Challenges to digital collaborative exchange for sustainable project delivery through building information modelling technologies

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Abstract

There has been growing recognition for the use of communication technologies to improve processes in sustainable infrastructure delivery. Building Information Modelling (BIM) based technologies have emerged for communication, data exchange and sharing between project delivery actors within a virtual 3D environment, where analysis and management of sustainability indicators is aided by information driven software and systems. Significant challenges, however, exist in relation to characteristics and current capability of technologies to deliver effective exchange. The challenges broadly relate to lack of interoperability, security and lack of adaptable standards, which is exacerbated by increasing intensity, size and complexity of data requirements to meet evolving knowledge base for sustainability management through communication and information modelling. In addition to dire effects on efficiency, effectiveness and cost of mitigation, it is argued that a key consequence of these challenges is an increasing perception of risk in relation to implementation challenges, information security and data integrity, which is causing reluctance to use BIM for information exchange. Research agenda is proposed to ascertain the relative impact of the above issues on the supply chain attitudes towards information exchange, as a premise for establishing their impact on overall effectiveness of BIM in delivering acceptable outcomes for data exchange including quality and adequacy of shared data.
Keywords: construction projects, digital data, sustainability, Building Information Modelling (BIM).

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1 Introduction

Successful delivery and management of sustainable infrastructure requires efficiently integrated, shared, and managed information within and across different departments and organizations. There is an increasing need for the application of improved methodologies of work that encourage collaborative workflow as well as take advantage of advancement in communication technologies for more integrated communication systems [1]. Building Information Modelling (BIM) is already delivering benefits within built environment practice enabling professionals to seamlessly communicate, evaluate, simulate and solve complex problems including sustainability analysis, on infrastructure more efficiently and in real time [2]. Challenges related to characteristics and current-state of capability of such technologies have however been reported as recurring, and hampering effective collaborative exchange of data [3, 4]. In addition to the practical difficulties imposed by these challenges, perceptions risk associated to information and implementation difficulties that emanate from these also need to be resolved before BIM can be used more effectively for communication between these diverse groups of stakeholders across the project delivery cycle [1].

BIM can be described as calculable representation of the physical and functional attributes of buildings or infrastructure including their operational and life cycle information, intended to be a storehouse of information for all stakeholders during its life cycle [1, 4]. Extended models can be used as representations of an entire city for population with spatial-related information, for enhanced simulation and computations that aid compressive analysis and management of sustainability indicators [5]. This characteristically requires integration sharing and exchange of digital forms of data across different stakeholders and Information Technology (IT) systems posing significant challenges in terms of heterogeneity, size and complexity of data involved [6]. This typical involves collaborators in respective specialities including building inspectors, planners, engineers, architects, and surveyors with their respective proprietary software and IT systems [5, 6]. Figure 1 is a diagrammatic representation of envisaged BIM based communication structure between various actors within the project delivery process.

Technological related challenges however exist and impede effective exchange of digital data. These are explored based on review of literature. The impact on collaborators' attitudes towards exchange is reviewed with the aim of establishing an agenda for research into the impact of digitisation on effective collaborative exchange for sustainable delivery projects through BIM based technologies.

1.1 BIM and sustainability in project delivery

The construction industry is a major user of the world's non-renewable energy sources and minerals [8]. With increased emphasis on sustainable delivery, various countries have developed respective rating systems in the last two

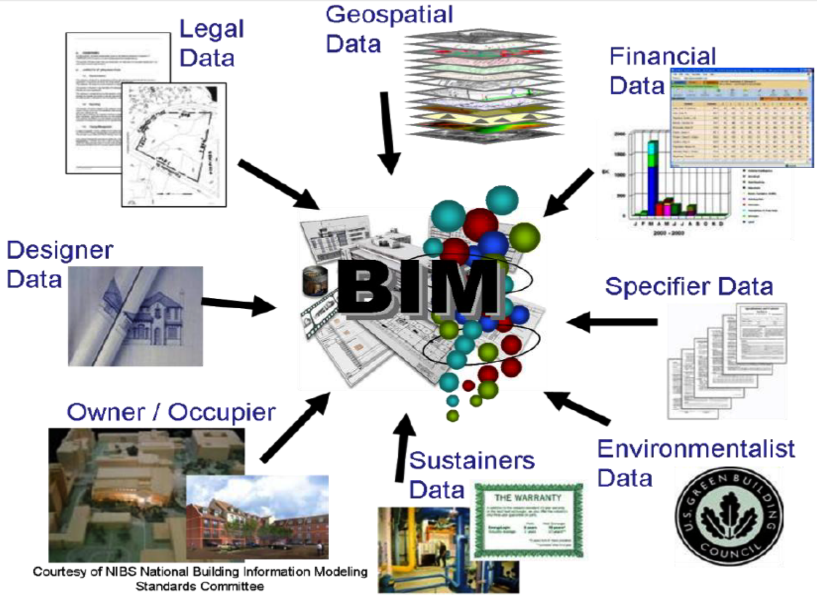

Figure 1: BIM communications in project delivery [7].

decades, notably: (i) Building Research Establishment's Environmental Assessment Method (BREEAM) and Institution of Civil Engineers' (ICE) Assessment and Awards Scheme (CEEQUAL) in the UK; and (ii) Leadership in Energy and Environmental Design (LEED) in the US for voluntary measurement and rating of sustainability indicators on building and infrastructure designs [2, 8]. These processes are information dependent and reliant the availability of adequate information and knowledge which should be sustained throughout the existence of the facility in a structured format [2]. BIM based tools are regarded as essential in delivering an automated approach to assessment of these indicators through enhanced capability in delivering simulations and analysis of indicators like: air comfort; heating Life-cycle costs; light, sound insulation and fire; environmental impact; and life expectancy of built assets [2, 8]. The monitoring of these issues also involve diverse parties whose ability to communicate, share and exchange data is key for success [2].

This is, however, still a challenge in practice, because of the diversity of participants, systems and processes. Some of the challenges also include the recent escalation and intensity in data as well as processing requirements, complexity of data formats and variables required for sustainability management [8, 9]. Despite the promise of BIM in dealing with these amounts of data the challenges persist and require further investigation particularly at city scale where the challenges are exponentially prevalent [5].

2 Technological challenges in multi-party collaborative exchange

Some of the critical challenges with BIM deployment relate to technology and its inherent characteristics. In this section some of the technological challenges and their influence on effective information exchange including attitudes towards exchange or use of technologies are explored. The technology domain of challenges relate to the technical aspects of BIM particularly in relation to software, infrastructure and the standards that regulate their use.

2.1 The challenge of interoperability

Interoperability refers to the ability of organizations to exchange, share or integrate information and business processes across information systems or organisational practice, lack of which refers to the inability of heterogeneous systems to interact effectively [1, 10]. Enterprises tend to represent their data using a variety of connecting data models and schemas, while users require access such data in an integrated and consistent fashion making reconciliation challenging [10]. The scope of interoperability ranges from the ability of technology to ensure that exchange of basic information is achieved to very complex task of ensuring harmonisation where the interaction between systems are completely embedded in the awareness of each other's context [10, 11]. This includes semantic level of interoperability used to refer to the ability of exchanged information or schema to map unto the real world or its expected meaning [12]. For instance, Doller and Hegedorn [5] reports that lack of congruence in semantic aspects between AEC and geospatial aspects of city scale information models is yet to be achieved in practice. Wu and Issa [9] similarly highlighted the most critical challenges to achieving integration of sustainability within the wider information modelling continuum.

Emerging data standards such as the Industry Foundation Classes (IFC's from International Standards Organisation-ISO) have been widely accepted as solution [11]. These provide an open and consensus based classification of information requirements to be adopted by both adaptors and technology vendors to aid better communication between systems and processes [11, 13]. The IFC's have been generally regarded as key to the delivery at a more semantic level of interoperable data exchange after rather modest achievements by ISO's (10303, 15531 and 13584) for simple product data exchanges [11]. Others have promoted platform-neutral web based file classifications (such as XML from World Wide Web consortium-W3C) due to increased internet based communication [14]. For instance, CityGML allows IFCs based encoding and transmittal information in geospatial environment [5]. This includes virtual 3D city models with appropriate semantics and appearance often defined to various levels of detail than can be displayed and exchanged through web services across systems including proprietary sustainability assessment tools [12]. This is daunting in practice as a result of the extent of fragmentation, diversity in information requirements; inflexibility of data schemas (standards); demanding technology competency requirements and wider commercial imperatives which prevent vendors' congruence in the development of software and systems that interoperate [5, 14, 11]. Projects are, however, heavily dependent on timely, efficient and effective data exchanges, however, interoperability is evidenced to be causing significant challenges in practice with attendant effects on delays and losses in information quality [10].

2.2 Data security, privacy and secure collaboration

Information security and privacy is very important for facility lifecycle information integration [15, 16]. It is imperative to guarantee that data and information are only accessible to the right people and software applications. Computer security and privacy techniques related to collaborative exchange border on the protection of valuable aspects of data, assets, information and resources including intellectual properties in these pervasive and often open data environments [17]. In addition to the dangers associated with access others have raised concerns over internet treats including hacking, malware and viruses with the increasing use of internet based collaborative exchange [17]. Protection and the safeguarding of data in collaborative IT environments should be accessible and available to the right people at the right times [15]. Technologies have been developed for computational approach to identification and preclusion of collaborators based on risk and rights and privileges [17]. Others have demonstrated the applicability of reduction in visual data quality with a combination of access control techniques to preclude collaborators with less access privileges from viewing data such as 3D models with full levels of detail [18].

There, however, remains a lack of understanding of the role of the characteristics of technology on these risks or perceived risk as this is critical for designing measures to foretell them in the deployment of IT systems for multiparty collaboration such as BIM. Key concerns raised include uncertainty among actors on where data goes, how long it is stored, accessed and who has such access to it [17]. Gu and London [15] and Singh *et al.* [19] report security and privacy concerns among the critical concerns and barriers to stakeholders wider adoption and use of BIM for collaborative exchange.

2.3 Other information risks

Scalability is a concern in the bid towards adopting BIM [11, 20]. The current size of most model based project data sets is also challenging as the capacities of collaborators or their systems might not be able to handle such volume, scale and transitional requirements of data across the lifecycle of facilities [21]. Fischer *et al.* [20] reported such information related risk as an influential factor in achieving data adequacy and integrity. This includes inconsistencies and losses in data in 3D models due to systems incapacities. Others have also highlighted limitations in terms of longevity ('shelf life') of these massive data models [20, 21]. Current technologies are also limited in ensuring appropriate version management is essential to ensure good audit trail and relevance of information at each time, particularly on shared models where multiple actors input information at different times [12, 15]. Some have advocated federated architectures for BIM systems where autonomous and distributed applications are integrated into a loosely-coupled coalition of systems for data sharing or exchange [12, 14]. While this may improve scalability and versioning issues, it is also regarded as a contributor to poor system performance and data quality due to deterioration caused by the execution of distributed queries for data retrieval [14].

2.4 The role of standards

The development of standards for data exchange in project delivery has evolved over the last two decades [1]. The Industry Foundation Classes (IFC) (by the International Alliance of Interoperability) and International Organization for Standardization's (ISO) specification (ISO/PAS 16739) have proliferated recently generally for the purposes of unified approach to describing data structures and rules for encoding project information [11]. With increasing web communication, XML (eXtensible Markup Language) by the World Wide Web Consortium (W3C) has similarly become the popular [13]. Including the ifcXML; aecXML for AEC in general; landXML for planning systems and gbXML for energy related applications [2, 6, 13]. Other standards have also evolved within other related fields including GML3 (e.g. cityGML ibid) by the Open Geospatial Consortium (OGC) [5, 6].

In recognition of the vitality of standards in meetings U.K's BIM implementation targets, the PAS 1192, provides overall guidance including file naming protocols, model information management and handling and levels of detail requirements [22]. Figure 2 is a representation of U.K targets for BIM maturation and required standards for achieving effective data exchange at each

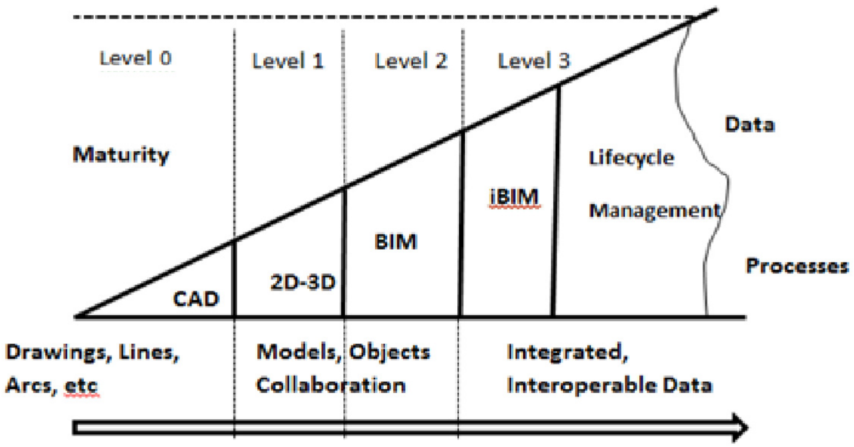

Figure 2: Roadmap to BIM implementation with essential documentation to support data exchange (After PAS 1192-2:2013).

phase. Data exchange requirements for levels 0-2 are generally rudimentary with object based standards generally acceptable (such as ISO 10303 Standard for the exchange of Product Model Data (STEP) [11]. Higher levels of maturity however require more excessive levels of integration with increasing complexity in data exchange requirements better unification in standards [14, 23]. There is the need for assessment of its applicability in practice to aid continuous adaptation at the higher levels of maturity and evolving practice.

There, however, remains the critical challenge of unification of the variety of world views of actors from diverse perspective towards semantically enhanced exchanges [5, 11, 23].

Standards continue to lack capability of dealing with incremental level of detail requiring continual revision. Widely fragmented state of development across the various disciplines has resulted in varying levels of maturity in the state of standards across AEC, geospatial, energy or sustainability fields in practice [6, 12]. Resultantly, few commercial applications support this state of development including lagging pace of development as compared to the technology itself [23]. For example, many proprietary tools do not still support IFC data export functions despite wide acceptance of its applicability, making data exchange still challenging in practice [13].

3 Influence of technology challenges on sharing and exchange of information

These challenges have dire consequence on the adequacy of exchanged data with reports of losses of information and detail as a result of issues such as interoperability [4, 14]. Issues such as security and privacy may cause deliberate reduction of detail which may cause asymmetric conditions [17, 18]. Most of the identified challenges also cause lack of automation in the areas of data fusion, geometry alignment and visual generation [5, 12]. Resultantly, laborious manual techniques need to be engaged to ensure successful exchange, transfer or sharing of digital data or models. This includes excessive manual acquisition and model data alignment between data from heterogeneous systems in order to create required levels of visual or data adequacy [5, 12, 19]. Such processes are time consuming and costly and also requires high levels of technological competence among collaborators for in-house rectification. Lack of inter-operability in general is estimated to cost the AEC up to $15.8 billion per year from estimations of projects in the USA due to inefficiency and ineffectiveness [24].

Varying levels of technology related competency, capacity and financial capability within the supply chain or stakeholders in the project delivery process also prevents effective adoptability of standards [12]. Significant privacy and security risk, causing some uncertainties which go a long way to restrain enterprises' willingness to share data across the supply chain through integrated ICT systems [17, 25]. It is evident that the resolution (the immediate consequence) of these problems was often the additional time and resources needed to model the required information [4].

3.1 Impact on organisational attitudes towards exchange and sharing

With the growing recognition of the socio-technical nature of IT for inter-organisational collaboration, it is important for the technological challenges to be examined in line with the interdependence on other organisational and environmental influences as depicted in Figure 3.

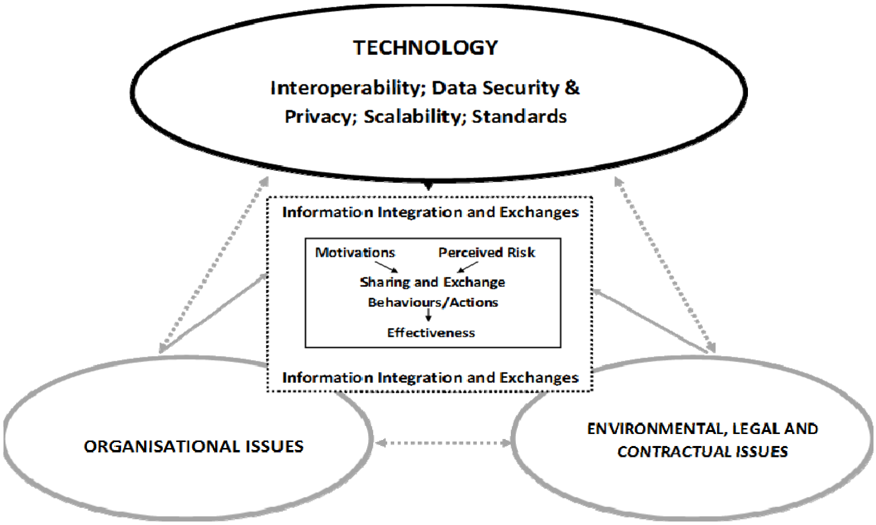

Figure 3: The Influence of Technology on BIM digital information exchange.

According to Adriaanse *et al.* [26] effective inter-organisational communication and use of ICT is dependent on actors (organisations) disposition to influencing mechanisms including inherent challenges (real or perceived). This was based on synthesis of concepts in Technology Acceptance (TAM), Planned Behaviour (TPB), Unified Model of Acceptance and Use of Technology (UTAUT). These theoretical models share the view that the intention to use has significant influence in actual use or extent of use based on subjective cognition of participants. Such intentions broadly influenced by motivation including user's perception of challenges, risks and willingness to overcome them. With a paramount influencing element being perceptions of the extent to which technological challenges restrict effective communications in acceptable way to the users. Information sharing theories share similar tenets and highlight the effects of characteristics of technology such as perceptions of ease of use on supply chain attitudes towards sharing information [25, 27]. Such theories including Information behaviour theory are critical as a result of the recognition of the need for balanced approach where the interrelationships between the technical and social dimensions of collaborative exchange are explored. According to Gu and London [15] perceptions of risk in relation to data security, access and integrity are among the most critical determinants of effective use of BIM for data exchange.

With such risks similarly identified as influential factors on willingness to participate in collaborative information exchange as well as detrimental to outcomes in terms of data adequacy as tendency to resort to traditional means of communication increases [26]. The influence of the technological challenges to exchange therefore have far reaching consequence beyond the practical difficulties. Their impact on effective exchange is evidently multidimensional as a result of the interactions and influences of organisational dynamics such as exchange attitudes and behaviours as well as environmental influences such as legal requirements on projects or industry's role in the development of adaptable standards. The impact of these on the effectiveness of exchange will, therefore, be key in determining the success or otherwise of the deployment BIM based technologies for information exchange.

3.2 Implications for future research

Based on the outlined discussions, the following pertinent questions need further investigation towards development of a deeper understanding of the impact of technological challenges on effective collaborative exchange.

- Do SC members feel vulnerable in information sharing and exchange on BIM technological platforms?
- If so, what are the behavioural consequences?
- What is the impact and contribution of the challenges in relation to the current state of development in the technologies and their use in practice?

4 Conclusion

Based on previous studies, parallels have been drawn from related industries towards the development of conceptual understanding of the emerging challenges to inter-organisational exchange of digital information for effective sustainable delivery of projects. The challenges pertaining to the technology relate mainly to the heterogeneous nature of systems and increasing complexity of data structures to meet evolving sustainability and information modelling requirements. From the review it is evident that significant challenges that inhibit effective exchange are as a result of lack of universality and poor adoptability of standards; unavailability of vendor-neutral data models for effective exchange; scalability and capacity constraints; accessibility availability and security of data. Assessing and fully addressing the implication of these on effective exchange including attitudes towards exchange will aid complementary design and use of other influencing mechanisms such contractual, procurement and operational protocols in addition to standards being deployed for tackling more overarching challenges that affect adoptability and use of BIM for exchange. This is in view of emerging evidence of their consequential effect on effectiveness in terms of integrity, quality and adequacy of exchanged data. As well, the impact of these challenges on perceptiveness of risk and motivation for digital exchange through BIM will aid a deeper appreciation of the role of challenges in effective information exchange.

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