Collaborative BIM in the cloud and the communication tools to support it

COLLABORATIVE BIM IN THE CLOUD AND THE COMMUNICATION TOOLS TO SUPPORT IT

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ABSTRACT

Process in the AEC industry is characterised by the distributed and temporary nature of project teams; discipline specific teams engage in a highly collaborative process with not yet fully standardised requirements for information exchange which often results in chaotic communication patterns. This collaborative process makes communication and coordination challenging and intensifies the need for sophisticated software tools.

Efforts to address some of the UK construction industry's problems have seen rapid acceleration of BIM adoption in recent years. The exchange of interoperable building information models across teams provides the opportunity for an improved communication paradigm, where the "structured model" rather than the "document" acts as the focal unit of communication. Since collaborators are geographically distributed, this communication type finds its natural environment in online collaboration platforms hosting building information models.

Effective collaboration requires coordinated communication and communicated coordination. BIM can be expressed as the "language of construction" and requires structure and standardization even on the human communication level. The life-cycle approach will pose additional collaboration requirements. Integrated, intuitive communication tools for BIM should replace e-mail.

A preliminary analysis of data from the usage of online collaboration software, including network graph representations, provides some insight into usage patterns and serves as a basis for similar analyses as more of project data becomes available. Improved results would come from a better designed analysis of more projects.

Keywords
BIM, cloud collaboration, requirements, usage data analysis, network graphs

1. INTRODUCTION

1.1 Background

The Architecture, Engineering and Construction (AEC) industry is characterized by project specificity and project-led nature, long product lifespan and low levels of standardisation in products and processes. These traits have made achieving productivity in the industry very challenging and have led to minimal profit margins and adversarial relationships. In turn, such issues have contributed to low levels of innovation, a guarded approach to the uptake of Information and Communication Technologies (ICT) and Lifecycle Management.

Despite the realisation of these systemic problems in the UK industry (Egan, 1998; Wolstenholme, 2009), efforts for their resolution have not been entirely successful due to compounding issues such as lack of government legislation, non-collaborative spirit, insufficient mobilisation, non-comprehensive implementation plans and lack of protocols.

1.2 State of BIM adoption in the UK

The government decision to mandate BIM Level 2 for public sector projects by 2016 seems to have addressed the factors above. Signs (Waterhouse and Philp, 2013) indicate that a significant proportion of the industry have realized the value in utilizing BIM technology and are looking at defining their role within the BIM process. In parallel with the drive created by government BIM requirements, organised governmental bodies are developing a BIM adoption and implementation framework in the form of standards, protocols and process tools (Demand Matrices, Employers Information Requirements, Digital Plans of Work etc.) (BSI, 2013).

It is widely acknowledged that, despite the benefits of Level 2 BIM, the most significant change will come with adoption of Level 3, collaborative BIM (BSI, 2011). It is often quoted that Level 3 will represent a paradigm shift requiring re-engineering of the process and mind-set within the industry. An adoption and implementation framework, equivalent to that of Level 2 does not yet exist. One of the major differences between Level 2 and Level 3 BIM is the use of a "collaborative model server" (BSI, 2011). The use of online collaboration platforms for hosting a central model is a solution for this BIM maturity step. The challenge remains to place the structured, integrated building information model as the focal unit of communication.

1.3 Outline of paper

The literature review studies concepts relevant to BIM and factors driving emerging requirements in process and software. The software-related review studies the manifestation of these concepts within software tools and draws out unaddressed requirements. Reference to relevant UK and international standards is made throughout. The preliminary data analysis uses data from five projects using an online collaboration platform to produce statistics on selected measures as well as network graph representations. Some preliminary observations are made and the utility of the analysis is evaluated before providing recommendations for improving similar analyses in the future.

2. LITERATURE REVIEW

2.1 Prerequisites for collaboration

Collaboration is a reciprocal process which assumes common objectives and involves sharing of resources and knowledge (Son et al. 2011). In practice, collaborating actors will work "in their own particular ways…whilst being able to communicate with the others" hence "…effective collaboration can only be achieved through effective coordination and communication" (Isikdag and Underwood, 2010). The necessity for a common understanding and coordinated ways of working is the basis for standards such as PAS 1192-2:2013 (BSI, 2013).

2.1.1 Communication

2.1.2.1 Classifying communication

Communication is the exchange of information between two or more different entities. Communication within construction ICT systems can be classified according to; formality and structure, purpose (e.g. RFI, RPQ, query on scheduled time or geometry), project phase context (design, construction or operation), reference/locus (to a document or a model) and level of integration within virtual environment ("not all information on a project will be originated, exchanged or managed in a BIM format" (BSI, 2013))

2.1.2.2 Measuring communication

Communication can be observed, tracked, evaluated (Becerik and Pollalis, (2006)) and quantified more distinctly and effectively than collaboration can be. Tribelsky and Sacks (2006) have developed and implemented performance indices for information flow. These have been adopted by others such as Manzione et. al (2011) and Demian and Walters (2013).

2.1.2.3 Depicting communication patterns

A communication pattern demonstrates common characteristics amongst communications. Process maps are used as the delineators of interactions between actors. For example, BS ISO 29481-2:2012 "provides a process context for information flow", formalizing the description of communication patterns hence fostering a common understanding around them. Alternatively, communication patterns can also be represented in network graphs (Pryke, 2013). Such representations can reveal different characteristics of communication patterns such as directionality, centrality of actors, network density, sequence, communication intensity and clustering (grouping) between actors.

2.1.2 Coordination

Coordination can be generally understood as "the orderly arrangement of group effort, to provide unity of action in the pursuit of a common purpose" (Mooney,1947). Isikdag and Underwood (2010) designate BIM coordination issues as versioning, data ownership, model breakdown, information consistency, workflow management and conflict management. Studies such as Goes and Santos (2011) and Sawhney and Maheswari (2013) demonstrate the utility of BIM technology in design coordination. Within online collaboration (Asite, 2013) coordination relates to scheduling, user action, user responsibility, model versioning and spatial co-ordination of models (clash detection).

2.1.3 Non-decomposability of collaboration tasks

BS ISO 29481-2:2012 (BSI, 2012) states that "coordination is dependent on communication, which should be well structured, unambiguous, explicit, and prompt." It is argued that coordination and communication tasks within a collaborative BIM process can never be understood as entirely distinct since every effective coordination task requires communication to take effect and every effective communication task requires coordination.

2.2 BIM as the "language of construction"

Coates et al. (2010) expressed BIM as the language of construction. It is proposed that this provides a useful metaphor as it portrays BIM as the primary communication medium for construction, hence highlighting the need for all communication processes within BIM to be as integrated as possible. El-Diraby (2012) notes that construction informatics are by nature "tied to linguistics and human communication". Succar (2009) creates a concept-rich ontology, providing a language principally for BIM research and adoption but less so for BIM practice. This idea can be extended to an international level; NIBS (NIST, 2007) describes the evolution of terminology-related standards across countries while Mondrup (2012) maps Danish and Swedish BIM standards, illustrating that BIM should be an international language. It is not suggested that an adequate universal terminology for objects or a set of ontologies (Beetz et al. (2008)) would deliver a comprehensive "language of construction". Rather, they represent a part of many communication dimensions in this "language".

2.3 The need for structure: protocols and standards

Continuing the metaphor, just like a written language needs grammar, a set of structural rules, to be an effective and universal medium for communication, the collaborative BIM process requires structure through protocols and standards to be an effective medium of communication. The need for interoperability, which can be thought of as a measure of communication effectiveness in BIM, spans from technology to culture (Cerovsek, 2011).While on the technological level, structure and standardization are clearly important, on the human communication level, especially in inter-organisational collaboration, they are often unacknowledged and difficult or unnatural to adhere to.

Aouad and Lee (2005) criticize the traditionally unstructured information in construction projects. Yeomans (2005) illustrates the importance of protocols, especially for multi-disciplinary collaboration. Shelbourn et al. (2005) explain that "it is vital to lay down ground rules for communication so that mechanisms and the need for communication are understood by project participants, and that the communication occurs in a structured and consistent manner." Grilo and Goncalves (2011) explain how Cloud computing in combination with BIM will transform e-procurement by enabling the mapping of "traditional unstructured information into structured objects" hence generating interoperability.

2.4 The life-cycle approach and its communication and coordination requirements

Time is one of the primary dimensions of BIM. The life-cycle approach imposes additional communication requirements. Inter-phase communication will support what Succar (2009) describes as the "phase-less workflow". COBie UK (Cabinet Office, 2013) provides a tool for structured, inter and intra-phase communication and coordination. The UK Government Soft Landings Policy (Cabinet Office, 2012) aims to bridge the disconnect between design-construction and operation by using BIM as a communication medium for client engagement .The "Employers Information Requirements" (EIR) template (BSI, 2013) is a form of a formal, structured, asynchronous, non-model based communication tool which enables better lifecycle management of information by instigating early definition of the employer's information requirements.

3. SOFTWARE RELATED REVIEW

3.1 The intrinsic difference between Machine-based and Cloud-based tools

Due to the geographic distribution of construction project teams, BIM finds its natural environment in the Cloud. Level 3 BIM (BSI, 2011) requires integrated working around a central model hence posing the need for Cloud working. Underwood and Isikdag (2010) point out that "Cloud computing will enable the next generation of "full state BIMs" where the "digital building model will evolve through the lifecycle of the building".

A brief overview of the functionalities offered by main software vendors reveals that coordination and communication naturally belong to the Cloud. The criticality of communication tools and their suitability to web-based services has been recognized by early BIM implementers (Jernigan, 2007). Nevertheless, an overview of marketed UK OCP functionalities by Liu et al. (2011) revealed that Communication was markedly the least satisfied category of tools compared to System Administration, Document Management and Workflow Management.

3.2 Requirements from a communication tool

Yeomans (2005) exposed the practical implementation issues of OCP communication tools; lack of immediacy compared to human interaction, difficulty in use compared to e-mail, lack of clarity on appropriate receivers of information and information overload. Jernigan (2007) recommended date-stamping, real-time chat and whiteboards. Coates et al. (2010) recommend linking BIM to "real world capture and feedback and customer feedback technologies". Kim et al (2011) proposed the integration of BIM with social media for more open contribution to the design, hence calling for additional, non-conventional communication channels. Son et al. (2011) use social network analysis to demonstrate the importance of inter-personal familiarity in collaboration effectiveness. This is in accord with Bertelsen (2003) who describes the construction project as a "transient social system". It is proposed that the online collaboration experience should foster a level of transparency by exposing information necessary for collaborator familiarity e.g. user profiles. Singh (2011) call for a more integrated experience, the ability to record communication as well as proposing instant messenger functionality. Shafiq (2012) reveals user requirements for "formal and informal communication channels as well as "static viewing of information in different reports generated from a model".

3.2.1 E-mail is the wrong medium

The inappropriateness of e-mail to serve as the communication tool for BIM has been noted by various studies. Nitithamoyong and Skibniewski (2004) recommend conferencing, whiteboard and threaded discussions. Liu et al. (2011) reveal that instant messenger functionality is only offered by 7% of examined OCPs. Shafiq (2012) warns that "email is the wrong medium" while Demian and Walters (2013) show that despite contradicting impressions on e-mail, it remains highly relied upon.

3.3 Model-centric approach vs. document-centric approach

A number of studies have called upon the need for collaboration to depart from the document-based paradigm and place the structured model as the focal unit of communication. Aouad and Lee (2005) have critically described project information as "unstructured and document based". Yeomans (2006) revealed that the "single build model" was the least adopted out of eight collaborative working techniques. In their ICT Vision mapping, Rezgui and Zarli (2006) suggest that document-centric information exchange should be replaced by model-based ICT. Succar (2009) describes progression in BIM maturity by replacing document-based workflows; Isikdag and Underwood (2010) claim that "the traditional nature of the industry is extremely 'document-centric'" while Shafiq et. al (2012) note that "drawing is the currency".

3.4 Integration between model and associated documents and processes

Integration between the building information model with the associated documents, the collaborating actors and supporting communication tools should always be sought after. A spectrum of integration can be understood which ranges from (1) environments of complete lack of integration; where there is inter-relatedness between objects in reality but it's not facilitated by the software platform to (2) partial integration where linkages like tags facilitate the associations to (3) real integration, where information can flow automatically. Integration is significant both from an information management/data fidelity perspective and a user-experience perspective. Real integration will enable what (Rezgui and Zarli, 2006) describe as the transition from "file-based exchange" to "flexible interoperability".

3.5 Learning from PDM/PLM

An examination of a leading Product Lifecycle (or Data) Management tool (Siemens, 2013) reveals a significantly higher level of integration. PLM/PDM software offers improved communication experiences where users are can be connect and chat through social network-style profiles, disclosing their experience and expertise. The, inherently more standardized, manufacturing industry is exploring benefits of higher interoperability such as Knowledge Management.

3.6 Summary of proposals

The proposals put forward in the reviews are identified below:

(a) The model should be placed at the centre of communication (3.3)

(b) The model should be as integrated with associated documents and processes as possible (3.4)

(c) Communication and coordination for effective collaboration cannot be performed distinctly (2.1.3)

(d) Information exchange at the human communication level will benefit from standardization (2.3)

(e) OCPs should provide informal communication channels and foster user familiarity (3.4, 3.5)

4. PRELIMINARY DATA ANALYSIS

4.1 Source of data and limitations

The data analysed was extracted from online "Workspaces" in Asite, an Online Collaboration Platform (Asite, 2013). The specific data sources were (1) Document Listings: listing all the documents, drawings and models hosted within the workspace and the associated fields (2) Comment Listings: listing all the comments made upon uploaded documents, drawings and models, and (3) Document Distribution Reports: listing all the Actions distributed (i.e. delegated or disseminated) by users to other users with reference to a specific document, drawing or model. Data from five projects are compared. Those five projects were selected based on their varying degrees to which BIM was utilised and availability of the data (i.e. mix of convenience and stratified sampling). The identity of the projects is not disclosed and ethical research protocols of the industry and academic research partners were followed. It should be acknowledged that only the actions, documents and communication performed through the three data source types were analysed. Other forms of communication such as RFIs, e-mails, physical meetings, telephone communication have not been analysed.

4.2 Project context and usage statistics summary

Table 1 summarises data from the workspace usage selected as relevant to the above proposals (3.6).

Table 1: Summary of Project Workspace Data: Project Context and Usage Statistics

		Project 1	Project 2	Project 3	Project 4	Project 5
Contract type		Design and Build	Design and Build	Design and Build	Design and Build	Design and Build
Level of project completion		Construction 80% complete	Complete	Complete	Complete	Detail Design
Collaborating organisations (approx.)		30	40	30	30	10
Collaborating individuals (approx.)		70	80	80	60	30
Software Configuration: Model coordination method, BIM applied?		Separate software for BIM model coordination. Email for communicating model coordination	Design coordinated through physical meetings. Partly paper-based.	Design coordinated through physical meetings. Partly paper-based.	No 3D models used	No 3D models used
No. file formats	**Total**	8	16	16	11	2
	2D drawing	1	1	1	1	1
	3D (including IFC?)	3 (yes)	3 (yes)	5 (no)	0 (-)	0 (-)
No. Comments (approx.)		1300	5700	2300	1300	170
Contractor comment share (or Land Developer for project 4)		71%	57%	34%	85% (developer)	83%
Architect comments share		19%	8%	21%	4%	16%
Engineer comments share		8%	6%	24%	2%	1%
Comments per 2D drawing or document (total 2D docs(approx.))		0.88 (1470)	0.87 (6230)	1.28 (2030)	0.20 (6240)	0.54 (510)
Comments per 3D model (total 3D models)		0.1 (20)	0.39 (23)	0 (15)	- (0)	- (0)
Revisions per 2D drawing or document		2.20	2.25	1.88	1.88	1.44
Revisions per 3D model		4.50	1.96	1.80	-	-
Average commenting "lag"* in days (standard deviation)		21 (23)	45 (77)	45 (71)	14 (34)	4 (11)

*(*Days between when a document/drawing/model was published and when a comment was made)*

4.3 Action Distribution Networks

Pryke (2013) identifies contractual conditions networks, performance incentive networks and information exchange networks as the most common types of networks in construction. The graphs presented below represent Action Distribution Networks.

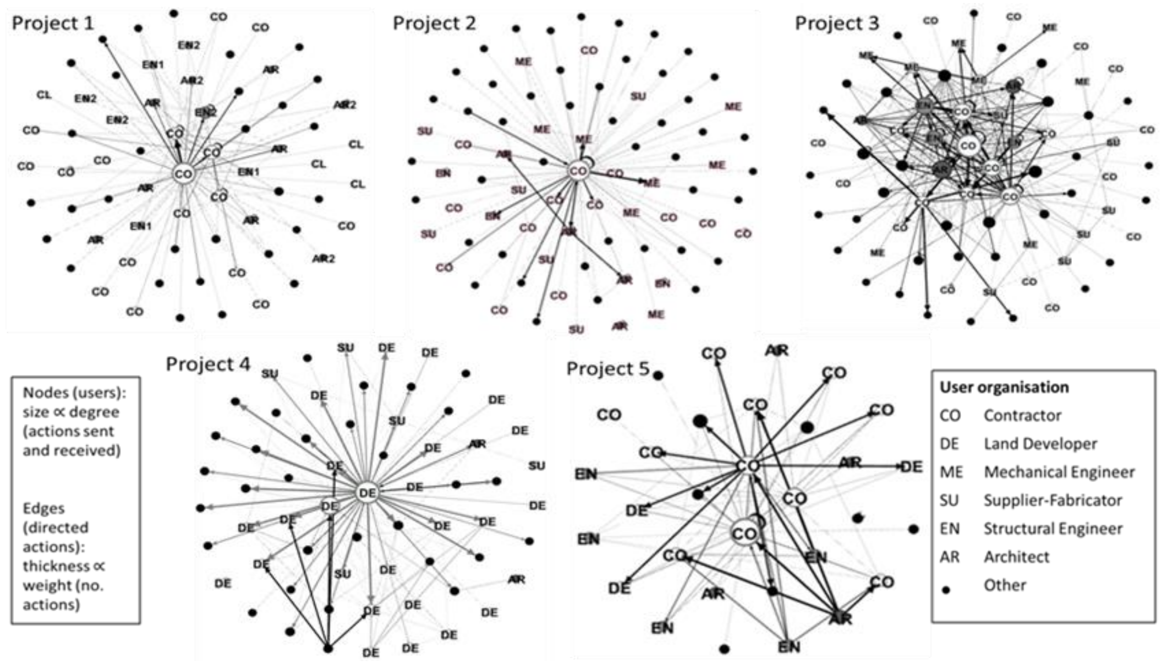

Figure 1: Action Distribution Network graphs from the five projects

The actor (user) behaviour depended partly on pre-defined project processes and protocols. The networks are directed since actions were distributed from one user to another and the edges are weighted according to the number of actions between users. Very importantly, the action distribution networks are in reality dynamic. The static depictions represent an overlay of the accumulated actions through project time. Any sequence between serially dependent actions is not depicted. Finally, the graphs do not provide any reference to the documents, drawings or models which the actions refer to or the decisions made to modify them.

Table 2: Network graph statistics and suggested interpretations

			(rank in parenthesis)				
Measure	**General definition of measure**	**Suggested interpretation within context of Action Distribution**	**Proj. 1**	**Proj. 2**	**Proj. 3**	**Proj. 4**	**Proj. 5**
Graph Density	Total number of observed edges divided by the total number of possible edges.	The spread of Action Distribution.	0.03 *(4)*	0.02 *(5)*	0.07 *(2)*	0.04 *(3)*	0.10 *(1)*
Average Degree	The average number of users a user has had at least one interaction with.	The degree of user interaction.	2.06 *(4)*	1.12 *(5)*	4.99 *(1)*	2.23 *(3)*	2.87 *(2)*
Average Weighted Degree	Average of sum of weights of the edges of nodes.	The intensity of Action Distribution.	369 (1)	130 *(3)*	130 *(3)*	161 *(2)*	117 *(5)*
Modularity	A measure of the definition of the	A measure of the definition of the	0.00 *(5)*	0.26 *(3)*	0.36 *(1)*	0.18 *(4)*	0.36 (1)

	communities within the network.	communities within the network.					
Connected Components	No. sub-graphs in which any two nodes are connected to each other, and which are connected to no additional nodes in the network.	A measure of isolated practice between groups of users.	0 *(5)*	1 *(3)*	1 *(3)*	3 *(1)*	2 *(2)*

4.4 Preliminary Observations

(1) Graph degree and graph density agree almost entirely (in terms of project ranking).
(2) Degree and weighted degree do not agree (in terms of project ranking).
(3) Users from the contractor organisation (or land developer in project 4) display the highest degree in all networks.
(4) The most central user in all networks is the document controller.
(5) Project 4 displays a very star-like network graph suggesting central control by the developer. This is in agreement with the high comment share of developer.
(6) Project 3 displays some particularities; It has the highest average degree, the second highest graph density, the highest modularity, visually the most discipline inclusive network with the densest network core, the most even comments share and the highest commenting lag.
(7) Project 3 and 5 both visually display the least uniform, least star-like networks as well as jointly having the highest modularity.
(8) (From observation of Comment content) Some comments on documents refer to other documents or to other communication (e-mail, telephone, meetings) which are not readily accessible to the user**.**
(9) The projects, going from 1 to 5, are decreasingly BIM-advanced (Table 1 "Software Configuration"). There is no observed correlation with any other measure.

5. DISCUSSION

Utility of applied data analysis

The analysis carried out reveals some correlations between the selected measures as well as providing some indications on what methodology improvements would yield more meaningful results. The presented analysis is not adequate to support the suggestions identified in (3.5) since the sample of five projects is not sufficient to respond to the high granularity resulting from the number of selected measures. In addition, underlying variables such as project type, contracting company and process protocols make comparison even harder. The measure most relevant to the reviewed themes is Software Configuration which includes indications of BIM-advancement.

Improving the analysis

A more meaningful analysis would result from (1) a bigger sample of projects, (2) keeping variables such as project type and contracting company identical, (3) accounting for underlying contextual factors such as process protocols, (4) including success indicators such as time and cost efficiency rather than just interaction pattern indicators, (5) refining or further breaking down the measures (this could lead to the development of indicators of "Model-centricity" or "Model-integration" and their correlation with the success indicators), (6) including projects where a BIM model-server was utilized, (7) accounting for the time element. (e.g. plotting different network graphs for each project phase) and (8) capturing the communication that occurred outside the online workspace environment.

Broader implications: Is a Big data analytics approach applicable to Cloud BIM?

The use of technology through which usage data is recorded is rising dramatically. The increasing amounts of this data might pave the way to the introduction of approaches equivalent to Big data analytics within construction practice. This would reveal previously unexplored patterns of interaction and their correlations to project success indicators. The analysis presented in this paper serves as a crude attempt for exploring these patterns. Apart from the presented metric-based and network graph-based analysis, approaches such as content analysis could reveal patterns in human communication (e.g. interpreting comment content) and provide a basis for codifying and automating communication within virtual environments.

6. CONCLUSION

The future of BIM lies in Cloud collaboration. Effective collaboration requires coordinated communication and communicated coordination. BIM as the "language of construction" provides a useful metaphor and supports the requirement for structure and standardization even on the level of human communication. The life-cycle approach will pose additional collaboration requirements. The model should be the focal unit of communication. Integrated, intuitive communication tools for BIM should replace e-mail.

The preliminary analysis of data from the usage of online collaboration software, including network graph representations, provides some insight into usage patterns and serves as a basis for similar analyses as more of project data becomes available. Improved results would come from a bigger sample of projects and from a better designed analysis.

Future work could include inclusion of the time factor and success indicators in usage statistics and network graphs and correlations with indicators for model-centricity and model –integration.

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