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A STUDY OF BIM COLLABORATION REQUIREMENTS AND AVAILABLE FEATURES IN EXISTING MODEL COLLABORATION SYSTEMS

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SUMMARY*: Established collaboration practices in the construction industry are document centric and are challenged by the introduction of Building Information Modelling (BIM). Document management collaboration systems (e.g. Extranets) have significantly improved the document collaboration in recent years; however their capabilities for model collaboration are limited and do not support the complex requirements of BIM collaboration. The construction industry is responding to this situation by adopting emerging model collaboration systems (MCS), such as model servers, with the ability to exploit and reuse information directly from the models to extend the current intra-disciplinary collaboration towards integrated multi-disciplinary collaboration on models. The functions of existing MCSs have evolved from the manufacturing industry and there is no concrete study on how these functions correspond to the requirements of the construction industry, especially with BIM requirements. This research has conducted focus group sessions with major industry disciplines to explore the user requirements for BIM collaboration. The research results have been used to categorise and express the features of existing MCS which are then analysed in selected MCS from a user's perspective. The potential of MCS and the match or gap in user requirements and available model collaboration features is discussed. This study concludes that model collaborative solutions for construction industry users are available in different capacities; however a comprehensive custom built solution is yet to be realized. The research results are useful for construction industry professionals, software developers and researchers involved in exploring collaborative solutions for the construction industry.*

KEYWORDS: *BIM, User requirements, Model Server, Design Collaboration, Model Collaboration Systems*

REFERENCE: *M. T. Shafiq, J. Matthews, S. R. Lockley, A study of BIM collaboration requirements and available features in existing model collaboration systems. Journal of Information Technology in Construction (ITcon), Vol. 18, pg. 148 - 161, http://www.itcon.org/2013/8*

1. INTRODUCTION

The UK Government will require fully collaborative Building Information Models for all public sector projects (with all project and asset information, documentation and data being integrated in a model) as a minimum by 2016 (CabinetOffice, 2011). The current collaboration practices in the UK construction industry are heavily document oriented which are in transition to be transformed towards integrated model centric collaboration to fulfil the BIM collaboration requirements. The available collaboration systems, such as project extranets, have significantly improved document collaboration in recent years; however their capabilities for model collaboration are limited and do not support the complex requirements of BIM collaboration. At present, a wide range of BIM applications are available to create intelligent building information models which has improved the visualization, coordination and management of project life-cycle information in the construction industry. Different industry roles are using BIM tools to create discipline specific building information models, where coordination is limited to visualization and clash detection. However, this situation is improving with the emergence of model collaboration systems (MCS), such as model servers, with the ability to exploit and reuse information directly from the models to extend the current intra-disciplinary collaboration towards multi-disciplinary collaboration. A model server is a type of database system built upon a set of server applications that host model data and allows multiple users to perform collaboration operations on model data using a common platform, (Jørgensen et al., 2008). A BIM hosting model server is expected to facilitate exchange of information in a multi-model environment supporting the various applications involved in a building project life-cycle including design tools, analysis tools, document management systems, facility management tools, and so on (Singh et al., 2011). There are few MCSs available for the construction industry, however their implementation is yet limited because (1) the technology to collaborate in a multi-model environment is still developing along with changing BIM collaboration requirements, (2) the users are not aware of existing model collaboration systems in terms of their potential and applications, and (3) the functionality and performance of MCSs have not been evaluated for the construction industry on real projects.

The functions of existing MCSs have evolved from the manufacturing industry and there is no concrete study on how these functions correspond to the requirements of the construction industry, especially with BIM requirements. This paper attempts to present a critical review and analysis of BIM collaboration requirements and corresponding functions in existing model collaboration systems. The research has categorised BIM collaboration requirements into four domains which are used to define and express the functionalities of existing collaboration systems. Testing and analysis is conducted for 10 existing MCSs reviewing the potential of individual MCSs and an overall availability of collaboration features for the BIM collaboration in the marketed products. The research findings showed that the technology for multi-model collaboration is available in different capacities, however a comprehensive custom built solution is still needed that can fit into the specific characteristics and work practices of the construction industry.

2. METHODOLOGY

User requirement analysis is an essential part of the technology development process and there are literally hundreds of methods used in the software industry to explore, consolidate and validate user requirements. Most commonly surveys or interviews are used to explore user requirements in a domain, by investigating the existing problems and potential needs of users in the functional context of the technology. The implementation of MCSs is limited in the construction industry, and it is very hard to find a suitable number of research subjects for significant results using surveys or one to one interviews. Therefore, this research has adopted participatory appraisal focus group interview sessions to investigate the requirements of three construction industry disciplines (i.e. architectural, general contracting and product manufacturing). Details of the research investigations and findings are presented elsewhere (Shafiq et al., 2012), however an indicative discussion is provided here to understand an overview of key industry requirement domains for BIM collaboration which are derived from the focus group investigations. These requirement domains are used to categorise and analyse the functionalities of existing MCSs according to the methodology described in Liu et al. (2011).

In order to analyse the functions of existing MCSs, four categories of functional requirements are developed from research investigations, which are model content management, model content creation, viewing and reporting, and system administration. These functional requirement domains serve as a base to define and categorise the features and functions of existing MCSs. Only MCSs which offer some functionality in these requirement domains are selected for analysis. A comprehensive desktop audit of existing systems is conducted to analyse their functions. Features and functionalities are audited against the requirement domains and expressed using the notation of "Y" for availability of a feature and "N" for unavailability of a feature in a sample MCS. It should be noted that this research is limited to review the functional availability in the analysed product and has not attempted to examine the performance of different products over similar functions. The analysis of features is concluded by calculating the number of features against a MCS and percentage of completeness of features for all MCSs in the requirement domains. The number of features for a MCS reflects the functional potential of a single product, whilst the percentage of completeness for MCSs reflects the availability of each feature in the market. The analysis is conducted through document audit, research publications, information on vendor websites, industrial reports, and press releases about products and trial use of accessible MCSs to test their functionalities. User requirements were captured in focus groups sessions and then translated in simple use cases which were used to prioritise and rank the user requirements in a follow up workshop. Results of functional analysis and requirement analysis are mapped together to indicate match and gap in user requirements and available collaboration features.

3. INDUSTRY REQUIREMENT FOR BIM COLLABORATION

The industry requirements for BIM collaboration were explored using participatory appraisal (PA) focus group sessions. The aim of these focus group sessions was to identify any problems in the current collaboration systems and explore user requirements for BIM collaboration in the future. Three such focus groups were conducted with an active participation of 7-12 representatives from a large architectural practice, a general contractor and a construction product manufacturer. In addition to these three explorative focus group sessions, an inductive workshop with 9 representatives was carried out which helped to rank the identified use cases in order to understand the user priorities for collaboration features. The research data was recorded, processed and analysed using the methodology described in Krueger (2002). Each discipline represented various roles within their organisation and expressed their views on the existing collaboration practices and their perception of future requirements for BIM collaboration. The focus group discussion revealed a number of concerns in existing collaboration practices which were generally centred towards process, technology and people related issues, as identified in earlier research (Taylor et al., 2009). The participants pointed out that the diversity of existing MCSs, nomenclature and compatibility issues, training and learning curve, controlling the BIM, change and version management in models, ownership and responsibility of model data, intellectual property rights, reliability of model contents and the volatile nature of models and uncertainty of the BIM market inhibit the scope of BIM collaboration (Shafiq et al., 2012).

The focus group investigations also reflected that there is considerable difference between the requirements for collaboration within a single discipline and the collaboration across multiple disciplines; for example, users tend to work and collaborate using their native tools and processes within their specific discipline. It is also observed that the understanding of collaboration features varies among industry users, and largely depends on the adopted modelling approach (e.g. central modelling or federated modelling). Therefore, some of the working tools and processes may not be valid across other disciplines or in different modelling practice. Multi-disciplinary collaboration as a minimum requires a common data format, such as the Industry Foundation Classes (IFC), in order to resolve interpretability problems. So, a multi-model environment will require collaborative supportive from MCSs using IFC and native data formats. Moreover, existing collaboration relies on emails and extranets to exchange project information which works for documents but for model collaboration, a sophisticated common data environment (CDE) is required, as recommended by BS1192 (2007) and PAS1192-2 (2013), that can facilitate and control the collaboration process. A model server or a MCS should provide such a CDE for BIM collaboration which will align model collaboration with the established industry collaboration protocols. The model server should also provide a CDE for multiple users to perform collaboration operations on model data which involves management of users, user requirements and functions that support the user requirements.

4. FUNCTIONAL ANALYSIS OF EXISTING MCS

From a user's point of view, four basic domains have been identified for the functional requirements for multi-disciplinary collaboration on models using a CDE; these domains are model content management, model content creation, viewing and reporting and system administration. These requirement domains are high level categorisations of use cases or user intended tasks for performing a role in the collaboration process which require features or functions of a MCS to support different use cases (Figure 1).

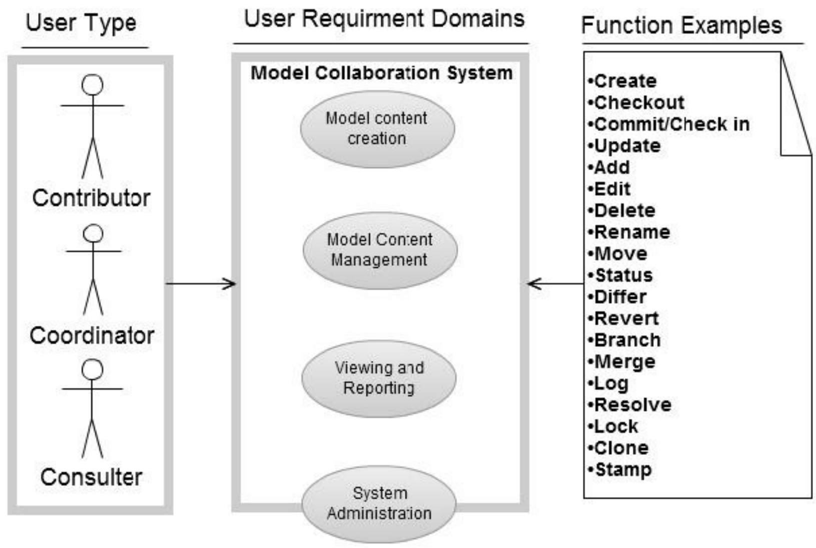

FIG 1: Users and requirement domains in a model collaboration system

The model content management domain reflect the use cases associated with the inter disciplinary collaboration tasks which are required to manage the integrity of a model repository on a MCS (i.e. model server). The users performing content management tasks will be acting as "coordinator" and would have a higher level of access and permissions to operate on model content than other users. Table 1 summarises and explains the identified features associated with the model content management domain.

TABLE 1*: Features associated with model content management*

Feature	**Description**	**Comments**
Model upload / download	Users can upload/download models using the model server/MCS as a collaboration hub	Information repository
Multiple data model formats	Viewing and coordination support for proprietary/native BIM and IFC models.	E.g. Revit, ArchiCAD, IFC
Partial model exchange	Users can exchange partial models or components of shared model	Data check in and check out
Versioning	Version management of shared models and partial models	IFC and native models
Model merging	Merging of partial models into a synchronized model	Geometry and semantics
Data locking	Restricting permissions to work on partial models to control authority and responsibility	Exclusive data check out/check in
Clash Detection	Two or more models can be analyzed to detect clashes between discipline models or different versions of the same model.	Geometry and semantics
Conflict resolution	Ability to manage the coordination workflow for clash resolution, e.g. support for BIM collaboration format (BCF).	Although it will always needs human intervention

Audit trail	Allows users to access the history and version trail of model development to track the authority and accountability of data.	History tracking for ownership
Data publishing	Users can store, share and publish their models for other users according to their authority and responsibility.	Controlled model sharing
Workflow management	Enables users to define and allocate the tasks in a network to execute predefined workflows.	BS1192 support, RFI workflow

The model content creation domain requirements are related to the creation of the information content in a Building Information Model where most of the use cases will be performed by the type of users who are "contributors" and have controlled permissions to work on parts of model. In a collaborative setting, this domain reflects the discipline specific line of development where users can add, delete, edit, modify, rename or update the content of their discipline models using their native modelling tools using reference content from other discipline models which is then synchronised with the central data repository. Model content creation is largely a local operation which may not depend on the functionality of a collaboration platform as long as the model content is not published. However, a collaboration server can support content creation operations to improve the quality of content being created making sure it is suitable for publishing on the central data repository. Table 2 contains the selected features associated with the model content creation domain which a user may expect from a collaboration system.

TABLE 2: *Features associated with model content creation*

Feature	**Description**	**Comments**
Model modifications	Enables users to commit their changes into the consolidated model on the central server.	"Shared model" as per BSS 1192 nomenclature
2D data modelling	This feature provides support to import or export 2D data into the models. This feature provides support for automated data conversion from 2D to 3D and vice versa.	Drawings, PDFs, Excel, Word files
Data querying	Provides support to search, select and filter specific data in a model.	E.g. all doors or windows
Reference data linking	Supports references to data which is not part of BIM	Linking documents, websites etc.
Product libraries support	Provide support for viewing and importing BIM content from product libraries	Commercial and open source product libraries
Model checking	Data validation and verification against pre-defined rules or constraints	E.g. code compliance
Rule-based modelling	Data modelling according to predefined or user defined rules.	Reciprocal of model checking
Model comparison	Enables users to compare two models to identify changes in those models.	Including comparison of different versions
Change management	Notifies and communicates any changes in the central model or relevant working model to users.	

Similarly, the viewing and reporting domain reflects the requirements which are related to review, mark-up and consultation of information in the models. This includes tasks like model/multiple model viewing, navigation/walkthrough, clash detection, colour customization etc. for design discussion, or reporting on a stage gate, or as per client/project requirement. Most of these use cases in this domain belong to a "consulter" who only needs to review or consult the model content. These users can be client representatives or other disciplines which cannot have permission to take the ownership of model content to make any changes, unless a stage gate in the project transfers authority and responsibility of model content. A user may be a "contributor" for an architectural model and a "consulter" for structural or MEP model content and vice versa. Table 3 groups the identified features related to viewing and reporting which a user may expect from a MCS.

The system administration domain reflects the requirements which relate to system, users and data management, for example, user profiling, access control, data backup, security etc. Use case definitions for the administration domain are complex and confusing because it can include use cases from an IT system administration, organisation or project administration standpoint. This study has limited the scope of the administration domain requirements to a project setting, where the role of "system administration" belongs to a BIM manager or project manager. User required features related to system administration while managing the project centric model collaboration are summarised and explained in table 4.

TABLE 3:Features associated with viewing and reporting

Feature	Description	Comments
Remote model viewing	Enables users to view models without downloading to their local machines. Users can overlay and view multiple models in the same geometric space at the same time.	Web supported, online viewing
3D Navigation	Users can navigate and view components of the model in 3D.	Walkthrough support
Mark-up	Users can mark up, comment, audit, and sign off the models or model components.	3D mark-up
Collaborative communication	Users can save a particular model view, assign a task or a discussion and share it with other users.	BCF supported
Report generation	Users can generate different reports from the model data,	E.g. schedule of components
FM data support	Users can generate facility management data for clients at selected project points.	Including COBie data extraction
Colour customization	Users can group objects/components, change colours, or transparency in order to highlight or indicate revisions.	
Workflow reporting	Enables the generation of project management reports at pre-defined intervals.	Daily/monthly progress report
Mobile computing support	Users can view and navigate models on hand-held devices.	Mobile phones, tablet computers

TABLE 4*:* *Features associated with system administration*

Feature	Description	Comments
User profiling	Users are classified hierarchically with suitable authorization to access the collaboration system.	User management
Access control	Multiple users are allocated authority to access models at various levels.	Project management
Data handling	The system can store, retrieve and handle large data for user operations whilst keeping the data integrated and workable.	Multiple project support
Interface customization	Users can customize the working interface according to their requirements. Ease of user interface.	Flexible user interface
Security	Regular checks can be performed on hardware and software components to ensure system and data security.	
Disaster protection	System maintenance and accessibility to avoid system crashes	Data backup
Data archiving	The collaboration system is capable of archiving data for long periods of time.	FM use

4.1 Research sample and results

Several research and commercial projects have led the development of MCSs for the construction industry over the last two decades. Over this period, many collaboration products have emerged and disappeared, e.g. IFC model server (Adachi, 2002); a few have had a stable existence, e.g. Express Data Manager (EDM), Eurostep, ActiveFacility (Jørgensen et al., 2008) ; and many are emerging and gaining success with the uptake of BIM in the industry, e.g. BIMserver (Beetz et al., 2010a). The list of MCS is growing rapidly as BIM tool vendors (e.g., Autodesk, Bentley, Tekla, etc.), and existing commercial extranets (e.g. Asite, 4Projects, etc.) are repositioning to upgrade their services to provide BIM collaboration capabilities. The functions of these products are very diverse and heavily depend on the origin and business logic of the vendor. So, in order to study MCS functionalities, only those MCSs which offer at least some features in all four functional requirement domains, as explained in Tables 1, 2, 3 and 4, have been selected for analysis. Table 5 presents the list of the selected MCSs.

TABLE 5*:* *Selected MCSs*

No	Symbol	Product	Vendor/Developer	Website
1	EDM	EXPRESS Data Manager	Jotne EPM Technology	www.epmtech.jotne.com/
2	SAS	Share a space	Eurostep	www.eurostep.com/
3	AF	ActiveFacility	Active facility	www.ActiveFacility.com/
4	ATW	ArchiCAD Teamwork	Graphisoft	www.graphisoft.com/
5	PW	ProjectWise	Bentley	www.bentley.com/
6	BSvr	BIMserver	BIMserver	bimserver.org/
7	GT	G Team	Gehry Technologies	www.gteam.com/
8	OBS	Onuma BIMstroms	Onuma	bimstorm.com/
9	cBIM	cBIM Manager	Asite	www.asite.com/
10	360	Autodesk® BIM 360 Field	Autodesk	bim360field.com/

The features of these collaboration products have been studied and examined through previous research efforts, white papers, product brochures, reports, vendor websites and use of (free or demo) products for a comparative analysis. The Y or N notation is used to describe the availability of a feature after one by one analysis using the available resources in the selected products. The analysis is presented in table 6, 7, 8 and 9.

TABLE 6: *Analysis of features related to Model content management*

Feature	**EDM**	**SAS**	**AF**	**ATW**	**PW**	**Bsvr**	**GT**	**OBS**	**cBIM**	**360**	**%**
Model upload /download	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Multiple data model formats	Y	Y	Y	N	N	Y	Y	Y	Y	Y	80
Partial model exchange	Y	Y	N	Y	N	Y	N	Y	N	N	50
Versioning	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Model merging	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Data locking	Y	Y	Y	Y	Y	Y	N	N	N	N	40
Clash Detection	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Conflict resolution	Y	Y	Y	Y	Y	Y	N	Y	N	Y	80
Audit trail	Y	Y	N	Y	Y	Y	Y	Y	N	Y	80
Data publishing	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Workflow management	Y	Y	N	Y	Y	N	N	N	Y	Y	60
Total Score	11	11	8	10	9	10	7	9	9	9	
Percentage	100	100	73	90	81	90	63	81	81	81	

TABLE 7: *Analysis of features related to Model content creation*

Feature	**EDM**	**SAS**	**AF**	**ATW**	**PW**	**Bsvr**	**GT**	**OBS**	**cBIM**	**360**	**%**
Model modifications	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
2D data modelling	Y	Y	Y	Y	Y	N	Y	Y	N	Y	80
Data querying	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Reference data linking	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	90
Product libraries support	Y	Y	Y	Y	Y	Y	N	N	N	N	60
Model checking	Y	Y	Y	Y	N	Y	N	N	N	N	50
Rule-based modelling	Y	Y	Y	N	N	Y	N	N	N	N	40
Model comparison	Y	Y	N	Y	Y	Y	N	Y	Y	N	80
Change management	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	90
Total Score	9	9	8	8	7	8	5	6	3	5	
Percentage	100	100	89	89	78	89	55	67	33	55	

TABLE 8: *Analysis of features related to viewing and reporting*

Feature	EDM	SAS	AF	ATW	PW	Bsvr	GT	OBS	cBIM	360	%
Remote model viewing	N	N	Y	N	Y	N	Y	Y	N	Y	50
3D Navigation	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Mark-up	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	90
Collaborative communication	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Report generation	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
FM data support	Y	Y	Y	Y	Y	Y	Y	Y	N	N	80
Colour customization	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Workflow reporting	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Mobile computing support	N	N	Y	Y	Y	N	Y	Y	Y	Y	70
Total Score	7	7	9	8	9	6	9	9	7	8	
Percentage	78	78	100	89	100	67	100	100	78	89	

TABLE 9: *Analysis of features related to system administration*

Feature	EDM	SAS	AF	ATW	PW	Bsvr	GT	OBS	cBIM	360	%
User profiling	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	100
Access control	Y	Y	N	Y	Y	Y	Y	N	N	Y	70
Data handling	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	90
Interface customization	N	Y	N	N	N	Y	Y	Y	N	Y	50
Security	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	90
Disaster protection	Y	Y	Y	Y	Y	N	N	Y	Y	Y	80
Data archiving	Y	Y	Y	Y	N	N	Y	Y	Y	N	70
Total Score	6	7	5	6	5	3	6	6	5	6	
Percentage	85	100	71	85	71	42	85	85	71	85	

4.2 Analysis and discussion of results

The score and percentage calculated for a product along the columns reflects the efficiency and availability of collaboration features in a requirement domain in that particular MCS, while the percentage calculated along the rows shows the availability of a feature across all MCSs in the market. The analysis presented in table 6, 7, 8 and 9 shows that the technology is available in some form, but it is still developing to fully support the requirements of model centric collaboration in the construction industry. Only a few collaboration features are delivered 100% in the user requirement domains, whilst the remainder are partially delivered, under development, or ignored by some vendors, mainly because of less demand by the users.

4.2.1 Efficiency of MCSs by the requirement domains

Jotne EDM and Eurostep share-a-space are identified as the most potent MCSs as they have scored the highest percentages for the most number of features in all four requirement domains of BIM collaboration. Despite its technical capability, EDM adoption is limited within the construction industry because the full range of EDM features is not available within a single product. EDM is delivered in a series of products and licences for the full series is costly. The functionality and flexibility is compromised in EDM products with partial use of their product range (Taylor et al., 2009), so the cost and complexity issues make it difficult to adopt for small and medium enterprises (SMEs). Eurostep has addressed these problems in their collaboration solution, i.e. share-a-space, as it can be customised to fit into the SMEs cost and hardware requirements without much compromise on the functionality of the system. But in practice, it is adopted in large companies and projects which involve cross industry collaboration, as it requires expert users to efficiently implement and execute the collaboration operations with this MCS. ActiveFacility has 100% availability of viewing and reporting features, and has scored a good percentage in the rest of the collaboration features which relate to exchanges between the client and other design disciplines. This is because ActiveFacility manages the data for the client from a facility management point of view, which is their core business case. Therefore the features associated with data coordination within different disciplines (e.g. model comparison, workflow management etc), are only partially available or absent in ActiveFacility. ArchiCAD Teamwork is supported by Graphisoft BIM Server and has scored well in a number of features in all four domains. However the implementation of Teamwork is restricted to the native model format of ArchiCAD. Bentley ProjectWise has addressed this limitation and it provides collaboration support for documents, files and models using multiple file formats and data models including IFC. Bentley has been an advocate of federated modelling (Bentley and Workman, 2003), and their collaboration solution reflects this, which is gaining attention as the industry is moving towards BIG BIM (Jernigan, 2008), despite the expensive product licences. BIMserver has evolved from academic research efforts (Beetz et al., 2010b) providing IFC supported collaboration features using a open source platform. BIMserver is becoming popular as it is free of cost and does not restrict collaboration to proprietary data formats; however its implementation in the industry is still experimental, due to low system administration support, a complex user interface, installation prerequisites and a lack of IFC implementation within the industry. There is also an emerging wave of new cloud hosted commercial MCSs which are focused on providing viewing and navigation capabilities, for example GT, cBIM, and BIM 360. Collaboration features in these products are built around the viewing and reporting requirement domain, mainly because of the growing need for model sharing with clients due to increasing BIM obligations. GT and BIM 360 are cloud hosted collaboration services which are expected to be the future collaborative environment; however the functional range of these products is still in an experimental stage.

4.2.2 Availability of collaboration features across all MCSs in the market

It is evident from the analysis that there are several features which are available to the users in all of the selected MCSs, which make those features a must have or basic feature required for model collaboration at all levels. In the content management domain, model hosting, sharing, model merging and versioning have emerged as core features with 100% availability in all MCSs. Despite the vendor's claim of availability of these features, the usability of a feature is subject to how users define and implement it in real time situations. For example, model merging is very complex if performed on geometric and semantic levels using deep comparison of properties (Nour, 2007). However, most of the MCSs claim that they do model merging, but this is a basic geometric fusion to create a composite model by overlaying various components or by shallow comparison of Globally Unique Identifiers (GUIDs) and object attributes, (Beetz et al., 2010b).

Similarly, the requirements of model content creation are technically difficult to deliver due to interpretability issues and lack of IFC implementation in the industry, as most of these features involve the translation of proprietary data into IFC and vice versa (Weise et al., 2004). The data loss in IFC round tripping has been a big challenge, but new solutions are emerging to overcome these difficulties (Berlo et al., 2012). Alongside the technical challenges, industry and research support is required to deliver some of the features related to the model content creation requirements. For example, the collaborative support for the use of product libraries depends on the effective development and accessibility of product libraries in open standards (i.e. IFC). The results in Table 8 demonstrate that the features associated with model viewing and reporting are most comprehensively claimed to be available by all of the selected systems. This can be attributed to the growing demand from clients and governments in response to increased understanding of the potential of BIM for facility management. The UK government has mandated fully collaborative BIM by 2016 on all public sector projects (CabinetOffice, 2011) and has already announced the requirement for COBie deliverables (CabinetOffice, 2012), which has catalyzed the development of model viewing and reporting features in existing MCSs. Most of the analyzed products are built around model servers which are capable of handling large product data and multiple user access; therefore these two features are delivered 100% in the presented analysis of the system administration requirements domain in Table 9. However, the system administration features highly depend on the vendor's orientation, business model and product type, but all MCSs should provide low cost, secure and accessible solutions for the wider adoption of MCSs in the construction industry.

4.2.3 User requirements satisfaction

As explained earlier, the industry requirements for BIM collaboration were investigated though three focus group sessions, which helped to express and analyse the requirement domains and functions in existing model collaboration solutions. A fourth focus group workshop was conducted with 9 participants representing a client, consultants, contractors, technology developers and research roles in construction organisations. This inductive workshop captured user priorities and ranking of collaborative features in a MCS. A total of 50 use cases in all four requirement domains were presented on cards to users and each user was given 500 in monopoly money to place on each use case card (Figure 2). The idea was to capture the financial drivers for product developers, by asking users how much they would like to invest on a particular collaboration function.

The data collected in this workshop was coded back into the model collaboration features in the four requirement domains, as explained in table 1, 2, 3 and 4. Use cases associated with the same function were grouped and scores given to each use case card were added up to provide a final user given score for a model collaboration feature. The user given score against a collaboration feature was mapped against the availability of that feature in the market, which reflects the match or gap in the delivery of user requirements for model collaboration. Table 10 summarises the results of the user evaluation and availability of a feature in existing model collaboration systems.

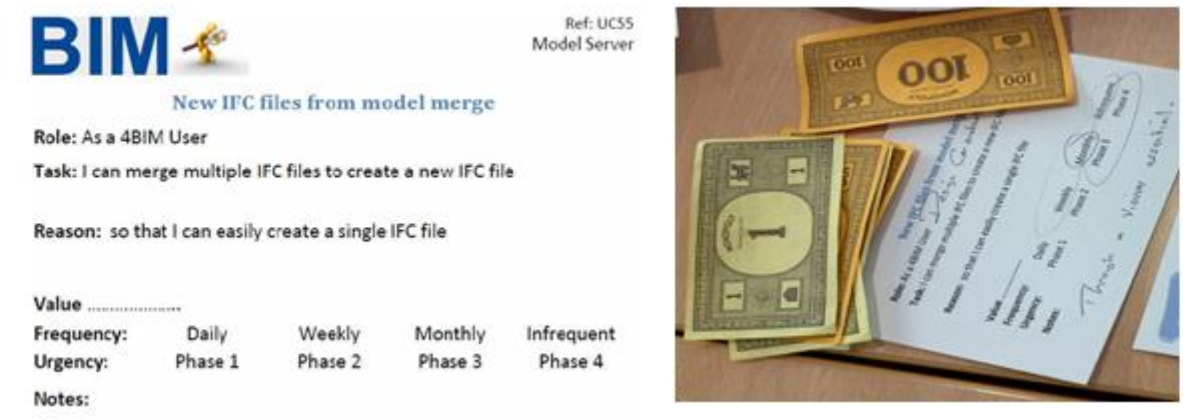

FIG 2: Sample of requirement analysis cards and user score capturing

TABLE 10: *Mapping of user priorities and availability of collaboration features*

MCS feature	User given score	Feature Availability
Interface customization	400	50 %
Multiple data model support	314	80%
Model merging	313	100%
3D Navigation	286	100%
FM data support	207	80%
Partial model exchange	150	50%
Workflow management	111	60%
Collaborative communication	65	100%

Model comparison	35	80%
Conflict resolution	30	80%
Reference data linking	30	90%
Model checking	30	50%
Security	30	90%
Mobile computing support	20	70%
Mark up	14	90%
Colour customization	11	100%
Data querying	10	100%

The correlation in user score and availability of collaboration features suggests that these features are accepted as core functions of model collaboration and all the analysed MCSs provide support for these features. Model merging and 3D navigation have emerged as the most wanted features by users which are also available in existing MCSs. However some systems provide these services better than others, which is not considered in this research, as the efficiency of a product is subject to a user specific utilization on a task, which will differ across users. Multiple data model support and FM data extractions have gained high scores from users and their availability in analysed products is fairly good and rapidly growing because of increasing mandatory BIM requirements, e.g., COBie (CabinetOffice, 2011). The divergences in user requirements and collaboration features is due to the varied nature of collaboration products and uneven user circumstances in different markets which drives the business case for software vendors. Users have given the highest score to "interface customisation" features as complexity of the user interface is a major issue in mastering new collaboration platforms. The diverse nature of collaboration systems, nomenclature and compatibility issues and the learning curve associated with adopting a new collaboration platform, are also contributing factors (Shafiq et al., 2012). In addition, some basic functions of collaboration platforms (partial model exchange, model checking, and model comparison etc) have not scored well on user charts which is mainly because of a lack of user awareness about the potential of model collaboration systems.

It can be observed that the functions which have shown 100% availability in the analysis have gained average or low user attention in the scoring process. This is because users tend to consider these functions as guaranteed and already available to them, for example collaborative communication, mark-up, data querying etc. On the other hand, user focus has been on the functions which are associated with increasing demand by governments and clients (e.g. viewing and FM related functions). User requirements and collaboration functions are subjective and are changing rapidly with BIM uptake and technology developments. For example, mobile computing support is becoming an extremely valuable collaboration tool which will appear in all MCSs in near future. Analysis of the collaboration features in current MCSs is a moving target as these systems are rapidly developing and respective collaboration features are constantly evolving in response to increasing business opportunities as the industry matures in BIM collaboration. The analysis of marketed features of MCSs provides evidence that model collaborative solutions for construction industry users are available in different capacities, however a comprehensive custom built solution is yet to be realised, especially to support the requirements of BIM collaboration integrated with established industry standards.

5. LIMITATIONS AND FUTURE WORK

This research has explored the industry requirements for BIM collaboration and potential of existing model collaboration systems. Collaboration functions and associated features have been analysed from a user's perspective. Therefore the findings of this research are useful for construction industry professionals in order to understand the tasks associated with model collaboration and available solutions in the market. A review of user requirements will help software developers to realise the potential of further developments in their products in comparison with their competitors. However, the functional analysis presented in this research is based on the trial use of the products, material disclosed by the developers and previous research publications. Therefore, an experimental inquiry using full product features may be needed on a case study to assess the actual capacity of the analysed collaboration products. A wide range of collaboration products are available in the market, so selecting a representative sample was difficult, therefore only those products which offer some functionality in all four domains of user requirements were analysed. It was noted that the product developers, and construction industry users, define collaboration functions on various levels, depending upon their technical maturity and the usefulness of a function for their business model. Therefore, this research has considered a non-technical stance on defining collaboration functions, so that an average construction user can understand it. Moreover, product developers are facing large markets, competition and rapid growth in technology, which usually results in products which are loaded with complex functions which work well for marketing, but are hardly needed by users. In addition, construction markets around the world have different characteristics with a variety of users and changing requirements which makes it difficult to generalise user requirements. In the future, the research will adopt a use case approach to capture project-based BIM collaboration workflows, which will provide a detailed investigation of industry requirements and system provisions for a model server enabled collaboration of building information models.

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