Paper Title: Factors for effective BIM governance

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Abstract

With increasing complexity of construction projects, a collaborative environment becomes essential to ensure effective communication during the project lifecycle. Conventional team collaboration raises issues such as the lack of trust; uncertainties regarding ownership and Intellectual Property Rights (IPRs); miscommunication; and cultural differences, among others. Additional issues can arise in relation to the generated data, including data loss, data inconsistency, errors, and liability for wrong or incomplete data. Furthermore, There is a shortage of studies that investigate collaboration practices, data management, and governance issues from a socio-technical perspective. This study investigates the development of a BIM governance framework (G-BIM) with support of Cloud technologies, identifying effectiveness factors that guarantee successful collaboration. Semi-structured interviews were conducted with informed BIM experts in the UK, with the aim of: (i) discovering current trends in Information Communication Technologies (ICT) and team collaboration during construction projects; (ii) exploring barriers to BIM adoption; (iii) exploring the role of BIM-related standards; (iv) consulting BIM experts to develop a Cloud-based BIM governance solution to tackle team collaboration on BIM-based projects; and (v) investigating the role of Cloud in supporting BIM governance research and development. The findings reveal several BIM adoption barriers and issues directly influencing team collaboration. The key findings led to the development of a BIM governance framework (G-BIM). The purpose of the G-BIM framework is to present and summarise effective factors resulting in successful governance and a collaborative BIM approach, to support the future development of a Cloud-based BIM governance platform. The G-BIM framework comprises three main components: (i) actors and team, (ii) data management and ICT, and (iii) processes and contracts. Furthermore, the study reveals the high potential of Cloud technologies to advance current BIM governance solutions, because of its performance capabilities, accessibility, storage, and scalability.

Keywords: Building Information Modelling (BIM), BIM Adoption, BIM Governance, Data Governance, G-BIM, Cloud Computing.

1 Introduction

Team collaboration during construction projects is becoming increasingly complicated, and new technologies such as BIM tools, processes and approaches have contributed to this. Team collaboration on conventional construction projects raises issues, including trust, ownership and Intellectual Property Rights (IPRs) concerns, miscommunication, and cultural differences, among others. Moreover, additional issues can arise in relation to the generated data, including data loss, data inconsistency, errors, and liability for wrong or incomplete data [1-3]. Typically, the adoption of a collaborative BIM approach complicates these issues further.

Recognising the importance of adopting a collaborative BIM approach, the UK government established 2016 as the target date for the adoption of BIM by the construction industry [4]. According to BIMTaskGroup [4], there are four levels of BIM maturity. Currently, the majority of construction firms are striving to reach BIM adoption at Level 2[1], while a minority of internationally leading engineering and construction organizations have started embracing some aspects of Level 3, such as shared model-based information delivery across the supply chain and lifecycle; this means it is possible to manage the data of all parties using 3D CAD models, but not necessarily to collaborate using a single, shared model. However, BIM adoption at Level 3[2] is more complex. To alleviate this complexity, a BIM governance model with a Cloud infrastructure offers a potential solution to facilitate team collaboration across the supply-chain during a building's lifecycle [5, 6].

To date, several researchers have sought to develop collaborative BIM frameworks and solutions [7-9]. However, these efforts lack detailed investigation of BIM governance and related characteristics. Yet, there is lack of theoretical framework for BIM governance. Therefore, this study aims to investigate the case for developing a BIM governance framework by: (i) exploring current ICT and collaborative practices among construction team members; (ii) discovering the barriers to BIM adoption in the construction industry; (iii) highlighting common collaboration problems in BIM-

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[1] In Level 2 BIM, Building data is managed in a 3D Environment, separate from the attached data. The data integration is then based on property or interfaces; e.g. as detailed in cloud middleware as "iBIM".

[2] In Level 3 BIM, all team members work from the same source of information (BIM Model).

based projects; (iv) identifying factors that support development of a BIM governance model; and (v) exploring the potential role of Cloud in underpinning that model. More importantly, this study seeks to establish a BIM governance framework (G-BIM).

Subsequent sections provide a literature review of related work on BIM collaboration research and BIM adoption barriers; present the research methodology, explaining the interview design; and, highlight and discuss the most significant findings from the interviews. Finally, a G-BIM is presented, followed by concluding remarks, and details of planned future work.

2 Related Studies

This section reviews current studies concerning barriers to BIM adoption, BIM-based collaboration solutions, BIM governance, and Cloud computing.

2.1 BIM adoption barriers

The construction industry is moving towards BIM adoption, recognising its many advantages, such as better modelling and design features, enhanced 3D rendering, and facilitation of team collaboration through a common model [10-13]. The slow adoption to date has inspired researchers worldwide to investigate existing barriers [14-17]; these barriers include: technical problems (compatibility and reliability), fragmentation of the project team, resistance to change, lack of training, and business process related issues [16]. Non-technical barriers concern people, culture, and processes [5, 14, 18]. The legal, contractual and organisational implications of BIM can also be problematic [9, 10, 19]. Although it is agreed that technical and socio-organisational changes should accord with BIM development [20], there is no general agreement about ownership and Intellectual Property Rights (IPRs) over BIM models, nor any clear roles and responsibilities for maintaining BIM models over a project's lifecycle [15, 21, 22].

2.2 BIM collaboration

Collaboration involves co-workers sharing information and processes by interacting, communicating, exchanging, coordinating and approving [23, 24]. BIM offers stakeholder collaboration at different stages of a building's 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 between stakeholders during a project [25]. However, in the construction industry, projects are handled in a collaborative environment across multiple disciplines and multiple actors, thereby raising trust issues, and generating a lack of clarity regarding roles and responsibilities, interoperability, etc. [5, 26].

Despite many researchers and practitioners maintaining collaborative work environments, challenges have impeded the development of a fully integrated multi-disciplinary collaborative mode of operation, or tool, to facilitate the adoption of BIM [18, 27]. Thus far, the development and deployment of integrative and collaborative technologies in the construction industry lags behind other industries [28]. Successful technology implementation requires the establishment of a tool to manage both electronic and manual operational procedures [23].

The gradual introduction of web-based technologies to construction project management has resulted in the integration of contractual, organisational and informational aspects. However, it is a challenge to encourage collaboration between geographically dispersed teams; especially where different practitioners represent different organisations, and where construction projects are large [23]. Collaboration technologies represent a shift toward virtual organisations, in which workers have the flexibility to work from any location, and computing technology makes it possible to communicate richer and more complex data [23]. Although, the technical requirements for developing collaborative BIM servers have been identified by Singh, Gu [27], this study aims to also explore functional and non-functional requirements that fall within the categories of socio-organisational, process, and legal requirements.

Developments in commercial BIM servers can resolve some collaboration issues, and options include the Onuma system [29], RevitServer [30], ProjectWise [31], Graphisoft BIM Server [32] and, more recently, Autodesk BIM 360 [33], alongside open-source solutions such as BIMServer [34], and EDMmodelServer [35]. However, BIM servers tend to be owned by their developers, utilise proprietary management data structures, and rely on central or local servers for data management and storage [5, 36].

2.3 BIM governance

This study aims to unite the experiences of construction practitioners with previous research and findings, to provide information to support the development of a Cloud-based BIM governance solution. Until recently, BIM governance has not been investigated in explicit detail in construction projects. Existing IT and ICT governance frameworks, e.g. [37-39] were not initially developed to meet construction industry needs. Data governance frameworks tend to focus on data-related aspects, although data governance refers to the overall management of the availability, integrity, and security, of the data used within an enterprise [40]. Newman and Logan [41] 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".

Rezgui, Beach [5], state that 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 makes decisions and how, whereas management implements decisions [41]. Almost all organisations that face challenges managing information, can benefit from a governance approach [42]. There is a known lack of overall governance within current construction projects; hence, there is a need to develop a generic data governance model to facilitate BIM adoption in a collaborative built-in environment across multi-disciplines and multi-actors throughout the building's lifecycle [5].

There are several requirements for overcoming limitations to BIM adoption and team collaboration from a governance standpoint: (i) protocol development, (ii) establishment of responsibilities across disciplines, (ii) sharing a common model that can be stored centrally or hosted by distributed environments, and (d) improved interdisciplinary communication. In addition, to raise awareness, intensive training should be introduced, and an explanation given of stakeholders' formal responsibilities, across disciplines and at different stages of the building lifecycle [5, 43-45]. Here, several aspects need to be taken into account in the development of a Cloud-based BIM governance solution: BIM data management processes, the project's lifecycle, supply-chain complexity, BIM, team members' rights and responsibilities, policies and standards, and the underpinning technology.

2.4 Cloud efforts in BIM

Cloud computing technologies have recently gained in popularity [46-48]. 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 [49-52]. However, apart from [5, 36], these research efforts have not targeted BIM governance directly. Hence, this study aims to investigate advantages and disadvantages of utilizing Cloud technologies in BIM governance. In general, Stadtmueller [53] 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 [54]. The current trend in the construction industry is to efficiently integrate and manage building information using BIM with Cloud [55]. In this context, Cloud offers a number of general benefits such as accessibility [36, 52], scalability [56], Reliability [57], Advance Interoperability for BIM applications [52] data security [48, 58, 59], real-time backup [60] Cost [61], and Green credentials[62].

Despite the fact that the Cloud has many benefits, potential drawbacks exist. According to Armbrust, Fox [48] these drawbacks are: (a) security concerns, (a) performance guarantee, (b) anonymous control, (c) cusiness 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, Hore [52] 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 remains unclear who owns the data hosted by a Cloud Service Provider (CSP) [63, 64].

3 Methodology

The collaboration process of construction teams differ from other disciplines [65]. There is a shortage of studies that investigate collaboration practices, data management, and governance issues from a socio-technical perspective. This forms the gap addressed by the present paper to identify factors for successful BIM governance using an appropriate method such as questionnaire and formal interviews. Therefore, the main aim of this research paper is to develop a theoretical BIM governance framework based on identified factors. This study is considered exploratory research, hence a mixed method approach using a comprehensive questionnaire and semi-structured interviews is adopted. Semi-structured interview is a qualitative method of inquiry that combines a pre-determined set of open questions with the opportunity for the interviewer to explore particular themes or responses further [66]. 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 have no prepared questions for; (d) allow the BIM experts to speak in more details on the issues that the researcher raises as well as introduce new issues that are relevant to the research theme [66].

The outcome of the comprehensive questionnaire were reported in Alreshidi, Mourshed [6]. However, the outcome of semi-structured interviews that helped in developing a BIM governance framework (G-BIM) forms the main focus in this paper. The preparation of semi-structured interview is done based on steps reported by Oates [66]. This is done by conducting a literature review exploring: (a) the current situation of BIM adoption, (b) ICT and collaboration practices, and (c) data management practices in construction projects. Consequently, this study is underpinned by the following research questions:

- RQ1. What are the current BIM adoption barriers, ICT and collaboration practices; and what issues arise during the collaboration process?
- RQ2. Do existing BIM-related standards promote collaboration and BIM integration?

RQ3. What potential factors could lead to effective BIM governance?

RQ4. What is the Cloud's potential role in a BIM governance solution?

This leads to the development of an interview guide (Appendix A). The interviews was designed to target BIM experts, including BIM academics, BIM practitioners and BIM technicians. The expert panel were chosen based on the following 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 semi-structured interview was conducted based on the interview guide with several BIM experts from different disciplines and backgrounds. 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 1 displays the BIM experts' backgrounds.

Table 1 BIM experts' demographic information

	No.	BIM Expert	Position	Experience in construction/BIM (years)	Place of the interview	Interview method
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

The interviews have been recorded using a reorder device for face-to-face interviews and recording software Pamela [67] for Skype interviews. A transcription of the recorded interview is done via transcription services provider. Then the interview transcripts were categorized according to common themes and analysed using a pattern coding technique. These themes are categorized in an Analysis Template (Appendix B). Each one of these themes is created in a single file that holds all the answers from BIM experts of the same theme. After that, all answers of each theme are grouped and discussed together with other results. A table to summaries the results of each category is then designed and filled in with the most significant result of each theme.

4 Results

Since BIM governance is evolving as a way to facilitated control over the fragmented components of construction projects, this study sought to present a comprehensive model to assist construction professionals. The findings were divided into categories as follows:

- Current BIM adoption barriers;
- Current ICT and collaboration tools and practices;
- Team collaboration issues;
- Role of BIM related standards;
- Factors linked to efficient BIM governance; and
- Prerequisites for a BIM governance solution

The outcomes of aforementioned categories are discussed below, as they guided the development of an effective G-BIM. The role of Cloud technologies in BIM governance research and development is also highlighted.

4.1 BIM adoption barriers

The findings from the consultation regarding BIM adoption barriers endorsed the findings of previous research [5, 68-71]. However, BIM adoption barriers were expanded upon in this study, to include socio-organisational, financial, contractual, technical, and legal barriers. Table 2 summarises the most significant BIM adoption barriers.

Table 2 BIM adoption barriers

Theme/category	Related barriers
Social-organisational	• 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	• BIM adoption cost • Personal Indemnity Insurance (PII) is not covered • BIM training cost • Limited budget • Expensive human-based services costs

Technical	• 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	• 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	• 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

4.2 ICT and collaboration practices during projects

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 [6]. 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 tele-conferencing 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 [72], ProjectWise [31], Asite [73], and Autodesk RevitServer [30]). 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 [74].

  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 tends 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 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 3 summarises issues that arise during team collaboration on BIM-based projects.

Table 3 Collaboration issues on BIM-based projects

Theme/ Category	Drafted results
People	• BIM maturity and understanding • People's behaviour • Team trust • Collaboration issues
Process	• 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	• Data ownership • Copyrights • Intellectual Property (IP) • Interoperability • Big data volumes • Data inconsistency • Data compatibility • Data transportation • Data storage • Data loss

4.4 The role of BIM-related standards in promoting collaborative BIM approach

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 BIM integration and collaboration. However, it is acknowledged 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 often only implement rules;
- They lack aspects of governance;
- They were developed by large companies, not by SMEs;
- They reflect the desires, issues and concerns of specific groups excluding others; and
- Standards and constantly evolving as a result of ongoing research and development.

So 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 in terms of cost and time. 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 may become the de facto standard. However, IFCs still have limitations because of the lack of widely-agreed semantic underpinnings, often resulting in semantic data loss when transferring BIM models to IFC.

4.5 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).

Table 4 Factors informing efficient BIM governance

Theme/Category	Factors

ICT factors	• 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	• 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	• 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	• 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	• 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

5 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, which are not shared with others 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) [75] and Responsibility Matrix [76] 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 interpret and implement, and often out-dated—not particularly suited for 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.

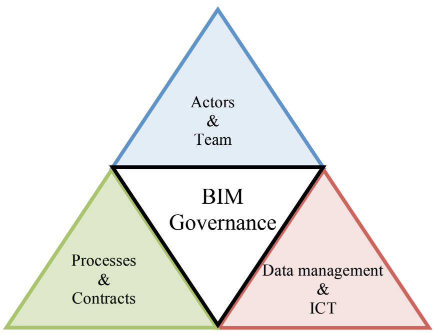

Figure 1 Prerequisite components of BIM governance

Figure 1 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, through collaboration. Multiple actors collaborating within a team produce data during the building lifecycle "process". They utilise "ICT" to facilitate collaboration during the BIM process, supported by "legal contracts and policies" agreements and considerations.

5.1 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.

5.1.1 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 unwanted errors. Knowing who is going to work on which model, as well as when and how, are key factors for effectively governing the BIM collaborative process. In addition, preserving actors' ownership and IPR is vital for an effective 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. The sub-factors 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.

5.1.2 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 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 security and privacy services, management support for different file formats, instant access to data according to each actor's access rights, allowing users to customize 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.

5.1.3 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 2 summarises and illustrates the six major components of the proposed BIM governance effective factors framework, including important factors for each component.

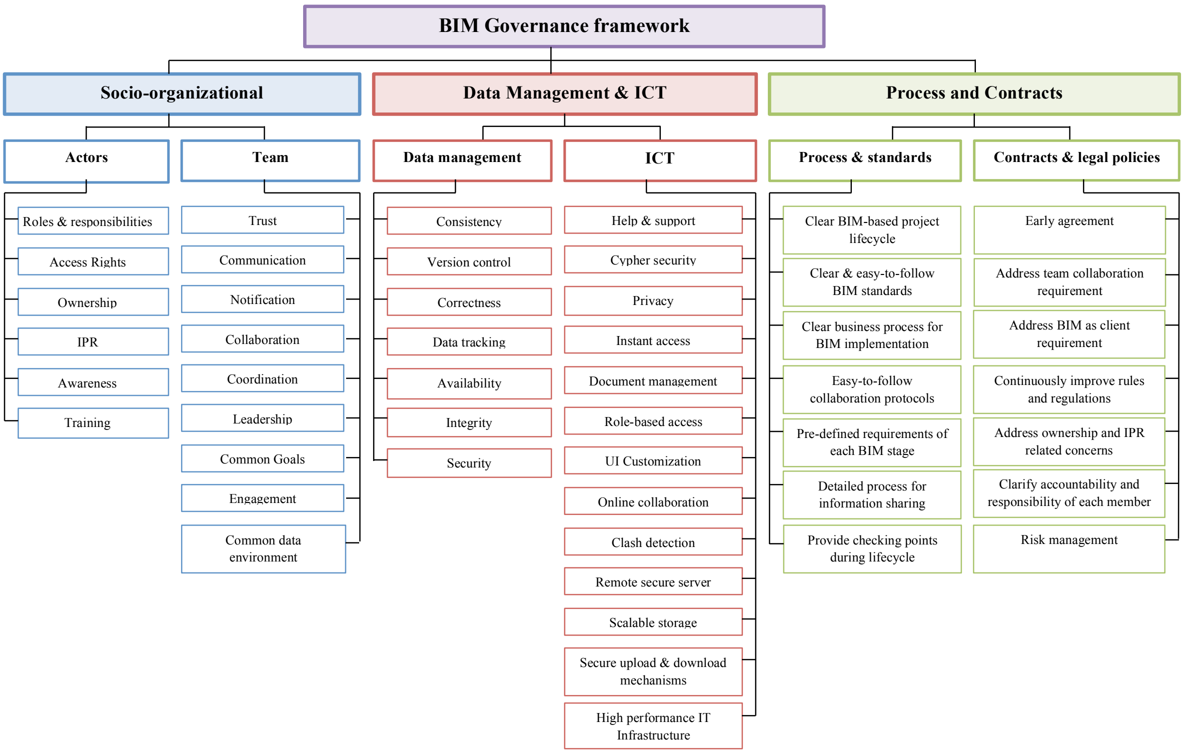

Figure 2 Framework of effective BIM governance factors (G-BIM)

6 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 [63]. It provides an ideal environment for hosting massive data files, such as those used in BIM governance models [47]; the advantages and disadvantages of using Cloud as a solution are listed in Table 5:

Table 5 Potential role of the Cloud in BIM R&D

Advantages	Disadvantages
• Data availability • Data accessibility • Cost effectiveness • Massive storage and backup capabilities • Easy to use • Interoperable • High computing capabilities • Positive environmental effects	• 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 provider 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 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 Cloud provider'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 Cloud provider'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 Cloud provider 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 Cloud provider 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 Cloud providers 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, people will stop working. 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 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 Cloud providers 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.

7 Discussion

BIM adoption in collaborative environment will still suffer form barriers such as socio-organizational, financial, contractual, and technical issues [5, 68, 70, 71]. However, adopting governance solutions that are built based on theoretical BIM governance framework could helps reducing such issues [6]. Issues raised during team collaboration due to different interpretation of BIM technologies [3, 6]. Such issues would have negative effects on the collaborative environment affecting the outcomes of a construction project [77]. BIM standards are considered to be a suitable solution towards minimising team collaboration issues, yet, there is huge effort to automate BIM standards and guidelines that makes it easy to be adopted by team members [78].

The present study identified prerequisite factors for effective BIM governance, leading to the development of the BIM governance framework (G-BIM). The G-BIM comprises three main components: “actors & team”, “data management & ICT”, and “processes & contracts”, with sub factors for each. The G-BIM is valuable because it shows effective factors of BIM governance within collaborative BIM environments. The development of G-BIM framework had been done based on views and experiences of BIM experts. Although, G-BIM framework has been validated by interviewed BIM experts, more effort will be made to further develop G-BIM framework to cover wider components and factors based on real construction projects.

Achieving convenient governance practices should be underpinned by ICT with specific focus on new and emerging technologies such as Cloud computing [79]. Although there are many concerns surrounding the use of Cloud, such as security, privacy, and Cloud service provider ownership, there are major benefits too; e.g. accessibility, availability, high performance capabilities and scalable storage [52]. Further, this research set a foundation for future development of a Cloud-based governance BIM solution. The development of such a solution should done based on proper software engineering approach to technically implement the cloud-based governance platform based on of BIM experts' requirements, as well as their collaborative environments, practices and tools. Eventually, this will lead to developing a cloud-based BIM governance platform that incorporate afford-mentioned factors of G-BIM framework.

8 Conclusion

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 on the technical dimensions, often without due consideration to socio-organisational, process, and legal aspects. To address this limitation, 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 semi-structured interviews, identified many barriers to BIM adoption and classified many issues associated with team collaboration during construction projects. The outcomes from the consultation suggested that achieving a fully integrated and collaborative BIM environment would require governing the collaboration process and data flow, underpinned by Cloud technologies. This can be achieved through the automation of BIM-related standards, concealing the complexity of these standards behind a user-friendly graphical interface.

Besides expanding on the body of knowledge regarding BIM adoption, team collaboration, and ICT governance, this study contributed toward the development of the G-BIM framework. 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 G-BIM. Although there are many concerns surrounding the use of Cloud, there are major benefits too.

The theoretical BIM governance framework is very valuable since it is forms the foundation of effective factors for adopting BIM governance solutions within collaborative BIM environments. Since it is on early stages of development, the model has been validated by re-meeting BIM experts where their critics and comments are incorporated in the final version of G-BIM framework. Yet, further socio-technical validation are to be done under real construction projects. This is a direction for future research, as the socio-technical development will involve software engineering approach via Unified Modelling Language (UML) and Business Process Modelling Notations (BPMN) to model process of BIM experts' requirements factoring in their expectations of a cloud-based governance platform, as well as their collaborative environments, practices and tools. Following the completion of the modelling stage, a cloud-based prototype will be developed, stress-tested and validated based on real construction projects. These efforts will be reported in a follow-up publication.

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