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Building Information Modelling in UK Construction Projects: A State of the Art Review

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This is an electronic version of a paper presented at *The 2016 Royal Institution of Chartered Surveyors (RICS) annual Construction, Building and Real Estate (COBRA) research conference*, Toronto, Canada, 19-22 September, 2016.

BUILDING INFORMATION MODELLING IN UK CONSTRUCTION PROJECTS: A STATE OF THE ART REVIEW

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ABSTRACT

This paper aims to present a state-of-the-art review of the scope and practical implications of the Building Information Modelling (BIM) platform in the UK construction practice. Theoretical developments suggest that BIM is an integration of both product and process innovation, not just a disparate set of software tools. BIM provides effective collaboration, visual representation and data management, which enable the smooth flow of information throughout the project's lifecycle. The most frequently reported benefits are related to Capital Cost (capex) and Operational costs (opex) and time savings. Key challenges, however, focus on the interoperability of software, capital installation costs, in-house experience, client preference and cultural issues within design teams and within the organisation. The paper concludes with a critical commentary on the changing roles and a process required to implement BIM in UK construction projects, and suggests areas for further research.

Keywords: Building Information Modelling, collaboration, data management, visual representation, UK construction industry.

INTRODUCTION

The construction industry is a major sector of the UK economy, in which public buildings alone equate to 40% of all construction works (NBS, 2014). At the same time, construction projects are becoming increasingly complex with technological innovation and sustainability two key issues affecting construction and asset management. Traditionally, buildings and infrastructure were designed, built and managed by the use of 2D drawings and paper-based documentation. The introduction of 3D Computer-Aided Design (CAD) transformed the labour-intensive drafting into a more efficient documentation. This is now superseded by Building Information Modelling (BIM), which is a shared knowledge platform and the new paradigm encompasses costs and production programming. BIM seeks to transform the prevalent fragmentation of the Architecture, Engineering, and Construction (AEC) industry into seamless flow processes between stakeholders. BIM uses 3D, real-time, dynamic building modelling software to increase collaboration and productivity in the design and construction stages.

Succar (2009; p.357) provides a comprehensive definition of BIM as a *"methodology to manage the essential building design and project data in digital format throughout the building's lifecycle"*; representing a reliable single platform for decisions from the early design stages up until demolition. A BIM object is a combination of (NBS, 2014): information content; geometry; visualisation data; and functional data. BIM is an integration of product and process innovation modelling, not just a disparate set of technologies and processes. This means that BIM is not just software (geometrical) modelling but it also involves collaboration, project management processes and database sharing skills (NBS, 2014; Sebastian, 2011; Succar, 2009). Succar (2009) argues that there are three interlocking BIM fields of activity:

- Technology: software and hardware developers, suppliers of equipment and networking systems.

- Process: clients, investors, architects, engineers, contractors, surveyors, facility manager involved in the design, delivery and operation of buildings and infrastructure.
- Policy: regulatory bodies, research centres, educational institutions, insurance companies endorsing integrated practices, training practitioners and preparing risk-sharing contractual agreements.

BIM is a value-laden concept, as the term can have different meanings for different professionals depending on their background and experience. Figures from the National Building Specification (NBS) BIM Report show that the percentage of practitioners that were aware and using BIM is increasing (NBS, 2014). Nevertheless, about a third is still not familiar with BIM. Hence, there is a disconnect between the appeal of BIM as a principle aligned with a project's lifecycle at a policy level and readily-available design approaches required for its wider adoption by the construction industry.

METHODOLOGICAL APPROACH

This is a review paper exploring the scope and practical implications of BIM implementation in the UK construction practice. A thorough literature review is undertaken to establish the state-of-the art regarding BIM adoption and maturity in the UK. Three drivers are explored in depth, which are discussed in three separate sections; i.e., collaboration; visual representation; and, data management. Identifying the key challenges associated with BIM, the maturity and level of industry readiness are revealed. The paper concludes by providing lessons learned and directions for further research and development in the field. The target audience includes building practitioners (e.g. developers, contractors, designers, architects, engineers, and clients/ investors) with aspirations to incorporate BIM into their organisation practices.

This is a review paper exploring the scope and practical implications of BIM-readiness across the construction sector, with a particular focus on the position of SMEs. The paper identifies current trends and gaps in the field and then discusses the implications of the research findings on the resilience and adaptive capacity required for construction SMEs. The target audience includes building practitioners (e.g. developers, contractors, designers, architects, engineers, and clients/ investors) with aspirations to incorporate BIM into their organisation practices.

The research follows a systematic literature review with the following five steps. First, the paper *frames the research question*, which is on establishing the state-of-the art regarding BIM adoption and maturity in the UK construction industry. Second, the study identifies *relevant work in the field*. 22 seminal peer-reviewed papers and reports in academic and UK industry databases published from 2008 onwards were reviewed. The main keywords were: 'BIM'; 'collaboration'; 'data management'; 'integration'; 'visual representation'; 'UK construction industry'. The third step involved *analysis of the quality of the existing studies*, looking for groupings and relationships and ultimately the establishment of logical connections between the classified data. The fourth step *summarises the evidence* into three categories of benefits related to BIM implementation as derived from literature; namely, collaboration, visual representation and data management. By identifying the key challenges associated with BIM, the maturity and level of industry readiness is revealed. Finally, the fifth step is about *interpretation of the research findings* through a set of theoretical propositions in the form of lessons learned and recommendations that can also serve as hypotheses for future research and development in the field.

THE UK POLICY AND CONSTRUCTION PRACTICE

Construction projects are becoming increasingly complex and difficult to manage. 71% of construction professionals in the UK agree that BIM represents the 'future of project information' enhancing energy efficiency, sustainability and overall effectiveness of project management (NBS, 2014). To meet the above targets, the UK Government Construction Strategy (HM Government, 2013) has mandated the use of 3D collaborative BIM Stage 2 models in all public building projects by 2016. This targets lies under the umbrella of the Government Construction Strategy, setting out a range of ambitious targets by 2025; namely (*ibid.*):

- 33% reduction in out-turn costs, including initial cost of construction (Capex) and whole life cost of built assets (Opex).
- 50% reduction in overall time, from inception to completion for both new-build and refurbished assets;
- 50% reduction in Greenhouse Gas (GHG) emissions in the built environment; and
- 50% reduction in the trade gap between total exports and total imports for construction products and materials.

There are three stages in BIM implementation. These include (Succar, 2009):

- BIM Stage 1: Object-based modelling, which refers to single disciplinary models within a single project lifecycle phase (e.g. design or construction).
- BIM Stage 2: Model-based collaboration, which deals with interchange (interoperable exchange) of models between one or two project lifecycle phases.
- BIM Stage 3: Network-based integration, which considers integrated models across all lifecycle stages.

The UK can be considered among the world leaders in BIM adoption and implementation. BIM is currently studied by academics, professional groups, and software vendors. A 2013 statistics indicate that about 54% of construction professionals in the UK are using BIM (NBS, 2014). This was only 13% in 2010, showing an increase in the adoption trend. As with every innovation in the AEC industry, BIM is expected to be a major driver in reducing costs, speeding-up the delivery time, highlighting service clashes, mitigating design risks and providing opportunities for value engineering. However, little research focuses on BIM from the project management point of view (Arayici *et al.*, 2012; Khosrowshahi and Arayici, 2012; Succar, 2009). The rising interest in BIM can be examined in conjunction with the Integrated Project Delivery (IPD) framework. The combination of product (BIM software) and process (integrated collaboration, visual representation and information retrieval) innovation is essential in the evolving IPD framework. IPD is a novel project delivery approach that integrates people, systems, business structures and practices into a collaborative process. This process optimises project results, increases value for the client, reduces waste, and maximises efficiency through all phases of design, fabrication, and construction. IPD can be applied to a variety of contractual arrangements and IPD teams can include actors well beyond the basic triad of client, architect, and contractor (Succar, 2009). The role of BIM in the IPD framework is to cater for the whole lifecycle for the project. The benefits that BIM brings to the IPD framework are centered on collaboration, visualisation, and data management, and are discussed in the following sections (NBS, 2014).

COLLABORATION

The UK construction industry is currently associated with having a fragmented nature. Various teams contribute with varied information at different stages of the project. This has caused various inefficiencies and miscommunication. To address this gap, the UK Government Construction Strategy seeks to endorse BIM as an integrated collaboration approach, which is reflected in the changing roles of the building professionals (HM Government, 2013; Sebastian, 2011). Comparing CAD and BIM, Banuelos Blanco and Chen (2014) argue that BIM’s greatest contribution is the ability to support integrated collaboration, as BIM comprises ICT tools that can exchange valuable information over the project’s lifecycle.

BIM allows stakeholders to retrieve and generate information from the same model, which is cloud-based, enabling them to work cohesively. Banuelos Blanco and Chen (2014) and Yoders (2013) outline the project teams ability to update models in real-time, eliminate clashes and discuss iterations early in the design process. Integrated collaboration facilitates cost and time efficiency, increase the overall success rate in planning and project delivery as well as monitoring maintenance and performance of the structure. For instance, BIM architects using *Archicad* can integrate conceptual design and engineers using *Revit* can make detailed 3D structural designs. BIM-based design process is according to Crotty (2012) clear, unambiguous and complete, thus helping key actors share common values and goals. Collaborative BIM relations require visual language tailored to different industry players (e.g. between an architect and a facility manager) to identify their changing roles and emerging tasks within organisations and project teams. At a minimum, there should be a tight, fair and open collaboration between the client, architect and the main contractor from the early design until handover, in which all of them optimally use their competencies. The effectiveness of integrated collaboration is also determined by the client's mindset, capacity and strategy to organise innovative tendering procedures (Sebastian, 2011).

Key to integrated collaboration is the role of the BIM model manager. This is an actor that does not take decisions on design solutions or organisational processes but is integrating the information supplied by different building actors into BIM, focusing on (Sebastian, 2011):

- the development and detail of the BIM model, including checking for clash detections, unforeseen errors or modifications;
- the contribution of BIM model to decision making and communication protocols, task planning and risk management; and
- the management of information in terms of data flow and storage, including the identification of communication errors.

VISUAL REPRESENTATION

BIM provides a holistic visual representation of an entire project and helps the AEC industry to plan and predict project delivery and logistics through information-rich software. 3D BIM means all project documentation and asset information should be in digital data flow format. Buildings can be inspected from various angles including sub-structures, intersections and building performance characteristics (Crotty, 2012). BIM goes further than a 2D or 3D CAD application and it eliminates the risk of making decisions based on assumptions when data is collected from outdated drawings. In conjunction with the 3D models, the BIM platform can also incorporate information on time/ scheduling (4D) and costs (5D) (Gudgel, 2008). BIM has also the ability to present information in different formats (Grilo and Jardim-Goncalves, 2010). This is particularly helpful for large-scale projects, which require volumes of different technical documentation.

Visual monitoring can aid accurate decision-making as it offers the ability to view the completed project. The outcomes affect all lifecycle stages to be modelled and agreed at an early design stage. *"BIM offers the double-edged promise of displacing abstraction with simulations, which is significant for architects to bring concepts into reality"* (Arayici, 2012, p.81). Through clash detection, the complexity of selecting and scheduling construction methods and materials is reduced and the risk of rework during construction or operation is eliminated (Sebastian, 2011). This is aligned with Weygant's (2011) argument that visual representation leads to quick revision of schemes and allows more accurate design prior to the start of construction, minimising costly change orders that often occur in the field. A better visual inspection helps avoid clashes where potential failures can be geographically illustrated and complex schemes can be viewed separately from different teams (Grilo and Jardim-Goncalves, 2010). A visual replica of the building helps also with facilities management. It impacts, for instance, on the regular maintenance of power systems, Building Automation Systems, mechanical engineering works, building fabric, security, fire detection systems and evacuation plans.

With BIM, clients are presented with a realistic visual model and they can feel closer to the design and construction process. Visual 3D modelling has the following benefits for the client; namely it: (Cant, 2012; Crotty, 2012; NBS, 2014; Sebastian, 2011):

- improves the working environment and creates common grounds for integrated collaboration between the building actors;
- brings clarity and increases the chances for project approval by the client;
- boosts confidence, manages expectations and enables participation in design and decision-making;
- improves an understanding of lifecycle implication of design decision-making; and
- improves quality of the design, leading to a more efficient and profitable project.

DATA MANAGEMENT

BIM is not architecture; it is a dynamic data management domain. According to NBS (2014), the real value of BIM is the production of high quality information-rich models that can reduce risk, save time and money. The use of cloud software allows blueprints and all required details to be accessed at any point in the lifecycle, which is a valuable digital asset. BIM has the ability to update, maintain, store and share data in multiple dimensions, reducing significantly transaction costs (Gudgel, 2008; Pramod Reddy, 2011). Data management is also a fundamental part of the Government Construction strategy, which requires precision, accuracy, and standardisation (HM Government, 2013). With BIM, however, data is not just drawings and data flows between computer systems are varied and include (Succar, 2009):

- databases; i.e., transfer of structured/ computable data;
- spreadsheets; i.e., semi-structured data; and
- images; i.e., non-structured/ non-computable.

Data management facilitates optimal information accessibility and exchange across disciplines and project phases (Sebastian, 2011). The gap between 'projected' and 'actual' activities may result in inappropriate forecasts, particularly for long-term projections, which can be notoriously erroneous. BIM has overcome this barrier by collecting activity-based Gantt charts showing the duration of the project. This, in turn, helps evaluating the design solutions against the programme of requirements and specifications. BIM involves scheduling activities and calculating project costs, ensuring cost reduction and on-time delivery. Steel *et al.* (2012) explain how data management helps to perform tasks related to quantity surveying, procurement, and material supplier integration, such as categorising and checking materials against building regulations. Finally, data management can also help integrate the architectural design with details of the structural analysis, energy analysis, and environmental performance, whole lifecycle costing and planning. Interoperable data sharing helps professionals to easily track production with support from schedules, highlighting delays and avoiding miscommunication.

DISCUSSION AND LESSONS LEARNED

Overall, BIM is widely seen as a "game changer" to reduce the level of fragmentation within the UK construction sector. It is a lifecycle evaluation concept that helps the adoption of accurate processes and improved documentation from inception onwards (Arayici *et al.*, 2012). BIM functionalities include: 3D visualisation and detailing, clash detection, material schedule, planning, cost estimate, production and logistic information, and as-built documents. The UK Government Construction Strategy has an overall aim of 'value for money' by reducing costs by 20% by 2025. Clients need to develop BIM capabilities themselves and facility managers should enter the decision-making process at an earlier stage in the project lifecycle, where they can influence the design and construction. Bryde *et al.* (2013) investigated 35 construction projects that utilised BIM to compare the UK practice with international exemplars. The findings suggest that cost savings is the dominant benefit, followed by time, communication, coordination improvement and quality. BIM can also offer added-value (or quality) benefits, which include (Arayici *et al.*, 2012; Bryde *et al.*, 2013; Motawa and Almarashad, 2013; Sebastian, 2011):

- Compatibility with the increasingly stringent UK Building Regulations, the zero-carbon 2016 and 2019 agenda, and the overall demand for sustainable low-carbon buildings.
- Flexibility to accommodate possible changes in the lifecycle, as a key factor for achieving long-term sustainability.
- Lean construction, as improved design, collaboration and information sharing can reduce non-value added waste in material, resources and costs.
- Risk management due to increased transparency in documentation.
- Safety management through accident prevention and property damage avoidance.
- Maintenance optimisation based on output specification and operational data; i.e., preventive maintenance (routine management) or reactive/ corrective maintenance (response to a cause of failure or break down). This has been identified as 'Soft Landings' in the Government Construction Strategy and was developed specifically to close the performance gap and place monitoring and feedback at the heart of the design, construction and operational stages. Through an integrative approach, Soft Landings will be an open-source framework for design teams, clients, building managers, and occupants in relation to energy performance, building management, and end-users' behaviour. The process generally has five stages; namely (Leaman *et al.*, 2010).
    - Inception and design briefing to establish clear design targets between the client, design and building teams;
    - Design development and review from specification to construction
    - Pre-handover with greater involvement of all above actors;
    - Initial aftercare during the occupants' settling-in period
    - Aftercare up to three years post construction with feedback from POEs.

The relative novelty of BIM drives practitioners to focus mostly on the design stage rather than adopting full lifecycle thinking. Adoption of whole lifecycle thinking is still at an early stage. It is essential, however, to ensure that procurement decisions are made on the basis of whole-life costs, moving away from pure short-term financial criteria. 85% of the lifecycle cost of a facility occurs after construction is completed with clients and facility managers benefitting mostly financially from BIM implementation (Arayici *et al.*, 2012; Eadie *et al.*, 2015, 2013). However, only 10% of BIM users tend to extent its use in the operation and management stages of projects (Eadie *et al.*, 2013). BIM implementation may impact on all processes through collaboration, visual representation, data management and it should not be treated in isolation as a software tool. Eadie *et al.* (2013) analysed 92 responses from a sample of BIM users in the UK to identify the level of awareness in project lifecycle benefits. Increased collaboration was ranked first, followed by management aspects, reduction of waste, and accuracy in the software. The findings reveal that the process innovation of BIM is more important than the actual software technology (product innovation).

Legislation can drive change in industry mindsets. It is through the Government's BIM mandate by 2016 that industry has responded rapidly and positively with large adoption of BIM (HM Government, 2013). Investment in BIM has risen from 58% in 2010 to 95% in 2013 (NBS, 2014). In 2013, 54% of UK building professionals had used BIM on at least one project, with 93% of predicting that in the next three years the AEC industry would be using BIM. However, it is recognised that key barriers to BIM render problematic any efforts for widespread adoption and effective implementation. These include: technical barriers, legal issues, financial barriers, client demand and cultural issues (Arayici *et al.*, 2012; Bryde *et al.*, 2013; Eadie *et al.*, 2015, 2013; Grilo and Jardim-Goncalves, 2010; Khosrowshahi and Arayici, 2012).

1) ***Technological barriers:*** Bryde *et al.* (2013) highlight that the most frequently reported disadvantage is the BIM software. Lack of interoperability is a key factor resulting in lack of collaboration amongst different vendors. Interoperability is the ability of two or more systems or components to exchange information without necessity of installing third party software. Packages may be unable to handle or exchange large amount of data and there is little knowledge and experience in software programming. Whilst interoperability issues vary between different BIM software packages, such technical issues are likely to be resolved as the IT industry matures in its response to BIM-related needs.

2) ***Legal barriers:*** It is challenging to resolve legal issues related to cloud ownership and IP rights of BIM-generated output. Design teams and organisations need to agree common IT platforms to share their BIM data models. Many existing Information and Communication Technology (ICT) systems do not support openness of data, which is a prerequisite for collaboration. While ICT developments, such as open standards and open-source server, are ongoing inputs from the real project experience, there is a need to close the gap between technological innovation and building practice. BIM still depends on "closed" applications; hence, openness, accessibility and extension possibility of object libraries may be limited. Another issues is the potential vulnerability to cyber-attacks due to data, which is available and shared on the cloud. As the AEC industry becomes more digitalised, it is important to consider digital security and privacy issues related to: liability for shared data (including subcontractors); classified information on sharing platforms; and, IP ownership and insurance.

3) ***Financial barriers:*** The price of popular BIM software packages is similar to that of common CAD software. Some vendors are selling packages that include both BIM and CAD platforms for the price of what used to be a CAD-only package. However, the initial costs are still substantial especially for smaller firms. Since BIM is relatively new, an obvious downside is the capital investment cost for software and hardware and the general lack in additional project finance to support its implementation. Higher costs are reported from 67% and 64% of small and large organisations in the UK, respectively (NBS, 2014). Moreover, limited in-house expertise results in extra training costs. This affects both the project team and the organisation, highlighting the need for awareness raising and up-skilling within the AEC sector. Using BIM to monitor operation and maintenance processes could justify better the investment in BIM technology. Moreover, some of these extra costs, such as CAD rework, education and training, or IT upgrading, may lead to optimal return on investment. These costs can be reduced or eliminated when implementing BIM from an early design stage and they will not be so prominent once people are trained.

4) ***Client demand:*** Client demand is a key barrier to BIM adoption and all members of the construction industry should engage fully, including Small Medium Enterprises (SMEs). SMEs are less likely to have adopted BIM, as clients of smaller organisations are not familiar enough with BIM use or their projects are too small for BIM use (Arayici *et al.*, 2012). Small organisations are less confident about their BIM skills. BIM adoption among smaller organisations is currently at the levels that the wider industry was two years ago (NBS, 2014). For organisations with fewer than six people, the figure is around 35% (NBS, 2014). Migilinskas *et al.* (2013, p.767) emphasise that *"obstacles are greater in small markets, were design and construction companies are small and have not enough resources to obtain and maintain theoretical BIM methodology"*. 75% of SME contractors report limited experience using BIM methodology (NBS, 2014). NBS (2014) statistics show that no client demand is the primary issue for 73% of SMEs in the UK. However, there is a counter argument from Eadie *et al.* (2013) suggesting that practices of all sizes can meet the Government target and the additional costs are not beyond reach for small practices.

5) ***Cultural barriers:*** This category involves challenges relate to people, established practices and resistance to cultural change. Contractual limitations in traditional procurement methods hinder the effective implementation of a performance-based system; i.e., a system that stimulates whole lifecycle assessment in the project design and delivery. In addition, actors contracted through a traditional procurement approach see no tangible (short-term financial) benefits to warrant its use. BIM requires novel contractual relationships shifting from traditional to integrated procurement methods, including both the supply and demand sides (Sebastian, 2011). In addition, the *"human factor"* hinders effective collaboration. This refers to the ability of people to understand and work with BIM given their personal experience and background and the specific company culture within they operate. This becomes increasingly important in large international projects with reluctance of team members to share information. To address this challenge, there is an evolving 'standardisation' framework of the internal data structure to enable software and companies collaborate with each other.

CONCLUSIONS

This paper presented an overview of the scope and practical implications of the BIM platform in the UK construction practice. The literature review suggested that adopting BIM may be less risky and less cost-effective than not doing so, as it provides a competitive advantage to the AEC industry. It reduces errors, rework and waste, and it promotes sustainability in design and construction. BIM embraces whole lifecycle asset management and provides documentation for the supply chain. This rapidly changing context posts a need for flexibility in design, which can be only achieved through multidisciplinary collaboration, visual representation and data management. BIM aids an integrated design approach and effective stakeholder engagement throughout the design phase. There is also potential for significant lifecycle cost savings, speed of delivery, and increase profitability, as long as, data is accurate. Overall, the benefits of BIM outweigh the possible challenges; the biggest proof is the Government mandate. However, implementation is still in a transitional period where challenges, such as interoperability, software costs, appropriate training, standardisation, client demand, legal and cultural issues need to be addressed. Another challenge lies with data validation, as there is a high chance of data being entered incorrectly, which would result in time delays or further costs.

Even with the emerging research and investment in BIM deployment, further research is required to bridge the gap between policy and practice. This involves empirical evidence through case studies that demonstrate the real benefits and issues of BIM implementation. The industry is also not clear enough on what BIM is. Theoretical developments suggest that BIM is an integration of product and process innovation modelling, not just a disparate set of software tools. BIM is not only a software model; technological implementation should not be analysed separately from the context of the implementing organisation. Further research should explore the integration of BIM into commercial metrics, client Key Performance Indicators (KPIs) and model data, including the supply chain. Applied research is needed to develop BIM processes, management tools, business concept and legal instruments to bring the existing conceptual knowledge of integrated collaboration into practice. This should be supported by rigorous Cost-Benefit Analysis (CBA) to prove the financial benefits for the upfront investment. The industry lacks clarity but it has a responsibility to be inclusive through open, software-neutral standards for data sharing. It is hoped that training and education providers will increase professional development so that the full benefits of BIM are realised by the Government's mandate in 2016.

REFERENCES

Arayici, Y., Onyenobi, T., Egbu, C., 2012, Building Information Modelling (BIM) for Facilities Management (FM): The Mediacity Case Study Approach, *International Journal of 3D Information Modelling*, **1**(1), 55 – 73.

Banuelos Blanco, F. G. and Chen, H., 2014, The implementation of Building Information Modelling in the UK by the transport industry, *Procedia – Social and Behavioural Sciences*, **138**, 510 – 520.

Bryde, D., Broquetas, M., Volm, J. M., 2013, The project benefits of Building Information Modelling (BIM), *International Journal of Project Management*, 31, 971 – 980.

Cant, D, 2012, *Realising the Benefits of BIM*, Available from: http://www.veritas-consulting.co.uk/blog/bim-consulting-services-building-information-modelling-explained/ (Accessed: 14th March 2015)

Crotty, R., 2012, *The impact of Building Information Modelling – Transforming Construction*, Routledge, New York.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., McNiff, S., (2015) A survey of current status of and perceived changes required for BIM adoption in the UK, *Built Environment Project and Asset Management*, Vol. **5**(1), 4 – 21.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., McNiff, S., 2013, BIM implementation throughout the UK construction project lifecycle: An analysis, *Journal of Automation in Construction*, **36**, 145 – 151.

Grilo, A and Jardim-Goncalves, R., 2010, Value proposition on interoperability of BIM and collaborative working environments, *Journal of Automation in Construction*, **19**(5), 522 – 530.

Gudgel, J., 2008, *Building Information Modelling: Transforming Design and Construction to achieve greater industry productivity*, McGraw-Hill SmartMarekt Report.

HM Government, 2013, *Construction 2025, Industrial Strategy: Government and industry in partnership*, London.

Khosrowshahi, F. and Arayici, Y., 2012, Roadmap for implementation of BIM in the UK construction industry, *Journal of Engineering, Construction and Architectural Management*, **19**(6), 610 – 635.

Leaman, A., Stevenson, F., Bordass, B., 2010, Building evaluation: Practices and principles, *Building Research and Information*, **38**(5), pp. 564-577.

Migilinskas, D., Popov, V., Juocevicius, V., Ustinovichius, L., 2013, The benefits, obstacles and problems of practical BIM implementation, *Procedia Engineering – Modern Building Materials, Structures and Techniques*, ***57***, *767 – 774.*

Motawa, I. and Almarashad, A., 2013, A knowledge-based BIM system for building maintenance, *Journal of Automation in Construction*, **29**, 172 – 182.

National Building Specification (NBS), 2014, *NBS National BIM Report 2014*, Royal Institute of British Architects, London.

Pramod Reddy, K., 2011, *BIM for Building Owners and Developers: Making a Business Case for* Using *BIM on Projects*, Wiley, UK.

Sackey, E., Tuuli, M., Dainty, A., 2015, Sociotechnical Systems Approach to BIM Implementation in a Multidisciplinary Construction Context, *Journal of Management in Engineering*, Special Issue, **31**, no page.

Sebastian, R., 2011, Changing roles of the clients, architects and contractors through BIM. *Journal of Engineering Construction and Architectural Management*, **18**(2), 176 – 187.

Steel, J., Drogemuller, R., Toth, B., 2012, Model interoperability in building information modelling, Software & Systems Modelling, **11(1)** 99 – 109.

Succar, B., 2009, Building information modelling framework: A research and delivery foundation for industry stakeholders, *Journal of Automation in Construction*, **18**, 357 – 375.

Weygant, R., 2011, BIM Content Development: Standards, Strategies and Best Practices, Wiley, UK.

Yoders, J., 2013, Collaboration: How architects and engineers can work together with BIM in the cloud, Available from: http://lineshapespace.com/how-architects-and-engineers-can-work-together-with-bim-in-the-cloud/ (Accessed: 14th March 2015).