KEY CONSTRAINTS TO OPTIMAL AND WIDESPREAD IMPLEMENTATION OF BIM IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

Adeyemi Akintola[1], David Root[2] and Senthilkumar Venkatachalam[3]

[1&2] *School of Construction Economics and Management, University of the Witwatersrand, Braamfontein, Johannesburg, 2000, South Africa*

[3] *Sustainable Construction Materials & Structural Systems Research Group, Department of Civil and Environmental Engineering, University of Sharjah, United Arab Emirates*

Building information modelling (BIM) implementation in South Africa, though spanning over a decade, has been neither widespread nor optimal, prompting a need to identify key constraints to achieving this. Data was collected through semi-structured interviewing of purposively selected consultants who have implemented BIM within their organisations and on projects. Key industry level constraints to optimal and widespread implementation of BIM in South Africa include lack of standards and uniform protocols as well as lack of government capacity, buy-in and support. These in turn contribute to varying patterns of implementation methodologies among collaborators along with non-interoperability of technology and business processes. The findings establish a clear demand for country-specific standards and institutional backing, though current implementers adopt or adapt standards and protocols from other countries. Taking the proliferation of BIM standards into account, rather than recreating such standards for the South African construction industry, it is more efficient to adopt or adapt existing standards from countries already leading in BIM. Therefore, as countries lagging in BIM continue to adopt or adapt existing BIM standards, diverse standards and methodologies across the world may evolve towards a dominant pattern of BIM implementation practice among existing variants, and with global collaboration global BIM standards may emerge.

Keywords: BIM, constraints, standards, South Africa

Implementing BIM as a way of improving the outcomes of construction projects has continued to gain prominence across the world, more so in the United States (US), United Kingdom (UK) and the Scandinavian countries (Shou *et al.,* 2015; Smith 2014; Wong *et al.,* 2010). Nevertheless, BIM has been in use in some form or another in many other countries than is commonly reported in literature. The distinction is made in the extent to which BIM is implemented within organisations, on projects, how many of such projects are executed, and how mature BIM-enabled project practices within such a country's construction industry context actually are (BSI 2013; Succar 2010). Other delineators among countries are the presence or otherwise of a deliberate mandate driving adoption and implementation, and to what extent that drive is supported by government, professional and educational institutions, and private sector organisations.

[1] adeyemi.akintola1@students.wits.ac.za

Akintola, A, Root, D and Venkatachalam, S (2017) Key Constraints to Optimal and Widespread Implementation of BIM in the South African Construction Industry *In:* Chan, P W and Neilson, C J (Eds) *Proceeding of the 33rd Annual ARCOM Conference,* 4-6 September 2017, Cambridge, UK, Association of Researchers in Construction Management, 25-34.

In particular, government (and related entities) involvement in driving BIM adoption and implementation is reasoned first on the position that they are often the biggest investor of resources in the construction industry and exercise considerable 'market' power as clients. They therefore hold a major stake in the success of the industry and every effort to innovate, such as with BIM, benefits from their support. Second is the heavy dependence of BIM-enabled project success on the uniformity of shared information and processes (Gu and London 2010; Porwal and Hewage 2013), for which government policies and legislation are essential drivers. These go a long way in driving support from construction professional institutions and even private clients' buy-in and demand for BIM on projects. Perhaps the most prominent example of this is the UK construction industry's approach to BIM adoption and implementation, which is the most structured among the leading countries when it comes to BIM implementation.

However, in these same countries leading in BIM, there is a proliferation of BIM implementation standards and methodologies as argued by Smith (2014) and evident in the analysis of Shou *et al.,* (2015). While the importance of standardising BIM practice is not in doubt, in setting standards guiding such practice, duplication of effort may not be beneficial. This therefore raises the question on whether it is needful for all countries to have separate BIM standards and guidelines. Nevertheless, in South Africa where BIM authoring software have been in use for at least a decade, some progress is being made even though its implementation has neither been widespread nor mature (Booyens *et al.,* 2013; Froise and Shakantu 2014). While there are several factors that might account for these, in this study the investigation is of industry level impediments to widespread and optimal implementation of BIM in the South African construction industry context.

RELATED LITERATURE

BIM Implementation Challenges

Numerous authors have studied BIM implementation challenges in different contexts. These challenges are many and are procedural, socio-cultural and technical in nature. Key challenges that have been identified as impediments to implementing BIM include inter alia varied readiness to implementing BIM among project stakeholders (Singh *et al.,* 2011), the need for adapting intra- and inter-organisational workflows, lack of clarity of stakeholder roles and responsibilities (Elmualim and Gilder 2014; Rekola *et al.,* 2010), and lack of proficiency that often requires huge investments in training (Becerik-Gerber and Kensek 2010; Elmualim and Gilder 2014). At the industry level, depending on the context, the challenges include the lack of standards, lack of government support and drive, lack of incentives (Abubakar *et al.,* 2014; Aibinu and Venkatesh 2014; Smith 2014), the need for cultural change in the industry (Ambrose 2012; Rowlinson *et al.,* 2010) and lack of demand by clients (Aibinu and Venkatesh 2014). These are challenges that are not specific to any organisation or project team, beyond their immediate control, and have become concerns at the industry level. These challenges nevertheless have far-reaching effects on the success of BIM implementation within organisations and on BIM-enabled projects.

The Importance of BIM Implementation Standards and Guidelines

BIM standards and guidelines are important for facilitating seamless coordination and collaboration through digital methods (Shibeika 2014). As a set of agreed upon rules, they are essential for achieving interoperability and standardisation of information across different areas (Wang *et al.,* 2013). By implication, the lack of widely accepted standards limits effective collaboration as alluded to by Beach, Rana, Rezgui and Parashar (2015).

However, it is not uncommon for individual organisations to develop their own guidelines and protocols to address procedural and contractual challenges, especially in countries where there are no commonly accepted BIM standards.

There have been several BIM adoption and implementation initiatives to facilitate the success of BIM implementation throughout the building lifecycle (Atkinson *et al.,* 2014; Shou *et al.,* 2015). The ultimate aim is to institutionalise a preferred pattern of collaborative practices for the delivery and operation of construction projects with the aid of BIM. Wong *et al.,* (2010), Smith (2014) and Shou *et al.,* (2015) provide valuable insight into patterns of BIM practice in various countries. Their analyses show two patterns: those who have taken a structured approach to implementing BIM countrywide through central standards and guidelines, and those who have been implementing without clear standards and guidelines.

Shou *et al.,* (2015), in a similar approach to Wong *et al.,* (2010), outlined a non-exhaustive list of about 40 BIM-related standards and guidelines from 10 different countries that define information creation, usage, sharing, storage and reuse standards and procedures. They are products of initiatives by government bodies, educational institutions and private sector entities, sometimes solely, and at other times in collaboration. Clearly some of these efforts are duplications. However, a proliferation of guidelines that dictate implementation methodologies may not necessarily mean progress for the construction industry globally.

BIM standards documents from different contexts often have closely-related purposes, although the UK approach to implementing BIM has been deliberate and structured, and is therefore often cited as a model for other countries. Theirs is a central, government-backed initiative to institutionalise a preferred pattern of BIM practice. The Australian and New Zealand Revit Standards (ANZRS) are said to have been downloaded, and perhaps used, in 72 different countries (ANZRS 2017). Furthermore, comparing existing BIM standards from the UK, US, Singapore and Australia, it is evident that they are all geared towards achieving largely similar purposes, namely: to ensure the production of coordinated information such that it can be used and reused throughout the project and life of the asset (BCA 2013; BSI 2013; NATSPEC 2012; NBIMS 2015).

Table 1: Comparing standards from different contexts

Standard	Purpose	Country	Year
NATSPEC National BIM Guide, (NATSPEC 2012)	Intended as a planning tool for consultants to clarify the services they propose to provide and to assist all stakeholders in defining their BIM requirements consistently	Australia	2012
PAS 1192-2:2013, (BSI 2013)	To ensure the production of coordinated information such that it can be used and reused throughout the project and life of asset	United Kingdom	2013
Singapore BIM Guide Version 2, (BCA 2013)	To demystify BIM and provide clarity on BIM implementation requirements at different stages of project delivery	Singapore	2013
National BIM Standard - United States® Version 3, (NBIMS 2015)	To provide a means for organising and classifying electronic data and also to streamline communications among project stakeholders and structure of collaborative practices	United States	2015

South Africa has striven to achieve a balanced socio-economic development through heavy capital investments in infrastructure with limited resources. In spite of the expectations of the construction industry, it contends with several impediments, the likes of which could potentially be alleviated through implementing BIM. These include generally poor levels of project performance (Emuze and Smallwood 2012), inadequate documentation, poor knowledge transfer and poor multidisciplinary project team interface (Emuze and Smallwood 2014). For instance, in the UK, the deliberate drive to implement BIM, among other things, is claimed to have delivered efficiency savings of up to 3 billion pounds over the years 2011 to 2015 (Cabinet Office 2016). Further targets have been set for the next 5 years for a 33 per cent reduction in costs, 50 per cent in emissions, and 50 per cent in delivery times (Cabinet Office 2016).

The limited use of BIM and low maturity of implementations in South Africa are the prompters for this study. The South African construction industry context is peculiar in its reliance on traditional methods of procurement and delivery. Notable is the absence of any widespread patterns of collaborative practices that might provide a fertile environment for BIM adoption. Therefore, unlike countries leading in BIM and on which much of existing literature focuses, the changes required for implementing BIM within organisations and on project teams are likely to be much more disruptive, as they have to change not only workflows, but also the prevailing industry culture to be optimally used. The aim was thus to investigate the impediments to implementing BIM to full maturity in the South African context.

METHODS

This study is positivist in philosophical leaning, qualitative and deductive in approach. Being mainly exploratory, it was carried out using a pre-prepared interview guide that facilitated conversations with 11 purposively selected construction professional service providers (key informants) (Marshall 1996). The selection consisted of architects, engineers and project managers representing 8 organisations who have implemented BIM within their organisations and on multidisciplinary projects. Probing questions were asked about their experiences with BIM implementation including their perceptions on industry-level impediments to widespread and optimal implementation of BIM in South Africa. Optimal BIM implementation is taken to be a level of implementation that coincides with the requirements for BIM level 2 by the organisations in implementing BIM within their organisations and on construction projects as defined in the PAS1192:2 document (BSI 2013). Using Succar's (2010) BIM maturity matrix model however, the organisations represented have achieved the 'defined' and, sparingly, the 'managed' levels of maturity. This is adjudged to be between BIM maturity level 1 and 2. They have been able to define implementation protocols, technological requirements and inter-organisational workflows around BIM. Further, while implementing BIM, the organisations have been able to integrate BIM technologies into their organisational strategies.

The key informants (as shown in Table 2) were consulting professionals who are in BIM leadership positions within their respective organisations. Their organisations were mainly multidisciplinary and involved in multinational operations, although their responses for this study were specific to the South African context. Audio recordings were taken during the interview sessions to ensure that all information was captured and thereafter transcribed verbatim. Handwritten notes and preliminary reflections from the interviews were summarised into memos, one for each interview. The organisations were largely operational internationally, and provide a wide range of construction-related

services. Data collected were analysed by analytical memoing, transcribing, coding and interpretation, and preparation of matrix data tables (Miles *et al.,* 2014).

Table 2: Participants Characteristics

Participant	Organisation Practice Type
C2_ Architect _BIM Coordinator	Multidisciplinary
C3: Structur. Engr._ Director_ Head VDC/BIM	Multidisciplinary
C4_Architect_VDC /BIM Facilitator	Multidisciplinary
C7_BIM manager	
C6_BIM Manager Architect	Multidisciplinary
C8_Architect	Architectural
C9_Architect_Director	Architectural
C1_BIM manager	
C10_Structural_ Civil Engineer_Director	Multidisciplinary
C5_Architect	
C11_Architect_BIM Coordinator	Architectural

The participants (as outlined in Table 2) were selected from organisations with mainly multinational experience and they provide a variety of services.

DATA ANALYSIS AND DISCUSSIONS

In summary, the findings establish the following:

- Lack of drive and support for BIM by government bodies including the Construction Industry Development Board (CIDB); a body that registers business entities in the industry and regulates industry practice through codes and standards;
- Lack of drive and support for BIM by South African construction industry professional registration councils that cover the architectural, quantity surveying, project management and engineering professions;
- A perception that there is lack of understanding of BIM among construction industry professionals; and
- Lack of uniform standards and guidelines for implementing BIM in a preferred uniform pattern.

The findings are presented below in themes.

General industry constraints to implementing BIM in South Africa

Despite all informants reporting BIM benefits in the form of improvements in productivity, integration, error/rework reduction, visualisation and competitive advantage, the findings also show serious challenges. Virtually all of the participants alluded to the lack of South African BIM standards to cater for the peculiarities of the South African construction industry context, which are deemed to set it apart from other contexts (as in Table 3 below). Furthermore, BIM adoption is mainly driven by private consulting organisations who act as clients' agents and, occasionally, private clients and client

organisations that are sometimes knowledgeable about BIM. Nevertheless, the findings also highlight the professionals' scepticism regarding the ability of public clients and construction industry councils for the built environment professions to drive BIM adoption and implementation countrywide, judging by their perceived lack of understanding and proficiency in BIM. One of the peculiar challenges of the South African construction industry has been a severe shortage of skilled professionals in the government's Department of Public Works, which prevents it from operating as an 'informed' or 'expert' client. Second, and also linked to skills shortages, is that government projects are executed and supervised by private consultants particularly at the delivery stage. Therefore, the capacity to drive and support innovation by government is doubtful. These are similar to the findings of Abubakar *et al.,* (2014) in a Nigerian study and the summation of Smith (2014) regarding countries like Brazil and India.

Table 3: General industry concerns for BIM implementation in South Africa

Concerns	Key informants
Lack of drive for BIM adoption and implementation from government and related institutions. Consequently, there are no local BIM standards and guidelines and private organisations are compelled to borrow from countries leading in BIM	C1, C2, C3, C4, C11, C7
Lack of buy-in and demand for BIM on public works	C2, C3, C4, C7, C11
Doubts and scepticism about the competence and capability of professional and regulatory councils and other government bodies to receive and assess such information as might be produced using BIM	C2, C3, C11, C7
Without increased awareness and client demand, construction-related organisations will not change	C3
Implementation maturity in the country is low	C4
Lack of supportive legislation and guidance from councils and government institutions	C4
There is no mandate for BIM use on public sector projects	C4
Many organisations are still not using BIM authoring software	C4
There is no incentive from government for construction organisations to change	C8, C11
Proprietary materials/component manufacturers have no incentives to begin developing BIM content	C1
Procurement methods have to be rethought	C7
Changes experienced outside the African continent would make it more difficult for non-adopting local firms to be competitive internationally	C1

Lack of Professional Councils' and Government Support for BIM

In South Africa, the responsibility for developing the construction professions, maintaining professional standards in the built environment professions and coordinating the different professional councils rests with the Council for the Built Environment (CBE) and its subsidiary professional councils, while that for promoting uniformity and efficiency in construction procurement and infrastructure delivery lies with the construction industry development board (CIDB). The Department of Public Works (DPW) holds the mandate for the provision and management of the government's fixed assets, with the CIDB and CBE both reporting to the Minister in charge of the DPW. Together, these provide guidance for, and also regulate industry practice. However, in

contrast to similar organisations like the Royal Institute of British Architects (RIBA) and the Construction Industry Council, among others, in conjunction with educational institutions in other countries, there are concerns about their level of awareness and knowledge about BIM (Atkinson *et al.,* 2014). Therefore, private organisations/entities are at the forefront of BIM advocacy and development without support from government. For example, key informants C2 and C11 questioned the skills and capabilities of government bodies to drive BIM. According to Informant C2, "There is a definite concern in the industry that councils (professional councils) do not have the capability to really assess the information that they are getting".

Need for South African BIM standards

The need for country-specific standards for BIM practice was also established in the findings, as Informant C3 associated the lack of "guidance and drivers from any government authority in the (Africa) region", while affirming that they have observed "much better uptake where there is a driver (for BIM)". Similarly, the availability of BIM guidelines was linked to improved adoption by Al-Shammari (2014). Presumably, the lack of guidelines and driver is attributable to the lack of understanding of its potential and implications by the relevant organisations. This lack is a source of frustration for BIM implementers in South Africa as illustrated below:

> It is hard for us in South Africa, I think Africa actually, around BIM implementation. It is driven by the private sector because we don't have the backing of government - C11

> … with new roles, we need some sort of BIM standards in South Africa to work towards, not for private companies pioneering and working towards other companies' standards that are not our standards - C8

While it is not uncommon for the private sector to lead in driving BIM, the evidence therefore illuminates the peculiarity of the South African case in the inability of government agencies to adequately drive BIM adoption and implementation, as well as lead in the development of guidelines. Nevertheless, existing standards from countries leading in BIM are being adapted for use in South Africa but have remained discrete efforts. According to informant C1; "In terms of guidelines, there is a lot of documentation these days which offer some kind of advice that is generally driven by government. The UK in particular has fantastic documentation that you can refer to when it comes to BIM".

While there is a demand for country-specific standards and guidelines for implementing BIM in South Africa, adoption and adaptation of standards from countries leading in BIM have been with reasonable levels of successes. Nevertheless, since these are discrete efforts, the direct implications are experiences of varying patterns of implementation among project stakeholders and, consequently, non-interoperability as supported by Beach *et al.,* (2015).

Experiences of Varying Patterns of Implementation and Non-Interoperability

Clearly, these two challenges are strongly linked to the lack of uniform guidance for BIM practice. The findings suggest that BIM implementers experience great difficulty in managing multidisciplinary team collaboration with BIM, often leading to rework on BIM models created by BIM coordinators. According to Informant C1, "the make or break of BIM and its ideology is ability to exchange information". This is further buttressed by informant C11, whose organisation has been quite successful with implementing BIM (achieving close to BIM level 2 maturity (BSI, 2013)) as illustrated below:

> In the last five years or so, the biggest challenge that we have been experiencing has been around team collaboration.

Poor collaboration whenever it occurred was attributed to lack of proficiency of collaborating project team members and the lack of uniform guidelines on which BIM-enabled projects may be executed. In response to the lack of uniform guidelines for implementing BIM, whenever two collaborating organisations come with different implementation methodologies or plans, a meeting is held to examine the pros and cons of each approach. Thereafter, an agreement is made on how to implement BIM on a project-by-project basis (Informant C3). On the other hand, whenever the integrity of a collaborating team member's model falls short of requirements, the BIM coordinator assumes the responsibility for reworking such substandard models.

The foregoing substantiates the need for uniform standards for implementing BIM in South Africa. Arguing from a different level however, it is questionable that all countries should require the development of BIM standards. Taking the current proliferation of BIM standards and guidelines into account (Shou *et al.,* 2015; Smith 2014), an alternative argument exists for the adoption and adaptation of what works in countries leading in BIM, rather than for re-creation of existing standards. According to Wortmann *et al.,* (2016), existing BIM standards and guidelines across different country contexts are quite similar but should be nuanced to cater for context-specific differences.

Therefore, BIM standards and guidelines will continue to be fundamentally similar, hence a globally acceptable standard and guideline would need to broadly dictate an agreed pattern of BIM practice that may be adapted as required. For instance, the BIM protocols drafted by a private South African initiative, the BIM Institute, were almost entirely adapted from the UK BIM standards and guidelines, thereby creating duplications. An option may therefore be for construction industry stakeholders in South Africa to jointly agree on which existing standards to adopt and thereafter provide guidelines for their adaptation to suit context-specific requirements. However, it is still incumbent on the relevant government and professional institutions to drive and shape the adoption and adaptation processes to suit the South African context and to ensure acceptance.

It can be posited therefore that as BIM implementers across the world, particularly from countries lagging in BIM implementation continue to adopt and adapt existing standards from those leading in BIM, a dominant pattern of implementation and supporting standards and guidelines may emerge. The UK approach towards implementation standards and guidelines, being very structured, is the closest to achieving such dominance as it is often adopted by project teams in countries lagging in BIM.

CONCLUSIONS

Even though the use of BIM has continued to increase, not many construction industries have taken a structured approach to its adoption and implementation. In the South African context, there is a clear demand for uniform implementation standards and guidelines. Without these, there have been experiences of varying patterns of implementing BIM among project stakeholders, often leading to technological and business non-interoperability. Without doubt, BIM implementation requires top-down strategic drive to facilitate widespread and high maturity implementation. Although the South African construction industry is not ready for a BIM implementation mandate at the moment, the industry would benefit greatly from incentives and motivations for adoption and implementation by public sector organisations and clients. However, given the proliferation of BIM standards and guidelines, an argument for adoption and adaptation of existing standards is made. That way, as implementers continue to adopt and adapt

what works, rather than recreate new guidelines or standards in this regard, global implementation standards may emerge therefrom.

REFERENCES

Abubakar, M, Ibrahim, Y M, Kado, D and Bala, K (2014) Contractors perception of the factors affecting building information modelling (BIM) adoption in the Nigerian construction industry. *In*: *International Conference on Computing in Civil and Building Engineering*, June 23rd-25th, Orlando, Florida, USA, 167-178.

Aibinu, A and Venkatesh, S (2014) Status of BIM adoption and the BIM experience of cost consultants in Australia. *Journal of Professional Issues in Engineering Education and Practice*, 140(3), 04013021.

Al-Shammari, M A (2014) An appraisal of the protocol that was published by the Construction Industry Council (CIC) to facilitate the use of Building Information Modelling (BIM) on projects. *In*: Raiden, A and Aboagye-Nimo, E (Eds.) *Proceedings of the 30th Annual ARCOM Conference*, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 623-32.

Ambrose, M A (2012) Agent provocateur - BIM in the academic design studio. *International Journal of Architectural Computing*, **10**(1), 53-66.

ANZRS (2017) *Australian & New Zealand Revit Standards*. Australian & New Zealand Revit Standards. Available from http://www.anzrs.org/blog/ [Accessed June 26th 2017)

Atkinson, L, Amoako-Attah, J and B-Jahromi, A (2014) Government's influence on the implementation of BIM. *In*: *International Conference on Computing in Civil and Building Engineering*, June 23rd-25th, Orlando, Florida, USA, 520-527.

BCA (2013) *Singapore BIM Guide Version 2*. Singapore: Building and Construction Authority.

Beach, T, Rana, O, Rezgui, Y and Parashar, M (2015) Governance model for cloud computing in Building Information Management. *IEEE Transactions on Services Computing*, **8**(2), 314-327.

Becerik-Gerber, B and Kensek, K (2010) Building Information Modeling in Architecture, Engineering and Construction: Emerging research directions and trends. *Journal of Professional Issues in Engineering Education & Practice*, **136**(3), 139-147.

Booyens, D, Bouwman, H and Burger, M (2013) The status of building image modelling in the South African construction industry. *Proceedings in ARSA - Advanced Research in Scientific Areas*, **2**(1), 422-430.

BSI (2013) *PAS 1192-2:2013 - Specification for Information Management for the Capital/Delivery Phase of Construction Projects Using Building Information Modelling*. London, UK: The British Standards Institution.

Cabinet Office (2016) *Government Construction Strategy 2016-20*. London, UK: Infrastructure and Projects Authority.

Elmualim, A and Gilder, J (2014) BIM: innovation in design management, influence and challenges of implementation. *Architectural Engineering & Design Management*, **10**(3/4), 183-199.

Emuze, F and Smallwood, J J (2012) Bridging public works project performance gaps in South Africa. *Proceedings of Institution of Civil Engineers: Management, Procurement and Law*, **165**(2), 111-118.

Emuze, F and Smallwood, J J (2014) Collaborative working in South African construction: Contractors' perspectives. *Journal of Engineering, Design and Technology*, **12**(3), 294-306.

Froise, T and Shakantu, W (2014) Diffusion of innovations: an assessment of building information modelling uptake trends in South Africa. *Journal of Construction Project Management and Innovation*, **4**(2), 895-911.

Gu, N and London, K (2010) Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, **19**(8), 988-999.

Marshall, M N (1996) The key informant technique. *Family Practice*, **13**(1), 92-97.

Miles, M B, Huberman, A M and Saldaña, J (2014) *Qualitative Data Analysis: A Methods Sourcebook*. New York: SAGE Publications, Inc.

NATSPEC (2012) NATSPEC National BIM Guide. Construction Information Systems Limited.

NBIMS (2015) National BIM Standard - United States® Version 3.

Porwal, A and Hewage, K N (2013) Building Information Modeling (BIM) partnering framework for public construction projects. Automation in Construction, 31, 204-214.

Rekola, M, Kojima, J and Mäkeläinen, T (2010) Towards integrated design and delivery solutions: Pinpointed challenges of process change. *Architectural Engineering & Design Management*, **6**(S1), 264-278.

Rowlinson, S, Collins, R, Tuuli, M and Jia, Y (2010) Implementation of building information modeling (BIM) in construction: A comparative case study. In: *American Institute of Physics Conference Proceedings*, **1233**(1), 572-577.

Shibeika, A (2014) Diffusion of digital innovation in a project-based firm: Case study of a UK engineering firm. *In*: Raiden, A and Aboagye-Nimo, E (Eds.), *Proceedings of the 30th Annual ARCOM Conference*, 1-3 September 2014, Portsmouth, UK, Association of Researchers in Construction Management, 997-1005.

Shou, W, Wang, J, Wang, X and Chong, H Y (2015) A comparative review of building information modelling implementation in building and infrastructure industries. *Archives of Computational Methods in Engineering*, **22**(2), 291-308.

Singh, V, Gu, N and Wang, X (2011) A theoretical framework of a BIM-based multi-disciplinary collaboration platform. *Automation in Construction*, **20**(2), 134-144.

Smith, P (2014) BIM Implementation - Global strategies. *Procedia Engineering*, **85**, 482-492.

Succar, B (2010) Building information modelling maturity matrix. *In*: J Underwood and U Isikdag (Eds.) *Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies*, IGI Global, 65-103.

Wang, S, Wainer, G, Goldstein, R and Khan, A (2013) Solutions for scalability in building information modeling and simulation-based design. *In*: *Proceedings of the Symposium on Simulation for Architecture & Urban Design*, Society for Computer Simulation International, 43-50.

Wong, A K D, Wong, F K W and Nadeem, A (2010) Attributes of Building Information Modelling implementations in various countries. *Architectural Engineering & Design Management*, **6**(4), 288-302.

Wortmann, A E, Root, D and Venkatachalam, S (2016) Building Information Modelling (BIM) Standards and specifications around the world and its applicability to the South African AEC sector: A critical review. *In*: *Proceedings of the 1st International BIM Academic Forum (BAF) Conference*, 13th-15th September, Glasgow Caledonian University, Glasgow.