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Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges

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ABSTRACT

Rapid advancement of technology continues to leverage change and innovation in the construction industry. Continued digitization of the industry offers the opportunity to totally reinvent contemporary construction design and delivery practice for future development. Building Information Modelling (BIM) within the context of Architecture, Engineering & Construction (AEC) has been developing since the early 2000s and is considered to be a key technology. Despite major technical advancements in BIM, it has not been fully adopted and its definitive benefits have not been fully capitalized upon by industry stakeholders. The lack of widespread uptake of BIM appears to be linked to the risks and challenges that are potentially impeding its effectiveness. This paper aims to discuss the reality of BIM, its widespread benefits and current level of uptake. The risks and challenges associated with the adoption of BIM, as well as recommendations regarding how future BIM adoption could be developed are also highlighted.

1. Introduction

The paper begins by introducing BIM as a concept, its definition and purpose, as well as its' historical context. It goes on to examine a wide range of current benefits associated with the use of BIM. The study reviews the current level of uptake of BIM in practice, which is limited in terms of geographic context and level of its industry implementation. Given this lack of BIM uptake it is important to establish the challenges associated with the use of BIM and to provide recommendations for future BIM adoption.

In totality the aim of this paper is to discuss the reality of BIM, its objective is to offer a state of the art review of the current levels of BIM implementation and the associated benefits and challenges available to industry stakeholders. The paper contributes to the level of understanding of BIM, highlighting its potentials and challenges and provides future recommendations regarding BIM uptake. The paper confirms the growing interest in BIM within the construction industry and it offers clarification to maximize its uptake.

2. BIM timeline

BIM is generally understood as an overarching term to describe a variety of activities in object-oriented Computer Aided Design (CAD), which supports the representation of building elements in terms of their 3D geometric and non-geometric (functional) attributes and relationships. Thus BIM refers to a set of technologies and solutions aiming to enhance inter-organizational collaboration in the construction industry, that will enhance productivity whilst improving design, construction and maintenance practices [1].

3D modelling began in the early 1970s based on CAD technologies developed in diverse industries [2]. As a result, the construction industry applied 2D design initially for utilizing CAD [2,3]. To enhance construction specific CAD, the concept of BIM was introduced in the early 2000s [3,4]. This sought to integrate the ability to add informational 'texture' to designed objects (in terms of properties, materials, lifecycle and other data) into the functional design created by architects and engineers. Since the inception of BIM it is a focus point throughout the building lifecycle for AEC [2].

The genesis, development and expansion of BIM has largely mirrored the growth profile of computerization. During late 1950s,

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the Itek Corporation, a US defence contractor, introduced a computer graphics system appropriate for engineering design. This aided the design of visual representational systems that were developed into commercial engineering design and drafting products. The concept was subsequently turned into an Electronic Drafting Machine (EDM) [5]. By the mid-1960s, EDMs had been commercialized for use by other companies. During 1970s and early 1980s Applicon (founded in 1969 as Analytics, Inc. in Burlington, Massachusetts by a group of programmers from MIT's Lincoln Laboratory) offered 2D products targeted at electrical design tasks. This included the schematic and physical design of printed circuit boards and a 3D product called BRAVO! intended for mechanical design and drafting [5]. By the early 1980s, the BRAVO! product had been advanced significantly. From the early 1980s, Autodesk became the principal competitor for Applicon and other CAD technology providers. Autodesk has continued as a pioneer in this field. Recently, specialized features such as structural analysis, building energy monitoring and analysis, construction scheduling and progress tracking and even job safety are offered in AEC computerized platforms [6,7].

BIM gained widespread use after Jerry Laiserin (a construction industry analyst) argued in 2002 that it should be an industry-standard term [8]. The term BIM attracted Autodesk, who started heavily promoting it along with their products [9]. The BIM concept was introduced to the construction industry as a means to improve efficiency, reduce costs and as an overall management aid during all stages of construction [10].

3. Clear current benefits of BIM

There is a wide range of clear and current benefits associated with the use of BIM. These range from its technical superiority, interoperability capabilities, early building information capture, use throughout the building lifecycle, integrated procurement, improved cost control mechanisms, reduced conflict and project team benefits.

3.1. Technical benefits

BIM has been proffered as a substantial technical advance on traditional CAD, offering more intelligence and interoperability capabilities [1,11]. Digital representation of physical and functional characteristics of a facility enables users to transfer design data and specifications between different software applications, both within an organisation and more widely in a multidisciplinary team. Since information is stored as a database in BIM, any data changes required during the design process can be logically undertaken and managed throughout the project life cycle. BIM has been described as "*the technology of generating and managing a parametric model of a building*" [11,12]. It has also been referred to as an evolving multi-faceted phenomenon with an object-oriented 3D model of a structure to enable interoperability and information exchange [1].

Thus BIM is a growing field of research and practice that integrates the diverse knowledge domains in AEC [10,13]. BIM tools provide optimized platforms for parametric modelling, enabling new levels of spatial visualization, building behaviour simulation, effective project management and operational collaboration of AEC team members. Interoperability capabilities of BIM are more effective when extending its application for construction, facility management and building maintenance stages [1]. BIM refers to a set of technologies and solutions that can enhance inter-organizational collaboration and productivity in the construction industry, as well as improving design, construction and maintenance practices [1]. BIM technologies are continually expanding and evolving new functionality.

3.2. Knowledge management benefits

BIM tools have enabled comprehensive information about the building to be captured during the design process, ranging from individual building components and locations to relationships between those objects. BIM incorporates building information ranging from geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components product's material, specification, fire rating, U-value, fittings, finishes, costs and carbon content. These features in turn allow designers and engineers to keep track of relationships between building components and their respective construction-maintenance details. Whilst the benefits of BIM are implicitly understood by the designer, they could become explicit to other project stakeholders such as owners, contractors, subcontractors, fit-out companies, council, etc. In the event of design changes BIM tools can integrate and systematise changes with the design principles, intent and design 'layers' for the facility/project [14]. Moreover, BIM could be used essential for facility management integration. One example is Onuma which offers Construction Operations Building Information Exchange (COBie) files to enable standardized external facility management data integration [15]. BIM tools provide interoperability opportunities plus the capability for proper integration, allowing inputs from various professionals to come together in the model.

3.3. Standardization benefits

In order to fully enable collaboration among BIM tools users, data exchange standards have been developed. The establishment of these standards in the form of Industry Foundation Classes (IFC) for construction objects was led by buildingSMART [16]. The operative definition of an IFC is "*a neutral and open specification that is not controlled by a single vendor or group of vendors*" [17]. IFCs have been a major step forward in organising the BIM development process [17,18]. This has contributed to enabling and systematising interoperability among AEC BIM users through the provision of standard models encompassing rich semantic and geometric information of building components.

3.4. Diversity management benefits

Research has suggested that the focus on applying BIM tools for existing buildings has emerged. It offers a range of alternative potential benefits for the built environment [19], ranging from:-

- facility management activities [3,6,20]
- as-built renders [21,22]
- heritage and historical documentation [2]
- maintenance [23]
- tracking warranty and service information [24,25]
- quality control [26]
- monitoring and assessment [2,6,25]
- energy management [27,28]
- emergency management [25,29,30]
- retrofit planning [31,32]

3.5. Integration benefits

In order to cater for the rising complexity of diverse projects [33,34], Information Technology (IT) and Information Communication Technology (ICT) have been developing rapidly to facilitate innovative solutions [35,36]. To reflect this BIM as an alternative method of design and construction has gained popularity amongst key players in construction industry [37]. BIM has developed to facilitate the increasing complexity of construction projects, able to facilitate design, construction and maintenance of projects through an integrated approach. It provides a collaborative platform for different stakeholders involved in a project lifecycle. Owners, designers, contractors and construction managers can use BIM to undertake construction projects more efficiently than ever before [38,39]. Furthermore, innovative IT/ICT tools are important factors in the AEC pedagogy. Likewise, BIM is expected to be utilized for knowledge integration in order to enhance AEC education [40–43].

BIM can be used as an interactive manual for safely managing and operating the building providing complete facility information [44], such as physical structure, mechanical and electrical systems, furniture and equipment. BIM models can simulate maintenance or the retrofit process [45] and therefore help reduce facility management costs [46,47] and improve the maintenance process as well as provide an accurate cost estimate of renovation [48]. It can also be used in simulating evacuation scenarios, crowd behaviour and crowd movement [49].

BIM provides accurate quantities for building materials and components involved within a design [50]. This can help coordinate the procurement process during the design and construction phases [51]. It can also serve as an accurate design model for the fabrication of building components [52]. The BIM model can be used as an input for automated fabrication machines for pre-fabricated building components. Where a building model is linked with time, it is possible to simulate the construction process [53,54] and detect clashes [55] in the procurement process and offer improvements before the actual construction commences. Capability of BIM tools to model complex building design concepts [56] provides architects with freedom in creativity. BIM is considered a key solution towards future enhancement of smart housing and intelligent buildings [57].

3.6. Economic benefits

BIM has also been identified as having significant economic benefits. A robust driver for technology adoption is monetary evidence [58]. Return on investment (ROI) is a key value to consider in such practices. In the context of BIM, various analyses have reported high ROI results. The importance of BIM-assisted design validation is acknowledged. Research has confirmed that the impact of BIM on preventing schedule delays has the most influence on increasing ROI while rework preventions based on initial model validation/assessment is also a driver [58]. This paper recommends future research concerning BIM perceived ROI versus actual ROI to ensure real-world benefits.

BIM users have outlined both short and long term benefits of using BIM. The most important short term impact of BIM was minimizing documentation errors. This was followed by using BIM as a marketing tool for the business. Less staff turnover was also seen as short-term benefit of using BIM. Fewer contractual claims and reduced construction costs are considered as long term benefits. Maintaining recurrent business with past clients is also a major benefit of BIM [59]. BIM can be used for initial planning and feasibility studies. A conceptual building model can be created with cost information to help developers in determining whether a building of a given size, quality level, and desired requirements can be built within a given cost and time budget. It can also help explore building's functions. For design, the 3D BIM model will provide a more realistic visualization of the design for all disciplines. Through improved collaboration, a continuous improvement between multiple design-disciplines can be achieved, which significantly reduce design errors and omissions. Any changes made to the 3D model can be generated immediately to 2D drawings. Cost estimates can be extracted from the building model to keep all stakeholders informed of the cost implications as the design evolves.

3.7. Planning/scheduling benefits

BIM 4D schedules are powerful tools for phasing, coordinating, and communicating planned work to a variety of audiences [60]. Since all materials and components are predetermined and their quantities are automatically calculated, building materials and components can be ordered electronically and delivered on site just in time, therefore increasing workers' productivity. The 3D model provides an acceptable visualization of working space while the 4D schedule offers simplified comprehension of various requirements throughout the project lifecycle. This is particularly useful for the stakeholders directly responsible for executing the construction-maintenance work. BIM has the ability to link manufacturers' data, construction data and communications into one fully integrated facility dashboard. Facility managers can use BIM to manage daily operations and prepare maintenance schedules. A key aspect of any real-time visualization system is to facilitate real-time and interactive updates. Thus ineffectiveness in performing so eliminates the benefits of applying such technology. Even an inconsistent update rate makes project monitoring and navigation more challenging potentially causing the team members to lose track [61]. Therefore, BIM tools are expected to provide smooth real-time updates and sufficient visualization performances to enable effective collaboration among team members [56].

3.8. Building LCA benefits

The utilization of BIM has expanded throughout the building lifecycle including activities such as building-structural design and configuration [62], cost estimation [63] and property management [64]. The use of BIM is suggested to be advantageous throughout the building project lifecycle from the early conceptual design stages [65,66] to demolition [67,68]. BIM is also considered to be a beneficial tool for project managers [35]. BIM provides project managers with the potential to re-engineer design-construction-maintenance progress for optimized collaboration amongst diverse team members [35,69]. Stanford University Centre for Integrated Facility Engineering (CIFE) confirmed that application of BIM has a number of benefits. It eradicates unforeseen modifications by up to 40%, provides cost estimation with an error threshold of 3% and up to 80% reduced generation time. It also provides clash detection capable of saving up to 10% of the contract value and reduces the project completion time by up to 7% [34]. More recently the research focus has shifted from the early building lifecycle stages to the maintenance and refurbishment phases. This has emphasized the advantages of utilizing BIM not only for design but also for maintenance of buildings [2,3,6,68,70,71]. The application of BIM provides optimum information exchange platforms for project stakeholders, designers, contractors and manufacturers. As a result, the quality of information is improved for facilitating informed decision making [64,72].

3.9. Decision support benefits

BIM offers all engineering stakeholders the opportunity to utilize a unified shared model to achieve the project goals at an optimum level. The data sharing provided by BIM among different team members allows for constant evaluation and information control [73]. Visual verification of design intent and knowledge sharing through virtual design and construction increase the clients' satisfaction levels. Exchange of visual information among designers and clients [74] mitigates the time needed for communicating complex ideas. BIM enables simplified knowledge management. Continuously collected, stored and maintained project data throughout the building lifecycle streamlines tracking and evaluation of project details [73]. BIM enables immediate and accurate comparison of different design options, which enables the development of more efficient, cost-effective and sustainable solutions. BIM can also facilitate the analysis and comparison of various energy performance alternatives to help facility managers dramatically reduce environmental impacts and operating costs.

Since projects utilizing BIM tools are visualized at an early stage, owners are given a clear idea of design intent facilitating easy alterations to meet the client requirements effectively. BIM also enables the project team to virtually rehearse complex procedures, such as planning, procurement, site equipment and manpower allocation.

Multidisciplinary integration of teams allows the identification and resolution of issues in advance of construction. This is important in both, designing new facilities and integrating new facilities with existing ones. Early multidisciplinary integration allows unnecessary cost and time impacts by reducing errors and requests for information and therefore reducing reworks. Conflict detection reduces the number of requests for information (RFIs). This is regarded as one of the most important advantages of BIM. Fewer RFIs means fewer change orders resulting in more accurate cost management and potentially significant cost savings. The majority of contractors consider the potential of BIM to reduce rework as the second most significant benefit after the reduction in RFIs. By using BIM tools contractors can also minimize construction risks by reviewing complex details or procedures before going onto site.

4. Current implementation

Given the various potential benefits reported in the literature of utilizing BIM [34,35,75], it is useful to examine the current level of BIM uptake in reality, where BIM is being used successfully and who is championing the use of BIM.

BIM has a range of design/construction/management purposes. It is currently being utilized in AEC inter-organizational design coordination [76], construction safety management [77], hazard identification/prevention [78], automatic detection of design-related errors [79] and automated building design review [80]. It is also being used for construction risk management [81], improving labour productivity [82] and reducing construction fatalities through geotechnical and safety protective equipment planning [83].

BIM use is rapidly expanding globally. The adoption of BIM in North America has increased dramatically [59]. Among BIM users the US has the largest market. This phenomenon has largely been driven by the US governmental requirement for all major infrastructural contracts to be BIM enabled [84]. Globally BIM implementation levels by contractors indicate very high adoption rates. There has also been a decreasing gap between the adoption percentages among different countries observed. BIM is expected to be comprehensively utilized in diverse countries and this utilization ratio is rapidly increasing [84].

The understanding of BIM is expanding with its implementation in many countries throughout the conceptualisation, design, construction and operation of buildings. Specific research has been undertaken to identify BIM adoption in different contexts. National Building Specification (NBS) represents BIM awareness and current utilization in UK, Canada, New Zealand and Finland [85]. This research indicated a high level of awareness of BIM in the UK, Canada, Finland and New Zealand, compared to a much lower level of current use of BIM. The UK indicates the highest level of disparity, suggesting that 94% are aware of BIM yet only 39% are implementing BIM. It is important to examine the causes for such a disparity between understanding and non-adoption. There has also been suspicions and scepticisms in the New Zealand construction sector surrounding BIM's usefulness [86].

The UK BIM adoption rate of 39% is explained by two possible reasons. The first reasons is that BIM seems to be seen as a life saver for the future of the construction sector, the public sector in Britain accounts for 40% of the construction sector investments, and most significantly the number of infrastructure projects is large [87]. The second possible explanation is, once the demand is from a source high in the hierarchy, it is seldom questioned and commonly acknowledged automatically [87].

Despite the level of BIM non-adoption, leading BIM adopting countries have shown a promising future for the technology. Very high rates (77–85%) of BIM utilization especially during 2016 have been observed [85]. This suggests that BIM is expected to reach a market saturation point in near future however, caution is required as these are future projections.

The NBS conducted a survey that generated over one thousand respondents which was followed up with the UK National BIM Report. This research confirmed that architects and architectural technologists are the largest groups using BIM with 37% and 21% respectively. With quantity surveyors (5%) and structural engineers (4%) and only 1% of construction materials manufacturers and building facility managers that have used BIM in any way [88].

The key players in the construction sector regarding the adoption of BIM are ranked in order of client, project manager, architect, principal contractor and engineer [87]. Contractors play a significant role in promoting/demoting the adoption of BIM. This is due to their significant role in operationalising design projects. In other words, building contractors have significant influence on whether or not BIM applications can be fully utilized during the building design, construction and maintenance lifecycle. BIM is most regularly used throughout the design phase followed by detailed design and tendering phase, construction phase, feasibility phase and maintenance phase respectively [89].

In the UK a BIM maturity model was developed to classify BIM users, it indicates the level and depth of BIM adoption/utilization [90]. Furthermore, the CIC BIM 2050 Group developed a futuristic forecast roadmap indicating potential prospects of BIM and socio-technological frontiers [91]. Here key technologies were placed in the context of the levels of BIM maturity across a timeline. This has also been mapped against other factors such as skilled labour and Moore's Law [92].

The UK National BIM Report (2012) confirmed that the majority of companies surveyed used CAD in one way or another. The number of CAD users had increased significantly from 58% in 2010 to 65% in 2011. CAD has been described as the ‘gateway technology’ for BIM use and an indicator of likely BIM adoption in the future. Some companies used 2D CAD (30%), while others used both 2D and 3D CAD (31%). Only 4% of CAD users had completely switched to 3D CAD use [93].

A2K Technologies (2014), sponsored by Autodesk, performed a survey among Australia-New Zealand professionals. They examined the need to better understand the thoughts, opinions and challenges of the industry with respect to CAD and BIM. Results indicated that technology adoption and the technology marketability were dependent on it being operationally ‘workable’ [94]. This highlights the significance of BIM workability within the AEC industry as a key driver towards successful BIM adoption. The survey went on to confirm that only 22% of AEC having successfully incorporated BIM into their design and construction operations and that inter-departmental collaboration is essential for AEC companies. Stressing interoperability as a key feature of BIM may arguably be an essential market proposition to overcome the current (relatively) low adoption rate. The BIM frequency index showed that BIM is highly used for modelling the building envelope, followed by positioning a project on its site to incorporate site logistics and storage areas. Both of these activities have a positive Value/Difficulty Ratio, this suggests that the BIM value is much higher than the degree of difficulty associated with it. Sustainability and safety on the other hand have negative Value/Difficulty Ratio. This also means that the degree of difficulty of using BIM for these tasks is much higher than the end value, resulting in a much lower frequency of BIM use for these tasks. The respondents identified the main difficulty factor as the ease of using the software (70%). This was followed by lack of skill at 52% and insufficient hardware at 31% [59].

This apparent inconsistency has been postulated as the result of a low adoption percentage of BIM by architects [95] as well as uneven adoption through the remainder of the delivery process. BIM adoption is considered to be related to five key issues: management support, technical support, BIM compatibility skills and organizational culture [12,59,95,96]. It is therefore important to unpack the challenges, risks and concerns that exist to using BIM.

5. BIM uptake challenges and risks

Despite the diverse potential benefits of utilizing BIM, developed strategies for implementation [97] and likely future high adoption rates [98], overall effectiveness of using BIM is not fully established [99]. Manageability of BIM outputs in real-time is a challenging task [100]. The application of BIM incorporates a range of risks including technical risk, management risk, environmental risk, financial risk and legal risk [34].

One of the main challenges involved in BIM progression is the intellectual property and cyber security of BIM tools outcomes [101]. As information sharing makes project data accessible to team members, cyber security is a concern due to the possibility of online unauthorised access and copyright infringement [34]. Additionally the development of comprehensive and clear re-use and adoption policies for BIM models either by the same team for different purposes or by others is a challenging task. The integrated concept of BIM blurs the level of responsibility among different project team members [102]. Legal concerns also exist, problems with ownership of data/design or licensing issues are likely where the information is provided by outside sources. Furthermore, joint authorship of different BIM model developers complicates joint and separate liability for any errors made during the project lifecycle. The accuracy of data behind the BIM model entails substantial risk and the responsibility for this accuracy must be backed by some sort of disclaimers of liability as well as limited warranties from the designers.

BIM managers and lead inter-operational professionals should be assigned to track and control errors and make decisions regarding responsibilities. The BIM manager would be required to implement a number of activities including the parties' agreement on model access, software, security, information, archiving, transmitting, etc. [102,103]. To avoid arguments concerning BIM responsibilities, limitations and liabilities, a new form of contract could be implemented. This would to cover all of the parties directly involved or any other party that may be affected by the BIM working method. Alternatively BIM protocols covering legal issues should be created, which could be used as an amendment to the main contract to make it suitable for BIM [102]. This will allow parties to retain the contracts they are accustomed to while adopting BIM.

Interestingly some legal terms in the BIM protocol may conflict with clauses of the principal contract. For instance a BIM protocol may require a more comprehensive intellectual property licensing procedure than that provided under current construction contracts [104]. Ensuring accuracy will also require additional time imputing and reviewing the BIM data, which will create new costs in the design and project administration process. Thus, before BIM technology can be fully utilized, the risks of its use must be identified and allocated, as well as, cost associated with BIM must be allowed for and paid [102,103,105].

6. Discussion

The review indicates that BIM has its own inherent advantages and shortfalls. BIM model design layers have substantial interconnectivity. As a result of the process, as the project develops, redrafting and redevelopment is automatically evolved.

The review suggested that the degree to which BIM comprehension occurs and is broadly adopted is closely related to the size of an AEC firm [106]. It seems quite clear that smaller firms tend to equate BIM to 3D modelling, while large firms perceive it as a way of managing design and construction itself, as well as, managing costs, schedules and exchange of information. It would appear that any significant benefit from the introduction of enhanced BIM technologies are most likely to accrue to larger companies, since they are the principle adopters [35].

The literature suggests that large, successful expert BIM adopters may become even more successful. It is likely that we will see the structural 'BIM inequalities' in the market place reinforced. The construction market may thus devolve into BIM projects and 'other' projects, where the entropy of change to move from the former to the latter will be challenging for most companies. On the other hand, an emergent set of technologies is anticipated to produce a series of unexpected daughter technologies and needs. Arguably, BIM is very much the AEC industry interfacing with the new age and is expected to have transformational impacts.

If we consider the wider context of construction, the differing rates of BIM adoption in different countries, to a greater or lesser degree leveraged by governmental procurement policy (ie. In the UK and US models) is instructive. It would appear that construction companies will invest in the infrastructure and software necessary to engage with future construction projects when the incentive is there. In both the UK and US the fact that only BIM enabled contractors and designers can tender for lucrative governmental work is, we would contend, the principle decider for BIM use.

Arguably the case for universal economic benefits has not been made sufficiently robustly to motivate contractors and designers to invest in BIM. Another feature of this decision 'go/no go' process also has to be the nervousness of the AEC industry to invest in infrastructure and software when a universal BIM industry standard software platform, let alone is still illusive. IFCs are argued over and extensive labours are invested in trying to establish globally accepted norms for BIM objects – let alone for standardised BIM platforms.

Finally we would contend that the current mechanisms for integration in the construction industry – including BIM processes – are substantially impeded by current norms for education of the various players in the AEC industry. In large portions of the world, architects are taught entirely separately from engineers, and both are again separated from constructors. Undergraduates rarely share the same teaching materials, are not taught in the same university schools and departments, or for that matter do not work on collaborative projects as undergraduates. The trade schools are (of course) entirely different constructs again. Is there any particular wonder therefore when the structural divisions and protectionism of our universities and colleges are then mirrored in industry practice in the 'real world'? Probably not. Teaching children and young adults separately, based on arbitrary justifications of 'difference' (i.e. religion, race etc) is often seen as a mechanism leading to suspicion, bigotry and conflict. In the AEC industry it is just accepted as the norm, which in turn is reflected in the inefficiencies and conflicts seen in construction procurement. In order to really gain the benefits of BIM techniques and collaborative design technologies, there is a strong case for rethinking how educators in the AEC disciplines actually teach, propagate and evaluate professional competencies to our future AEC professionals.

No doubt, BIM has huge potential and could lead to a wide range of changes in construction practice, however its rate of implementation has yet to match its benefits. This could be due to the modest scepticism that exists concerning its full feasibility and real risks and challenges. The popularity of BIM has grown over the last decade, uptake levels are improving and is likely to continue as long as the risks can be systematically mitigated and the challenges overcome.

7. Conclusion

The most significant reasons for not adopting BIM include the lack of demand, cost and interoperability issues. The low value to difficulty ratio of BIM in some practices due to lack of software interoperability and non-user-friendly format combined with the lack of skills and experience is a major concern. Many BIM users around the world experience low return on investment, this can be attributed to the users' level of experience and BIM engagement. Smaller companies tend to suffer the most since their engagement in BIM projects is less and therefore they are less experienced. Successful BIM adoption requires significant investments by AEC firms including investment in software, hardware, training and other requirements. BIM also requires some process investments, such as developing internal collaborative BIM procedures, and business investments for developing future BIM capabilities [59].

BIM has the potential to offer its skilled proponents substantial and diverse benefits. These include client satisfaction through the visualization of the model and clear expectations; enhanced team collaboration in the delivery of better outcomes; improved data sharing, information control and the delivery of green buildings [107]. These benefits can be achieved through carbon foot printing, solar, wind and water analysis etc. Other benefits associated with BIM include: improved performance outcomes by comparing different design alternatives; reduced errors and omissions leading to reduced requests for information; reduced rework and safety risks; precise scheduling [108] and the provision of the end product with an interactive Facility Management tool [109].

BIM has been increasingly adopted in the AEC industry since its inception in the 1970s, yet the implementation of BIM has not been fully exploited even in leading contexts. For instance, in the UK, the government is actively encouraging the industry towards this collaborative environment, however, one in five companies "*remains in blissful ignorance of BIM's existence*" [110]. In contrast, promising insights indicate a potentially successful adoption rate for BIM implementation in near future [84].

8. Future recommendations

It is suggested that BIM is a wide concept and should be considered to be a process. This would replace its current reference as a common name for a variety of activities related to object-oriented computer-aided design (CAD) for representation of building elements in terms of their 3D geometric and non-geometric (functional) attributes and relationships. BIM is also observed as a collaborative process covering business drivers, design, construction and maintenance processes, and it provides open information standards for all parties involved in the project.

In the foreseeable future it is likely that a large proportion of the construction industry will be 'BIM aware' and 'BIM competent' rather than 'BIM expert'. The threshold for expertise in this context is high and is likely to increase with time. It is anticipated that an integrated design methodology combined with efficient engagement with stakeholders will be the key to sustainable BIM success [35,111–113]. Furthermore, the BIM-enabled design development process must be fully incorporated into the project management process. This is important to successfully fulfil the clients' needs in terms of project performance, as well as contractors and consultants' needs in terms of potential financial and legal risks. It has been observed that the most common risk factors of BIM during all levels are "*Inadequate project experience"* and *"lack of available skilled personnel*" [34]. Given that the project management process is still unclear around BIM this set of risk factors is unlikely to change in the short term. Many companies will continue to lack BIM expertise and the circularity of the situation could be self-reinforcing. Companies without BIM experience could also be excluded from tendering future BIM-enabled projects.

It appears that the potential problems associated with the general adoption of BIM combined with the unknowns of BIM in construction projects is significant. Companies are concerned specifically with the initial cost of BIM and the potential long term effects of investing in rapidly outmoded technology without sufficient time to achieve return on the investment made. This is an area for current and future research. There is a need to comprehensively quantify the benefits of BIM beyond the level of simple case studies and to provide clear evidence of BIM effectiveness. The effect of this developed dataset of expectations will be to provide industry with the information it requires to decide on key technologies, platforms and levels of investment with a reasonable expectation of return.

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