SPANNING THE MULTILEVEL BOUNDARIES OF CONSTRUCTION ORGANISATIONS: TOWARDS THE DELIVERY OF BIM-COMPLIANT PROJECTS

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Abstract

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 are a result of 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. Building information modelling (BIM) is increasingly being promoted both within academia and in practice as enabler in collaborative practices and efficient work delivery. Nevertheless, the efficiency gains cannot be realised without the clear understanding of the multilevel knowledge-processes and workflow management that accompanies BIM deployment. Accordingly, the premise of this paper is on the interdependent boundary spanning activities that characterise the level of permeability of knowledge, information-flow and learning among construction supply chain involved in the delivery of BIM-compliant construction projects. The concept of multilevel boundary spanning practices has been recognized as critical in moderating the relationship between project stakeholders with consequent impacts on project performance.

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 the appropriate best practices for managing multilevel boundaries in BIM-enabled construction project organizations. The paper has revealed that different generic organizational BIM strategies as developed in specialized boundaries are reconfigured as appropriate at the project-level to produce project-specific BIM execution plan (BXP). The outcome of the project BXP is dependent on the project organizational 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 instigates their practice through negotiation and persuasion which eventually are reinforced by contractual agreement and obligations.

Keyword: organizational boundary; Building information modelling, multilevel perspective; construction project

Introduction

The recent progress in technological development 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 practice. BIM is associated with virtual representation of the physical and functional characteristics of a facility that facilitates a seamless exchange of information across all tiers of the architecture, engineering, and construction (AEC) supply chain (e.g., 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 (e.g., 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 et al., 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 on 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 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 due to interface mismatch between two or more organisations such as information mismatch, coordination difficulties, or vendor platform's performance failures (Chua, 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 interdependency in the work system originates from multilevel operations of specialists stakeholders representing different organisations. The conditions of the interactions in this respect provide the specific opportunities for adaptation and activity adjustments (Gadde, 2014). Hence, the project level BIM activities should align with organization-specific work processes, compatibility, tolerance and accommodation (Fellow 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, data collection strategy for the paper, including interviews by experts' sampling and case study research approach is discussed. Finally, analysis of the research findings and discussions of the results are presented.

Literature review

Perspectives on the 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 specialized skills (Karrbom Gustavsson & 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 & Liu, 2012). Many of the challenges that manifest in construction projects are a result of both the temporary and 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 in order to technologically couple their different facets together. The idea of an integrated AEC sector with seamless information exchange as facilitated by BIM where a decision by one specialist firm could have reactionary effects on the rest of the project team, also comes with a paradigm shift from the linear, fragmented planning process. For instance, the question of interfaces in the data transfer from one interdisciplinary model to another arises - synchronizing the heterogeneous data structure from different software into a coordinated model, and - coordinated exchange and simultaneous use of synchronous project data are becoming pertinent issues that need to be addressed (e.g., Richards, 2010). 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 & Griesemer (1989) on knowledge boundary object categories, Whyte & Lobo (2010) highlighted three different digital artefacts for infrastructure delivery as: 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 storage 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 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 & 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 & Horst (2013) termed, '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 (constituents) alignment through mutual adaptation of common perceptions and pursuits. Molina & Kinder, (1999) argue for the joint consideration of sociotechnical components in a multilevel context through consensus building in order to align both social and technical constituents until a successful work system or a constituency is established.

The main premise of Molina's approach deduces 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 term of contextual influences. Multilevel researchers have particularly recognise the relationship among variables at different levels of analysis. The multilevel perspective is conceptualised in this study as a nested hierarchies that constitutes the micro (organisation), meso (inter-organisation or project team), and macro (broader environmental influences) levels (e.g. Lundvall, 1988). The multilevel perspective (MLP) recognises the myriad institutional, managerial and technological aspects – the strand of competing and complementary boundary practices that intertwine to influence project outcomes (Whyte & Sexton, 2011).

Dossick & Neff's (2011) research into the use of BIM by multiple knowledge groups found that users were having opposing interpretations of its promise neither was it 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 improve alignment and 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 analytical lens for strategy development towards the transformation of BIM-enabled construction project organisations (e.g., Markard et al., 2012; Berggren et al., 2015).

Bridging, or spanning the multilevel boundaries in order to achieve overall success cannot be overemphasised. The concept of boundary spanning can refer to activities across organizations (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 the assimilation and collaborative norms, knowledge and information interface towards a collective goal. Thus, a multi-level analytical approach to boundary spanning can be envisioned to be of relevant within a BIM-compliant project environment (Abbott et al., 2013).

Spanning the construction project boundaries towards successful BIM deployment

The key contribution of this study is to enrich understanding on the multilevel boundary spanning activities towards the 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 (e.g., Gopal and Gosain, 2010). Organizational 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 characterized by negotiating the interactions in order to build a sustainable relationship between the organizations involved (Brion et al., 2012). The scope of boundary action and issues relating to effective operation can be analysed in reference to multi-layer activities. At the individual organisation layer, each organization offers its particular perspective on what to perceive as relevant boundary activity (Araujo et al., 2003), and this manifests with organization-level BIM implementation strategies. Such specialist orientation and differentiation between firms' activities is 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. Fellow 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.

This viewpoint corroborates with Thompson's (1967) distinction between "boundaries as buffers and boundaries as bridges". These two boundary practices are in the opposite ends of a continuum. Buffer boundaries feature limited or low permeability rate, whiles bridge-up boundaries epitomise openness or ease of movement across a boundary or amongst collaborating firms (Gadde, 2014). The level of permeability thus dictates the level of information flow, knowledge sharing and learning (Fellow and Liu 2012). The boundary continuum also presents to the organisations involved a series of choices and consequential effects. Such choices have been identified to alternate between "confronting versus conforming or creating versus consolidating" (Ritter & Ford, 2004). The present of *confrontation* seeks specific changes or demands transparency within existing relationships, whiles *conforming* aims to keep specific aspects of the status quo. *Consolidation* firms-up existing relationships by actively participating in the related work system's corporate activities, whilst *creating* represents the efforts to alter or transform existing activities in order to balance the boundary relationship or to align into the work system (e.g., La Rocca & Perna, 2014).

In the context of construction project organisations, the practice of boundary spanning has been recognized as critical in moderating the relationship between project stakeholders with consequent impacts on project performance. For instance, Fellow and Liu (2012) use 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 & 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, or interoperable data interchange is an important antecedent for inter-organisational performance. This study therefore aims to gain more insights into how construction organisations mobilise boundary spanning practices to manage boundary issues towards a successful BIM-compliance project delivery.

Research methodology

The paper is particularly interested in 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 the 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 embedded case study (Scholz & Tietje, 2002) and experts' sampling interviews (Daniel, 2011) was adopted as the primary source of empirical data for an in-depth analysis to help offer a better insight into the contemporary construction practices. The experts sampling helped informed better understanding regarding the first aim of boundary configuration and the required BIM-compliant boundary activities and the embedded case study 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. 12-number interviews were conducted with construction professionals with relevant but varying experiences regarding BIM. The interviews lasted between 30 minutes to 90 minutes. The interview data helped in understanding the extent of the multilevel boundaries influencing the BIM enhanced project delivery. Such information was used to augment and triangulate the findings of the case study findings. The embedded case study involved a project based activities as the main unit of analysis and the subunits includes the myriad organisations and their boundary practices as they focus on salient aspects of the project activities (e.g., Scholz & 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 9 case study project team members 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 in 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 UK. The housing division is established as one of the UK'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 UK. 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 UK, employing around 2,800 staff and has annual turnover of circa £1 billion. With regards to technological deployment, ConsTech has invested in a R&D innovation team who have researched into the widespread application of information technology, with the view of transforming all its three divisions and various local offices into BIM-enabled entities with the capability to deliver BIM-compliant projects.

To examine the manifestation of boundary spanning activities with regards to BIM implementation on construction project, the research team spent time in ConsTech's East Midland office, where the head of BIM and his team are based. The researcher also visited one of the organisation's first major BIM project site on different occasions between November 2012 and August 2013, observing the project teams and participating in site BIM meetings whiles 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 made to capture observations of interactions and seemingly critical issues that were emerging. The series of interviews, document reviews and non-participating observation were spread out over 9 months spanning from November 2012 to August 2013. 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 by condensing the data, coding the condensed data and interpreted using the adopted theoretical framework (e.g., Taylor-Powell & Renner 2003). This approach helped to reveal the constructs of interests relating to boundary spanning activities. The analysis as described in the result section was in accordance with the constituted segments of the multilevel boundary spanning theoretical framework (Star & Griesemer 1989).

Experts' sampling results and discussions

Boundary specific BIM implementation strategies

The discussion of BIM deployment in relation to boundary management specifically contributes to the understanding of organizational 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. The study therefore revealed that in order 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 CIC Research (2012) 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. There is therefore a clear demarcation line between the organisation-level BIM implementation strategy and the project strategy. The latter represents project specific BIM strategy whilst the former defines 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.

From the organisation perspective, BIM strategy documents contain the organisation's BIM competence-building, encompassing appropriate technical competencies, procedures and knowledge workforce, which ultimately leads to BIM project delivery. This means reaching for the straight forward targets of the available processes and technological infrastructures that can instantly add value to the project or mobilising competences that can ultimately form the project team to bring the project goals into fruition. What is problematic however, the organizational BIM implementation plan does not necessarily guarantee a BIM-competent organization without the effort of embedding the required processes, knowledge and the technology within the organization (e.g., Sackey et al., 2013). Nevertheless, it provides a pathway for the policy makers to follow in order to develop people, processes and to mobilise appropriate technological platforms to augment the organisation's BIM ambitions.

From the project perspective, careful consideration is given to the often referred project 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 the project level BIM delivery, emphasis may vary according to the nature and the desire outcome of the project. The BEP actually defines the way the BIM project will be delivered. 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, comprising: 1) early involvement of the supply chain; 2) development of BIM project protocol and plan; 3) define each supply chain BIM deliverables; 4) clarify the compatible BIM software platforms for use; and 5) contractual relationships. Lack of "buy-in" of the strategy from the project stakeholders can likely jeopardise the ambition of the project BEP. These 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 it is influenced by the boundary spanners. Accordingly, Holzer (2007) has stated that it is valuable to consider how BIM is incorporated into the project workflow, thus the manifestation of these boundary spanning activities are further explored in the case study analysis. The next section however examines the key stakeholders that influence the emerging boundary practices to ensure successful BIM-compliant project delivery.

Exploring the BIM-enabled stakeholder organisations that influence boundary practices at the project-level

It has been acknowledged that multilevel organisations are confronted with forces of fragmentation due to specialisation (Tushman and Scanlan 1981). Fellow 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 project context where each individual (i.e., organisational representatives) brings a unique set of skills and knowledge to the project, it is critical therefore, to identify and understand the represented boundaries, their ambitions and capabilities, in order to bridge any diverse and disconnected boundaries that do not align with the overall project ambition. This is particularly becoming imperative especially as the rapid pace of technological evolution is indorsing a wholesale transformation within the AEC practices (Osan et al., 2012).

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 (Evbuomwan & 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 process by garnering the benefits offered by the latest construction technological product solutions – and offering project teams the avenues to create reliable, accessible, and easily exchangeable building information on digital platforms for the supply chain who needs such information at any particular phase of the building lifecycle. The transition is however accompanied by a wholesale transformation in boundary activities and multilevel configurations. The responses from the interviewees have characterised the transition to BIM as a "*paradigm shift from drawing on 2D media to modelling*," others see 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 the 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 etcetera. Also, new organisational layers are becoming vital partners of the contemporary project team, and these are mainly as 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 (e.g., BIM task group report 2011); and also, independent BIM consultants who are mediating between the traditional practices and the BIM practices, purporting to helping construction organisations towards a successful transition (e.g., Sackey et al., 2014). Academic institutions and R&D organisations are also playing a critical boundary-spanning role toward BIM deployment (e.g., Penn State CIC research on BIM implementation guides, & AEC UK BIM Initiative) (The CIC Research, 2012; AEC UK, 2010). Based on the responses, figure-1 has attempted to depict the typical multilevel stakeholders that influence the best-practice or otherwise of the project BIM deployment process.

The multilevel boundaries depicted 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 & 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 assemblage of business relationships and knowledge integration and ideas among both tightly coupled and loosely coupled project partners in order to foster norm of unanimity towards a common project goal (Gadde et al., 2012).

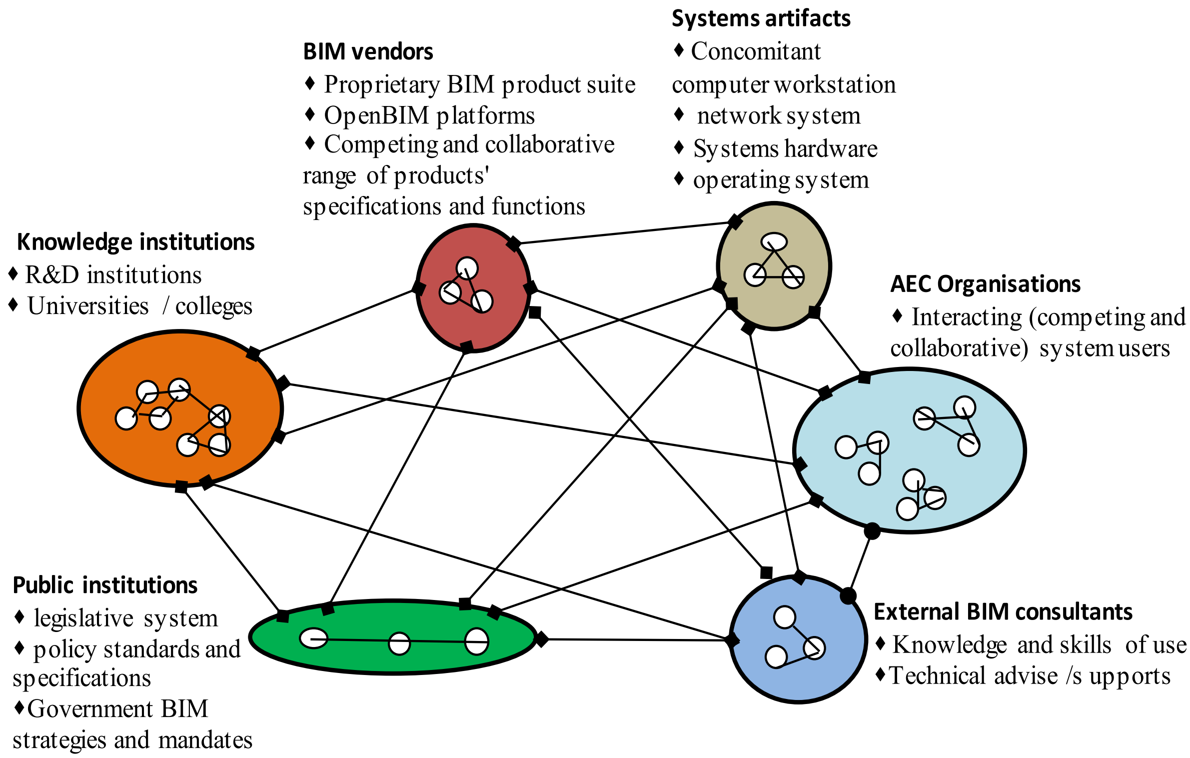

Figure-1 Multilevel boundary organisations influencing BIM-compliant project delivery

The expert's sampling analysis has provided enlightenment on BIM-enabled boundary configuration and practices. It also triangulates and feeds into the subsequent case study analysis – which ultimately aims at establishing the manifestation of boundary activities towards a successful delivery of a BIM-enabled construction project.

Results and discussions of the case studies

Organisation specific BIM-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 headed by BIM expert who has been working in the organisation for over 9 years in a different capacity as the head of design management, until 2012 when he took on his new role as 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, which include: 1) client's BIM requirements; 2) BIM working protocols; 3) 4D programme 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.

ConsTech's strategy on the rollout of appropriate BIM technological platforms within the organisation focuses on "open BIM" approach in order 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 proprietary interface as it does not particularly focus on any single vendor product suite (Eastman et al., 2011). The open BIM approach is the building SMART initiative (Sabol, 2008) which provides the Industry Foundation Classes (IFC) standard that enables collaborative project teams to 'mix-and-match' different software tools to provide 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 higher level is that, interoperable data interchange across disciplines should be possible (Ghassemi & 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 opens standard. The BIM platforms also demanded an upgrade of the existing hardware computer systems towards a 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, hence, calling for the need of higher spec computer workstations in order to ensure performance gains.

Crossing the boundary: integrating organisation-specific expertise with BIM 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 include 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 ConsTect 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 due 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 "design and build" contract. Thus, being the lead contractor under this procurement arrangement, ConsTech was contractually obliged to lead the design and construction team to fulfil the overall project BIM requirements. As part of the project BXP strategy, all the 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. Due to 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 a multilevel specialised boundary capabilities meant that the case organisation, being the main contractor, had the responsibility to unify the rest of the project team under a cohesive project-specific BIM agenda, procedure and ambition, in order to ensure a common data interface.

Despite ConsTech's initial technology strategy of open-BIM interfaces, on this particular project however, it was decided that a single product suites would be used across all the specialised project organisations, this is to safeguard against data exchange and coordination problems during the BIM project delivery process. This single vendor interface enables product families to be supported and coordinated on 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 contrasts 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 has shown that, problems arise with the used of industry-neutral IFC formats when exchanging model information across different BIM platforms. In some instances, it is only the graphical data that transfers from one platform to the other without any accompanying non-graphical data. In other instances too, the parametric relation of the model is lost when it transfers from its native platform into a third party platform.

Due to the challenges associated with the open-BIM interfaces, Autodesk range of BIM products was recommended as the preferred project BIM software. Hence, the dominant Autodesk products that were observed on the project include: Revit architecture; Revit MEP; Revit structure; Naviswork manager (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 however, it was not all the supply chain members that regard 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 perceive 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 its main tool for detailed production drawings because, the current version is not able to create a detailed design to the level that the MEP service engineers or installers will require. Hence, the MEP contractor opted for CAD Duct to develop 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 number BIM tools that were used on the project, only 6 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 the emerging BIM technological platforms to span the multilevel boundary activities

It has been witnessed that the project-level technology rollout strategy has been the requirement for each specialist organisation to use Autodesk platforms to ensure proprietary data interface. Nevertheless, as almost 50% 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 the 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, thus, 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 in bridging the various boundary BIM activities across the supply chain is presented in figure-2.

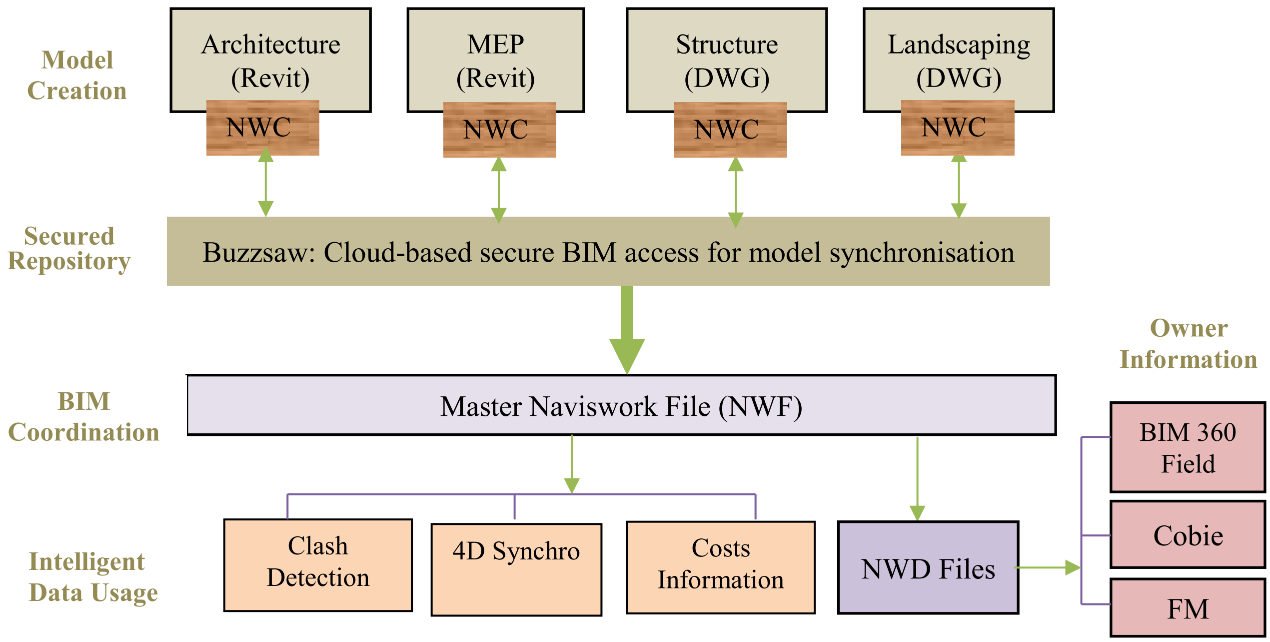

Figure 2: Integrating boundary activities across the multilevel project network

The NWC files are cache files containing a 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 used regularly to update information and reload updates from the linked sources. Thus, if changes are made to the nwc files by the architect, MEP 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 is because it is highly compressed and does not link the data with the native file.

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 were supported by native CAD file formats such as DWF and DWG, which are also able to interface with the Navisworks. For instance, the Vectorworks platforms used for the design of the landscaping layout synchs 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 represents an overview of how the various BIM applications are configured from the individual workstations through the cloud-based repositories to 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 in order 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 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 (e.g., McAuley et al 2013).

Thus, moving beyond the individuals' workstation to the open BIM platform, the project has two different hosting systems, both doing two separate things. The 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 O&M data. However, both of the hosting platforms produced a protocol that ensured that all the 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 produced 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 the 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 enabling and constraining phenomenon. The technological platforms contributed to a 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 depicted 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 suite 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 any other use of the model is considered as a "by-product" of the contractual BIM arrangement.
- Additional cost and delay associated with the use of two different BIM applications by the MEP contractor in order to accommodate both the project coordination requirement and internal work delivery standard

The individual organisations diverge when the practicalities of implementing the BIM platforms at the project level is 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 (e.g., 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 reached and subsequent actions coordinated (Plesner & Horst 2013). The research thus far has shown that the project-level BIM alignment can only be achieved by finding the right balance between the individual and the collective, and coupled with the right configuration of the myriad competing and collaborative technological platform required on any particular project setting.

From the case analysis there were clear differences between the professional project organisations with regards to the selections 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 selecting specific product solutions into the grand vision of the work system. Rather, it was as a result of merging practices and coordinating various artefacts based on negotiations between many juxtaposed visions across the multilevel project constituencies, 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 this is 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, due 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 interfaces (Eastman et al., 2011). This suggests that the adopted BIM strategies spanning between organisations to project levels are not immutable or a 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 were 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 platforms, one platform was purposely to enable the MEP model to integrate with the project coordinated model and its aligns with the project-specific BXP whiles the other platform was used to facilitate offsite prefabrication and onsite installation purposes and aligns with the MEP organisation's BIM execution plan. The two choices were made by the MEP contractor as none of the two platforms can effectively perform the dual functions on their own. The use of dual MEP technological platform was desirable and feasible, albeit impacting on the overall MEP programme and cost. Again, the landscape contractor not particularly persuaded in adopting the default project technology due 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 have to produce file formats that are 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 the 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 due 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 (e.g., Saunders & Mosey, 2005). The coordinated project model was also commissioned to serve two main purposes on the project: as a platform to facilitate the design and exchange of coordinated information for the construction of the project, and; to produce a handover operations and maintenance (O&M) model, coordinated with all necessary manuals for use at the facilities management stage. The integrated boundary activities have depicted how the project overall BIM ambitions were achieved as presented in figure-2.

The case organization has provided insights into BIM transformation processes based on negotiations and mutual compromises that transcend technological optimisms across the multilevel project organisations. Although the implementation analysis is situated 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 instigates their practice through negotiation and persuasion which eventually are reinforced by contractual agreement 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 applications of the emerging construction technologies. The paper is designed to contribute to the academic dialogue in two ways. The first contribution is to broaden the understanding on 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 organizations. The former aim was achieved through experts' sampling research approach which served as a preamble in achieving the latter aim 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 have suggested that the BIM uptake on construction projects is not a value-neutral innovation and ambition that is just appropriated by the willing organisations, but rather the technologies translate and are translated throughout the implementation processes due to the inter-connected boundary activities. This corroborates with the idea that companies that operate in a multilevel relational network are often not free in choosing their strategies as the formation of a business relations involves to choose, but also to be chosen (Wilkinson et al., 2003).

The BIM rollout within the project organization 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 optimisms 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 optimize the BIM rollout. It has been shown that the innate practices confined within the individual boundary settings tend to constrain the overall project-level agenda due to the variation in visions of, and expectations from, BIM applications which inform strategies for both the organization and project 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 has depicted a framework of the BIM compliant boundary spanners that influence the development, deployment and appropriation of the emerging construction technologies across the multilevel supply chain. Also, figure-2 has presented a framework that aligns the seemingly separate yet interconnected technological artefacts, professional dialects and project practices, hence 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 is 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.

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