

Spanning the multilevel boundaries of construction organisations

Towards the delivery of BIM-compliant projects

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Received 9 September 2016
Revised 26 January 2017
Accepted 11 March 2017

Abstract

Purpose – The purpose of this paper is to study the interdependent boundary-spanning activities that characterise the level of permeability of knowledge, information flow and learning among construction supply chains involved in the delivery of building information modelling (BIM)-compliant construction projects. Construction projects are mobilised through a number of interdependent processes and multi-functional activities by different practitioners with myriad specialised skills. Many of the difficulties that manifest in construction projects can be attributed to the fragmented work activities and inter-disciplinary nature of project teams. This is nevertheless becoming ever more pertinent with the rise of technology deployment in construction organisations.

Design/methodology/approach – The study combined experts' sampling interviews and a case study research method to help offer better insights into the kind of emerging multilevel boundary practices as influenced by the rapidly evolving construction technological solutions. The experts' sampling helped inform better understanding by unravelling the key changes in contemporary boundary configurations and related boundary-spanning practices within technology-mediated construction project settings. The case study also helped to establish the manifestation of best practices for managing multilevel boundaries in BIM-enabled construction project organisations.

Findings – The study has revealed that different generic organisational BIM strategies as developed in specialised boundaries are reconfigured as appropriate at the project level to produce project-specific BIM execution plan (BXP). The outcome of project BXP is dependent on the project organisational teams that cooperate in creating new solutions and on conceding space for negotiations and compromises which conflicting interests at the project level can find to be both desirable and feasible. The implementation effort is therefore contingent on mutual translation in which different actors with different insights instigate their practice through negotiation and persuasion which eventually are reinforced by contractual agreements and obligations.

Originality/value – The paper has presented a novel and well-timed empirical insight into BIM-enabled project delivery and best practices that span multilevel boundaries of construction organisations.

Keywords Construction technology, Building information modelling, BIM-compliant project, Construction organization, Multilevel perspective, Organisational boundary

Paper type Research paper



Introduction

The recent progress in technology has inspired a rich literature both within academic research and professional practices, with a strong surge in the deployment of technology-related building information modelling (BIM) within construction practices. BIM is associated with the virtual representation of the physical and functional characteristics of a facility that enables a seamless exchange of information across all tiers of the architecture, engineering and construction (AEC) supply chain (Eastman *et al.*, 2011; Sackey *et al.*, 2014). In most cases, research attention has been directed at the significant benefits and the transformations associated with BIM uptake (Singh *et al.*, 2011). What seems to be lacking, however, is the emphasis on knowledge-process beyond technological optimism, such as workflow management, and business practices accompanying the real benefits of BIM (Rekkola *et al.*, 2010; Kovacic and Filzmoser, 2015). Even so, there has been much less emphasis on the influences of the different AEC specialists or the multilevel boundary-spanning activities that significantly impact the success, or otherwise, of the rollout of BIM at the project level. Moum (2010) has argued that the main challenge hindering the pace of BIM deployment in an interdisciplinary setting has something to do with a lack of interrelationship and a non-compromise on integrative practice and interdisciplinary collaboration. Boundary issues often occur owing to an interface mismatch between two or more organisations, such as information mismatch, coordination difficulties or vendor platform's performance failures (Chua and Godinot, 2006).

The premise of this paper is on the interdependences characterising the boundary between different BIM-compliant activities amongst the project supply chain that constitutes the work system. The activity interdependencies at the construction project level originate from multilevel operations of specialist stakeholders representing different organisations. The conditions of the interactions in this respect provide specific opportunities for adaptation and activity adjustments (Gadde, 2014). Hence, project-level BIM activities should align with organisation-specific work processes, compatibility, tolerance and accommodation (Fellows and Liu, 2012). The study therefore aims to understand the demarcations or the borderlines helping to divulge the BIM-compliant project stakeholders and the kind of emergent boundary practices influenced by the use of contemporary construction technologies. The study also aims to examine how the BIM-compliant project stakeholders manoeuvre and negotiate different emergent boundary practices to derive an insight into the context of technology-mediated construction processes.

The paper is structured as follows. First, the impact of technology-mediated practices on the contemporary construction project settings is examined. Second, the theoretical perspective on multilevel inter-organisational boundaries and the potential of boundary-spanning practices towards successful BIM uptake is explored. Third, the data collection strategy for the study, including interviews by experts' sampling and case study research, is discussed. Finally, an analysis of the research findings and discussions of the results are presented.

Literature review

Perspectives on contemporary construction project setting

Construction projects are mobilised as temporary undertakings (Winch, 2010) through a number of interdependent processes and activities by different practitioners with myriad specialised skills (Karrbom Gustavsson and Gohary, 2012). Given the multiplicity of expertise required for construction projects and the multi-temporal organisations in which the knowledge workforce resides, there are substantial variations in professional dialects, values and allegiances (Fellows and Liu, 2012). Many of the challenges that manifest in

construction projects are a result of both the temporary and the inter-disciplinary nature of project teams (Dainty *et al.*, 2006). This is nevertheless becoming increasingly pertinent with the rise of technology deployment in construction organisations. Dossick and Neff (2009) acknowledged that BIM makes obvious the highly interdependent nature of the AEC project organisations by identifying their individuality to technologically align their different facets together.

Whyte (2011) acknowledged that construction technological artefacts often do not exist in isolation and mobilised the concept of “boundary objects” to articulate how technological artefacts are used in coordination across different organisational contexts. Drawing on the works of Star and Griesemer (1989) on the development of boundary objects, Whyte and Lobo (2010) highlighted three different digital artefacts for infrastructure delivery:

- (1) object geometries, of assembly drawings and engineering simulations to digitally represent physical and functional realities of facilities;
- (2) standardised formats, for structured distributions of digital data across the multilevel boundaries of the project organisations; and
- (3) repositories, representing the storage of digital libraries which also facilitate easy access of project information across inter-organisational boundaries.

This perspective suggests that the implementation should emerge out of the multilevel assemblage of boundaries between collective actor organisations, to broaden the interpretation, and out of the technology capabilities and its subsequent applications as it mutates across the project lifecycle.

Theoretical perspective: multilevel inter-organisational boundaries

Faced with an exponential proliferation of connections (Plesner and Horst, 2013), construction organisations are focused on relations between in-house or micro expertise and external stakeholders or macro expertise with references to each other in their efforts to assemble the world. Likewise, visions and the use of construction technologies vary from one construction organisation to the other. The concept of BIM innovation thus should not refer simply to the visions of the innovators or the functions of the technical objects alone but also to, what Plesner and Horst (2013) termed as, “innovative assemblages”. The assemblage emphasises on how actors envision and mobilise a combination of different solutions (e.g. type of BIM platform, technological tools and workstation types, expertise, vision, clients’ specifics, BIM strategies, politics, etc.) in different ways and thereby create understandings of reconfigured workflows to fit a particular project circumstance. Molina (1998) introduced the concept of sociotechnical “constituency alignment” to illustrate the multiple dimensions of successful intra- and inter-organisational alignment through mutual adaptation of common perceptions and pursuits. Molina and Kinder (1999) argued for the joint consideration of sociotechnical components in a multilevel context through consensus building for aligning both social and technical constituents until a successful work system or a constituency is established.

The main premise of Molina’s approach deduced that the processes involved in creating BIM technological capabilities always require the development of dynamic assemblage and mutual consideration of technical constituents in terms of artefacts and social constituents in terms of contextual influences. Multilevel researchers have particularly recognised the relationship among variables at different levels of analysis. The multilevel perspective (MLP) is conceptualised in this study as nested hierarchies that constitute the micro (organisation), meso (inter-organisation or project team) and macro levels (broader environmental influences) (Lundvall, 1988). The MLP recognises the myriad institutional,

managerial and technological aspects, the strand of competing and complementary boundary practices that intertwine to influence project outcomes (Whyte and Sexton, 2011).

Dossick and Neff's (2011) researched the use of BIM by multiple knowledge groups and found that users were having opposing interpretations of its promise and neither was able to foster closer collaboration across different companies without prior inter-organisational alignment strategies. Understanding of the multilevel constituency alignment, coupled with effective interface or boundary management strategies, can potentially reduce conflicts between the myriad stakeholders by increasing visibility on roles, responsibilities and project deliverables (Shokri *et al.*, 2014; Archibald, 2003). The potential of this concept is explored in this study as an analytical lens for strategy development towards the transformation of BIM-enabled construction project organisations (Markard *et al.*, 2012; Berggren *et al.*, 2015).

Bridging or spanning the multilevel boundaries to achieve overall success cannot be overemphasised. The concept of boundary spanning can refer to activities across organisations (Tushman and Scanlan, 1981). The multilevel boundary spanning practice shifts attention to adaptation by accommodating the important determinants of innovation success in a holistic manner across diverse technological and contextual priorities (Whyte, 2011). This however requires assimilation and collaborative norms, knowledge and an information interface towards a collective goal. Thus, a multilevel analytical approach to boundary spanning can be envisioned to be of relevance within a BIM-compliant project environment (Abbott *et al.*, 2013).

Spanning construction project boundaries towards successful BIM deployment. The key contribution of this study is an enriched understanding of the multilevel boundary-spanning activities towards a successful uptake of BIM on construction projects. The management of inter-organisational project activities such as facilitating knowledge exchange, developing roles and responsibilities and multi-party contractual relationships and agreements can be construed as boundary practices (Gopal and Gosain, 2010). Organisational boundaries can be understood as lines of distinction between the inside and outside of a community of practice and their peripheries that represent mutual connections and distinctions (Wenger, 1998; Gustavsson, 2015).

Boundary spanners manage the interface between organisations and their environment and are characterised by negotiating the interactions to build a sustainable relationship between the organisations involved (Brion *et al.*, 2012). The scope of boundary action and issues relating to effective operation can be analysed in reference to multilayer activities. At the individual organisation layer, each organisation offers its particular perspective on what to perceive as relevant boundary activity (Araujo *et al.*, 2003), and this manifests with organisation-level BIM implementation strategies. Such specialist orientation and differentiation between firms' activities are very useful in understanding the related boundary knowledge profiles, operations and capabilities. It also helps in the constituency-building process at the project level as knowledge of other firm's activities and resources is significant for the assemblage of corporate project activities and capabilities. Fellows and Liu (2012) expanded the analysis of boundary activity by asserting that the focus must not only be on the specialist border lines, but equal attention must also be given to the permeability of the boundary.

In the context of construction project organisations, the practice of boundary spanning has been recognised as critical in moderating the relationship amongst project stakeholders with consequent impacts on project performance. For instance, Fellows and Liu (2012) used fragmentation in engineering construction projects as a precursor to discuss the nature of boundaries and approaches to their management. They concluded that project organisations

involving numerous specialised firms, each having its own boundary to contribute an important fragment of the overall functional activities, influence how well the boundary activities are planned and managed and how well the boundaries allow information permeability, knowledge sharing and learning. [Karrbom Gustavsson and Gohary \(2012\)](#) also provided insights on boundary actions that contribute towards more integrated construction project practices. [Abbott *et al.* \(2013\)](#) noted that the term “boundary” reifies the distinction and separation of two or more territories or a line of demarcation that can artificially be bridged through a well-organised means. In contrast, it has been argued that in reality, construction project organisations are not necessarily spanned or bridged, but rather, they are socially constructed, often contested, negotiated, reconfigured, broken down and even reinforced ([Orlikowski, 1992](#); [Harty, 2008](#)).

Nevertheless, the concept of boundary spanning can be useful in interpreting how certain members of a community of practice, or in this case the construction project community can take on, a boundary role and create an arena for mutual engagement where new practices are likely to emerge as facilitated by BIM technological solutions ([Wenger, 1998](#)). The ability of a boundary spanner to develop, communicate or share synchronous information, also known as interoperable data interchange, is an important antecedent for inter-organisational performance. Therefore, this study aims to gain more insights into how construction organisations mobilise boundary-spanning practices to manage boundary issues towards a successful BIM-compliant project delivery.

Research methodology

The paper is particularly focused on the boundary issues relating to BIM-compliant construction project delivery. The research therefore aims to contribute to the academic discourse in two ways. The first contribution is to unravel the key stakeholders that influence the emerging boundary practices within contemporary project settings. The second contribution is to understand the appropriate, best practices for managing multilevel boundaries in a BIM-compliant work system. Based on the aspiration of the paper, a qualitative research method ([Patton, 2005](#)) that combines an embedded case study ([Scholz and Tietje, 2002](#)) and experts’ sampling interviews ([Daniel, 2011](#)) was adopted as the primary source of empirical data for an in-depth analysis of the contemporary construction practices. The experts’ sampling helped inform better understanding regarding the first aim of boundary configuration and the required BIM-compliant boundary activities. The embedded case study also helped fulfil the second aim by establishing the manifestation of such boundary activities within an embedded project environment.

The experts’ sampling research approach served as a preamble to the embedded case study and its involved semi-structured interviews designed to mainly uncover a holistic view on BIM practices and the key stakeholders involved in bridging the multilevel boundaries. A total of 12 interviews were conducted with construction professionals having relevant but varying experiences regarding BIM. The interviews lasted between 30 to 90 min. The interview data helped in understanding the extent to which multilevel boundaries influence BIM-enhanced project delivery. Such information was used to augment and triangulate the findings of the case study. The embedded case study involved a project-based activity as the main unit of analysis and the subunits included the myriad organisations and their boundary practices as they focus on salient aspects of the project activities ([Scholz and Tietje, 2002](#)). The case study data was rich with field notes from participants’ observation, numerous site walks, site meetings, formal and informal interviews and project documents.

A total of nine team members of the case study project were formally interviewed, taped-recorded and transcribed and complemented by a series of observed meetings and

document reviews. ConsTech (pseudonym) has concentrated its functional structure on three main facets of the AEC market, which include infrastructure projects, housing development division and maintenance department. Each division provides national coverage with locally based teams across the United Kingdom. The housing division is established as one of the United Kingdom's leading social housing contractors. Likewise, the maintenance division has a steady position as one of the leading building fabric maintenance service provider in the United Kingdom. The infrastructure division executes major contracting works on non-residential projects. The group is among the largest privately owned construction, housing and property companies in the United Kingdom, employing around 2,800 staff and has an annual turnover of circa £1 billion. With regards to technological deployment, ConsTech has invested in an R&D innovation team that has researched the widespread application of information technology, with the view of transforming all its three divisions and various local offices into BIM-enabled entities having the capability to deliver BIM-compliant projects.

To examine the manifestation of boundary-spanning activities with regards to BIM implementation on a construction project, the research team spent time in ConsTech's East Midlands office, where the head of BIM and his team are based. The research team also visited one of the organisation's first major BIM project sites on different occasions, observing the project teams and participating in site BIM meetings whilst the construction development was in progress. Cross sections of the major types of BIM meetings such as BIM review, coordination, clash resolution and snagging meetings were observed and briefing notes were made to capture the observations of interactions and any emerging seemingly critical issues. The series of interviews, document reviews and non-participating observation were spread out over 9 months. In the context of this case, it proved particularly useful for gathering rich qualitative insight into the project team organisations and their BIM strategies. It also provided additional scope to augment and triangulate the experts' sampling findings. The data transcripts from both the experts' sampling and the case study data were analysed using the qualitative content analysis technique. This involved condensing, sorting data categories and relationships and interpreting data using the adopted theoretical framework (Taylor-Powell and Renner, 2003). This approach helped to reveal the constructs of interests relating to boundary-spanning activities. The analysis as described in the Results section was in accordance with the constituted segments of the multilevel boundary-spanning theoretical framework (Star and Griesemer, 1989).

Experts' sampling results and discussions

Boundary-specific building information modelling implementation strategies: organisation versus project boundaries. The discussion of BIM deployment in relation to boundary management specifically contributes to the understanding of organisational boundaries in strategy formulation and implementation. From the responses, it was evident that the *de facto* implementation process of BIM occurs at two levels: the organisation level and the project level. Thus, the study revealed that to develop a BIM-enabled working environment, the business requirements, as well as the project requirements, need to clearly be elicited and implementation plans developed. This is in agreement with The CIC Research's (2012) finding which suggests that the decision to implement collaborative construction technologies ought to be based on resources, competency and anticipated value to all the parties involved. Thus, there is a clear demarcation line between the organisation-level BIM implementation strategy and the project strategy. The latter represents a project-specific BIM strategy whilst the former defines a generic organisation's BIM implementation strategy. The BIM implementation plan provides opportunity for the BIM-enabled

organisations to understand, define and clearly communicate their organisational goals and procedures to inform the overall project-specific BIM ambitions.

Organisation-boundary building information modelling strategy. It was drawn from a narrative given by an interviewee that BIM implementation should not be treated as an *ad hoc activity*. The more grounded the plan is in relation to a company's strategic goal, the more successful the implementation is likely to be. One interviewee for instance stated that:

You need to have a vision of what you do. If you try to implement BIM without a vision you are actually not going to get there really [...] it is more of if we are going to do it, this is the reason and an appropriate implementation plan lay out to the company to say this is what we need to do.

There is no consensus on a common set of criteria for the organisational BIM strategies. Nevertheless, several recurrent organisation-specific strategies influence the BIM implementation plans. On that basis, an organisation-specific BIM document is developed to guide through the development of people and processes, mobilising existing technologies, team working and access to a common data environment (CDE).

The organisation-specific BIM strategy documents contain the organisation's BIM competence-building measures, encompassing appropriate technical competencies, procedures and knowledge workforce, which ultimately leads to BIM project delivery. This means reaching for the straightforward targets of the available processes and technological infrastructures or mobilising competences that can ultimately form the team to bring BIM project goals into fruition. Ultimately, the organisation-boundary BIM strategy provides a pathway for management to follow for developing people and processes and for mobilising appropriate technological platforms to augment the organisation's BIM ambitions.

Project-specific building information modelling strategy. From the project perspective, careful consideration is given to the often-referred project-specific BIM execution plan (BEP) which is co-developed by the multidiscipline project team (the BEP is developed on a project-by-project basis as each project is often unique). For project-level BIM delivery, emphasis may vary according to the nature and the anticipated outcome of the project. The BEP actually defines the way the BIM project will be delivered. [The CIC Research \(2012\)](#) has acknowledged that it might be necessary for project teams to develop a feasible BIM action plan containing deliverables that are feasible for all project stakeholders. The project-level BIM implementation strategy emerging from the responses can be categorised under five broad headings:

- (1) early involvement of the supply chain;
- (2) development of BIM project protocol and plan;
- (3) defining each supply chain's BIM deliverables;
- (4) clarifying the compatible BIM software platforms for use; and
- (5) contractual relationships.

Both the boundary-spanning organisational and project BIM strategies were considered necessary by the research participants, and as a BIM manager explained, "the existing process is fragmented, silos of architects, builders and dead data. BIM process is joining everybody up" but it is also a "game changer" because the emergent process is causing "an overhaul of the conventional trend and practices". Lack of "buy-in" of the strategy from the project stakeholders can likely jeopardise the ambition of the project BEP. The five highlighted themes establish clear criteria of boundary activities requiring participation from the multilevel project partners. It is therefore appropriate to understand how the project-level BIM ambitions manifest in reality and how they are influenced by the boundary

spanners. Accordingly, [Holzer \(2007\)](#) has stated that it is valuable to consider how BIM is incorporated into the project workflow. Therefore, the manifestation of these boundary-spanning activities were further explored in the case study analysis. The next section examines the key stakeholders that influence the emerging boundary practices to ensure successful BIM-compliant project delivery.

Exploring building information modelling-enabled stakeholder organisations that influence boundary practices at project level. It has been acknowledged that multilevel organisations are confronted with forces of fragmentation because of specialisation ([Tushman and Scanlan, 1981](#)). [Fellows and Liu \(2012\)](#) have also stated that each specialism of the construction profession constitutes an important fragment and the specialism layers have their own boundaries to delineate functional activities towards a collective project goal.

In the traditional sense, project activities are well recognised to be influenced by multiple professional participants such as owners, architects, engineers, consultants, main contractors and specialist sub-contractors. The responses from the study have indicated that the conventional construction activities are particularly different from the contemporary BIM-compliant activities. The conventional project activities were described by the respondents to involve PDF data flow, information sharing via email, coordination in a 2D environment, hard copy mark-ups for drawing changes and unstructured handover of as-built documents to clients with paper-based operations and maintenance manuals. This sequential workflow has been described as “over-the-wall silo” working practices ([Evbomwan and Anumba, 1998](#)).

The current BIM practice runs counter to the fragmented and sequential work processes. The BIM concept is alleged to provide opportunities for construction project teams to improve processes by garnering the benefits offered by the latest construction technological product solutions. This presents project teams the opportunity to create reliable, accessible and easily exchangeable building information on digital platforms for the supply chain that needs such information at any particular phase of the building lifecycle. However, the transition is accompanied by a wholesale transformation in boundary activities and multilevel configurations. The responses from the interviewees characterised the transition to BIM as a “paradigm shift from drawing on 2D media to modelling”. Others saw it variously as “a game changer”, “a wholesale change” or “an overhaul of the paper-centric” predecessor processes. Within the construction project organisations, the various roles and project activities of the myriad knowledge workforce have also been clearly affected by the widespread BIM transformation. For instance, some of the traditional roles are being transformed with accompanying new titles such as “BIM coordinators, BIM managers, modellers, cost and programme analyst” etc. Also, new organisational layers are becoming vital partners of the contemporary project team, and these are mainly a result of the technology spin-offs. Examples include the vendor market and technology enablers (both hardware and software developers and suppliers) who are actively seeking to discover their niche market in the construction practice such as Autodesk, ArchiCAD and Tekla; government-backed BIM policy initiators with a view of ensuring optimal design solutions and integrated lifecycle information exchange for public sector projects ([BIM Task Group Report, 2011](#)); and independent BIM consultants who are mediating between the traditional practices and the BIM practices, purporting to help construction organisations towards a successful transition ([Sackey et al., 2014](#)). Academic institutions and R&D organisations are also playing a critical boundary-spanning role in BIM deployment (e.g. Penn State CIC Program on BIM implementation guides, & AEC UK BIM Initiative) ([The CIC Research, 2012](#); [AEC UK, 2010](#)). Based on the responses, [Figure 1](#) shows the typical multilevel

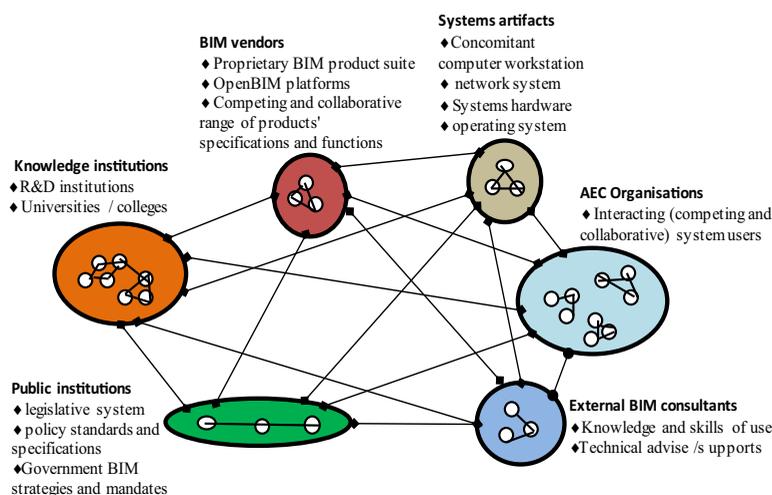


Figure 1.
Multilevel boundary
organisations
influencing
BIM-compliant project
delivery

stakeholders that influence the best practice, or otherwise, of the project-specific BIM deployment process.

The multilevel boundaries shown in [Figure 1](#) represent organisations that are actively seeking or contributing new knowledge, technologies or best practices which ultimately influence project-level BIM uptake. It also increases the extent of boundary interdependencies, disparate visions, expectations and knowledge capabilities of the project stakeholders. It is vitally important to consider these key stakeholders as formidable members of the innovative assemblage ([Plesner and Horst, 2013](#)). Although the boundary-spanning role shows how contextual variables can interact to influence an implementation outcome, it also establishes a requirement for developing an assemblage of business relationships, knowledge integration and ideas among both tightly coupled and loosely coupled project partners to foster norms of unanimity towards a common project goal ([Gadde et al., 2012](#)).

The expert's sampling analysis provided enlightenment on BIM-enabled boundary configuration and practices. It also triangulated and fed into the subsequent case study analysis, which was ultimately aimed at establishing the manifestation of boundary activities towards a successful delivery of a BIM-enabled construction project.

Results and discussions of case studies

Organisation-specific building information modelling-compliant boundary activities

Recognising that BIM implementation is a catalyst for corporate business process change, a BIM implementation strategy team was formed in ConsTech to provide a direction and a strategy to govern the implementation. The team consists of a whole mix of membership and is headed by a BIM expert who had been working in the organisation for over nine years in a different capacity as the Head of Design Management until he took on his new role as the Head of the BIM Team. There were other team members with professional titles which seemed uncommon in the conventional era of AEC practice, including a BIM project manager, BIM technical lead, BIM coordinators and local BIM champions. The BIM team develops and sees to the successful implementation of organisation-specific BIM procedure across the local offices of the business.

The BIM team's main strategy revolves around organisation-specific BIM execution strategy, process change, knowledge upgrade and rollout of appropriate BIM technologies. ConsTech's vision for BIM has been communicated to every staff of the organisation through a computer-simulation awareness toolkit known in the organisation as "BIM Jigsaw". The jigsaw is designed to help the workforce understand the organisation's comprehensive BIM strategy, and it covers seven main BIM knowledge themes:

- (1) client's BIM requirements;
- (2) BIM working protocols;
- (3) 4D program simulation;
- (4) certainty of project cost from BIM model;
- (5) energy analysis and sustainability modelling;
- (6) integration of project supply chain with coordination tools; and
- (7) as-installed model and ongoing facilities management.

The BIM toolkit provides a great insight into and instigates a lively discussion among the workforce regarding the organisation's strategy of deploying BIM across the different stages of a project lifecycle.

Selecting building information modelling platform for boundary-spanning activities

ConsTech's strategy on the rollout of appropriate BIM technological platforms within the organisation focuses on "open BIM" approach to augment a blend of the "best-of-the-breed" product solutions. This strategy could best be described as an open-BIM interface rather than a proprietary interface as it does not particularly focus on any single vendor product suite (Eastman *et al.*, 2011). The open BIM approach is a buildingSMART initiative (Sabol, 2008) which provides the Industry Foundation Classes (IFC) standard that enables collaborative project teams to "mix-and-match" different software tools for providing functionality beyond what can be offered by any single BIM platform. This contrasts with the sole use of proprietary tools from one particular vendor suite, which potentially could hinder seamless data exchange and federated model coordination from the specialised boundaries with consequential impact on efficiency and communication. The reliance on different BIM technological platforms by ConsTech for its project delivery conforms to a higher BIM maturity level (Succar, 2009; NBIMS, 2007). However, one of the criteria at such a high level is that interoperable data interchange across disciplines should be possible (Ghassemi and Becerik-Gerber, 2011). Therefore, the preferred BIM tools should comply with industry-neutral open standards such as the IFC formats (Sabol, 2008). Interoperability is achieved by ensuring the possibility of "easy and reliable exchange of project data between the different BIM platforms" via industry-neutral open standards. The BIM platforms also demand an upgrade of the existing hardware computer systems towards more compatible workstations and operating systems. Compared to the CAD-based platforms, BIM software applications contain 3D geometric data with associated non-graphical data and parametric relations, thus calling for the need of higher-specification computer workstations to ensure performance gains.

Crossing the boundary: integrating organisation-specific expertise with building information modelling project strategy

ConsTech was the main contractor on a £48 million higher educational building project. The project client specifically requested the project to meet some defined BIM criteria. As part of the tender process, ConsTech developed an initial project-specific BXP (BIM execution plan),

highlighting how the client-specific BIM criteria could be achieved. The BXP also established some key benefits which could be brought onto the project as a result of the BIM adoption. These included the applications and beneficial use of the information contained in the coordinated model both for the project delivery and subsequent management of the facility. The tender information presented by ConsTech particularly demonstrated the application of BIM on the project activities such as “clash resolution at the design phase, energy and sustainability analysis, schedule and cost information and sequencing and flythrough simulation”. Subsequently, ConsTech was the successful bidder for the project owing to its ability to demonstrate its understanding of the BIM processes and the development of the project-specific BIM procedure based on the client briefing.

The project was procured under a “design and build” contract. Thus, being the lead contractor under this procurement arrangement, ConsTech was contractually obliged to lead the design and construction team for fulfilling the overall project BIM requirements. As part of the project BXP strategy, the entire supply chain project team, including the architect, the engineering team and the specialist contractors, were to have a demonstrable BIM capability that would materialise on and ultimately benefit the overall project BIM ambitions. Because of this selection criterion, it was recognised that the various organisations occupying various specialised boundary roles on the project had their own generic in-house BIM strategies. Such multilevel, specialised boundary capabilities meant that the case organisation, being the main contractor, had the responsibility to unify the rest of the project teams under a cohesive project-specific BIM agenda, procedure and ambition to ensure a common data interface.

Contrast between organisation- and project-specific technological choices

Despite ConsTech’s initial technology strategy of open-BIM interfaces, on this particular project, however, it was decided that single-product suites would be used across all the specialised project organisations. This was done to safeguard against data exchange and coordination problems during the BIM project delivery process. This single vendor interface enabled product families to be supported and coordinated on a proprietary basis without relying on the public standard exchange format such as the IFC (Eastman *et al.*, 2011). After one of the project coordination meetings, a BIM manager was asked to clarify the reason behind the use of product suites from a single vendor, especially as it contrasted with the organisation’s BIM strategy of “mix-and-match best-of-the-breed” BIM solution. He explained that the organisation’s experience on other previous BIM projects had shown that problems arose with the use of industry-neutral IFC formats when exchanging model information across different BIM platforms. In some instances, it was only the graphical data that was transferred from one platform to another without any accompanying non-graphical data. An engineer narrated that, even with the use of the IFC:

[...] although they say you can basically exchange information with IFC on these different software – that’s fine, but they don’t really talk about the level of information that you lose when you do that.

In other instances too, the parametric relation of the model was lost when transferring from its native platform to a third-party platform.

Owing to the challenges associated with the open-BIM interfaces, Autodesk range of BIM products was recommended as the preferred project BIM software. The dominant Autodesk products that were observed on the project included Revit architecture, Revit MEP, Revit structure, Naviswork Manage (used for coordination purposes to integrate federated models that were individually generated by the specialised project organisations), BIM 360 Field

(construction field management system) and Buzzsaw (cloud-based interactive project data management system).

Interestingly though, not all the supply chain members regarded Autodesk products as the “best-of-breed” solutions for their boundary roles. Hence, despite the lead contractor’s requirements for a proprietary data interchange on the project, some of the team members used alternative suite of BIM applications they perceived to be comparatively better or more appropriately suited towards their niche project boundary activities. For instance, although Revit MEP was used for creating the design model up to RIBA stage F by the consultant, the MEP contractor refused to use it as the main tool for detailed production drawings. This was because the current Revit MEP version is not able to create a detailed design to the level that the MEP service engineers or installers require. Hence, the MEP contractor opted for the use of CAD Duct in developing the production drawing, while they retrospectively used the Revit MEP for coordination purposes.

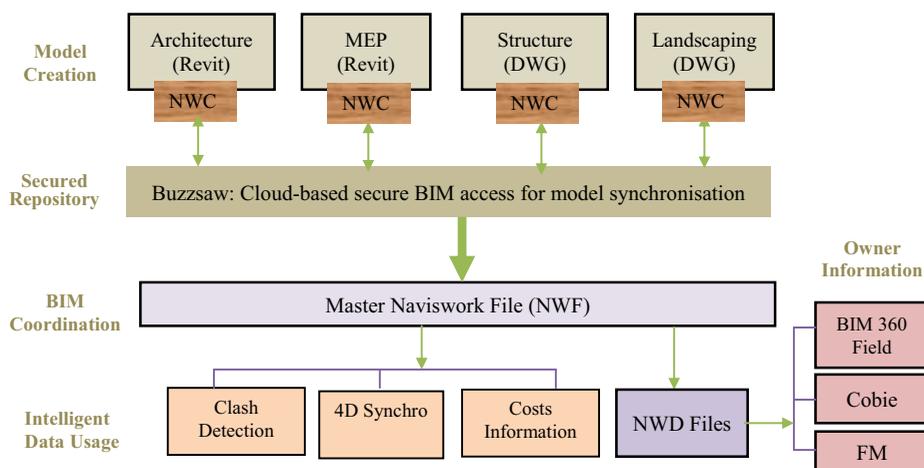
It was observed from the empirical data that, out of the 11 BIM tools that were used on the project, only six were from the “approved” vendor and the rest were from different vendor sources. Some of the non-Autodesk platforms that were used on the project include Vectorwork (for modelling the external landscape), CAD Duct (for modelling the production MEP graphical data), Bentley ProSteel (for the structural detailing and fabrication details), Synchro (for the 4D construction planning and programme sequencing) and Causeway BIMmeasure (used for cost planning purposes and evaluating design change). However, all the indicated alternative products were supported by Native CAD file formats such as DWF and DWG, which are able to interface and synchronise with the Autodesk’s Navisworks.

Engaging with emerging building information modelling technological platforms to span multilevel boundary activities

It has been witnessed that project-level technology rollout strategy has been the requirement for each specialist organisation to use Autodesk platforms for ensuring a proprietary data interface. Nevertheless, as 45 per cent of the platforms used on the project did not come from the approved vendor’s suites of proprietary products, the lead contractor was then obliged to blend the use of both CAD files and Autodesk compatible files on the project. To some extent, the native AutoCAD file formats such as DWG and DWF are compatible with Autodesk. Hence, those CAD formats are convertible by Autodesk’s Navisworks (.nwc), albeit, as the CAD files are synchronised with .nwc files, it is only the 3D geometric information, excluding the non-graphical data and parametric leverages that can be accessed. However, it is an unwritten rule that boundary coordination activities incorporate file formats convertible by Autodesk’s Navisworks. The project team relied on the use of Autodesk’s Navisworks with the associated conversion (.nwc) to interrogate and coordinate the federated models from the individual project organisations. Therefore, it was a project requirement that all the platforms conform to the file exchange standard including Naviswork cache file (.nwc), Naviswork file (.nwf) and Navisworks document file (.nwd). These three file formats assisted the project team in appending and coordinating the individual federated models into an integrated project model. The use of these file formats for bridging the various boundary BIM activities across the supply chain is shown in [Figure 2](#).

The .nwc files are cache files containing conversion data which converts certain files (e.g. Revit .rvt and AutoCAD dwg) into a readable format for Navisworks which otherwise cannot directly be appended into a Navisworks platform. The NWF file, which helps with the coordination effort, links to a number of federated working files (i.e. the architecture, MEP structure and landscaping), and it is regularly used to update information and reload updates from the linked sources. Thus, if changes are made to the .nwc files by the architect, MEP

Figure 2.
Integrating boundary
activities across
multilevel project
network



coordinator, structural engineer or the landscape designer, such as moving geometry objects and adding and/or deleting components to their original 3D data files, Navisworks will look for the linked files when the nwf is opened to re-cache and overwrite the nwc with the latest update. Lastly, the nwd file is a highly compressed file containing a complete data set, with all of the geometry and any of the information created within the Navisworks. The nwd was the format used by the project team members to share progress data with the client and other external stakeholders; this was because it is highly compressed and does not link the data with the native file.

Interfacing different project information via compatible file formats

Critical to the data exchange protocols across all the phases of the project lifecycle and between the different knowledge workforce, all the alternative suites of BIM platforms used on the project are supported by native CAD file formats such as dwf and dwg, which are also able to interface with the Navisworks. For instance, the Vectorwork platforms used for the design of the landscaping layout syncs with the dwg file. The CAD Duct application used for the development of the detailed MEP production models is also supported by dwg, including the Bentley ProSteel which was used for the design of the structural detailing and fabrication models. Also, the 4D Synchro which was used to synchronise the sequencing and planning of works is supported by dwg file format, and lastly the Causeway BIMmeasure which was used for cost planning purposes and measuring quantities in the coordinated model interfaces with exported models from Revit via dwf. Figure 2 shows an overview of how the various BIM applications are configured from the individual workstations through the cloud-based repositories for coordination analysis using Navisworks native file formats and passing on the as-installed models to the client.

All the federated models in the individual workstations were converted into nwc before importing into the cloud-based Buzzsaw repository. The Buzzsaw repository contains a folder for the project. The project folder also contains several subfolders for the various disciplines (e.g. architect, MEP engineer, structural engineer, etc.). The team held biweekly coordination review meetings to coordinate and crash-detect the federated models. At the coordination level, the project team used the nwf file as the working file, and it linked directly to the individual subfolders. The information in the coordination model was used for

different analyses such as clash detection, cost planning and construction scheduling. Also, from the project repository, the nwd file was used to generate a static representation of model information to archive specific milestone events, which were then passed on to the client in preferable formats such as in the Construction Operations Building Information Exchange (COBie) spreadsheet format (McAuley *et al.*, 2013).

Cloud-based hosting platforms for developed project models

Moving beyond the individuals' workstations to the open BIM platform, the project had two different hosting systems: Buzzsaw and BIM-360, both performing two separate tasks. Buzzsaw is managed by the contractor for general exchange of the working models and was used by the team to resolve the project data collaboration issues (coordination, clash detection and resolution), whilst the BIM 360 Field is managed by the client to host the FM models and was also used to update the client with progress information and operations and maintenance (O&M) data. However, both the hosting platforms produced a protocol that ensured that the entire supply chain of the project knew where, how and when to upload or access model information. The protocol also ensured that data quality and consistency could be ensured throughout the project phases.

The analysis thus far has shown how the emerging boundary practices directed towards a successful BIM project delivery is enabled by negotiations and compromises on contextual practices and by the configuration of competing and collaborative range of technological products which are considered to be feasible and preferable by the different knowledge organisations that constitute the project team.

Discussions on divergent boundary antecedents, visions and expectations in alignment with project delivery

The distinct differences in the project organisations and their multifarious boundary practices coupled with the use of the nascent BIM technological platforms on the project could be seen as both an enabling and a constraining phenomenon. The technological platforms contributed to project practices that lean towards addressing the most prominent issues of integrated processes and synchronous information flow that have often been lacking within the construction industry. The project activities and the appropriate configuration of technological platforms have particularly revealed the trend of collaborative initiatives and best practices which are gradually becoming the trait of the contemporary construction settings. Nevertheless, the innovation assemblage that brought about the realisation of the coordinated, best practices, as shown in [Figure 2](#), is also as a result of compromises and accommodation of competing and collaborative BIM solutions. Some of the constraining concerns that emerged as a direct result of the BIM uptake but ultimately had to be accommodated through boundary-spanning activities are highlighted as follows:

- Lead contractor (ConsTech) amending its generic organisation BIM strategy and technological preferences to suit the project-specific BIM execution plan and also to accommodate different interest groups and their technological choices;
- Lead contractor giving dispensation to some subcontractors to work with standard AutoCAD file formats, thus having a blend of coordinated model and traditional CAD information;
- Limiting the utilisation of BIM capabilities under the contractual agreement to only the production of construction drawings and as-installed facilities management information. Thus, use of any other model is considered as a "by-product" of the contractual BIM arrangement; and

- Additional cost and delay associated with the use of two different BIM applications by the MEP contractor for accommodating both the project coordination requirement and the internal work delivery standard.

The individual organisations diverged when the practicalities of implementing the BIM platforms at the project level was critically examined. This particularly distinguishes the situated or context-specific aspects of the project participants such as different visions and expectations, different professional dialect and technological preferences, existing organisation conditions and levels of organisational capabilities. Crucially, the different boundary contexts and visions produce different assemblage of artefacts and the boundary activities then shape the technology artefacts and the environment of use. Hence, successful contemporary construction activities or the “bridging-up” of the various facets of the knowledge boundaries is largely dependent on the causal balance not only in the immediate implementing organisation but also at the project level where the actual multilevel work activities manifest. The analysis of the case result has reemphasised that no single constituent can solely augment the development and appropriation of innovative practices and technological rollout in multilevel organisational settings (Molina, 1998). The concept of multilevel innovation assemblage has also suggested that multilevel alignment can be achieved only if divergent organisational perspectives are acknowledged, appropriate compromises are reached and subsequent actions are coordinated (Plesner and Horst, 2013). The research thus far has shown that project-level BIM alignment can only be achieved by finding the right balance between the individual and the collective, coupled with the right configuration of the myriad competing and collaborative technological platforms required on any particular project setting.

The case analysis indicated clear differences between the professional project organisations with regards to the selection of BIM platforms which are appropriated to specialised boundary niches as they contribute an important fragment to the overall functionality of the project. These fragmentations in the individual boundary practices particularly manifest in their organisation-level BIM implementation strategies which are ultimately configured and integrated to form a holistic project-specific BXP.

As the lead contractor on the case project, ConsTech’s approach relating to the development of the project BXP was not a simple case of incorporating specific product solutions into the grand vision of the work system. Rather, it was a result of merging practices and coordinating various artefacts based on negotiations between many juxtaposed visions across the multilevel project constituencies. This was intertwined with priority setting of the project-based technologies on the basis of usefulness, proprietary interfaces and ease of integration with other competing and collaborative technological platforms. All these were done to accommodate the various facets of the project team’s competencies, available best practices and current technological capabilities and in line with the project’s BIM ambitions.

For instance, the original intention of the lead contractor’s BIM strategy was at best to “mix-and-match” software tools to get a “best blend of capabilities” beyond what could be offered by any BIM suite from a single vendor. But it was later acknowledged that, owing to data transfer issues, it was better to engage a single vendor range of BIM platforms to ensure information exchange across the project phases and also across the project organisations. The latter strategy could more appropriately be described as proprietary rather than an open-BIM interface (Eastman *et al.*, 2011). This suggests that the adopted BIM strategies spanning between organisations at project levels are not immutable or fixed concepts but rather they can be transformed as new knowledge or innovative ideas are acquired. Likewise,

the project BIM output was a blend of negotiations between technological possibilities and organisational practices to meet the requirements highlighted in the client briefing documents.

Eventually, the project BXP was configured based on common grounds where conflicting interests across the boundaries can find their associated activities to be both desirable and feasible for the project. Hence, as visions are eventually narrowed, the principles of the project-level BIM processes are perceived to be jointly developed and the technological choices and uses become standardised or more fixed. For instance, the MEP contractor selected a dual technology platform; one platform was purposely selected to enable the MEP model to integrate with the project-coordinated model and its alignment with the project-specific BXP whilst the other platform was used to facilitate offsite prefabrication and onsite installation purposes and alignment with the MEP organisation's BIM execution plan. The use of dual MEP technological platform was desirable and feasible, albeit impacting on the overall MEP program and cost. Again, the landscape contractor not particularly persuaded in adopting the default project technology owing to the small size of its contract package, was given the dispensation to use its preferred BIM tools to design the landscape layout. This meant the landscape design information was in dwg file format and it restricted the level of landscape information that could be generated from the coordinated model to only graphical data but not the accompanying non-graphical data. Indeed, Navisworks was the main platform used on the project to interrogate and coordinate federated models from the different practitioners. Thus, all the individual platforms had to produce file formats that were convertible with Navisworks cache file (.nwc) to facilitate the synchronous exchange of usable data across the phases of the project.

Also, despite the client's willingness to adopt BIM to support long-term facilities management and maintenance of the project, it was clear that the client's interests were protected, especially in financial and contractual terms. Undeniably, the client safeguarded against any impending uncertainty associated with the "unchartered nature" of the BIM process by espousing a fixed-price design-and-build approach as the main contractual arrangement. The choice of the contract type was mainly to shield the client from any unanticipated cost increase that could potentially arise owing to the rarely developed and largely untested project-based BIM implementation processes. In particular, it has been acknowledged that fixed-price design and build contracts tend to create a conflict of interest between parties, whereas contract measures that allow some sharing of project risks and associated pain/gain are construed as supportive of collaborative relationships (Saunders and Mosey, 2005). The coordinated project model was also commissioned to serve two main purposes on the project:

- (1) as a platform to facilitate the design and exchange of coordinated information for the construction of the project; and
- (2) to produce a handover O&M model, coordinated with all necessary manuals for use at the facilities management stage.

The integrated boundary activities have depicted how the overall project-level BIM ambitions were achieved, as shown in [Figure 2](#).

The case study organisation has provided insights into BIM transformation processes based on negotiations and mutual compromises that transcend technological optimisms across multilevel project organisations. Although the implementation analysis is based on feasible and purposeful activities that traverse multilevel constituents, the translation of ideas, technologies and practices eventually divulge innovative assemblages that present reciprocal compromises. The implementation effort is therefore contingent on mutual

translation in which different actors with different insights instigate their practices through negotiation and persuasion which eventually are reinforced by contractual agreements and obligations. This is particularly essential for generating sufficient momentum to confront resistance which is inevitable in multi-organisational boundaries (Molina, 1993).

Conclusions

The study has mobilised the concept of multilevel boundary-spanning activities to provide insights into the contemporary construction project practices enabled by the application of emerging construction technologies. The paper is designed to contribute to the academic dialogue in two ways. The first contribution is to broaden the understanding of the multilevel boundary spanners and their influences on the emerging boundary practices as a result of deploying technological solutions within the contemporary construction project settings. The second contribution is to establish the appropriation and manifestation of best practices within BIM-enabled construction project organisations. The former was achieved through experts' sampling research approach which served as a preamble in achieving the latter which was analysed using a case study research approach.

The multilevel boundary spanning concept has suggested that, when boundary activities increasingly become interdependent, through for instance integration of federated models from different sources into a composite sharable model, such an activity requires the configuration and assemblage of proprietary or open-BIM technological interfaces with the appropriate innovative activities. In such a situation, complementary adaptation and realistic practices that connect with the different facets of the contextual inter-organisational antecedents become critical. The insights gained from the theoretical analysis and the empirical observations suggest that the BIM uptake on construction projects is not a value-neutral innovation and ambition that is just appropriated by the willing organisations, rather, the technologies translate and are translated throughout the implementation processes owing to the inter-connected boundary activities. This corroborates with the idea that companies that operate in multilevel relational networks are often not free in choosing their strategies – the formation of a business relationship involves choosing and also being chosen (Wilkinson *et al.*, 2003).

The BIM rollout within the project organisation is a process of adaptation and appropriation of the functional traits endowed in the technological artefacts in alignment with the overall project BIM ambitions. The right balance is achieved through mutual compromises and boundary practices that conflicting interests can find to be both feasible and desirable, but not necessarily determined by the design intents or technological optimism of the developers. The important contribution of this paper relates to the findings of the project-level practices and the pertinent multi-organisational configurations that optimise the BIM rollout. It has been shown that the innate practices confined within individual boundary settings tend to constrain the overall project-level agenda because of the variation in visions of, and expectations from, BIM applications which inform strategies for both the organisation- and project-level BIM execution plans. Hence, finding the right balance between the collective project organisations and their myriad technological platforms is vitally important.

The empirical analysis has also shown how the multifunctional settings and multi-skilled workforce cope with the messy situations that emerge at the project boundary as facilitated by the BIM uptake. Figure 1 shows a framework of the BIM-compliant boundary spanners that influence the development, deployment and appropriation of emerging construction technologies across a multilevel supply chain. Also, Figure 2 shows a framework that aligns the seemingly separate yet interconnected technological artefacts, professional dialects and

project practices, thus facilitating insights into the much-anticipated coordination and information flow from design through construction to handover of a project. The negotiation and adaptation of purposeful practices of BIM-compliant solutions which the various stakeholders find to be desirable and realistic towards the fulfilment of the overall project BIM ambitions are then instituted as boundary activities under binding contractual obligations. The insights from this paper are timely and relevant to the contemporary construction practices, particularly as BIM is increasingly being mandated to facilitate collaborative culture, thereby transforming the AEC sector into an efficient work system. A limitation of this study relates to the evolving nature of BIM as it is relatively new and its evolution is inextricably linked to the rapid advancement in information technology. This study however offers a starting point for future longitudinal empirical study to build on for providing better clarity on the challenges that may confront the construction organisational boundaries across time as BIM mutates into the realm of development, deployment and utilisation.

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