A Systematic Review for the Challenges Related to the Implementation of Building Information Modelling, Big Data Analytics and Internet of Things (BBI) in the Construction Sector

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Abstract

Under scrutiny for the past several years, the adoption of Building Information Modelling (BIM), Big Data Analytics (BDA) and Internet of Things (IoT) (together also known as BBI) is yet to grow significantly in the construction industry. The industry itself is realising the complexity and challenges which admittedly inhibit BBI implementation. The identification of these challenges is an imperative precondition for successful implementation of BBI. Even though there is a paucity of empirical data in this area, a notable body of research has reported such challenges which are the target consideration of this paper. However, no study has comprehensively reviewed, and synthesized existing research on the basis of treating BBI implementation as an integrated process and viewing these challenges as the cause for laggard manifestations, which underpins the originality and value of this study. To bridge this gap in literature, this paper primarily undertakes a critical systematic review of research around challenges related to BBI implementation. It emphasises a variety of important challenges inter-alia, skills and training needs, level of interoperability, infrastructure associated costs, data security, privacy, data ownership and supply chain concerns. This synthesis shows that BBI implementation is complex and challenging, and suggests that the industry as a whole need to take immediate actions. The need for more concerted research efforts to bridge the gaps are also identified. Finally, the paper proffers recommendations for managers and workers, which have social, technological, and economic capability and capacity dimensions.

Key words: big data analytics, building information modelling, challenges, internet of things, systematic review.

1. INTRODUCTION

As remarked in seminal construction industry reports, inefficiencies in processes, less collaboration and innovation deficiency have caused entrenching and persistent UK construction industry problems of fragmentation, less productivity and poor delivery. Moreover, the industry has long been subjected to criticism for not being able to meet target costs. There are delays, time and cost overruns, deep-rooted adversarial culture, poor risk management, fragmentation, improper standards for safety and quality, lack of consideration given to life cycle sustainability, high energy consumptions and high waste generation (Bryde *et al.*, 2013; Liu *et al.*, 2015; Davies and Harty, 2012). The mainstream literature has identified 'technology' as one possible solution for overcoming these challenges and uplifting the contemporary status of the industry. To that end, Building

Information Modelling (BIM) is advocated as being a technological driver in addressing 'the lack of innovative adoptions' (Navendren et al. 2014).

BIM is defined as a collaborative platform (consisting of set of technologies, processes and policies) that integrates all the stakeholders in designing, constructing and operating a facility (Qadir et al. 2016). Internet of Things (IoT) makes devices (smart phones, remote controllers, sensors, actuators) capable of interconnecting and communicating with each other over the Internet. The increase in population and billions of devices used in businesses that communicate with each other, results in enormous amount of Big Data. Big Data Analytics (BDA) is required to manage these big data to form a sort of understandable information, knowledge and valuable insights (Bilal et al. 2016). Data generated from BIM can be analysed and managed by BDA and can be used for insightful decisions through IoT. This is the concept of BBI.

2. BBI IMPLEMENTATION: AN OLD BUT NEW CONCEPT

BIM, BDA and IoT have long been buzzwords associated with innovation, often representing an improved quality of life with digitalisation. Nevertheless, the concept of BBI: considering all three domains as an integrated process is still at a pristine state. This emerging concept targets transforming the way products and services are delivered with the best value by achieving sustainable competitive advantage goals. Figure 1 summarises the practical application of BBI as an integrated process.

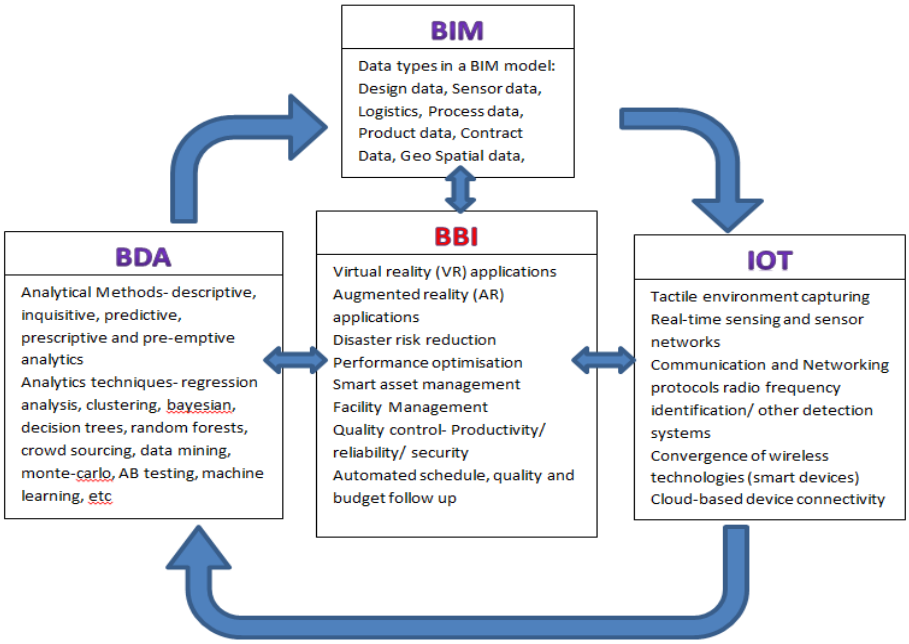

Figure 1- Application of BIM, BDA and IoT in construction

BBI implementation involves a set of activities undertaken by an organisation to prepare for, deploy or improve its deliverables (products) and affected work flows (processes). BBI implementation process can be described, with reference to the BIM implementation model suggested by Succar and Kassem (2015), as a three-phased approach segregating an organisation's readiness to adopt; capability to perform; and its performance maturity. The point of adoption is where organisational readiness transforms into organisational capability

and maturity. In order to make a successful BBI implementation, a clear understanding of what prevents readiness, capability and maturity is imperative. Hence, this paper is specifically focused on the contemporary challenges of BBI implementation.

3. RESEARCH METHODOLOGY AND METHODS

In order to identify the challenges related to BBI implementation, the paper predominantly follows Tranfield *et al.'s* (2003) systematic review approach; for a systematic review has the potential to inform both practice and scholarship of the gaps existing in the literature. For practitioners, a systematic review can assist in their decision making process for managerial challenges as the review itself provides some reliable knowledge bases through a range of findings. For scholars, a systematic review sheds a light in perceiving the robustness and rigour in research methodology for the given area as well as an idea generator for future research. The systematic review manifests its richness in twofold; firstly, interrogating the strength of the research evidence found in past (peer-reviewed) studies and secondly, consequently identify fresh, interesting research questions that peer scholars can take forward as separate research. This method offered the advantage of being extremely specific on the scope: 'challenges' and the logical steps required to be followed in order to select the articles.

In terms of theory, the study has demonstrated that the idea behind the concept of BBI is not entirely new, analysing BBI separately (with each domain) in the context of construction sector provided in the literature. However, these remain little or no studies that have considered the three concepts together. The study has explained the academic interest in BBI in relation to organisational strategic development. To this end, the paper itself proffers significant managerial implications related to BBI implementation to help managers understand and grasp these implications as well as suggestions provided for future research to help upcoming scholars.

A systematic literature review has to be systematic (organized according to a process designed to address the review questions), transparent (explicitly stated), reproducible, updatable, and synthesized (summarizes the evidence relating to the review question) (Briner & Denyer 2012). The steps employed for the systematic review is one suggested by Tranfield et al. (2003) and Briner and Denyer (2012). This included (1) Identify the review question, (2) Locate the study, (3) Study selection and evaluation, and (4) Analyse and synthesise the findings from the studies and (5) Disseminate the review findings.

Step-1 Question Formulation

The paper firstly provides an overview of the contributions to 'challenges in BBI' by analysing all the documents retrieved from the systematic review in order to answer the following review question: 'how BBI is positioned in the existing literature, in terms of challenges for implementation?'

Step 2- Locate the study

The review has taken in to account all available published and unpublished (journal articles, conference articles, conference proceedings, monographs, report chapters, report reviews,

editorial material, theses and working papers) studies as evidences based on best quality contributions using 'search strings' (Denyer & Tranfield 2009). The key words used were 'BIM', 'Big Data Analytics', 'Internet of Things', 'Challenges' and 'implementation' with search strings (AND/OR) in major AEC research databases in all fields (subject, title, abstract, keywords, full text, etc.), from 2006-2016. The search also expanded in to grey literature in google scholar and basic google searches because of the paucity of empirical data available to date. The study excluded data received for year 2017 as at, the date that the review is consulted; half of the year does not represent the year as a whole. Insignificant number of articles was found covering all three domains, while some have addressed more than one domain and some were specifically focused on a single domain.

Step 3- Study selection and evaluation

The output of the comprehensive search offered a list of studies (Table 1) which helped to address the above review question and the list of documents were stored in a citation management software package, 'Mendeley'. Table 1 gives an overview of the raw data extracted from each database including duplicates, as documents could be retrieved from more than one databases.

Table 1- Initially selected articles that address the review question

Consultation date: 27/06/2017; Data set (2006-2016) Key theme: Challenges for Implementation								
	Singleton			**Twinned**			**Triplet**	
AEC Database	**BIM only**	**BDA only**	**IoT only**	**BIM+BDA**	**BIM+IOT**	**BDA+IOT**	**BIM+BDA+IOT**	**Total**
Emerald	95	67	31	4	6	5	0	208
Web of Science	68	14	9	3	2	4	0	100
Elsevier	38	24	6	1	2	4	0	75
Scopus	93	58	21	6	7	5	0	190
ITCON	14	6	10	4	4	4	0	42
Google scholar	86	26	12	7	7	8	2	148
Other unpublished	27	15	16	13	15	14	6	106
Total								**869**

The initial selection was then further sorted with two successive steps: elimination of duplicates/ irrelevant documents and verification. The filtered list was then subjected to classification into four distinct categories (A-primary subject, B-secondary subject, C-anecdotal, D-others. The final sample was composed of 121 pieces to review (Table 2).

Table 2- Document categorisation

Category	**Attributes - (*BIM* 'OR' *BDA* 'OR' *IOT*):**	**Number of documents**
A- Primary subject	Are the main topic	12
B- Secondary subject	Are not the main topic, but the concept is detailed discussed with a strong link to the main topic	36
C- Anecdotal	Are only mentioned (often as a future research	27

	avenue)	
D- Others	Are mentioned but not in the sense of a broader concept specifically related to AEC sectors	46
Total		**121**

Step 4- Analyse and Synthesise the Findings from the Studies

The aim of the analysis is to break down each article content in to constituent parts (in terms of challenges identified) and describe how each relates to the other while synthesis makes associations between the parts identified in each study (Denyer & Tranfield 2009) . The synthesis is a generation of knowledge out of all the information collected which is not apparent from reading each individual paper alone. In order to organise the findings, it is expedient to build an analytical framework (Mishra et al. 2016) which was built using 48 articles from the A and B categories (see Table 2) and extracted the key challenges associated with BBI implementation separately for each domain based on a 'manual content analysis'. Table 3 summarises this framework. Out of the selected 48 articles nearly 75% were descriptive while the rest 25% were prescriptive. The articles were approximately equally distributed among conceptual (theory based) and practical (case study based) papers.

4. CHALLENGES RELATED TO BBI IMPLEMENTATION

The articles analysed (document types A and B) revealed 63, 68 and 73 challenges for BIM, BDA and IoT respectively (See Table 3). Araciyi et al. (2012) in their systematic survey and interviews confirm that the practitioners need clear guidance, training and technical support for BIM implementation in practice as they are not knowledgeable and experienced about BIM. Supporting the same argument, many authors (Davies and Harty, 2012; Merschbrock and Munkvold, 2012; Bryde *et al.*, 2013) claim that skills and training needs are on the top among barriers for implementation of BDA and IoT. Considering the consensus that has been reached in the literature, reluctance to initiate new strategies, benefits not being tangible to warrant its use, lack of capital investments, and unfamiliarity of use are some of the other challenges common for all three domains (Vrijhoef and De Ridder, 2007; Azhar, 2011; Singh *et al.*, 2011).

Table 3- Analytical framework for challenges

C No	Category of Challenges	Number of Challenges		
		BIM	BDA	IoT
C1	Design-specific	9	4	5
C2	Project-related	12	13	13
C3	Industry-related	11	12	11
C4	Organisational/ strategy attributed	9	10	13
C5	Technological	10	17	15
C6	Environmental	12	12	16
	Total Number of challenges	***63***	***68***	***73***

Table 4 encapsulates the variety of challenges that were discussed in the literature for BIM, BDA and IoT. Out of all the challenges identified, only 15 challenges (from each domain) were taken for evidence demonstration. Please note that all the authors who have

identified the challenges in their papers are not cited here- instead few of the authors who have mentioned the challenges as 'most critical' and evidences which belong to '*category A-Primary Subject'* are only included here. The category that each challenge belongs to (According to Table 3) is mentioned in front of each category as from C1-C6.

Table 4- Most cited challenges for BBI implementation

Domain		Challenges \ Authors	Arayici et al, 2011	Miglinskasa et al, 2013	Mogk, 2017	Navendren et al, 2014	Newton and Chileshe, 2012	Singh et al, 2011	Succar and Kassem, 2015	Davies and Harty, 2012	Merschbrock and Munkvold,	Bryde et al., 2013	Liu et al, 2015	Vrijhoef and De Ridder, 2007	Azhar, 2011	Total
BIM	1	Education and training costs- C4	•	•		•	•	•	•	•	•		•	•	•	11
	2	Lack of interoperability-C5	•		•	•	•				•		•		•	7
	3	lack of integration and effective communication-C2	•			•	•				•		•			5
	4	start- up costs-C4	•		•	•	•						•			5
	5	Changing the way companies do business-C4				•	•		•					•	•	5
	6	Lack of understanding about BIM-C3				•	•			•		•				4
	7	legal issues regarding data ownership, copyright, data protection and licensing issues-C6	•			•	•								•	4
	8	Data inaccuracies-C2			•	•						•		•		4
	9	Resistance to change, and getting people to understand the potential and the value of BIM over traditional approaches-C4	•	•		•							•			4
	10	Adapting existing workflows to lean-oriented processes-C4				•		•						•		3
	11	organisational learning curve, lack of senior support-C4	•						•						•	3
	12	Control, supervision and authority over usage in such integrated environments-C2				•				•		•				3
	13	scalability and capacity constraints; accessibility and security of data-C1	•			•		•				•				3
	14	lack of high-end hardware resources and networking facilities-C5				•		•					•			3
	15	lack of standardised BIM processes with defined guidelines-C6			•	•							•			3

		Challenge \ Authors	Sivarajah et al, 2017	Fayet, 2015	Spiegel, 2015	Ariker, 2015	Crouch, 2016	Wang et al, 2014	Quadir et al, 2016	Martiniko et al, 2016	Gandomi et al, 2015	Bilal et al, 2016	Usmani, 2015			Total
BDA	1	Infrastructure high costs and operational expenditures-C3	•	•		•		•		•	•	•	•			8
	2	Data security- ethical consideration/ownership and privacy-C3	•		•	•	•		•			•				6
	3	inadequate infrastructure and insignificant data warehouse architecture C5	•				•			•			•			4
	4	Keep the data quality in the output-C2			•			•			•	•				4
	5	lack of skilled personal and sufficient resources-C4	•	•	•		•									4
	6	Identifying the right data, accessibility and connectivity-C1		•			•					•				3
	7	change management-C4		•	•				•							3
	8	analytics maturity and using the insights gained to transfor your operations and impactful decisions- value creation-C4			•		•					•				3
	9	Reliability of analytics-C2		•												2
	10	chosing the right technology-C5		•					•							2
	11	Lack of proper understanding and often confusion-C3		•					•							2
	12	data integration complexities-C1	•										•			2
	13	synchronising large data and integration with existing systems- Data governance-C1	•										•			2
	14	Storage of large amount of data-C5	•				•									2
	15	Extreme- fastly evolving data landscape-C6	•													1

		Challenge \ Authors	Chapin et al, 2015	Borgia, 2014	Banafa, 2017	Linderoth et al, 2010	Roussey , 2016	Byfield, 2016	Sarkhel, 2016	Mitchell , 2015	Lima, 2015	McCauley, 2016	Gaura et al, 2015	Dutton, 2014	Mishra et al, 2016	Total
IoT	1	Legal, regulatory and rights-C6	•	•	•	•	•	•	•	•	•		•	•	•	12
	2	Supply chain concerns-C3	•		•	•	•	•	•	•		•	•	•	•	11
	3	Security-C5	•		•	•	•	•	•	•		•			•	9
	4	Privacy-C5	•		•	•	•		•	•					•	7
	5	Interoperability standards-C1	•			•	•		•	•						5
	6	Emerging economy and development issues-C6			•		•		•	•						4
	7	Networking, connectivity and gateway access issues-C5		•	•		•					•				4
	8	Compatibility and longevity-C2			•				•		•					3
	9	Intelligent analysis and action-C1			•						•		•			3
	10	Slow adoption of new technologies-C4			•						•			•		3
	11	Lack of understanding or education by consumers-C3		•		•	•									3
	12	Implmentation is expensive and take time and resources-C4			•							•		•		3
	13	Sensing a complex environemnt-C1							•					•		2
	14	Criticality of power and energy- Battery life-C1						•			•					2
	15	Data manageemnt and Storage issues-C5						•			•					2

Interestingly, many industry/ project/organisation/environmental related challenges were common to all three domains while design specific and technological challenges were distinctive to each domain (See Figure 2).

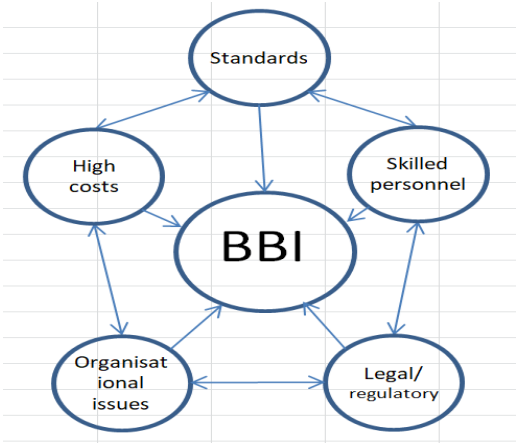

Figure 2- Relationship between common challenges for BBI implementation

Out of the number of challenges mentioned in Table 4, only 6 key challenges (one to represent each category and two to represents each domain) are discussed in this paper. The remaining challenges will be addressed by a subsequent publication to this. The 6 challenges were selected on the basis of frequency of citation as mentioned in Table 4, through manual content analysis in light of 'mostly cited' challenges. Thus, first two challenges of each domain are selected (See Table 5).

Table 5- Refined most cited challenges for BBI implementation

	Three Domains		
	BIM	**BDA**	**IoT**
Challenges	1.Education and training costs for upskilling staff (C4)	3.Infrastructure's high costs (C2)	5.Legal Regulatory and Rights issues (ownership) (C6)
	2.Inter-operability standard issues (C1)	4.Data security- ethical consideration and privacy (C5)	6.Supply Chain Concerns (C3)

These challenges are not at the same gravity- one which is most challenging for BIM is regarded as least challenging for IoT. Hence the challenges can be 'moving' in-parallel with the technology development over time.

5. DISCUSSION

Challenge-1 (BIM)

Khosrowshahi and Arayici (2011) have described the need of organisational upskilling for successful BBI implementation and how it can be positioned via training and education protocols. However, the authors also claim that this relates to the potential lack of marginal utility and risk weighted business benefits to be realised by BIM adoption. Bringing out the same opinion, Bryde et al., (2013) highlight the need for providing education and specific support services to those who practically trigger the implementation process.

Some positions may need certified standards of education and training. Mastering a particular area with proper education and training eventually would prevent employees fear/ reluctance to change and promote embracing the change in a positive way. Moreover, upskilling through training must target all the tiers of an organisation (See Figure 3).

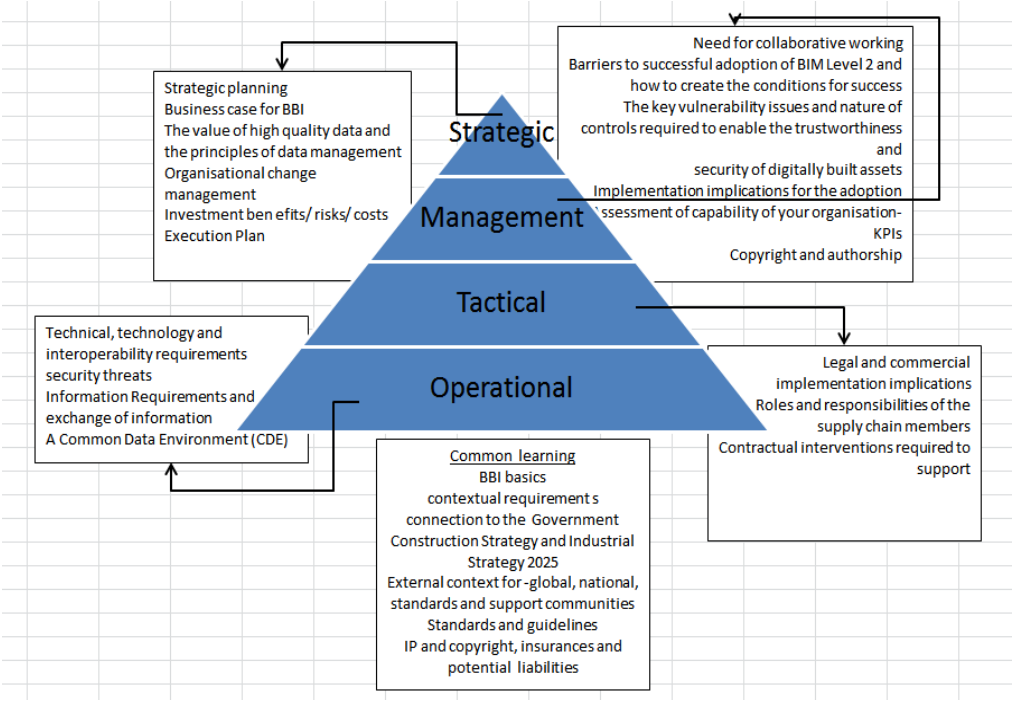

Figure 3- Dimensions for organisational skills and training needs

Challenge-2 (BIM)

The high expectation of information sharing requires organisational interoperability, which is often associated with legal requirements in ambiguity about data ownership, copyright and data protection (Newton & Chileshe 2012). In a collaborative environment, design data exchange should take place between all the interconnected IoT devices. But the actual complex scenario of these interconnected devices seriously inhibits the design data flow in responses to the incompatibility of data. Bringing an array of different perspectives, Singh *et al.* (2011) affirm that the problems around interoperability often occur due to lack of standardised approaches to sharing data across diverse proprietary information systems and software; and inability of organisations to share or integrate information across heterogeneous information systems. Not only the lack, but also the non-existence of interoperability itself often emanates from legally handled disputes because of the ambiguity of data ownership, copy right, data protection and confusion of who shares the risks and benefits (Mogk 2017). A collaborative platform, arguably, allows access to all the involved individuals. In addition, computer systems or software offers the opportunity to exchange and make use of information grounded in the common platform. Therefore, adoption of 'open BIM' concept is regarded as one best solution for 'common data environment' related issues. A systematic licencing procedure could also help to protect the ownership of data where guidance could come from standardised professional bodies.

Challenge-3 (BDA)

Wang and Wiebe (2014) highlight infrastructure associated costs as one big problem for BDA implementation. Even though the cloud computing technologies have now reached an improved level of maturity, the hardware equipment is still very expensive. This sometimes cost more for the organisations. Supporting the same argument, Gandomi and Haider (2015) emphasise the potentials of using BDA as 'endless' but restricted by the cost of technologies, tools and skills. Most organisations are therefore reluctant to invest in such, as benefits are not tangible enough to warrant its use and the benefits do not outweigh the costs to implement it.

Many managers claim that the BDA investment costs are way too high (Usmani 2015). Small businesses compare their profit with their investments, costs, and claim BDA is not for them. In a significant work, Mahamadu, *et al.* (2014) suggest organisations need to be convinced that investing in BDA, is a worthwhile long term investment. Undertaking a SWOT analysis to assess the current and future competitive advantages and 'action planning' for BDA could help to determine whether to go ahead or not (See Figure 4).

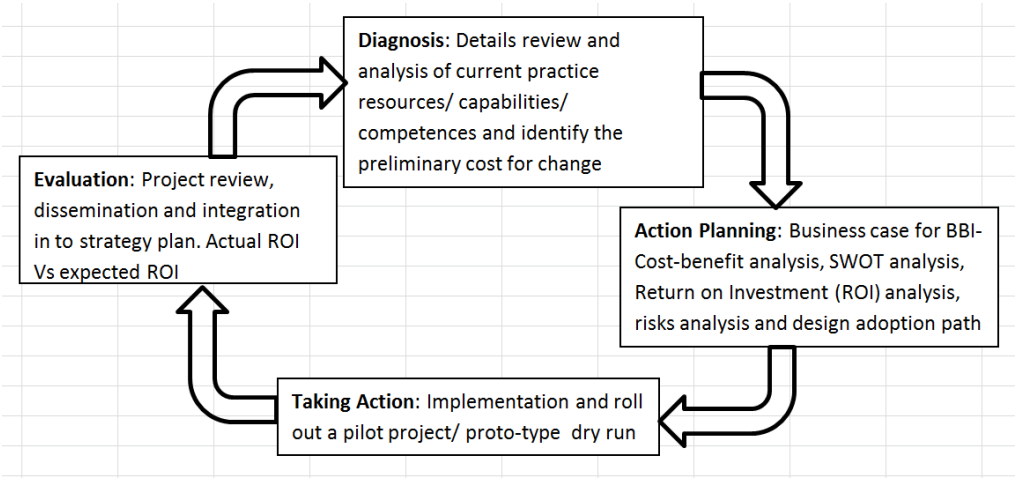

Figure 4- Action planning for costs

Adopted and revised from; (Arayici et al. 2011)

Challenge-4 (BDA)

Issues of data security, ownership, privacy and ethical considerations relevant to data mining (Jacobsson and Linderoth, 2010; Fayet, 2015; Spiegel, 2015; Ariker, 2014; Crouch, 2016) are some of the major reasons why organisations stop halfway through their big data journey. In an era where protecting privacy in the digital age is a prime challenge, organisations are more concerned with streamlining the processes. The threat of location-based information being collected by BD applications and transferred over networks, where city is smartly connected with strong IoT power, results in higher risk of privacy. It is increasing the case that the more data sources become ubiquitous, the more the threat to data privacy and security. In terms of security, systems that are vulnerable to malware attacks are commonly known as a threat to data security. It has been identified that, inadequate security controls to ensure information is securely locked up and no third party is able to hack in to the system is one major cause of this. Consequently, third parties

receive endless opportunities to access the network flows/ system. The need for forensics and intrusion detection has been a major concern in the prevailing digital age; however this is not entirely addressed.

Challenge-5 (IoT)

As long as real time data is shared over connected socially embedded devises, the ownership is at a high risk (Roussey, 2016; Byfield, 2016; Dutton, 2014; Gaura *et al.*, 2015; Lima, 2015; McCauley, 2016; Mitchell, 2015; Sarkhel, 2016). It is generally perceived that the receiver/user and the producer/ sender own the IoT data. On the contrary, Sivarajah *et al.*, (2017) argue that this ideology is very ambiguous and still needs to be settled, for the ownership gives the right for some party to control and ensure the accuracy of information. Once the ownership becomes unclear, the information accuracy and maintenance / control also become weak. Extreme sensitive data transferred through IoT without well-defined ownership results in mounting errors and may further lead to inconsistent data where misinterpretations are made. Ownership often categorised as a 'deep social issue' (Migilinskasa *et al.*, 2013) as the creators always expect an acknowledgement for their effort.

Challenge-6 (IoT)

Since functionality is not the only concern, cost and industrial reliability also play a major part in early adopters to encourage IoT implementation. It is therefore vital to maintain the integrity of the supply chains (Chapin et al. 2015; Banafa 2017). Borgia (2014) emphasises the fact that, IoT elements that are used within critical infrastructures need direct concern with respect to politics, public opinion, and other industrial perspectives. To this end, it is important that organisations must consider how they can maximize transparency and standardisation in their contribution to supply chain. The potential source of resistance can be maximised by creating devices according to an open standard that is agreed by the supply chain partners. This can then be evaluated as progress, to make sure that only the approved and agreed application techniques/ hardware/ software is employed.

6. CONCLUSION RECOMMENDATION AND FUTURE RESEARCH

There are number of challenges in the implementation of BIM, Big Data Analytics and Internet of Things in AEC sector. The study deployed a systematic review approach to critically reviewing existing literature around key challenges for BBI implementation. Out of all challenges identified in 6 different categories, only 6 key challenges were taken (two to represent each domain) for the discussion in this paper. These are: Education and training costs for upskilling staff, Inter-operability standard issues, Infrastructure's high costs, Data security- ethical consideration and privacy, Legal Regulatory and Rights issues (ownership) and Supply Chain Concerns. The challenges take economic, technological and social perspectives as well as significant managerial implications. There is also an ample scope for research to investigate motivational constructs, and business case positioning that promotes BBI implementation. Being destined to intensify over the years, BBI requires to be ensured that this practice is thoroughly studied to help organisations for successful implementation.

Social Dimensions

During an innovation transition period, support from the top management is crucial in formulating strategies and directing people. The need for a participative, democratic style leadership which encourages subordinates to be involved in implementation decisions encourages creativity and to feel able to suggest novel ideas without fear of disapproval is recommended for the social/ cultural well-being.

As underlined by Martinko *et al.* (2014), changing people's behaviours to handle new tools is one of the biggest reasons for people being reluctant to adopt new technologies. Therefore, getting people to understand the potential and the value of BBI over traditional approaches and adapting existing workflows to lean-oriented processes need to be a key concern in implementation process. Further, according to J-curve as suggested by RICS BIM adoption guide, the stages of any implementation often involves an actual steep fall from current status than expected in order to reach the desired outcome, where the value creation is born. This is an important fact that the managers need to bare in their mind in strategic planning.

Technological Dimensions

As technology become more pervasive and integrated into our daily lives, it is crucial to ensure that the users trust IoT devices and BDA services to be secured from vulnerabilities. As a matter of principle, developers/vendors and users both are collaboratively obliged to ensure their protection against security and privacy threats. In order to seize the benefits, strategies will need to be placed to respect individual privacy choices, ownership and data protection while fostering innovation in new technology services. On the other hand, even though full interoperability across products and services is not always feasible, there are still options that can beat fragmentation. Appropriate, generic and open standards, policies and regulatory structures will greater user benefits and innovation opportunities.

Economic Dimensions

The BBI concept has a major potential for use in construction life cycle management, providing a central focus on the collaboration between parties involved, in which saving are made in cost, time and quality. Moreover, the potential value of BIM, BDA and IoT could be gauged, when the analytical information is leveraged to the drive decision-making process. Many research studies have evidently proven that BBI is capable of adding substantial value and competitive advantage for organisations by taking corrective and effective decisions based on systematically analysed data. To that end, managers must make long term strategic plans to gain real value over cost.

Avenues for future research

The review has led to the following research suggestions:

- Highlight the importance of IP and copyright, insurances and potential liabilities, contractual and regulatory legal aspects behind BBI implementation

- Improve the identification of the risks associated with BBI implementation in order to help organisations successfully trigger their innovative strategy in this regard;
- Further explore knowledge, skills and training protocols and process mapping to address the 'skills and training needs';
- Consider different financing options for the organisations who substantially strive towards BBI adoption
- Defining a more firm-perspective organisational cultural aspects that support BBI implementation

REFERENCES

Arayici, Y., Coates, P. & Koskela, L., 2011. Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*, 20(1), pp.189–195.

Ariker, M., 2014. Making data analytics work: Three key challenges. *Digital McKinsey*, pp.10–15.

Azhar, S., 2011. Building information modelling (BIM): trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, 11(3), pp.241–252.

Banafa, A., 2017. Major Challenges Facing IoT. *IEEE- Internet of Things*, 2(3), pp.35–43.

Bilal, M. et al., 2016. Big Data in the construction industry: A review of present status, opportunities, and future trends. *Advanced Engineering Informatics*, 30(3), pp.500–521.

Borgia, E., 2014. The Internet of Things vision: Key features, applications and open issues. *Computer Communications*, 54(2), pp.1–4.

Briner, R.B. & Denyer, D., 2012. Systematic Review and Evidence Synthesis as a Practice and Scholarship Tool. In D. M. Rousseau, ed. *The Oxford Handbook of Evidence-Based Management*. Oxford University Press, pp. 328–374.

Bryde, D., Broquetas, M. & Volm, J.., 2013. The project benefits of building information modelling (BIM). *International Journal of Project Management*, 31(7), pp.971–980.

Byfield, B., 2016. The Internet of Things: Challenges. *Communication and ICT Manageemnt*, 12(10), pp.440–457.

Chapin, L., Rose, K. & Eldridge, S., 2015. *The Internet of Things: An Overview*,

Crouch, A., 2016. The Top 5 Big Data Analytics Challenges Facing Big Business. *Journal of Data Management*, 6(2), pp.22–28.

Davies, R. & Harty, C., 2012. Control, surveillance and the "dark side" of BIM. In S. D. Smith, ed. *28th Annual ARCOM Conference*. Edinburgh, UK: Association of Researchers in Construction Management, pp. 31–39.

Denyer, D. & Tranfield, D., 2009. Producing a Systematic Review. In P. D. Buchanan & P. A. Bryman, eds. *The Sage Handbook of Organizational Research Methods*. London: Sage Publications, pp. 671–677.

Dutton, W., 2014. Putting things to work: social and policy challenges for the Internet of things. , 16(3), pp.1–21.

Fayet, L., 2015. Implementation Challenges of Big Data Analytics. *Communication Protocol*, 8(3), pp.83–101.

Gandomi, A. & Haider, M., 2015. Beyond the hype: Big data concepts, methods, and analytics. *International Journal of Information Management*, 35(2), pp.137–144.

Gaura, A. et al., 2015. Smart City Architecture and its Applications based on IoT. *Procedia Computer Science*, 52(4), pp.1089 – 1094.

Jacobsson, M. & Linderoth, C.J.., 2010. The influence of contextual elements, actors' frames of reference, and technology on the adoption and use of ICT in construction projects: a Swedish case study. *Construction Management and Economics*, 28(1), pp.13–23.

Lima, J., 2015. Challenges facing the internet of things today. *Computer Business Review (CBR)*, 3(12), pp.69–81.

Liu, S. et al., 2015. Critical Barriers to BIM Implementation in the AEC Industry. *International Journal of Marketing Studies*, 7(6), p.162.

Martinko, M.J., Henry, J.W. & Zmud, R.W., 2014. An attributional explanation of individual resistance to the introduction of information technologies in the workplace. *Behaviour & Information Technology*, 15(5), pp.313–330.

McCauley, J., 2016. The internet of Things in people's perspective. *Art and Design Inspiration*, 8(5), pp.11–20.

Merschbrock, C. & Munkvold, B.E., 2012. A Research Review on Building Information Modeling in Construction- An Area Ripe for IS Research. *Communications of the Association for Information Systems*, 31(10), pp.207–228.

Migilinskasa, D., Popovb, V. & Ustinovichius, V.J.L., 2013. The Benefits, Obstacles and Problems of Practical Bim Implementation. In *11th International Conference on Modern Building Materials, Structures and Techniques, MBMST 2013- Procedia Engineering*. pp. 767–785.

Mishra, D. et al., 2016. Vision , applications and future challenges of Internet of Things A bibliometric study of the recent literature. *Industrial Management \& Data Systems*, 116(7), pp.1331–1355. Available at: http://dx.doi.org/10.1108/IMDS-03-2015-0075.

Mitchell, R., 2015. The Internet of Things: An Overview – Understanding the Issues and Challenges of a More Connected World. *APNIC*, pp.3–8.

Mogk, C., 2017. Autodesk Research: What happens when BIM meets the IoT?

Navendren, D. et al., 2014. Briefing: Towards exploring profession-specific BIM challenges in the UK. *Management, Procurement and Law*, 167(4), pp.163–172.

Newton, K.L. & Chileshe, N., 2012. Awareness, usage and benefits of BIM adoption – the case of south Australian construction organizations. In S. D. Smith, ed. *28th Annual ARCOM Conference*. Edinburgh, UK: Association of Researchers in Construction Management, pp. 3–12.

Qadir, J. et al., 2016. SDNs , Clouds and Big Data : Mutual Opportunities. *Automation in Construction*, 12(3), pp.1–6.

Roussey, B., 2016. 5 challenges facing the Internet of Things. *World of Internet of Things*, 15(4), pp.18–26.

Sarkhel, A., 2016. challenges to Internet of Things. *ET Tech*, pp.4–6.

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

Sivarajah, U. et al., 2017. Critical analysis of Big Data challenges and analytical methods. *Journal of Business Research*, 70, pp.263–286.

Spiegel, E., 2015. Challenges of Big Data. *The wall street journal*, pp.3–6.

Succar, B. & Kassem, M., 2015. Macro-BIM adoption: Conceptual structures. *Automation in Construction*, 57(5), pp.64–79.

Tranfield, D., Denyer, D. & Smart, P., 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, 14(7), pp.207–222.

Usmani, F., 2015. Towards thriving success in big data analytics. *Journal of Data Management*, 16(6), pp.278–291.

Vrijhoef, R. & De Ridder, H.A.J., 2007. Integrating the construction supply chain by applying systems thinking. In C. . Egbu & M. K. . Tong, eds. *3rd Scottish Conference for Postgraduate Researchers of the Built and Natural Environment Glasgow*. Glasgow, UK: Glasgow Caledonian University, pp. 469–479.

Wang, Y. & Wiebe, V.J., 2014. Big Data Analytics on the characteristic equilibrium of collective opinions in social networks. *International Journal of Cognitive Informatics and Natural Intelligence (IJCINI)*, 8(3), pp.29–44.