Software engineering approach using BPMN and UML

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Abstract

Utilisation of cloud technologies has recently attained a profile in Building Information Modelling (BIM). Many studies have investigated the potential role of cloud in facilitating the use of BIM in the construction domain. In addition, recent studies have focused on the role of cloud in facilitating team collaboration across a building's lifecycle by applying a BIM governance model. The lack of suitable means for the governance of collaboration, and access and archival of data has been cited as the key barrier for the widespread adoption of collaborative BIM environments. This study, therefore, investigates the requirements for BIM governance and develops specifications for a cloud-based BIM governance platform (GovernBIM). The study also uses findings from wide consultation in combination with software engineering approaches using Business Process Model Notation (BPMN) and Unified Modelling Language (UML) to define the platform's requirements and specifications. This platform also aims to provide a computerised solution for overall BIM governance solution to facilitate team collaboration and mange generated BIM data during a project's lifecycle. This ensures that data is consistent, available and hosted in a scalable storage environment with high performance computing capabilities. The results from this study: (a) define functional, non-functional, and domain specific requirements for developing a GovernBIM platform, (b) develop a set of BPMN diagrams to describe the internal and external business procedures of the GovernBIM platform lifecycle, for setting, configuring, managing, and using a GovernBIM platform, (c) evaluating several fundamental use cases for the adoption of the GovernBIM platform, (d) presenting a core BIM governance model (class diagram) to present the internal structure of the GovernBIM platform, and (e) providing a well-structured, cloud-based architecture to develop the GovernBIM platform for practical implementation.

KEYWORDS: BIM, BIM GOVERNANCE, CLOUD COMPUTING, BIM GOVERNANCE PLATFORM, OBJECT ORIENTD PROGRAMMING, BPMN, UML

1 Introduction

With wide adoption of BIM technologies, construction projects become more complex, as construction teams involve many actors from different disciplines who must collaborate and share large data during a project's lifecycle (Shafiq et al., 2013). Construction projects continue to be fragmented, and thus many problems arise during the collaboration process (e.g. data lost, data inconsistency and massive data files) (Jiao et al., 2012, Gu and London, 2010). Although team members have adopted decent collaboration tools and practices, these solutions tend to overlook the collaboration process and the internal governance model of software vendors i.e. the internal data structure, policies, procedures and control processes required to manage access to data at an enterprise level (Beach et al., 2013).

Several challenges associated with the development of BIM governance solutions still need to be addressed. For example, socio-organizational, legal, technical, and contractual aspects are process oriented, the understanding of which is required for effective BIM governance There is an identified gap in research on the contextual aspects of BIM and in particular how processes can be effectively integrated with the product-oriented solutions, while keeping the overall system flexible and adaptable to future needs. This research is therefore aimed at establishing a robust foundation for cloud-based BIM governance solution. Cloud technologies are chosen to assist the development of BIM governance solutions because of its high performance capabilities (uptime), accessibility, and massive scalable storage capacities. It should be noted that several cloud-based BIM solutions already exist; however, these are proprietary and not based on a holistic BIM governance concept that fosters multi-disciplinary collaboration without vendor lock-in and lack considerations of the concerns for legal and contractual uncertainties.

In order to develop cloud-based governance platform requirements and specifications, this study introduces findings from: (a) wider consultation with BIM experts using questionnaire and semi-structured interviews, (b) analysis and modelling using software engineering approach of the adopted collaborative BIM management process of three construction companies that are: Arup, Mott-MacDonald, and Patel Taylor. Hence, the objectives of this study are to: (a) investigate functional, non-functional, and domain specific requirements for developing a cloud-based BIM governance platform (GovernBIM) through case studies involving leading organisations who have already some knowledge and expertise in BIM management, (b) use BPMN approaches to build a set of BPMN diagrams that describe the internal and external business procedures of the GovernBIM platform lifecycle, (c) explore and discover potential use cases for the GovernBIM platform, (d) develop a core BIM governance model (class diagram) that presents the internal structure of the GovernBIM platform, and (e) explore existing cloud software architecture as a foundation on which to develop well-structured GovernBIM platform architecture for practical implementation.

Following this introduction, the next section presents related studies concerning BIM-based collaborative solutions, BIM governance, and cloud computing, supported by a detailed description of their methodology, and the most significant outcomes from the developmental stages. A discussion of the outcomes is then provided, and followed by concluding remarks, including details of planned future work.

2 Related Studies

This section provides an overview of current studies in BIM-based collaboration solutions, BIM governance, and cloud computing.

2.1 BIM collaboration

Collaboration involves co-workers sharing information and processes by interacting, communicating, exchanging, coordinating and approving, thus sharing visions among stakeholders and maximizing the team's effort on a particular job (Ilich et al., 2006, Hobbs, 1996). However, BIM seeks to allow stakeholder collaboration at different stages of the building lifecycle, enabling stakeholders to insert, extract, update, or modify information during the BIM process. Thus, BIM is emerging as a new way to manage information flow among all stakeholders during the project (Motamedi and Hammad, 2009). However, in the construction industry, where projects are handled in a collaborative environment among multi-disciplines and multi-actors, many issues can arise e.g. trust issues, lack of clarity regarding roles and responsibilities, interoperability, etc. (Holzer, 2007, Rezgui et al., 2013).

Although many researchers and practitioners maintain collaborative work environments, there are still challenges to be met in many parts of the world, specifically with respect to the development of a fully integrated multi-disciplinary collaborative mode of operation, which necessitates a specific tool to facilitate the adoption of BIM (Gu and London, 2010, Singh et al., 2011). However, the development and deployment of integrative and collaborative technologies in the construction industry lags behind, because of the unique nature of the industry (Shen et al., 2010). Successful technology implementation requires the establishment of procedures for both electronic and manual operations (Ilich et al., 2006).

There has been a gradual usage of web-based technologies in construction project management in order to achieve the integration of contractual, organizational and information aspects. It is challenging to encourage collaboration among geographically distributed teams, with different practitioners representing different organizations, working on typically large construction projects (Ilich et al., 2006). Use of collaboration technologies creates a shift towards virtual organizations in which users are not strictly required to occupy adjoining workspaces, providing the flexibility to work from any location. In addition, integration of communication with computing technology makes it possible to communicate richer and more complex information (Ilich et al., 2006). Although, technical requirements for developing collaborative BIM servers are identified by Singh et al. (2011), these requirements, however, fall into one category i.e. technical requirements, whereas this study explores more functional and non-functional requirements which falls within the following categories: socio-organizational, process, and legal requirements.

Accordingly, existing BIM solution can be either commercial or open source servers. Commercial BIM servers can resolve some collaboration issues such as data sharing, transferring, and storing. Examples of this solution include: Onuma system (OPS, 2014), RevitServer (Autodesk, 2011), ProjectWise (ProjectWise, 2015), Graphisoft BIM Server (Graphisoft, 2015) and, more recently, Autodesk BIM 360 (AutoDesk, 2015). However, the majority of these solutions only focused on technical perspectives. Moreover, it lacks overall transparency as these commercial BIM servers tend to be owned by their respective entities, not allowing developers and clients to access their proprietary management data structures (Beach et al., 2013, Rezgui et al., 2013). On the other hand, open-source collaborative BIM solutions such as BIMServer (BIMServer.org, 2015), and EDMmodelServer (Jotne, 2015) focus on technical aspects and are not developed to be integrated with cloud technologies yet. These are intended to serve as an IFC-based server (Beetz et al., 2010). In contrast, beside the technical aspects, this study covers socio-organizational, legal, business process and contractual aspects. More specifically, it offers a comprehensive theoretical framework for cloud-based BIM governance solution.

2.2 BIM governance

As this study aims to join the experience of construction practitioners with previous researches and findings, to provide information supporting the development of a BIM governance platform. Until now, BIM governance in construction projects has not been investigated in explicit detail. Existing Information and Communication Technologies (ICT) governance efforts and frameworks e.g. (Turner and Keegan, 2001, Grant and Ulbrich, 2010, Isaca, 2014) are not initially developed to meet construction industry needs and requirements. Data governance frameworks tend to focus on data-related aspects, which represent only one aspect of this study. However, data governance refers to the overall management of the availability, integrity and security of the data used within an enterprise (Principia, 2006). Newman and Logan (2006) define data governance as *"the collection of decision rights, processes, standards, policies and technologies required to manage, maintain and exploit information as an enterprise resource"*.

However, for Rezgui et al. (2013), BIM governance is *"the process of establishing a project information management policy across lifecycle and supply chain underpinned by a building information model, taking into account stakeholders' rights and responsibility over project data and information"*. It is essential to differentiate between governance and management. Governance determines who enters and makes decisions and how, whereas management implements these decisions (Newman and Logan, 2006). Almost all organizations face increasing information governance challenges, which can be met by an effective governance approach supported by standards (BSI, 2014). However, there is a lack of overall governance within current construction projects; hence the consensus on the need to develop a generic data governance model to facilitate BIM adoption in a collaborative built-in environment across multi-disciplines and multi-actors during the building lifecycle (Rezgui et al., 2013).

From a data governance standpoint, there are several requirements for overcoming BIM adoption and team collaboration limitations, namely: (a) protocol development, (b) establishment of responsibilities among disciplines, (c) sharing via a common model that can be stored centrally or hosted on distributed environments, and (d) improved communication among disciplines. In addition, to raise awareness, intensive training should be introduced, along with definition of formal responsibilities among stakeholders, across disciplines and at different lifecycle stages (Smith et al., 2005, Eastman et al., 2011, Rezgui et al., 2013, Alreshidi et al., 2014). However, in this study there are several aspects need to be taken into account in the development of cloud-based GovernBIM platform: BIM data management processes, project's lifecycle, supply-chain complexity, BIM, team members' rights and responsibilities, policies and standards, and underpinning technology.

2.3 Cloud computing

Cloud computing has recently became a phenomena in the IT revolution as it growth 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 high –performance and storage infrastructure through 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).

Due to its status as a new technology 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 as "*new computing paradigm which offers a huge amount of computational and storage resources to the masses*". However, cloud can be seen as a high virtualization for data centres infrastructure that are distributed geographically and linked via high speed network cables which provides verity 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.

2.4 Cloud efforts in BIM

Cloud computing technologies have recently gained in popularity (Kolodner et al., 2011, Kumar et al., 2010, Armbrust et al., 2010). Due to the advantages that cloud technology offers, many researchers in the construction field have considered cloud computing as a solution to underpin future BIM technologies (Jiao et al., 2012, Fathi et al., 2012, Chuang et al., 2011a, Redmond et al., 2012). However, apart from the work conducted by (Rezgui et al., 2013, Beach et al., 2013), previous research efforts have not targeted BIM governance directly. There is an overall lack of research into, and development of, BIM governance solutions. This shortage of BIM governance related studies encouraged the authors to resolve this research gap by establishing a robust foundation with respect to a cloud-based BIM governance solution. However, several challenges, which still need to be addressed, were observed to be associated with the development of BIM governance solutions; such as BIM experts' requirements for developing a BIM governance solution, as well as for exploring business processes and the workflow of a cloud-based BIM governance platform. Hence, this study aims to explore requirement for a BIM governance solution as well as investigate the lifecycle process of developing and hosting a BIM governance platform over a dedicated cloud infrastructure (e.g. Google).

In general, Stadtmueller (2012) identifies 5 main advantages for an enterprise when adopting cloud: (i) reduced investment in hardware, (ii) scalability, (iii) reduced time when launching new applications, (iv) quality, and (v) continual upgrade. However, a number of case studies reveal the benefits of using cloud technology in BIM (Leon and Laing, 2013). The current trend in the construction industry is to efficiently integrate and manage building information using BIM with cloud (Chuang et al., 2011b). In this context, cloud offers a number of general benefits to BIM as discussed below:

- Accessibility: it is possible to access stored BIM data or data files from anywhere at any time wherever there is an Internet connection (Beach et al., 2013, Redmond et al., 2012).
- Scalability: due to the massive amount of BIM data that is generated during a construction project, this is key. Beach et al. (2011) stated that cloud has ability to decrease and increase space and resources according to the needs of the user or organization.
- Reliability: Jiyi et al. (2010) emphasize that cloud platforms provide massive storage scalability that are reliable up to 99.999%. This reduces developers concerns when adopting cloud as the underlying infrastructure for their BIM solutions.
- Advance Interoperability for BIM applications: According to (Redmond et al., 2012) cloud technologies eliminates the problem of different working environments having different firewalls, technologies, and hardware/ software. Cloud has the capability to provide an advanced heterogeneous environment for hosting all various file formats of BIM all in one place (Abadi, 2009). This environment facilitates the implementation and the integration of developed solutions such as Industry Foundation Classes (IFC) and Information Delivery Manuel (IDM) to tackle interoperability issue in BIM (Redmond et al., 2012, Juan and Zheng, 2014).
- Security: Different opinions exist on the advantages and disadvantages of cloud with respect to security. Some argue that because of location and centralized management, it is more resource efficient to secure cloud storage and thwart potential breaches of security. Whereas, others consider cloud to be unsafe for use, as long as it is connected to the Internet (A Vouk, 2008, Abadi, 2009, Armbrust et al., 2010).
- Automatic backup in real time: Using the cloud provider's automatic backup services to backup large volumes of data, enabling the user to retain sufficient local disk space (Takahashi et al., 2012).
- Cost: This is disputed, as the cloud is cost effective in terms of buying and managing a hardware infrastructure (Santos et al., 2009) , but long term access and storage can be costly for a small or medium sized construction companies (Zhang and Issa, 2012).
- Green credentials: reduced hardware costs, fewer electronics, less need for data centre cooling systems (Buyya et al., 2009).

Despite the fact that the cloud has many benefits, potential drawbacks exist. According to Armbrust et al. (2010) these drawbacks are: a) security concerns, (a) performance guarantee, (b) anonymous control, (c) business continuity and service availability, (d) data lock-in, (e) data confidentiality and auditability, (f) data transfer bottlenecks, (g) performance unpredictability, (h) bugs in large distributed systems, (j) speed of scaling, (k) reputation fate sharing , and (l) software licensing. However, major concerns relate to the use of cloud in BIM; Redmond et al. (2012) raised three issues: security, privacy, and dependency on internet connection. Data ownership and control are commonly raised as obstacles when considering cloud storage, as it maybe unclear who owns the data hosted by a Cloud Service Provider (CSP) (Wong et al., 2014).

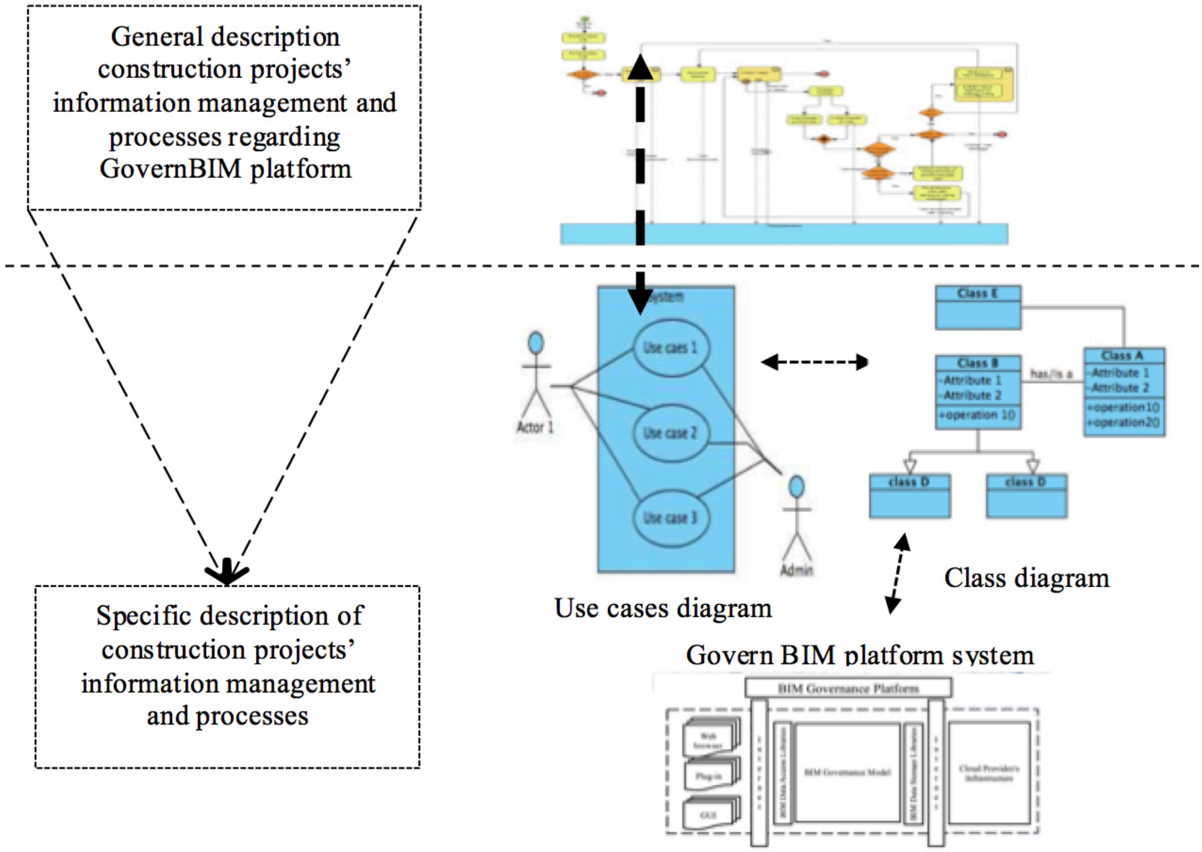
3 Methodology

The main aim of this study is to establish and develop a cloud-based GovernBIM platform with requirements and specifications given using BPMN and UML. The work is underpinned by the research question: *"What are necessary requirement and specifications to establish a cloud-based BIM governance platform for facilitating team collaboration during a BIM-based project lifecycle?".* 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 comprehensive 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 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 utilized 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 (López-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.

BPMN diagrams: Describe overall GovernBIM platform's processes, activities, and data flow between activities.



UML diagrams: Provide detailed description of GovernBIM platform procedures, rule and activities' process and flow

Figure 1 BPMN & UML usage in defining GovernBIM platform's requirements & specifications

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 (IDEF), a discussion on which can be found in (Aguilar-Saven, 2004). These modelling tools are recognized as traditional tools; thus, they do not meet our project scope and requirements (Campos and Márquez, 2011). On the other hand, 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, visualizing and constructing the artefacts of a software intensive 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 recognized modelling standards around the world in a variety of fields, form informatics science to management. Furthermore, one advantage of using BPMN and UML is that it is easy to translate their models into software code (LÓPEZ-CAMPOS et al., 2014).

Although, UML shares some similarities with the BPMN approach; both aim to provide a basis from which to understand and define the captured requirements of the proposed system (López-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 (López-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) (López-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.

4 Result and analysis

Results of this study are presented according to the following topics: (a) BIM Experts' requirements for developing cloud-based BIM governance platform, (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) concluded with a tailored software architecture for applying GovernBIM platform.

4.1 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) via a wide consultation, to be considered, that distinguish it from other online collaboration tools. The consultation took the form of: (a) comprehensive questionnaire with 118 BIM experts from various disciplines and companies; followed by (b) semi-structured interviews with 18 BIM experts. This consultation supported an exploration of current trends in ICT and team collaboration practices during typical construction projects. The consultations with BIM experts for this study identified many barriers to BIM adoption and classified many issues associated with team collaboration during construction projects. It identified several barriers to wider BIM adoption, and classified many issues associated with team collaboration during construction projects. Furthermore, it assisted in fully understand the lifecycle of BIM-based collaborative environments within BIM-leading companies.

The consultation also explored and identified BIM experts' requirements and needs when developing a cloud-based BIM governance solution. Nonetheless, in order to resolve the issues identified successfully, the BIM experts emphasized the importance of developing governance solutions capable of facilitating team collaboration, and enhancing the process of decision-making during a construction project. The main outcomes from the consultation suggested that a good method for achieving fully integrated and collaborative BIM would be by governing the collaboration process and data flow, as underpinned by cloud technologies. This can be achieved through automation of BIM-related standards, and by concealing the complexity of these standards behind a user-friendly graphical interface.

Moreover, the consultation contributed toward the development of a theoretical BIM governance framework (G-BIM). The G-BIM framework presented a summary of effective factors, ensuring successful governance of a collaborative BIM approach. Furthermore, the consultation also revealed several advantages to using cloud as a BIM governance solution, e.g. data availability and accessibility, powerful computing capabilities, and scalable storage. Conversely, several disadvantages to using cloud computing to support a BIM governance solution were identified; e.g. security and privacy, Internet connection dependency and lack of legal considerations.

However, 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 categorises; (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. Table 1 shows a categorised list of all the requirements explored and collected from consultation stage. Herein "it" refers to the cloud-based GovernBIM platform.

Table 1. BIM experts' requirements for developing a cloud-based GovernBIM platform

<table>
<tr><th>Category</th><th>Sub-category</th><th>Sub-sub-category</th><th>BIM experts' requirements</th></tr>
<tr><td>1. Functional requirements</td><td>-</td><td>-</td><td>➢ Cloud-based GovernBIM platform should:
– 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.</td></tr>
<tr><td rowspan="2">2. Non-functional requirements</td><td rowspan="2">2.1. Product requirements</td><td>2.1.1. Accessibility requirements</td><td>– 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.</td></tr>
<tr><td>2.1.2. Portability requirements</td><td>– 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</td></tr>
</table>

		2.1.3 Scalability requirements	– 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	– 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	– It should be easy for all team members to use. – It should have a simple user interface.
		2.1.6. Efficiency requirements	– It should effectively improve coordination among team members.
	2.2. Organisational requirements	-	– 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. – 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. External requirements	2.3.1. Legal requirements	– 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	– 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.
		2.3.3. Privacy requirements	– It should provide access rights to the stored data based on actors' roles and responsibilities.
		2.3.4. Security requirements	– 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	– 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	-	-	– 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.

4.2 Core BPMN diagrams for the cloud-based GovernBIM platform

Overall inputs into the GovernBIM platform are CSP’s services and a set of initial requirements; including, (a) client requirements, (b) construction project requirements, (c) legal requirements, and (d) industry requirements. 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/API and CSP’s services.

In this section, we begin with the bigger picture (Core) and BPMN modelling outcomes. Figure 2 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: (4.2.1) provide and manage the GovernBIM platform’s services, and (4.2.2) provide and manage the GovernBIM platform project.

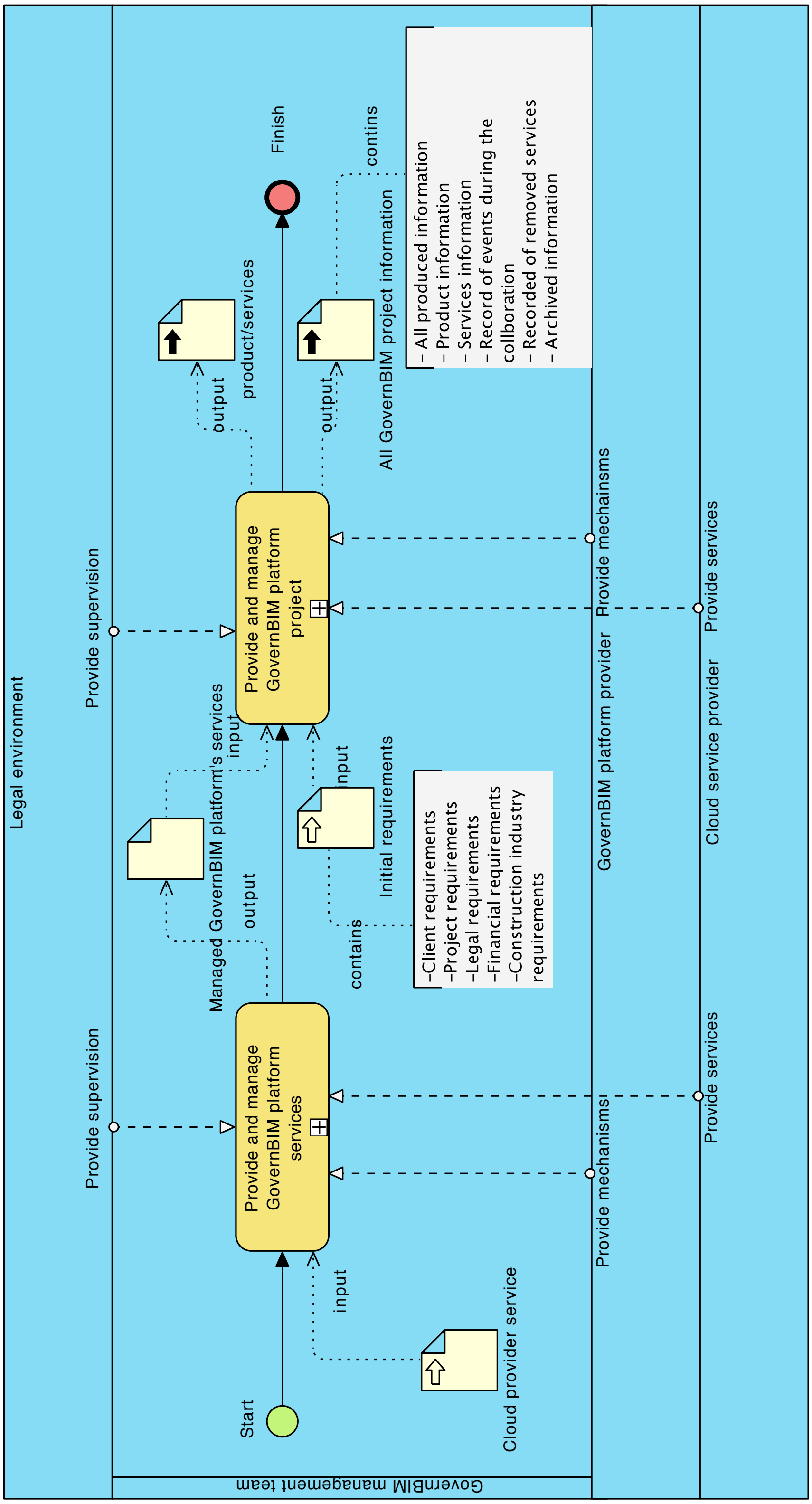


Figure 2 BPMN diagram: Preliminary GovernBIM platform setup

4.2.1 BPMN activity: GovernBIM platform's services

Providing GovernBIM platform services requires a set of activities to establish the GovernBIM platform's project. Figure 3 illustrates the BPMN diagram, used to provide and manage the GovernBIM platform's services. The BPMN activity comprises four main activities:

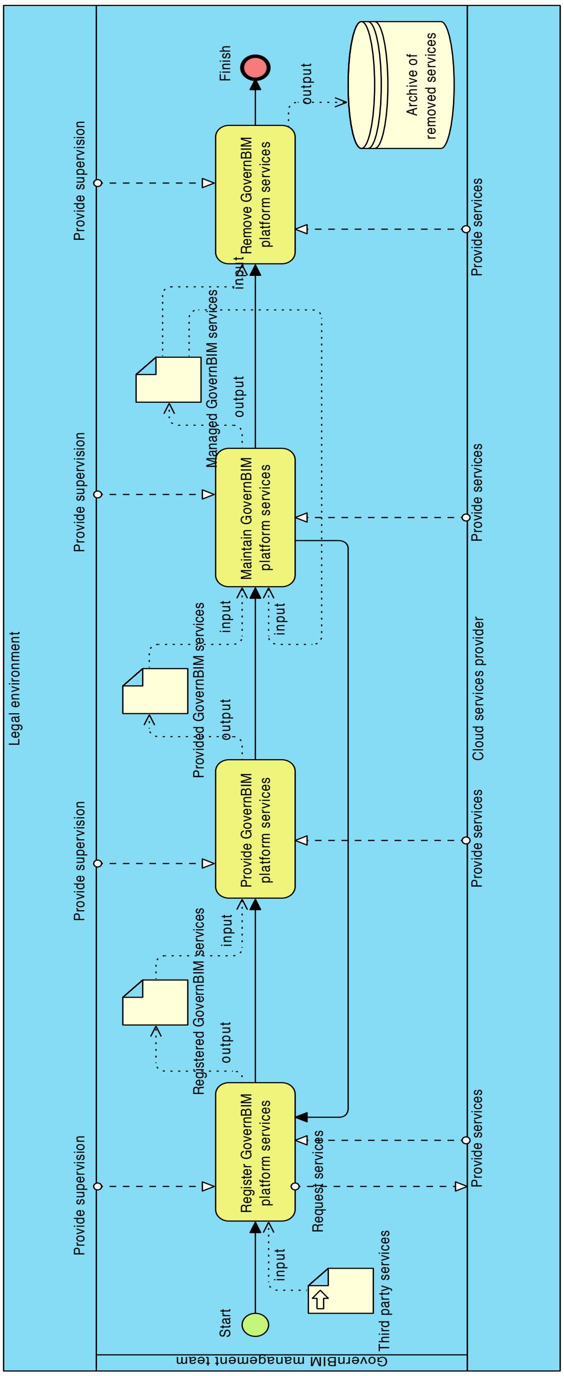


Figure 3 BPMN diagram: Provide and manage the GovernBIM platform's services

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 removed services from the GovernBIM platform is made.

4.2.2 BPMN activity: GovernBIM platform’s project

Figure 4 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:

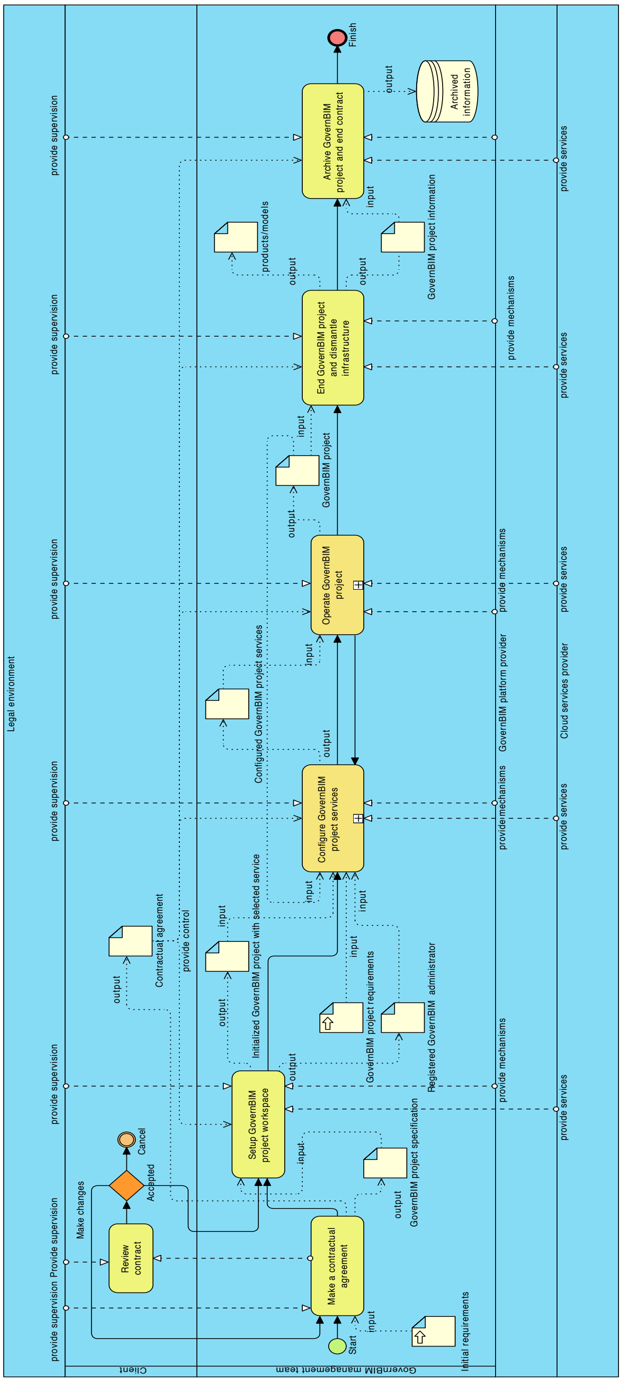


Figure 4 BPMN diagram: Provide and manage the GovernBIM platform’s project

- **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 initialised within the selected service. The outputs from this activity are then registered with the GovernBIM project administrator, and the initialised 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 initialised GovernBIM project with selected services form the input for this activity. A configured GovernBIM project will provide the output from the activity. The GovernBIM project Administrator performs the activity using the GovernBIM Tools. This activity is broken down further (see figure 10).
- **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 11).
- **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: Configure GovernBIM platform's project, and operate the GovernBIM platform's project. This is because the selected BPMN activities are considered the key to successfully offering and providing the GovernBIM platform.

4.2.3 BPMN activity: Configure GovernBIM project

As figure 5 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.

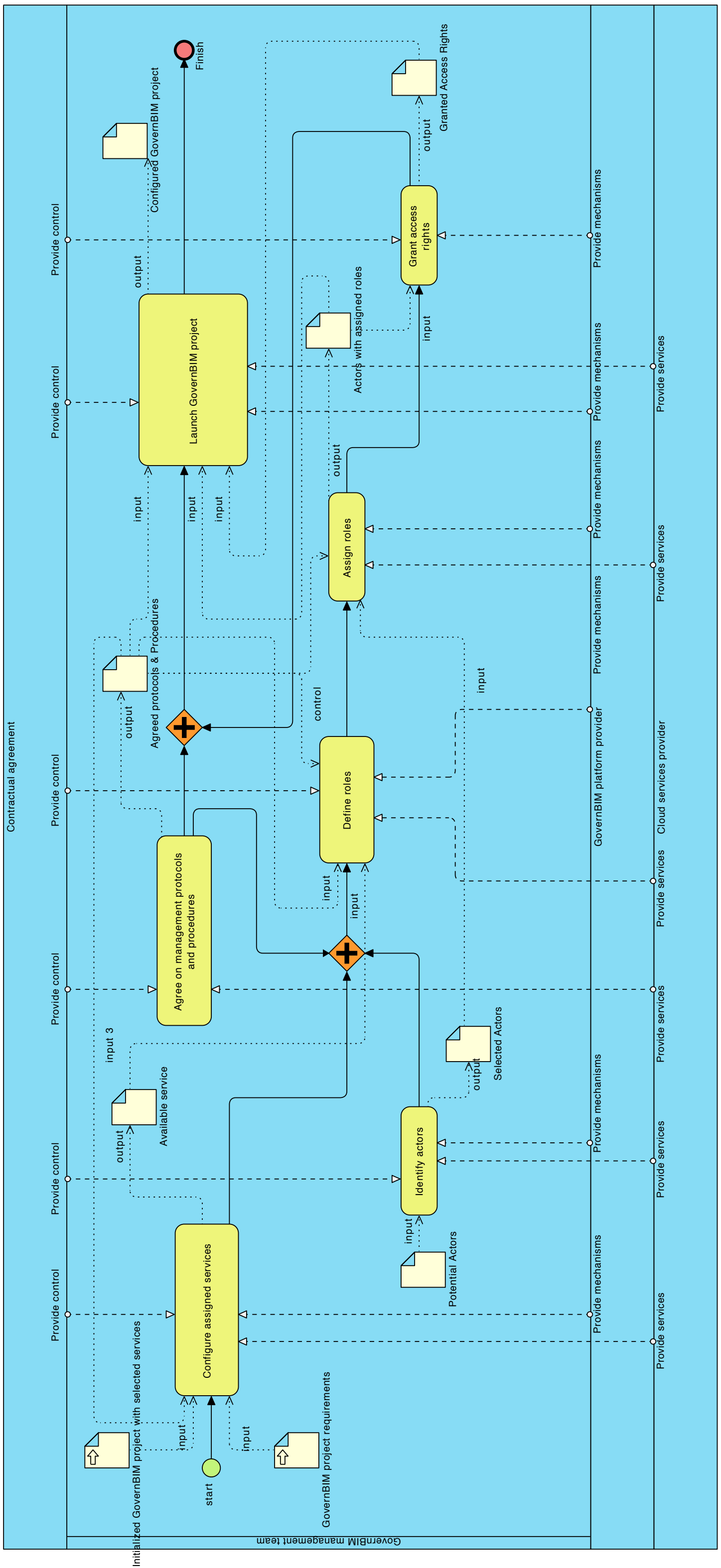


Figure 5 BPMN diagram: Configure GovernBIM project

- **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. Inputs to this activity contain the initialised GovernBIM project and selected services, GovernBIM project requirements, and agreed GovernBIM management 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.

4.2.4 BPMN activity: Operating GovernBIM platform's project BPMN

Figure 6 below depicts the BPMN diagram for operating the GovernBIM project. It involves five 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.

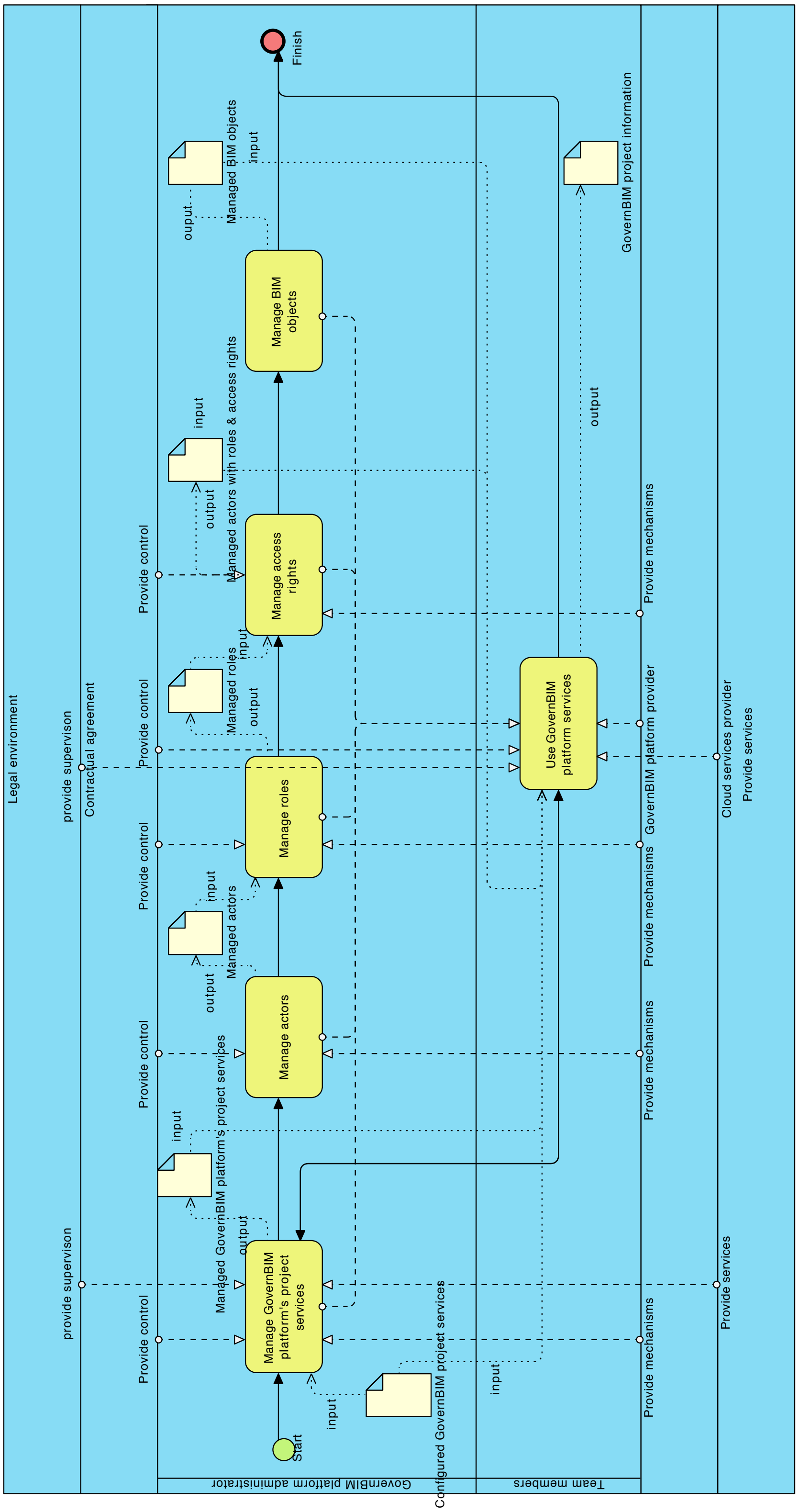


Figure 6: Operate GovernBIM platform's project BPMN

- **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 the 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.

4.3 Cloud-based GovernBIM platform's UML diagrams

As was identified earlier in the BPMN modelling process, the configuration and operation of PBMN 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 uses 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.

4.3.1 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 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 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 a 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 7 presents the providing and maintaining GovernBIM platform services use case diagram.

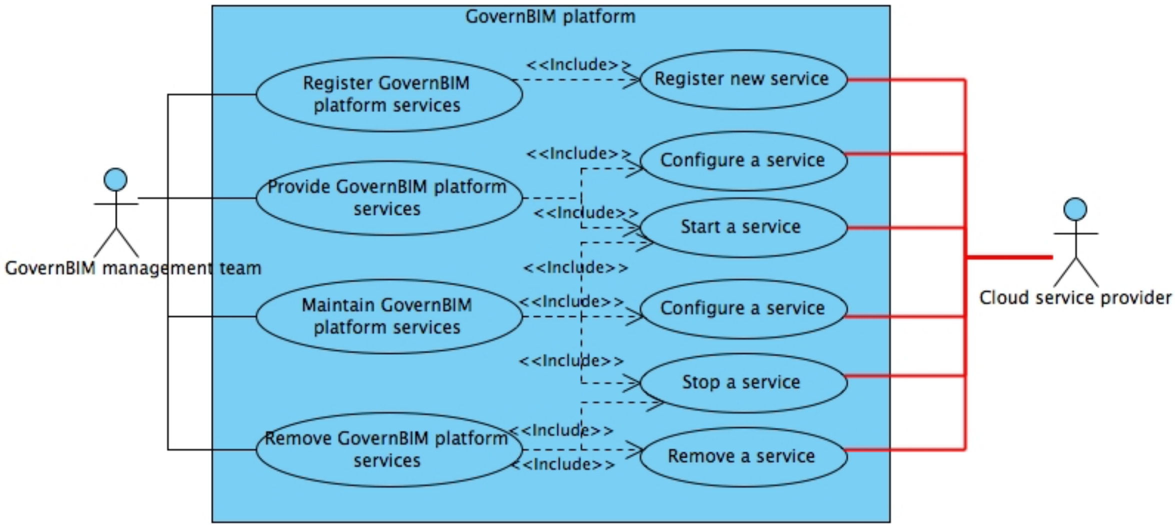


Figure 7 Uses Cases 1: Provide and manage GovernBIM platform services

4.3.2 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 preformed. The GovernBIM management team use GovernBIM tools/API provider's mechanisms and CSP services to preform these use cases. Figure 8 presents the use case diagram for providing and configuring a GovernBIM platform's project. It includes the following principal use cases:

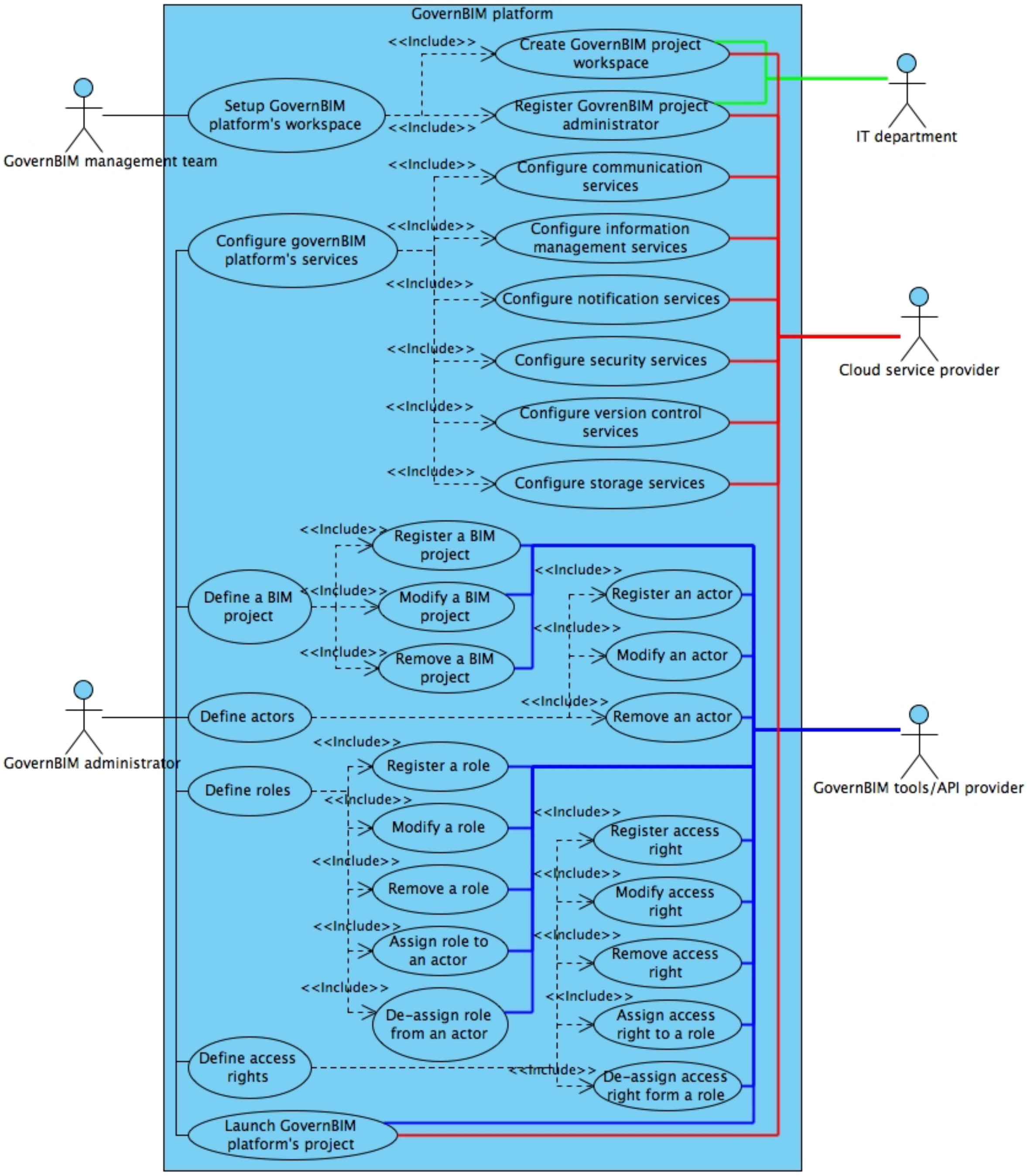


Figure 8 Uses Cases 2: Provide and configure a GovernBIM project

- **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 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.

4.3.3 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 provider mechanisms and CSP's services to preform all the use cases presented in this diagram. Figure 9 presents use cases diagrams to manage the GovernBIM's project in operational mode. This use case diagram includes the following use cases:

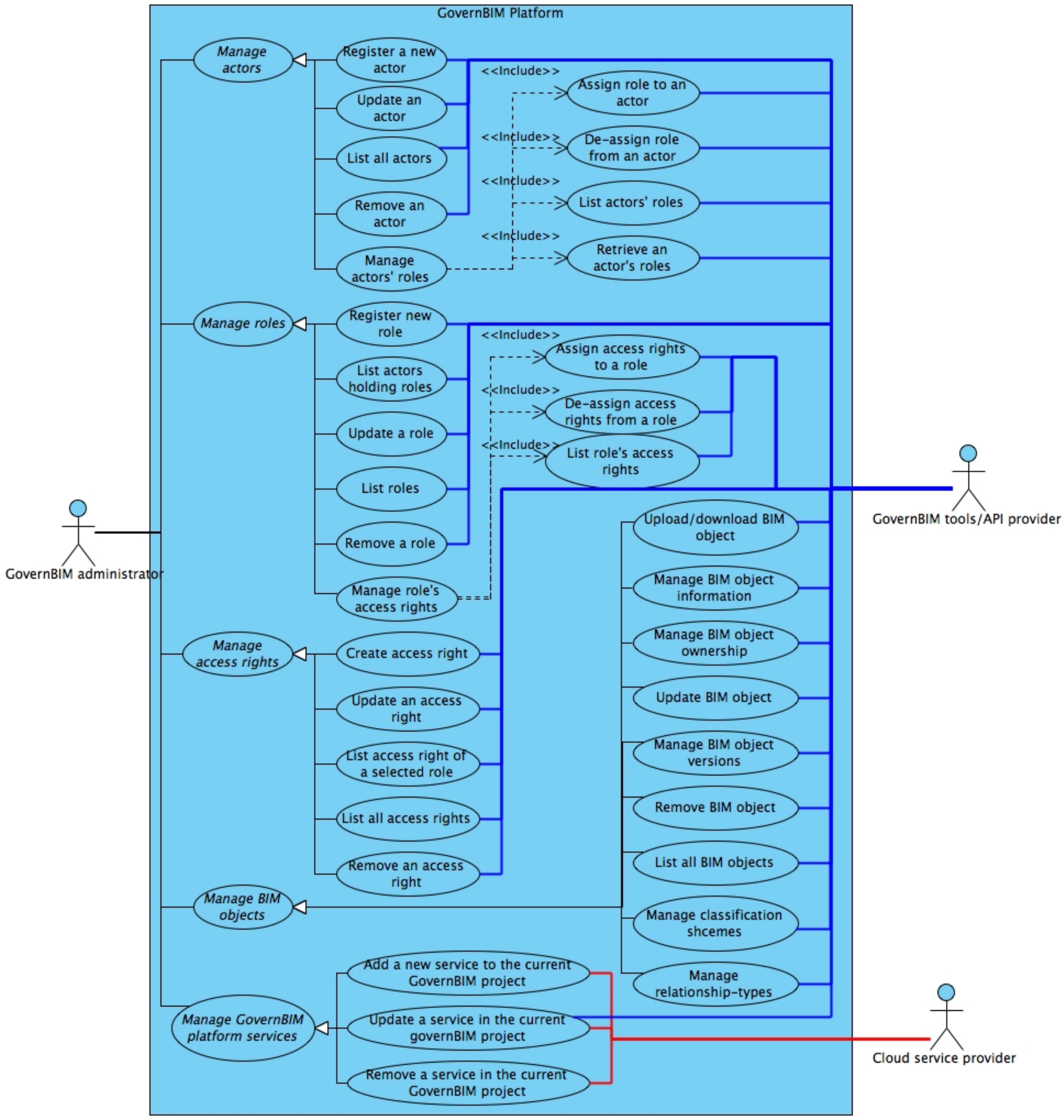


Figure 9 Uses Cases 3: Manage GovernBIM's project during operation

- **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: 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 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 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.

4.3.4 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 provider. Figure 10 presents use case diagrams for the GovernBIM project's environment. The GovernBIM GUI allows actors to perform the following use cases:

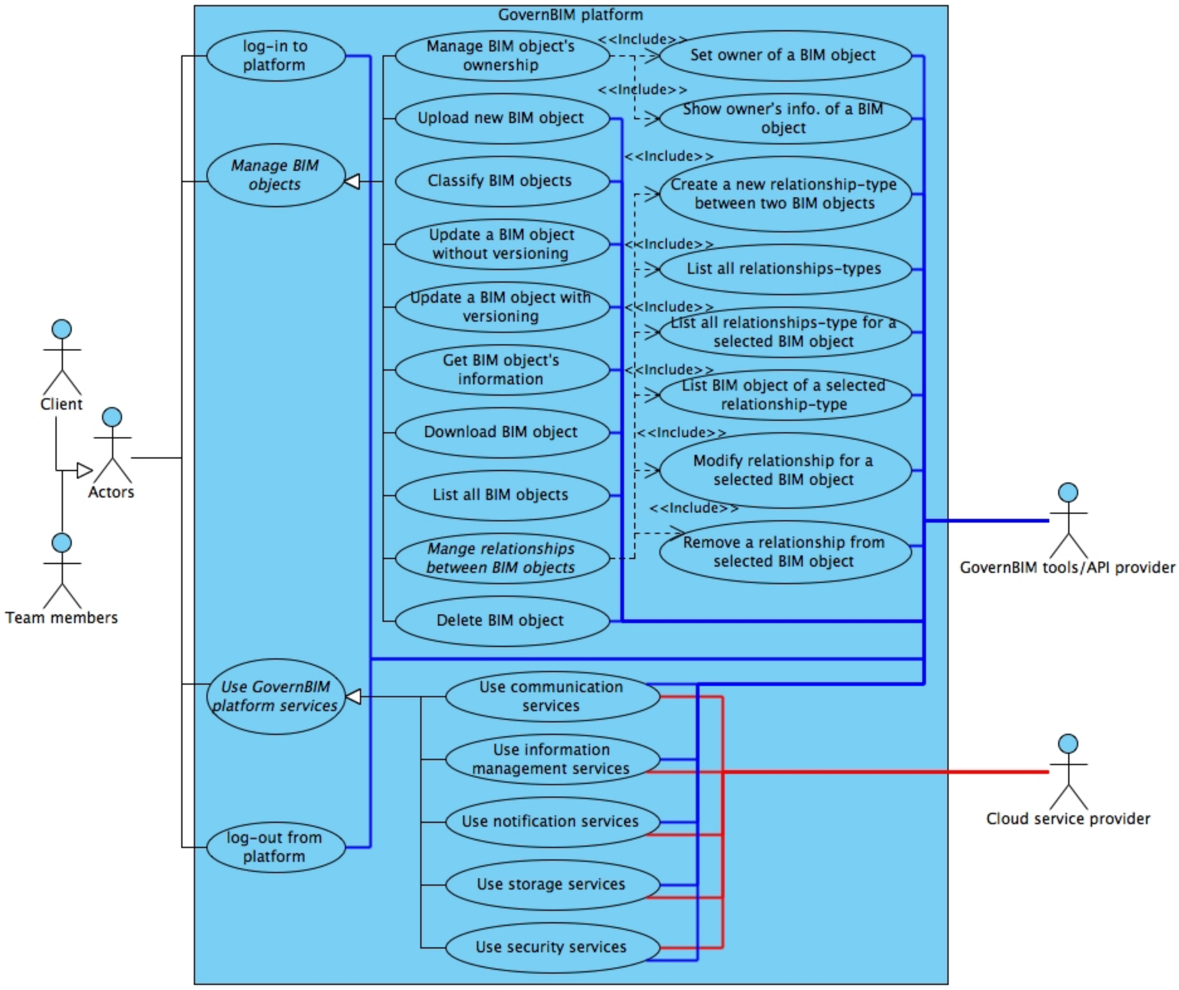


Figure 10 Use Cases 4: Using GovernBIM's project's environment

- **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.
    - **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.

4.3.5 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 11 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 (form, 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. 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.

- o ***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.
  - o ***Discipline:*** this class presents the actors' disciplines and role in the construction project. Each actor is assigned as class according to his discipline.
  - o ***Workspace:*** this class contains all information regarding the common data environment during the project lifecycle. It contains BIM objects shared between multiple actors.
  - o ***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:
  - o ***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.
  - o ***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.
  - o ***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.
  - o ***Decisions:*** this class records all the decisions made about BIM objects by actors during the GovernBIM platform project's lifecycle.
  - o ***Transactions:*** this class records all the transactions being made regarding BIM objects motivated by actors' decisions.
  - o ***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.

Figure 11 GovernBIM platform's class diagram

Despite the many classes that exist during the construction project's lifecycle; the afore-mentioned classes are key to the initial development of BIM governance model.

4.4 Cloud-based GovernBIM platform's architecture

This section describes the proposed GovernBIM platform architecture, as illustrated in figure 12. 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.

- **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.

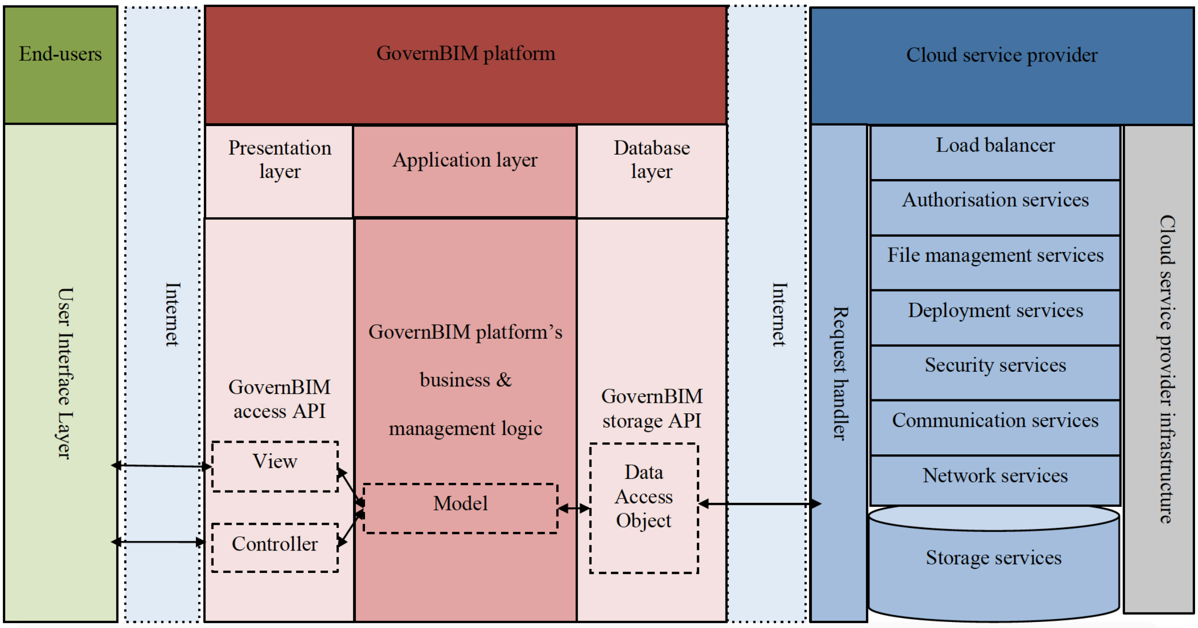


Figure 12 Software architecture design for cloud-based GovernBIM platform

5 Discussion

This aim of this study is 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 section will focus on the following four main points: (a) BIM governance platform requirements; discussing identifiable BIM governance requirements, and comparing them with other identifiable requirements; (b) GovernBIM platform lifecycle, discussing the use of BPMN to develop lifecycle processes for the GovernBIM platform; (c) GovernBIM platform UML diagrams, including a discussion about the use of UML for modelling key use cases for the GovernBIM platform; and (d) GovernBIM platform software architecture; providing a discussion regarding its design.

- **BIM Governance platform requirements:** 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. After collating these requirements, the data was classified and categorised using requirements regarding the engineering approach (Sommerville, 2007) into the following three main categorises; (a) *Functional requirements*; (b) *Non-functional*; (c) *Domain specific requirements*. Moreover, in addition to identifying general requirements for a cloud-based BIM governance platform, emphasis was also place 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 (Alreshidi et al., 2014).
- **GovernBIM platform BPMN:** Many researchers have used BPMN in the BIM field (Saluja, 2009, Wu and Issa, 2013), 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 PBMN 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 interaction between the main class components. The class diagram was developed based on the work of Kubicki et al. (2006) 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 creation of 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, 2012). 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 virtualized. 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).

6 Conclusion

Team members collaboration during BIM-based projects increase the need to use complex data management systems for facilitating collaboration process, Yet, the current cloud-based data management solutions have restrictions to their internal data governance structure and their external cloud architecture structure. Moreover, their data structure follows the developing companies' policies and regulations. 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 paper 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 cloud service provider's infrastructure.

This study 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 consultation with industry leading global stakeholders provided us with the opportunity to incorporate state-of-the-art practices in understating the collaborative process within BIM-based projects. Thus, the outcomes of this paper are valuable to project managers, researchers, BIM users, and BIM-based software developers, as it tends to reveals the holistic process of managing collaborative environments during a construction project's lifecycle. Furthermore, cloud-based architecture in the platform could be considered as a reference point when developing any cloud-based collaborative solution for BIM. Future work will involve the implementation of a technical prototype with the aim of producing GovernBIM tools/APIs and testing the potential role of cloud technologies in GovernBIM platform developments.

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