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A theoretical framework of a BIM-based multi-disciplinary collaboration platform

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ABSTRACT

Most complex projects in the Architecture, Engineering, and Construction (AEC) industries involve multi-disciplinary collaboration and the exchange of large building data set. Traditionally, the collaboration efforts across the disciplines have been based on the frequent exchange of 2D drawings and documents. However, during the past decade, the widespread adoption of object-oriented Computer-aided Design (CAD) tools has generated more interests in Building Information Modelling (BIM). A number of BIM-compliant applications such as analysis tools, model checkers and facility management applications are being developed. This paper develops a theoretical framework of technical requirements for using BIM-server as a multi-disciplinary collaboration platform. The methodologies that are used to develop the framework include focus group interviews (FGIs) with representatives from the diverse AEC disciplines, a case study of an Architectural project using a state-of-the-art BIM-server, and a critical review and analysis of current collaboration platforms that are available to the AEC industries. This paper concludes that greater emphasis should be placed on supporting technical requirements to facilitate technology management and implementation across disciplines. Their implications for user-centric technology development in design and construction industry are also discussed.

1. Introduction

Traditionally, the inter-disciplinary collaboration in the Architecture, Engineering, and Construction (AEC) industries has revolved around the exchange of 2D drawings and documents. Even though the separate design disciplines have been using 3D models and applications for visualization and design development, the collaboration practices have remained more or less 2D-based until recently. The widespread use and proliferation of object-oriented Computer-Aided Design (CAD) packages and increased constructability and level of automation in construction processes provide encouraging motives for the exchange of 3D data in the collaboration process. Building Information Modelling (BIM) is envisaged to play a significant role in this transformation. BIM is an advanced approach to object-oriented CAD, which extends the capability of traditional CAD approach by defining and applying intelligent relationships between the elements in the building model. BIM models include both geometric and non-geometric data such as object attributes and specifications. The built-in intelligence allows automated extraction of 2D drawings, documentation and other building information directly from the BIM model. This built-in intelligence also provides constraints that can reduce modelling errors and prevent technical flaws in the design, based on the rules encoded in the software [11,16,21]. Most recent CAD packages such as ArchiCAD and Revit have adopted the object-oriented approach with certain BIM capabilities. A number of supporting applications have emerged that can exploit the information embedded in the BIM model for model integration, design analysis, error checks, facility management (FM), and so on [20]. The emergence of multiple applications with the ability to directly use and exchange building information between them provides opportunities for enhanced collaboration and distributed project development. BIM is increasingly considered as an Information Technology (IT)-enabled approach that allows design integrity, virtual prototyping, simulations, distributed access, retrieval and maintenance of the building data [12]. Hence, the scope of BIM is expanding from the current intra-disciplinary collaboration through specific BIM applications to multi-disciplinary collaboration through a BIM-server such as EDMmodelServer™ that provides a platform for direct integration, storage and exchange of data from multiple disciplines. A BIM-server is a collaboration platform that maintains a repository of the building data, and allows native applications to import and export files from the database for viewing, checking, updating and modifying the data. In general, a BIM-server by itself has limited built-in applications. BIM-servers are expected to allow exchange of information between the various applications involved in a building project life cycle including design tools, analysis tools, FM tools, document management systems (DMS), and so on. In principle, BIM-servers aim to provide collaboration capabilities which are similar to DMS. However, while DMS are meant for collaboration through exchange of 2D drawings and documents,

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BIM-servers provide a platform for the integration and exchange of 3D model data with embedded intelligence.

This paper presents a conceptual framework that categorizes the features and technical requirements for a BIM-server. The findings in the framework are based on (a) focus group interviews (FGIs) with representatives from the diverse AEC disciplines for industry needs analysis, expectations and perceptions of existing technology; (b) a case study conducted with a state-of-the-art BIM-server to identify its technical capabilities and limitations; and (c) a critical review and analysis of current collaboration platforms that are available to the AEC industries. Data analysis reveals that BIM-servers should not be developed solely for functional and operational purposes. Rather, the features and technical requirements that facilitate BIM implementation and usage should also become a critical part of the BIM-server development. Based on the findings, the technical requirements for a BIM-server are classified into four main categories including both operational technical requirements (OTR) and support technical requirements (STR). They are (a) BIM model management-related requirements; (b) design review-related requirements; (c) data security-related requirements; and (d) BIM-server set-up implementation and usage assisting requirements. It is found that the support technical requirements are a critical cog in technology adoption and technology enhancement. The proposed framework will enhance BIM-server research and development and better facilitate the adoption of the technologies, leading to greater support for intelligent and automated collaboration in design and construction.

2. Research methodology

The research data were collected in two stages. Initially, a thorough literature review and desktop analysis were conducted to assess the development trends and capabilities of various BIM-related applications. After the initial review, preliminary research data were collected through focus group interviews (FGIs) to identify industry needs, expectations and perceptions of existing BIM applications. In the second stage, a case study with an existing BIM-server and detailed analysis of existing collaboration platforms were conducted to validate the technical requirements for a BIM-server in light of the industry needs identified in the preliminary phase. Findings from the two stages were used to identify the technical requirements. Therefore, the findings reported in this paper are based on the following combined research approaches:

- FGIs with representatives from various disciplines involved in the AEC industry: These FGIs were conducted to (1) identify differences in awareness, expectations and perception of BIM across the different disciplines, and (2) identify industry needs and technological requirements for BIM- server in particular.
- Case study using a state-of-the-art BIM-server: A state-of-the-art BIM-server was tested on a real-world project with the following research objectives: (1) to test the current functionalities, usability and limitations of the BIM-server as a collaboration platform, and (2) to use the result of (1) as a benchmark to propose features and technical requirements for an ideal BIM-server.
- Analysis of document-based collaboration platforms in the AEC industry: A review of current document-based collaboration platforms and their use in the industry was conducted to identify features and technical requirements that users may expect in a BIM-server. This enables us to extract essential and relevant functions of collaborative technologies that are currently in use, to be integrated into the ideal BIM-server environment. This analysis also provides a benchmark to assess the strengths and limitations of the tested BIM-server.

3. Stage one research—industry needs analysis

In the first stage of the research, FGIs were conducted with representatives from diverse AEC sectors to identify industry needs, expectations and perceptions of BIM-based collaboration platform across the AEC disciplines. Two FGIs were conducted in different Australian capital cities. Each FGIs gathered between 15 and 20 representatives from leading organizations that have partially incorporated or are planning to incorporate BIM-based collaboration activities and data exchange in their practice to discuss key issues on BIM development and adoption for the research. Apart from the various disciplines from the AEC industry such as architects, contractors, engineers, design managers, and facility managers, the FGIs also included representatives from application vendors and government agencies who play an important role in development and adoption of the technologies. The FGIs were moderated by the research team. Although the FGIs participants were from Australia, most participants and their organizations have been involved in international projects and are aware of the professional and cultural differences across regions, which ensured the general relevance of the FGIs outcomes.

The FGI data were recorded on tape and the transcripts were segmented for protocol analysis, based on a coding scheme reported in Gu et al. [13]. Protocol analysis is a research method used for behavioural analysis of research participants and their thinking [5,7]. In summary, the coding scheme was designed to classify the various BIM-related issues discussed in the FGIs into technical, business, legal, work practice, data management, process- and training-related issues. Data analysis based on this coding scheme allowed ranking and prioritizing of the various issues discussed by the FGI participants. As reported in Gu et al. [13], work practice, training- and process-related issues featured significantly along with the technical issues.

The FGI data echo some of the earlier findings that lack of initiative and training [6], technical concerns and lack of technical knowhow [4,15], fragmented nature of the AEC/FM industry, varied market readiness across geographies, industry's reluctance to change existing work practice [2,17,19], the lack of clarity on roles, responsibilities, and distribution of benefits in adopting the BIM approach [14] are some of the important factors inhibiting BIM adoption in practice. The FGI data also suggest that the development and adoption of a BIM-server, meant for interdisciplinary collaboration, require an inclusive approach based on the understanding of the collaboration requirements and project specific contingencies. Thus, the BIM-server usage and capabilities should be flexible to suit the project requirements. Based on the findings from this preliminary phase, the perception and expectation of BIM against the industry's current practice are summarized in terms of the following three main aspects: tools, processes and people.

1. Tools: Expectations of BIM vary across disciplines, as shown in Fig. 1. For design disciplines, BIM is an extension to CAD, whereas for non-design disciplines such as contractors and project managers, BIM is a more like an intelligent DMS that can quickly take off data from CAD packages directly. While there are evident overlaps, BIM application vendors seem to aim to integrate the two requirements. The existing BIM applications are not yet mature for either purpose. Users with CAD backgrounds such as designers, expect BIM-servers to support integrated visualization and navigation that are comparable with the previous applications they are familiar with. Users with DMS backgrounds such as contractors and project managers, expect visualization and navigation to be the important features of BIM-servers that are missing in existing DMS solutions.
2. Processes: BIM adoption would require a change in the existing work practice. An integrated model development needs greater collaboration and communication across disciplines. A different approach to model development is needed in a collaborative setting where multiple parties contribute to a centralized model. Standard processes and agreed protocols are required to assign responsibilities

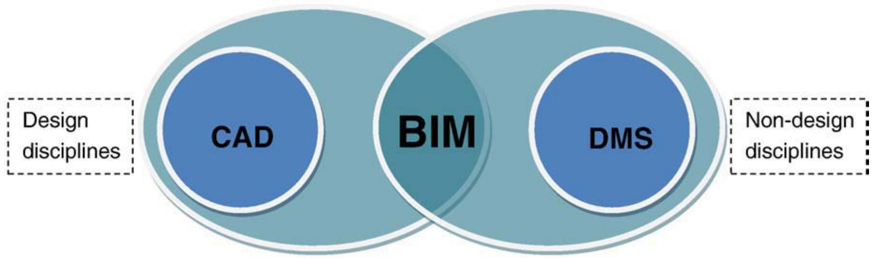

Fig. 1. Disciplinary backgrounds and differences in expectations from BIM-servers.

and conduct design reviews and validation. Experience from Database Management System (DBMS) will be useful for data organization and management; however, organizations will need to develop their own data management practices to suit their team structure and project requirements. Different business models will be required to suit varied industry needs. A BIM model can be maintained in-house or outsourced to service providers. In the latter case, additional legal measures and agreements will be required to ensure data security and user confidence.

3. People: New roles and relationships within the project teams are emerging. An examination of the existing workflow and resourcing capabilities would begin to highlight whether this would be an internally or externally resourced role. There was much diversity in the two FGIs and it was agreed that the scale and business models of the different players in the industry mean that organizations need to develop strategies that suit their requirements and practices, contingent upon the capabilities of their current firms that they work with. In general, dedicated roles, such as BIM model manager and BIM-server manager will be inevitable for complex projects. Team members need appropriate training and information in order to be able to contribute and participate in the changing work environment.

Discussions in the FGI suggest that the industry can often be stuck in a status-quo loop, as indicated in Fig. 2. The lack of knowledge and awareness about BIM can result in a lack of confidence and motivation to adopt BIM-based collaboration. Conversely, as a result of the inhibition to adopt and use BIM, the level of knowledge about BIM remains low.

This is particularly critical to the rate of development of BIM technologies. Some of the BIM applications have not yet matured, which may lead to dissatisfaction among some of the potential early adopters. However, these tools can only improve with experience and feedback, for which early trials and adoption are essential. Thus, for the BIM-based technologies to mature and industry to adopt these technologies, the status-quo loop needs to be reversed into a recursive development cycle, Fig. 3. This development cycle reflects the discussions in literature that suggests that the introduction of new work practices and introducing new ICTs must go hand-in-hand [10,25,30].

In summary, as BIM matures it is likely to integrate the existing CAD packages and DMS into a single product. For BIM to succeed and be adopted widely in the industry, all the stakeholders have to be informed about the potential benefits to their disciplines and the project. The findings suggest that (1) the lack of awareness, (2) the over-focus on BIM as advancement of CAD packages only, and (3) the relative downplaying of BIM's document management capabilities have inhibited the interest of non-design disciplines of the AEC/FM industry in BIM adoption. A user-centric BIM research has to be more inclusive, since the success of BIM adoption lies in collective participation and contribution from all the stakeholders in a building project. For this study, the above understanding of BIM adoption shows that the development of BIM-server technologies is not entirely for functional and operational purposes. BIM-servers should not only have the technological capability to support the collaboration requirements of diverse user groups, but also provide adequate support features to assist the users in assessing, designing and implementing BIM in their projects.

4. Second stage research—case study and analysis

As observed in the first stage research, the lack of industry experience with BIM-based interdisciplinary collaboration resulted in limited feedback from industry on technical requirements for a BIM-server [13]. Therefore, the following case study on a real project was carried out in the second stage to collect primary data for reflection.

4.1. Case study using a state-of-the-art BIM-server

The renovation and re-functioning of a service block of an existing Australian landmark building are used for the case study of BIM-based collaboration platform. The existing building data, such as the original design drawings, the existing infrastructures in the service block and its spatial relationships with other surrounding spaces become very important and increase the complexity of the project. These factors were considered and respected when constructing each individual discipline-specific models and merging the models into an integrated BIM model using EDMmodelServer™ (www.epmtech.jotne.com).

The two main tasks of this case study are (1) the construction of the discipline-specific models and (2) the integration of the models as an integrated BIM model using EDMmodelServer™. The disciplines involved in the case study are architecture, hydraulics, and lighting. Applications used for constructing these discipline-specific models include ArchiCAD for the architectural model and DDS-CAD (www.dds-cad.net) for the hydraulic and lighting models. In addition, there are also some applications used for various processes within the case study including Solibri Model Checker, Solibri Model Viewer (www.solibri.com), DDS-CAD Viewer and Octaga Modeller (www.octaga.com) (a plug-in of EDMmodelServer™ for instant 3D model viewing). The selection of the

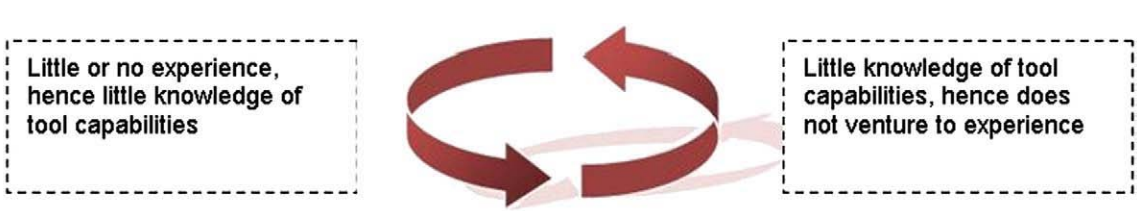

Fig. 2. Status-quo cycle inhibiting technology adoption and enhancement.

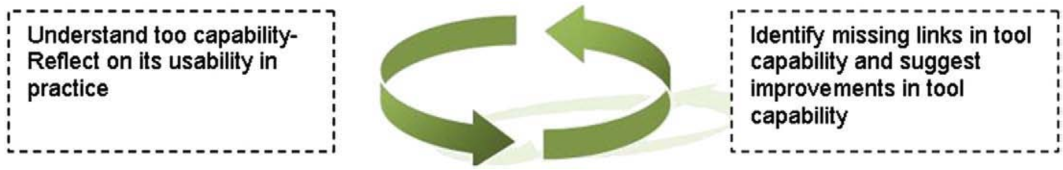

Fig. 3. Recursive development cycle for technology adoption and enhancement.

particular applications did not aim to be exhaustive. They were included in the case study to represent typical discipline-specific applications and user scenarios.

In order to test the collaboration-related issues with the chosen BIM-server, the model development team (2 modellers) was geographically distributed, avoiding face-to-face meetings. One modeller was responsible for the architectural model while the other modeller developed the hydraulics and lighting models. The facility manager from the client organization (the building trust) coordinated the model development and was available for clarifications regarding the original drawings and model naming conventions. Thus, three different users (two modellers and one facilities manager) were involved in distributed collaboration across the BIM-server.

The construction of each discipline-specific model and the development of the integrated BIM model, first, were based on the original design drawings to produce the architectural model. The architectural model of the service block was then converted into Industrial Foundation Class (IFC) format, which was subsequently uploaded into EDMmodelServer™. Furthermore the other project partners downloaded the architectural IFC file from the EDMmodelServer™. Based on this architectural model and the original design drawings, they constructed the hydraulic and lighting models respectively and then converted these models into IFC files and checked-in the data in the BIM model server and merged together with the architectural model to produce the integrated BIM model. Fig. 4 shows snapshots of the disciplinary models and the integrated BIM model in EDMmodelServer™.

The case study tests a wide variety of issues including building data visualization, analysis and collaboration. Specific features that are tested include (1) object attributes in the discipline-specific models; (2) intelligent relationships within a discipline-specific model and between different models in the integrated BIM model; (3) data representation, visualization and access functions; (4) analysis functions that focus on design analysis and model evaluation; and (5) project collaboration and communication functions.

In general, the BIM-server has been found useful for design collaboration in the case study. EDMmodelServer™ is a database that

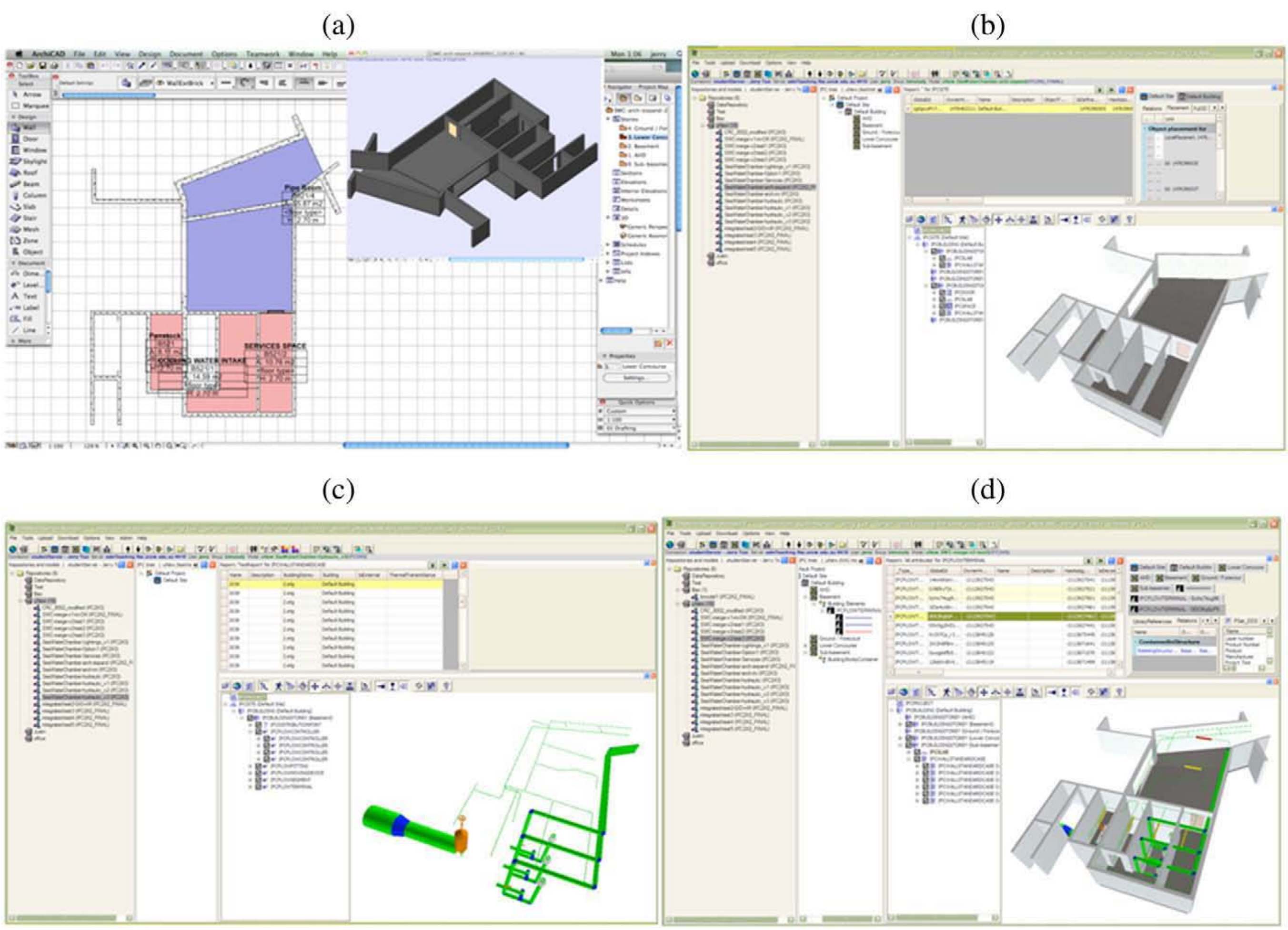

Fig. 4. Models developed for the case study (a) architectural model in ArchiCAD, (b) architectural model uploaded in EDMmodelServer™, (c) hydraulics model uploaded in EDMmodelServer™, and (d) integrated BIM model (architectural, hydraulics and lighting) in EDMmodelServer™.

enables building information to be integrated and shared using IFC controls (Mitchell and Jorgensen 2007). Key aspects of the BIM-server include partial models/views, ad hoc queries, merge function, concurrent usage, team members' rights/security, speed/performance/integrity, version control, transaction processing, audit (user's roles, decisions, and issue tracking), data protection (mirroring/back-up) and storage. The EDMmodelServer™ has well developed features across most of these aspects including data upload, model integration and information extraction such as documentation and report generation. However, some technological and implementation issues are identified during the case study, which are likely to scale up and develop into a major roadblock in adopting the server for more complex projects. These issues are primarily related to:

- Set-up and access to the BIM-server
  The model server allows the definition of access rights and permissions based on participant's roles and responsibilities. In the case study, few participants were involved. Even in the simplified scenario, interventions were required midway through the project and personal meetings were organized to coordinate activities. In a full-scale project, roles and responsibilities are not only likely to increase in complexity, but also overlap. Thus, it will be useful to provide support features to methodologically identify role dependencies and responsibilities, which are critical to the set-up and access to the integrated BIM model.
- Help function and tutorials
  Although the participants in the case studies had some training and familiarity with the BIM-server, during the case study, some difficulties were reported in tool usage and technical support. Though the technology vendor provides a help function in EDMmodelServer™ and a helpdesk is available through email and telephone, participants emphasize the need for improved help functions and tutorials. There were suggestions for open-source training materials where users can learn form each others' experience.
- User interface
  The user interface (UI) of the BIM-server is reported to be complex and confusing. Users, who have extended experience with native disciplinary applications (e.g. CAD tools), find the BIM-server interface non-intuitive. Users from different disciplinary backgrounds such as contractors, facility managers and designers may have different usage patterns, which will require different standard interfaces. Currently, different data and information are shown and limited in one single window. A flexible, user-friendly UI that allows customization to suit different user profiles is required. 3D visualization of the plug-ins for viewing the BIM model is good. However, further tests are required for project with larger data sets.
- Data management and modification
  In the BIM-server, objects and its operations are well defined. However, during model integration, object duplication or model conflict may occur especially when the same object is created in parallel in different discipline-specific models. Data back-up is critical, especially in the likelihood of the crash of the BIM-server. The upgrades of the BIM-server are organized in downloadable modules. If a new version is available, a message from the application provider will notify the users when they login to the server.
- Extended functionalities for project communication
  Some other features and technical requirements reported as wish-lists in an earlier study [13] were reiterate, with most suggestions related to improving project communication. For example, although the BIM-server allows object tagging and change notifications, if an object is tagged on the BIM-server, and the tagged model is downloaded, the tagged message is not downloaded. The user needs to manually check and update the tagged object separately in the native disciplinary model. Flexibility to download the appended project communication records along with the model may be useful. It was also suggested that the BIM-server should provide more synchronous communication features such as an embedded instant messenger for the ease and clarity of project communication.

4.2. Analysis of collaboration platforms in the AEC industry

The analysis includes the examination of existing online collaboration platforms, primarily DMS such as Incite (www.incite.com), Aconex (www.aconex.com), TeamBinder (www.teambinder.com) and Project Centre (www.projectcentre.net), along with inquiries and interviews with the industry partners who have adopted the technologies in their practices. The review was conducted to understand the implementation and application of web-based collaboration platforms in the AEC industry. Such collaborative practices exist within the industry and therefore, they may act as a gauge for using BIM-servers as collaboration platforms. Once again the selection of the particular collaboration platforms did not aim to be inclusive. They were included in the case study to represent typical applications and collaboration scenarios. The analysis suggests the following issues that should be considered when implementing BIM-servers as collaboration platforms in the AEC industry.

- The initial collaboration platform set-up is a complex process. In general, setting up the collaboration platform in a project takes multiple iterations and the DMS provider conducts multiple workshops with the various user groups before the DMS is operational in the project. Fig. 5 shows the flowchart of the typical set-up process adopted at Incite. Various dependencies within the processes and between activities and people need to be identified before the collaboration platform is operational. Even for an experienced team this process of identification of dependencies and setting up the collaboration platform may take up to 3 months and involve multiple travels incurring further cost. The complexity in setting up a BIM-server as a collaboration platform for building project development may be even greater because model-based data exchange will require greater coordination owing to a larger size of the data set, varied file formats and tool compatibility issues. Therefore, any decision support system that may facilitate identification of the dependencies can significantly reduce the cost and time in setting up the collaboration platform.
- There are various levels of DMS usage. In some projects, DMS is used across the entire project lifecycle, involving most of the project participants. In other cases, only some of the project participants coordinate their activities through DMS, or the DMS is used in specific stages only. This scoping of DMS as a collaboration platform is usually conducted at the initial phases of the project. Such scoping is also critical for BIM-server adoption [23].
- In the current practice, a customized project instruction document is generally developed to serve as a guide for the project operation. This ensures that as the project develops and the team dynamics change, key terminologies and standard procedures are agreed and complied by all participants.
- In general, DMS automate the process of uploading, validating, approving and distributing documents. A series of business rules encoded within the applications at the start of the project automate the decision making such as which folder to upload documents to, how to validate the document, who to distribute documents to (based on a distribution matrix), and so on. The inbuilt intelligence in form of business rules and distribution matrix would require knowledge elicitation from project partners.
- Once the protocols are established, the DMS is configured for the project. The administration team and project partners are trained, before the system goes online.
- Training programs are available for all functional levels, from the standard tools that all project teams will use, to the more advanced construction project management tools such as workflows and tender

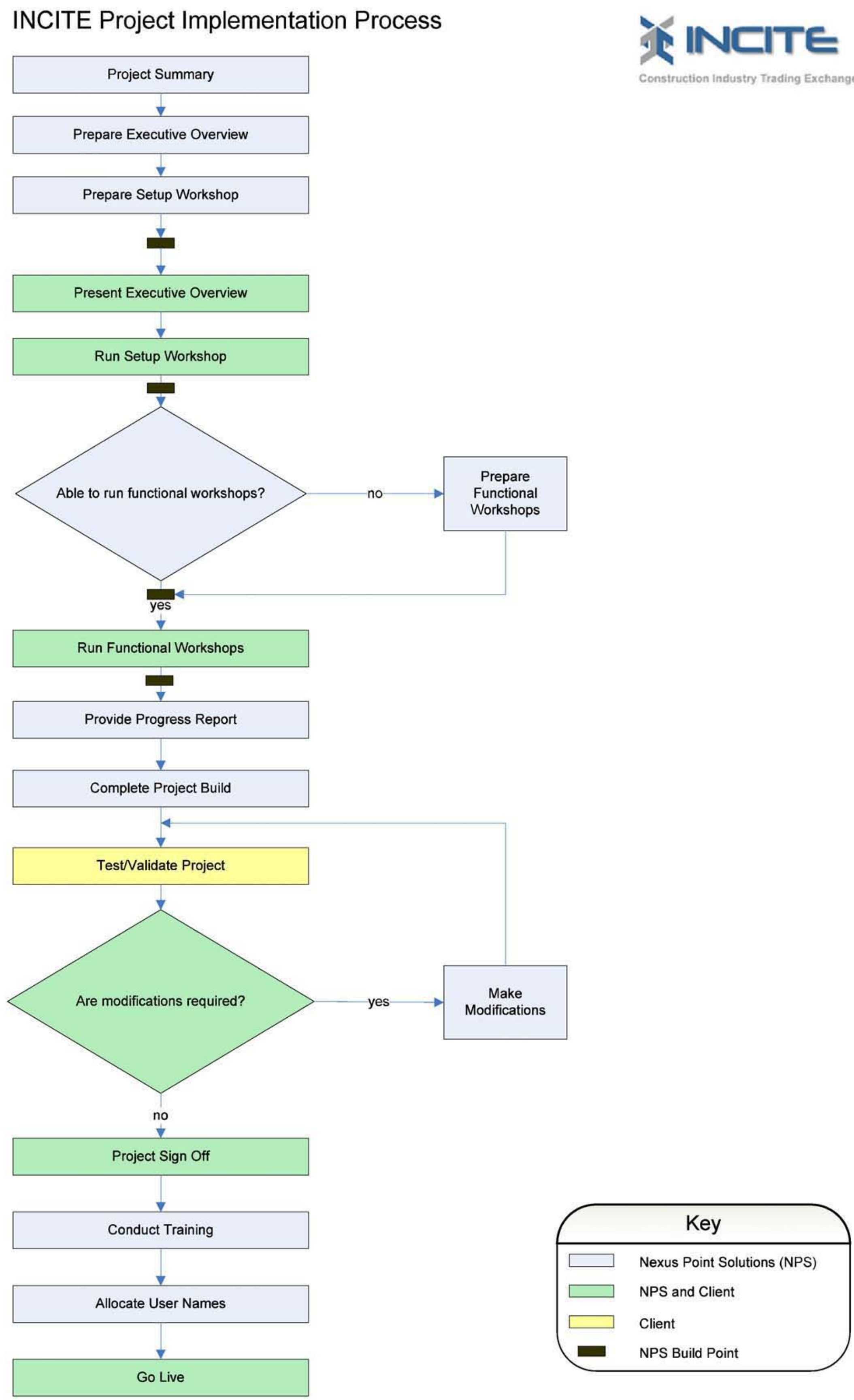

Fig. 5. Incite project management process for setting up the document-based collaboration platform (image copyrights: Incite).

modules. Help is provided in form of manuals, technical support and video demonstrations.
- The project administrator requires in-depth knowledge of the required document flow process as well as basic configurations and user requirements on the DMS. In general, a company administrator is appointed to coordinate with the project administrator and has access rights similar to project administrator.
- Communication is a critical part of all DMS. Most DMS provide multiple modes of communication including instant messages, SMS texts, emails and voice communications. They support both synchronous and asynchronous communications, and are used for multiple purposes, such as direct project communication, documentation, as well as sending notifications, reminders and clarifications.

5. Framework of technical requirements for a BIM-server

Based on the case study and the analysis above, a framework is developed which categorizes the features and technical requirements for BIM-servers as operational technical requirements (OTR) and support technical requirements (STR). Depending on the actual project, there may be overlaps between OTR and STR. This paper argues that the technical features of the BIM-servers should enable technology adoption and usability as much as the technical capabilities, which correspond to the two categories of technical requirements, STR and OTR respectively.

- OTR refers to the features and technical requirements needed during the usage of the BIM-server in direct support for a building project. OTR can be further divided into the following three categories.
  - BIM model management-related requirements: These features and technical requirements are directly related to the storage, operation and maintenance of the BIM model that contains 3D geometries, 2D documents, and other related building information. These correspond to the basic operational requirements of the BIM-server that repeatedly occurred across the FGIs, technology audit and the literature review.
  - Design review-related requirements: These features and technical requirements are specifically related to design review activities, including various functions needed for design visualization and navigation, as well as team communication and interaction. Design review-related issues discussed during the FGI involved both technical and process-related aspects. Therefore, BIM-server technical features of these categories should facilitate both technical and process-related needs of design review.
  - Data security-related requirements: These features and technical requirements are related to network security and the prevention of unauthorized access into the system. Data security was a recurrent theme in the FGI discussions, and hence, an important category of BIM-server technical requirements.
- STR, such as, help menus and FAQs, has been recognized as an integral part of technological tools (Dicks and Lind 1995) and is likely to be critical to technology adoption. In project collaboration tools, such as some of the DMS (e.g. Aconex, Team Binder, Project Centre, and Incite), support features to facilitate the set-up and implementation of the collaboration platforms include assessment matrices, templates, etc. Hence, besides the common support features such as help menus, tutorials, and FAQs for facilitating the usage of the BIM-server, the other important part of STR for a BIM-server includes project decision support features that facilitate and assist the set-up and implementation of the BIM-server for a particular building project.
  It is argued that, analogous to project management tools (for project managers), a BIM management tool (for BIM model/server managers) that implements the BIM project decision framework is a very likely possibility. Such applications may eventuate as plug-ins to existing project management tools, embedded in BIM-servers or be developed as standalone applications. In any of these forms, the project decision support framework functions as a critical STR for BIM-servers.
- BIM-server set-up, implementation and usage assisting requirements: These features and technical requirements refer to the functions that are expected to facilitate and assist the set-up, implementation and usage of the BIM-server. The FGIs discussions and the review of the existing collaboration processes highlighted the need for these requirements. Though these were not explicitly discussed as technical requirements, it is proposed that these features when considered as technical requirements can facilitate the collaboration process and the adoption of BIM-servers as collaboration platforms.

Table 1 illustrates the above classifications with some possible overlaps in between.

Sections 5.1 to 5.4 elaborate on each of the features and technical requirements for a BIM-server that are listed in Table 1.

5.1. BIM model management-related requirements

BIM model management-related requirements consist of further requirements from BIM model organization, Model access and

Table 1
Features and technical requirements for a BIM-server.

Features and technical requirements
(a) BIM model management-related requirements
BIM model organization
Model repository
Nomenclature system editor
Sub-models, and objects with different levels of details
Public and private model spaces
Globally Unique Identifier (GUID) for all object data
Information Delivery Manuals (IDM)-based specifications
Model access and usability
Secured log-in with access rights
Hierarchical model administration structure
Download/upload model, and check- in/ check-out/ check-out with lock
Version lock and archiving
Model viewing options
Documentation and reports
UI
Customizable interface
Online real-time viewing, printing and markups
On-click object property check and modification
(b) Design review-related requirements
Design visualization and navigation
Team communication and interaction
(c) Data security-related requirements
Features supporting confidentiality, integrity, and availability
System security
User authentication
Data security
Access control
Encryption
(d) BIM-server set-up, implementation and usage assisting requirements
Project decision support
Project scoping support
Software tool compatibility matrix
BIM scoping support
Server administration support
System configuration manager
System configuration layout viewer
System status viewer
Help support and training
Legal and contractual support

usability features, and UI. The following sections will give details of each of these categories.

5.1.1. BIM model organization

Features and technical requirements for model management and organization should include the following.

- Model repository: A BIM-server should provide a centralized data repository for the building project. This data repository can be linked to other federated data repositories to increase data capacity and efficiency of the server.
- Hierarchical model structure: A BIM model on a server is organized in a hierarchical structure. For example, at present the model-tree in EDM has the following hierarchy: project>site>building>building storey. However, users may want a different model structure based on their requirements, e.g. a client may want to group projects within a site rather than the other way round, i.e. site>project>building>building storey, and so on. Thus, BIM-servers should support the flexibility to customize the model structure. The BIM model server should support cross-project information exchange, if desired by the client.
- Nomenclature system editor: Features should be provided to support easy edit/rename/modification to nomenclature system mid-way through the project, with appropriate edit rights.
- Sub-models, and objects with different levels of details: the BIM-server should provide the ability to map objects with different levels of details. For example, if the level 1 detail only shows a rectangular volume for a room, the level 2 detail of the same volume may show all the openings, and doors and windows. Users should be able to navigate and switch between the different views through simple functions (toolbars) and shortcut keys. In order to support such functionalities, mapping of objects with different levels of details will be required.
- BIM-server should support the ability to store and present objects of the model as text-based information in repositories, and link 3D object-model with model viewer. Choosing object in one window (text-based model tree or 3D model in model viewer) should highlight the corresponding data in the other window.
- Object and model history, such as ownership and modification records, should be maintained in the data repository.
- Object property: The BIM-server should provide the ability to overlay additional object properties, if customized object property is desired. For example, the quality of survey may not be a default object property. If this is the case, in the BIM-server this can be an overlayed property linked with each object. Technical issues may arise if the data are downloaded and uploaded again. Additional technical measures will be required to deal with such issues.
- Public and private model spaces: The BIM-server should allow differentiation and management of public and private models. Public models are accessible to all users with access rights. Private models could be models in progress, but not ready to be shared with others. However, private models may be shared with a select group of users.
- GUID and IDM: GUID allows each object to be uniquely identified, preventing duplication. IDM details specifications and approaches for connecting the BIM approach with business processes [8]. BIM-servers should enable efficient integration of GUID and IDM to deal with problems encountered in merging different discipline-specific models.

5.1.2. Model access and usability features

Some of the features and technical requirements related to model usability are discussed below.

- Secured log-in with access privileges: it should be possible to import roles and personnel data from information flow dependency matrix generated in the BIM-server set-up phase. See Section 5.4 for details.
- Hierarchical model administration structure: BIM-server administration deals with management and allocation of model access rights, data control and security. Typically, hierarchical administrative structures exist across distributed teams and in large organizations to manage day-to-day local and global issues. Thus, the BIM sever should allow administrative structures that reflect and support existing organizational practices.
- Download/Upload model: Various modes of interaction for model download (upload) are possible to include download (upload) buttons as well as drag and drop options. Ability to download (upload) data straight to (from) an email account, which is possible in existing DMS when dealing with documents, will be useful.
- Check-in/check-out and version lock: Check-in options should allow addition of new partial models or merging with existing models. Again, different modes of interaction are possible to include buttons and drag and drop capabilities. Similarly, check-out options should allow download of complete model or partial model using different modes of interaction. A check-out with lock feature should be provided to notify other users that the checked-out data have been locked and deemed not usable. A version lock feature should be provided to lock version of the model after sign-off, as a form of archiving.
- Model viewing options: The BIM-server should support the ability to capture and save screen shots, which is a standard functionality provided across CAD packages. Other features, such as the option to choose the level of detail for viewing should be available through toolbars and shortcut keys, i.e. sub-sets should be managed such that users can choose the level of detail for viewing by selecting options on a checklist, e.g. conceptual block model, space layout model, etc.
- Documentation and reports: When downloading a part model from BIM-server, there should be options to generate reports on parametric, linked, and external information for selected objects and the other objects in the rest of the model. This information can be in form of a checklist, where users can choose to get details of only those objects they intend to modify, delete or replace. Ideally, a facility to append this information to objects will be helpful, but that would be useless until the native applications can receive those additional data.
- BIM-servers should support the ability to generate and export PDF or other document formats. This capability also allows direct offloading of ready to use information to DMS, in which case some users may not need to access the BIM-server. They can continue interacting with DMS as they have been doing at present.
- BIM-servers should support the ability to integrate information from product libraries. It should be possible to create a comparison report for alternative product options.
- Features should be provided to validate rules while uploading the files on the BIM-server. Users should have the option to switch validation check on or off.
- Technical provisions are required for data ownership transfer and handover in a BIM-server environment. These functionalities should account for security measures to deal with such change of hands, log-ins and passwords.

5.1.3. UI

Other than the standard UI features, the BIM-server interface should include (1) model tree view position and 3D viewer position; (2) support for online real-time viewing, printing and mark-ups; (3) the ability to click on an object, and check what sub-sets it belongs to; and (4) the ability to click on an object, and switch between the sub-sets it belongs to, for another sub-set selection. Users should also be able to customize and choose the available UI functionalities.

5.2. Design review-related requirements

The following basic features and requirements are related to distributed design review.

- Team communication and interaction: Distributed design reviews may require parallel video conferencing and similar interaction media. BIM-servers should be compatible with such technologies

and some basic integration of BIM-servers with these technologies that will be useful for model navigation and viewing. Organizations may want to maintain a record of the design review interactions in the data repository. Thus, BIM-servers should provide the ability to capture real time interaction data from meetings and online reviews. Some of these interaction platforms, such as instant document/ message exchange windows, may be directly hosted on the BIM-server environment.
- Design visualization and navigation: Building projects often result in large data files, which reduce the online navigation and viewing capabilities. Hence, for effective design review across distributed teams, capabilities to create lightweight 3D data are essential. 3D model viewers supported (provided) by BIM-servers should have high data compression capabilities while maintaining the image quality. It will be useful to provide technical features that allow instant, online mark-up, and tagging on a shared document, model or object being viewed by design reviewers and users.

5.3. Data security-related requirements

Security of data on a BIM-server should account for confidentiality, integrity and availability of data. These features and related technical requirements are discussed below.

- Confidentiality: The data stored on the BIM-server should be available to authorised users only, and on the need-to-know basis. This service is crucial to secure sensitive data from malicious intruders.
- Integrity: All BIM data should be only created, modified and deleted by authorised users having an authorised access, and should be a subject to integrity cross checking.
- Availability: Data and services provided by a BIM-server should be available to users when they need them. As BIM-servers have a role of a central data repository serving simultaneously a range of users involved in a project, availability requirements are of greater consequence than in specialised systems.
- System security: The BIM-servers should have user authentication facilities to ensure that only authorised users can access it. The current BIM-servers only partially satisfy the security requirements. While they would typically provide for internal user authentication in form of log-in and password, they fail to provide other forms of authentication. Moreover, if sufficient password management is not put in place, by the system and users alike, such authentication procedures may be regarded as inadequate.
- Data security: BIM-server should provide effective data access control, with access privileges to individual pieces of data, including create, delete, read, write and execute. While access control is typically implemented by the tested BIM-server, it does not provide for fine granularity. It would be desirable for BIM-servers to adopt the Role Based Access Control (RBAC) [29], which is already used by leading Database Management Systems (DBMS). RBAC allocates access privileges to roles, rather than users, which greatly simplifies the privilege management task, especially in such a dynamic environment as BIM. The BIM data should be protected by means of encryption, both when stored on the system and transferred over a network. This feature is available in major DBMS and it should be adopted by BIM-servers.

5.4. BIM set-up, implementation and usage assisting requirements

BIM set-up, implementation and usage assisting requirements consist of further requirements from project decision support, server administration support, help support and training, legal and contractual support. The following sections will give details of each of these categories.

5.4.1. Project decision support

The project decision support consists of three main requirements: (1) project decision support to identify project dependencies in terms of people, processes and resources, (2) software tool compatibility matrix for selection of tools to be used by each collaborating partner contingent on project requirements and technological capabilities and limitations of dependent collaborators, and (3) BIM scoping support to decide on BIM approaches contingent on project requirements and technological capabilities of collaborators.

- Project scoping support: Initially workflow process maps/flowcharts should be developed. Various charts/forms would be a useful way to gather these data from project team members and the client. These should be accessible online through a web-based interface with secured log-in. Users should be able to download the charts/ forms, work offline and upload them when they are filled. Users should be able to save partially filled forms and complete and submit the same in multiple sessions. Once the data are collected, ideally, users should be able to generate dependency matrices [32] automatically, with flexibility to develop these manually in the first instance. Graphical representation of the dependencies for easy comprehension and viewing, and text-based search of required dependency data is desirable. For example, if the user enters an activity such as design review, the viewer should show various dependent activities and people, based on what dependency is being sought to observe. Dependencies can be based on activities, people or resources (tools). Once the dependencies are approved and agreed upon, there should be a feature to allow setting up automated reminders and notifications. These notifications should be sent across the medium of communication preferred by the target user, i.e., sms, fax, email, etc.
- Software tool compatibility matrix is required on the BIM-server, which should be accessible online to provide details of tools in terms of compatibility, data formats and interoperability, and capabilities. A directory of tool experts, and related online tutorials and FAQs can be linked to the matrix. Project partners can coordinate tool selection by applying the matrix.
  A comprehensive knowledge of the available commercial BIM applications and their capabilities in relation to interoperability is important. Tools are constantly evolving and tool compatibility is dynamic. Given that 100% interoperability across the various proprietary tools is unlikely in the near future, knowledge of the degree of compatibility between the different tools will be useful in tool selection. Importing and exporting capabilities from native file formats into other file formats and associated matrices or efficiency indicators would be useful. Import and export efficiency indicators can guide BIM Model Managers' decision making in the early setup stages. Early consideration of tool compatibility will reduce conflicts that typically arise midway through the project. It is also useful to have a summary of conflict resolution strategies between tools, links to online tutorials on tool usage, and contact details of tool experts.
- BIM scoping support: In a typical project there are various levels of roles and associations. Some of the personnel in the project may not have direct access to the BIM-server for various reasons. Also, in order to successfully use the BIM-server as a collaboration platform, it should be possible to receive and upload building information to the BIM-server through media such as email and fax that are preferred by different users. Such technical capability is supported by document-based collaboration platforms, and, hence, similar expectations exist for the BIM-server as a collaboration platform. These requirements enhance the scope of BIM usage in a project. Some technical capabilities such as ability to capture real-time data from site are also important for on-site/ off-site project coordination.

5.4.2. Server administration support

A BIM-server integrates with other tools such as CAD tools, analysis tools, other discipline specific applications, DMS, etc. This integrated system should be flexible enough to configure differently to suit different project requirements.

- System configuration manager should ensure that the system configuration complies with project dependencies, allows interactivity between models, documents and appended information. The system configuration manager should have a customizable UI. It should support rules that regulate the information provided to be suitable for, and easily adopted to meet the requirements of (1) different users including designer, contractor, facility manager, client and so on, (2) different building project life cycles ranging from project identification to bid, start up, design, contract and operate, and (3) different scales of collaborative projects. Synchronous communication, e.g., chat channel, videoconference, and asynchronous communication, e.g., broadcasting and email, should be supported to improve the project communication.
- System configuration layout viewer is required that graphically shows how different types of data are linked. Similarly, system status viewer is required for notification of errors, activities update, update on system performance, and user status, e.g., how many users are logged-in at a given time, who is working on what data, and so on.
- Data change register is required to maintain the history of the changes made to the data.

The administration support should also facilitate report generation, data back-ups and archives, either manually or through a pre-set default value (time or size) for automated activation.

The need for web-enabled BIM-server set-up, implementation and usage assisting requirements can be further argued based on related literature on project and construction management [3,9,22,24,27,31].

5.4.3. Help support and training

Help support and training are critical to the use of the BIM-server as a collaboration platform. Training support varies with the roles and responsibilities of the users. For example, administrator or sub-administrator training needs to be more detailed and intense than that for other users. Various types of training materials and approaches can be used in conjunction such as:

1. Traditional training and support tools that include help menus, FAQs and helpdesk.
2. Open-source training materials such as technical support blogs that maintain threads of earlier complaints and resolution methods reported by other users and experts. Such blogs allow users to learn from each other's experience and are commonly used in open source software development.
3. Project-wiki [18] can be created on the server to share project information and tool usage information.
4. Interactive tutorials such as those already available from various proprietary tools.
5. An expert directory maintained in the tool-compatibility matrix can provide another point of contact for training support.

5.4.4. Legal and contractual support

The model development, reviewing, uploading, downloading, and analysis activities could be quite complex within an integrated BIM-server environment. Specifying ownership, updating liabilities and responsibilities would need careful consideration. A BIM-server use contract agreement is required which should be signed and agreed upon by the project partners at project initiation. Business rules are needed as a technical feature for model management and data organization such as archiving, record keeping, backups, and so on. It should be possible to automatically check if these rules conform to IDM specifications, a comprehensive document that details the approach to using and developing a BIM model. Alternatively, a conflict check feature should be provided to ensure that the business rules generated from IDM do not conflict with the contract agreements.

Among other aspects, the legal and contractual support should ensure that the agreements account for (1) intellectual property agreements and policies for data exchange, (2) classification of public and private data, and (3) correspondence protocols.

6. Conclusions

This paper presents a framework that categorizes and specifies features and technical requirements for a BIM-server to serve as a collaboration platform. This study is not intended to provide a comparison of the different applications. Rather, the goal of this study is to identify the technical features relevant to a multi-disciplinary collaboration platform as reflected across the different applications. As with earlier studies on requirements for collaboration platforms [26,28], this study found that BIM-servers should provide technical features to support information sharing, communication media, process management, exploration space, privacy and flexible system configuration. In addition, this study found that the development of BIM-server technologies should not be limited to functional and operational requirements only because AEC projects are mostly multi-organizational and multi-disciplinary. This implied that among other factors, lack of history and experience, conflicting goals, and varied roles and responsibilities inhibit adoption of groupware technologies. These findings conform to the prior research on group support systems for multi-organizational collaboration [1]. Therefore, apart from the technological capability to support the collaboration requirements of diverse user groups, BIM-servers should also provide adequate supporting features to assist the users in assessing, designing and implementing the BIM approach, contingent on the project requirements. As a result, the developed features and technical requirements have been broadly grouped as operational technical requirements and support technical requirements. Three categories of operational technical requirements: (a) BIM model management-related requirements, (b) design review-related requirements, (c) data security-related requirements, and one category of support technical requirements: (d) the BIM-server set-up implementation and usage assisting requirements are subsequently presented and discussed. This paper argues that the support technical requirements are critical to adoption and enhancement of BIM-server technology. The success of the BIM-server depends on collective adoption by the stakeholders that are expected to participate in the collaboration activities. Based on the contingency theory, it is argued that the collaboration requirements would vary from project to project, and, hence, support technical requirements should be an integral part of the BIM-server development rather than an after thought. Findings from this study will enhance BIM-server research and development to better facilitate the adoption of the technologies, leading to greater intelligent and automated collaboration support in design and construction. The emphasis on support technical requirements and decision support applications, as argued in this paper, may also be applicable to other technologies in AEC industry that may require multi-party usage and project specific customization. Future work may involve refinements of the conceptual framework and further studies to expand the set of technical requirements. This study identifies the set of technical features and requirements but future studies are needed to ascertain the technical specifications for each of the requirements such as file size, meshing resolution, bandwidth, and so on besides investigation into aspects such as a compatibility with mobile devices and wireless environments. This study suggests that as experience with existing applications increases, new sets of technical requirements are created. Therefore, the framework is proposed as an ongoing conceptual approach for technology development and enhancement.

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