Review Article

Comparative Analysis of BIM Adoption Efforts by Developed Countries as Precedence for New Adopter Countries

ABSTRACT

Building Information Modelling (BIM) adoption is generally assessed through one of these two main approaches: statistical evaluation of stakeholders' survey operating within a country or market and the use of macro BIM-adoption models and metrics. The recent paper "macro-BIM adoption: Comparative market analysis" sets a pace to continues development of comparative market studies. However, precedence is important for continues learning and adoption contextualisation of this evolving field. This study aimed to set a unique precedence through comparative analysis of BIM adoption trends in the USA, UK and Australia to set a pace for beginners or early BIM adopting countries to learn from. This study is literature based analysed using content analysis. The study reveals the following:

- ✓ For a vibrant and even BIM adoption, government is involved;
- ✓ Government mandate facilitates wide BIM adoption and integrates a country's industry to the world;
- ✓ The mandate also facilitates BIM research and training that lead to rise in country's income through providing trainings and work force export;
- ✓ Diffusion dynamic varies at different times, depending on country's flexibility to adoption of innovation;
- ✓ The dynamic also changes as the industry's culture/regulation changes.

Recommendations are made based on the study findings especially to the new adopter countries planning to develop a strategy for macro-BIM adoption.

Keywords: adoption, AEC, Australia, BIM, framework, UK, USA

1. INTRODUCTION

Building Information Modelling (BIM) may be define as the current expression of digital model of a building or infrastructure and its process of production/procurement [1]. Chartered Institute of Builders (CIOB) explained the fundamental idea behind BIM as *to create and share the right information at the right time throughout the design, construction and operation of a building or facility, in order to improve efficiency and decision-making* [2]. Thus, BIM is a process rather than a piece of software or set of software. The technology behind the BIM is one of the three BIM fields [3]; this it is the tool (technology) that aids the BIM concept.

The BIM awareness is going universal, while adoption across the world is still underway and remain uneven. Continues development in BIM fields (technology, process and policy) including its technological advancement and Noteworthy BIM publications (NBPs) are predominately evolving from the developed nations. On the other hand, recent publications revealed considerable number of developing countries that are keying into the BIM adoption

process, mostly at infancy stages; countries like Malaysia, Brazil, Qatar, UAE and Egypt to mention but a few are some of them considering a macro scale BIM adoption [4]. Some of these countries have just embarked on Macro-BIM adoption study to develop their national policy while some have already finished [4]. The developed countries that are moving very fast in this digital shift learnt so much from the early adopter (i.e. USA). Some scholars believed that the significant successes recorded by the UK is related to a successful lessons learnt from the USA BIM adoption strategies. However, there is limited attention to the entire process precedence to match with the developed macro-BIM adoption models in decision making at policy development stage.

More developing countries are considering a strategy development to adopt BIM working process, which ultimately involves lots of planning and commitment. These countries are building up in terms of awareness and experts, as ignorance of the modalities and benefits of BIM is significant reason behind low BIM adoption [5]. Efforts like BIM advocacy programme by BIM Africa Initiative is one of leaps to developing NBPs to African countries [5]. These countries can simply referred to as new adopter countries or at early stage of adoption, mostly Middle East, Africa and South America [6]. Moreover, the new adopter countries are seen to have been developing BIM at design stage only, every survey (global or country based), received low participation which is attributed to a low level of maturity and or knowledge [5], hence considered (mostly) at early adoption stage. This paper set to lay down a balanced trend and experiences of USA, UK and Australian efforts on BIM adoption for the developing countries' context matching ahead of BIM adoption.

2. BIM ADOPTION EFFORTS BY DEVELOPED COUNTRIES

The UK, USA and Australia are selected as sample case study countries for this comparative analysis (study) due to their construction culture similarity in advance framework for managing construction using BIM; and their BIM participation at world stage, availability of national BIM adoption surveys as well as NBPs [7, pp.7-10]. Moreover, these countries have highly established processes, standards and guidelines for BIM adoption and public availability of data for assessment as well [7,8,9].

USA and the UK are the leading BIM implementing countries in the world; Australia is one of the adopter countries whose rapid performance is outperforming the more established countries in terms of BIM guide, Standards, National Specification and corporate research centre [10, p.486]. Thus, these countries are selected for the comparative analysis.

Collaboration contracting approach within the USA, UK and Australian construction industries has been well established, and there are substantial literatures that set out to demonstrate their main principles, practices and benefits [7,11]. These subject countries have diverse diffusion dynamics and policies associated with their BIM adoption. The diffusion dynamic does not actually remain constant, but changes from one mode of directional pressure to another, all depends on who is leading the adoption at a time. For example, USA was initially middle-out dynamic, but subsequently changing to top-down due to state governments' involvement. More to that, big companies in the USA were so established in the use of BIM concept that facilitates the middle-out dynamic running concurrently with a bottom-up dynamic [12]. In the case of the UK, it was initially bottom-up dynamic but later changed to top-down due to government involvement as well.

2.1 BIM ADOPTION EFFORTS BY THE UNITED STATES OF AMERICA

The General Services Administration (GSA) in the USA launched a national 3D-4D BIM policy program in 2003. This came up in the effort of the government in promoting a digital transition in the construction industry. The policy program objectives were to:

- Establish policy to additionally adopt 3D, 4D and BIM for all major projects
- Lead 3D-4D-BIM pilot applications and incentives for current and future capital projects.
- Provide expert support and assessment for ongoing capital projects to incorporate 3D, 4D and BIM technologies
- Assess industry readiness and its technology maturity
- Partner with BIM vendors, professional associations, open standard organisations and academic/research institutions.

And subsequently, BIM usage is mandated in 2007; the GSA requested the use of BIM process in all new projects.

The USA Construction Industry has the following key stakeholders: Architects, Engineers, MEP, contactors, sub-contractors and the clients. Architects appear to be a driving force for the adoption of innovation within the USA AEC industry. This can be notice from the nomenclature of the head of GSA "Chief Architect" Public Buildings Service. Architects have been utilising BIM tools and process for years before the 2003 GSA policy.

Digitalisation in the USA AEC industry started since 1990s with the establishment of the International Alliance for Interoperability (IAI) and later changed to buildingSMART [13]; while National BIM policy and mandate were introduced in 2003 and 2007 respectively. The industry in the USA has been operating in an innovative way. Architects derive the use of Integrated Project Delivery (IPD) and further to BIM utilization. The American Institute of Architects were actively utilising the BIM concept thus, that facilitates the central government involvement. The government subsequently legislated it in 2007. The BIM diffusion mechanism in the USA market appear “middle-out” [12, p.292] although before then, a sign of “top-down” approach due to the government agencies and large clients’ involvement were experienced [14, p.341].

The increase in BIM implementation over the years within the USA is been driven by the government mandates [10]. Contractors reported considerable realisation of benefits of using BIM concept [9], likewise rapid rate of adoption seen as due to the fear of been left behind if one refuses to embrace the BIM revolution. Having the industry relatively developed (driven by American Institute of Architects) before the governments' policies, it was a bit easier towards a development and enforcement process. The BIM development in the USA is seen a middle-out diffusion dynamic [3] because of large organisations and industry associates (i.e. AIA) involvement.

Considering United States as the early country to adopt BIM (early adopters), the adoption process was slow and occasionally painful, but the USA endured to learn from those challenges they faced, building better solutions at the end. Nations that were slower to adopt BIM were able to avoid some of those issues encountered by the USA, hence having quicker and more efficient process. This has also resulted in some countries having either wedged or even exceeded the USA in BIM utilization or standardization (i.e. United Kingdom).

Utilisation of BIM in the USA lacks a unified national standard for project delivery. Absence of this standard is providing open-deliverables that become dependent on a client-to-client or even project-to-project basis. Various government departments in the USA are producing their own standards (independently created) and publishing them in places like National Institute of Building Sciences (NIBS), and these are independently use on projects without

connectivity. Some may see this as an opportunity to develop new ideas. For example Steve Jones [15], Senior Director of Dodge Data & Analytics see this as a good thing, believing that it would allow fresh ideas to 'problem-solving' contrary to other part of the world where government standards limits new ideas. Furthermore, key findings of a recent Dodge Data & Analytics survey on contractors demonstrated an increase ROI from BIM utilisation. Amongst the proclaimed successes, include:

"A 5% reduction in the final construction costs, a 5% increase in the speed of completion, a 25% improvement in labour productivity, and a 25% reduction in labour." [16].

Policy are seen to have played a role in speedy BIM adoption at design stage, most importantly the Architects; thus, Architects were found to be championing post-policy BIM adoption in the USA, while clients lagged behind [13]. Notwithstanding, USA contractors are also very advanced in BIM implementation against others around the world [9, pp.44]. On the contrary, owners are still the laggards despite the well-established record of BIM in the USA construction industry.

The initiated National 3D-4D BIM Program by the US General Services Administration (GSA) through the office of the chief architect, public building services came immediately after Autodesk acquired Revit Technology Corporation (2002). Subsequently, the BIM technologies adoption began to spread across the USA; BIM is set as a requirement in all final concept approval for all major projects in 2007. The 3D, 4D, and BIM technology deployment were encouraged in all GSA projects and supported by GSA BIM Guide Series. Two years after the mandate (2009), BIM adoption almost doubled from the start-up (28%) in 2007. NIBS published many National Building Information Modelling Standards (NBIMS) and specifically on building energy performance [13].

The USA is considered as a hub for technology development, the availability and affordability of technology made USA public and even private sector top in the world. This is what brings about competition and enormous development in all sectors. Availability of technology infrastructure facilitated a quick development, adoption and implementation of BIM within the industry even before the government mandate in 2007 [17]. Figure 1 presents efforts/process toward BIM adoption in the USA.

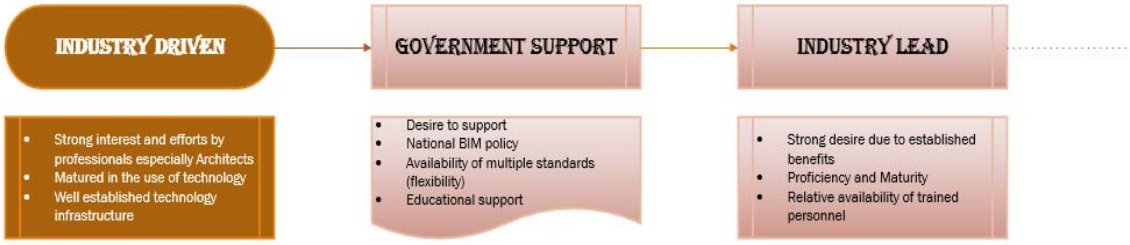

Figure 1. The USA efforts to BIM adoption

BIM education in the USA began since 2002 when many countries have not built up its awareness at industry level. Morses [18] carried out a BIM teaching survey on USA Academic Institutions, the result indicated that 82% are providing formal teaching in BIM. As for research, GSA collaborates with International Real Estate Organisations, CAD/BIM Technology Centre and Construction Engineering Research Laboratory to support open standards and guide for BIM software and system.

2.2 BIM ADOPTION EFFORTS BY THE UNITED KINGDOM

The UK government developed a Task Group to support and assist both government clients and supply-chain contractors in transitioning their work practices to BIM and electronic delivery, as part of an overall digital economy (digital Britain). The overall goal of the strategy is to improve the performance of the government estate in terms of reduction in capital costs and carbon performance. In addition, targets to become a world leader in BIM concept [19].

Construction industry comprises of the following key stakeholders: Architects, Engineers, MEP, contactors, sub-contractors and the clients. In the UK, clients are considered as a driving force in the industry. Before the recent development in the industry, clients are discrete and vary greatly; Latham [20] reveals that individual Government Departments were operating different procurement practices. Moreover, contracts were mostly running under traditional form involving Standard Forms such as JCT 80 or ICE 5th/6th who are considered unsuitable for collaborative working.

Five different contract strategies are the conventional practice contracts within the UK construction industry; these are: traditional, construction management, management contracting, manage & design, and design & build contracts. The digital transformation strategy has however favoured one contract over another, and this strategy has a target to achieving this transformation through encouraging the growth of new digital businesses or helping traditional businesses to transform into a digitally-enabled one [21].

Bew and Richards [22] developed BIM maturity wedge in 2008, the maturity nomenclature starts with level 0 (paper based) to level 3 (integrated web based) hub. The most popular amongst these maturity levels is BIM level 2. The British Standards Institution (BSI) describes BIM Level 2 maturity as a series of domain and collaborative federated models; different parties prepare the models, consisting of both 3D geometrical and non-graphical data, during the project life-cycle within the context of a common data environment. BIM is highly publicised in the UK due to the government interest and involvement. The UK government mandate on all central projects in excess of £5m to be BIM level 2 enabled by 2016 was a long leap taken in 2011. However, 2017 NBS report revealed 62% BIM usage in the UK [23]. The UK government policy for the 2016 BIM level-2 mandate was a driver for quick uptake of BIM in the UK. Significant development was recorded (from 31% to 62%) within the five years' period ahead of the mandate deadline (2016). It was noticed that the government policy accelerated the adoption, portraying a clear "top-down" diffusion dynamic [24], which is now the dominant UK BIM adoption strategy as reported in the government construction client group report (2011). On a further discovery, the approach subsequently changed (to middle-out) due to higher adoption by bigger companies hence becoming the leaders to moving the adoption further.

BIM implementation strategy in the UK is a "Push-Pull" type where the "Push" is the five years horizon given to the supply side of the industry to having all the players attained BIM level 2; while the balance "Pull" comes from the client side to specify, collect and use the generated information [21]

Availability of Noteworthy BIM Publication to achieving the 2016 mandate played a significant role in speedy BIM involvement by owners [13]. Despite the government mandate, the technical shift encountered some challenges, these include: resistance to changes, lack of experts, investment cost and feeling at risk of starting something new. Moreover, Dainty et al [25] reported lack of spelled out opportunities in the UK policy on BIM adoption as a barrier to its adoption.

On the other hand, the targeted benefit of this digital shift is to achieve an improve efficiency, reduction in whole life cost assets, reduction of carbon footprint and capability of

construction information storage and management. The investment benefits are rather not limited to the above benefits but extend to a long term plan of *selling expertise and cutting edge technologies across the world and seize a share of the $15trillion global construction market forecast by 2025* [21]. To corroborate these, quite tremendous achievements were recorded in the UK construction industry in terms of BIM adoption benefits. For instance, the construction cost savings of £804m (in 2013/2014) announced by the Cabinet Office was significantly contributed by the adoption of BIM [21, pp.5].

The legislation is introduced to facilitate the BIM adoption; a time horizon was established together with milestones. The British Standards Institute created an information-sharing standard called PAS 1192:2 to delineate a workable explanation of the key exchange points between client and supply chain at different stages of a building project, specifically on BIM Level 2 technology compliance. The BIM Level 2 suite of documents is being developed to help the Construction industry adopt BIM Level 2. The documents are reviewed periodically to meeting requirements and needs of the industry. These set of standards are:

- BS 1192:2007+A2:2016: Collaborative production of architectural, engineering and construction information
- PAS 1192-2:2013: Specification for information management for the capital/delivery phase of construction projects using building information modelling
- PAS 1192-3:2014: Specification for information management for the operational phase of assets using building information modelling
- BS 1192-4:2014: Collaborative production of information. Fulfilling employer's information exchange requirements using COBie
- PAS 1192-5:2015: Specification for security-minded building information modelling, digital built environments and smart asset management
- BS 8536-1:2015: Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure)
- PAS 1192-6:2018: Specification for collaborative sharing and use of structured Health and Safety information using BIM.

Following the recommendation of BIM level 2 as a standard practice from 2016 and the establishment of the BIM level-2 mandate. BIM Industry Working Group [15] recommends a collaborative form of contract (i.e. NEC), guideline and protocols to avoid ownership and responsibilities issues. Upon all these, the group did not perceive copyright and IP issues as significant to act as barriers to BIM adoption.

The technology infrastructure supporting this digital process is not a big issue in the UK having transformed the publishing, retailing, financial and travel services in the same way [17]; the same applied to the technology accessibility. This kind of system has been in use within the UK public sector, such as planning portal, OCG procurement systems and paperless open borders systems; these were deployed for more than a decade ago [21].

Despite the government efforts however, the digitalisation process faces numerous challenges, rating the top barriers amongst which is a shortage of BIM technology experts [23, pp.25]. This has come despite various efforts to benefit from the UK educational programs like, BIM for education, BIM for SMEs etc. Upon these, education and training is still lagging; and the main drivers in academia are the individual academics and or departments that particularly have interest [26]. Underwood et al. [27] described Architecture and Construction related subjects as dominants to incorporating BIM in their teaching, however the rest of the built environment related disciplines are low interested parties. Architectural schools are ahead of all other built environment disciplines on BIM education.

The industry and educational institutions are dominated with the following BIM software: Autodesk Revit (Arch, Struct, MEP), Navisworks and Sketch Up. Furthermore, in the *whole Built Environment disciplines, there are generally low levels for BIM maturity awareness hence; higher education institutions (HEIs) were largely underperforming* [26, pp.4]. The lack of BIM expertise in the UK can be attributed to the underperformance of the HEIs with predominantly low levels of engagement with the industry [27]. Consequently, this high level of detachment has been an obstacle to the full implementation of BIM in the UK. Figure 2 presents efforts/process toward the BIM adoption in the UK.

Figure 2. The UK efforts to adopt BIM

In the late 2011, BIM Academic Forum (BAF) establishment aimed to develop and promote teaching and learning with research aspect of BIM through cooperation and collaboration. Many UK universities are represented in the forum which serves as a conduit between industry's needs and BIM training within the higher educational institutions. Succinctly, the forum is to promote the academic prospect of BIM in the UK [27]. Other organisations/ professional bodies that promote the BIM training through short courses programmes include:

- Institute of Civil Engineers (ICE),
- Building Design (BD),
- Construction Industry Training Board (CITB),
- Building Research Establishment (BRE), and
- Building Services Research and Information Association (BSRIA).

BRE [28] discovered only about 10% of those who got trained on BIM go for training or got trained in universities and colleges while the remaining 90% got trained from other places (i.e. training providers, software vendors etc). Thus, higher institutions are not producing sufficient BIM skilled candidates as needed by the industry. SMEs occupy 98% of the construction sector in the UK [29] and lack of BIM trained personnel is mostly effecting the SMEs in the adoption process. This is also coupled with lack of funds to train their employee; this suggests SMEs as the immensely beneficiary of 'BIM ready' graduates from higher institutions.

2.3 BIM ADOPTION EFFORTS BY AUSTRALIA

In an effort to increase the productivity of asset management in the built industry, the National Building Information Modelling Working Party was established to report to the Built Environment Industry Innovation Council (BEIIC) on BIM activities. NATSPEC (National Specification) National BIM guide is a body under NATSPEC Construction Information maintained by the government and the industry that was developed in 2011 to establish standardised practice for digital building information exchange in Australia. These include documents for guides to BIM implementation on project, open BIM object standard (OBOS) and object properties standardisation tool [30]. The National policies and standards played an important role in the Australian construction industry for their vibrant BIM adoption.

During a series of buildingSMART MESH conferences in early 2011 sequel to the suggestion from the Productivity in the Buildings Network report, the buildingSMART Australia held a stakeholder's consultation workshops in early 2012 across Australia. The workshop recommends the need for national action on some identified areas as a matter of priority to facilitate BIM adoption in the Australian construction industry. Seven key areas of priority are considered; these are:

- Procurement contracts that support collaborative BIM processes
- BIM Guidelines
- BIM Education
- Product Data and BIM Libraries
- Process and Data Exchange protocols
- Regulatory Frameworks
- Pilot Projects [31].

Although, contract that supports collaborative BIM processes was amongst the recommendation by the Australian construction industry stakeholders, there is still no published contract form incorporating the BIM process in the Australian market, other than a bespoke contract which is conventionally adopted even at the highest of the most broadly used levels of BIM (level 2) [17].

Subsequently, ACIF-APPC BIM framework was released in 2014 [13] and the New South Wales' Health mandates BIM deliverables on all projects in excess of $30 million [32]. This action significantly raised the BIM adoption level in Australia although there still no BIM mandate at central government level. Thus, the New South Wales' Health BIM mandate inscribed Australia as a country with a "restricted mandate" [32]. Succinctly, Australian government did not mandated BIM on public projects [33, pp.3] as such the government and non-profit organisations help in providing a levelled ground (guide) but did not imposed BIM on public projects.

Australia appears to have an industry driven BIM adoption. Albeit there is recommendations by the Australian construction industry stakeholders to mandate BIM, so much heated scrutiny on the plan, however the Australian government did not mandated BIM on public projects [33].

The inherent resources gap between SMEs and large companies is the soul challenge to mandating the utilisation of the country's BIM framework. Consequently, the top-down BIM diffusion mechanism will appear extreme [24] within the country's construction market.

Hosseini [34] study clearly reveals a fear of 'risk' associated with ROI on BIM as a major barrier to BIM adoption by Australian SMEs, replacing the previously known 'lack of experts and knowledge on the innovation' as the major barriers. Thus, 'Pilot Projects' is recommended in the report of DIISRTE and such can go a long way to clearing the ROI issue and remove that as a barrier.

The Australian Institute of Architecture (AIA) and Consult Australia established an industry - academia BIM working group in 2011; it was on this basis that a foundation was set with series of Noteworthy publications in 2012. The Australian Government Office for Learning and Teaching (OLT) supported a project on BIM technologies known as 'collaborative design education - CODE BIM' that engages three universities (University of South Australia, University of Newcastle and University of Technology Sydney). A developed complimentary framework is now out to help Academics to implement BIM training. On the other hand, poor

implementation of BIM education was mainly associated with curriculum issues, cultural resistance (afraid of trying new things) and class size (population) [26].

Subsequently, a joint research centre for BIM was formed for sharing knowledge amongst researchers, engineers and innovators achievably through collaboration between Huazhong University of Science and Technology and Curtin University. Furthermore, the buildingSMART's BIM initiative in moving the industry forward is a strong desire to a 'multi-disciplinary BIM education'. Figure 3 presents efforts/process toward BIM adoption in the Australia.

Figure 3. The Australia efforts to adopt BIM

Despite the provision of BIM training by higher institution within the countries where BIM is dynamic, the training moves in a slow pace [26]. The slow pace of BIM training is due to challenges in terms of overcrowded modules (as no space to introduce new ones) as well as remodelling of the lecture-based modules to smaller multi-disciplinary teamwork based modules.

3. RESEARCH METHOD

In about a decade, case studies and academic literature revealed some developed countries leading the development and implementation of BIM. The USA, UK and Australia are part of these countries. These countries (USA, UK and Australia) are playing significant role in the BIM implementation at world stage. This study adopted comparative analysis as to categorisation of their efforts toward the development, adoption and implementation of BIM. Thus, efforts as well as factors that motivated BIM adoption in these countries were categorised. This study aimed to determine these countries' common efforts and otherwise for their applications in context where necessary.

4. SUMMARY/DISCUSSION

The table 1 presents each country's effort in relation to different sections of BIM fields. While table 2 presents the BIM Adoption guide and standards developed by these countries. There is commonality between countries in availability of BIM technology [7]; therefore, the categorisation will rather focus more on the technology infrastructure and training in the technology field. On the contrary, policy and process fields differ amongst countries and require contextualisation.

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392 **Table 1. Categorization of efforts by the USA, UK and Australia in adopting BIM concept**

	BIM Field Type	United States of America	United Kingdom	Australia
Reason for BIM adoption	**Process**	To improve productivity and performance of government built asset.	To improve the performance of the government estate in terms of reducing capital costs and carbon performance. "*Government has a vision to reduce whole life costs of assets by 33% by 2025"*	The initiative aimed to increase productivity and improved asset management in the built industry. Value for money, procurement transparency and emission reduction [31].
Digitalisation	**Technology**	Digitalisation started in the USA since 1990s with the establishment International Alliance for Interoperability (IAI) and later changed to buildingSMART [13]; while National BIM policy and mandate were introduced in 2003 and 2007 respectively.	UK has successfully transformed its publishing, retailing, financial and travel services [21]; thus, the technology for digitalisation is available and open to the construction industry. These kind of system has been in use within the UK public sector for over a decade, such as planning portal, OCG procurement systems and paperless open borders systems [19]. However, the industry's digitalisation big challenge is the shortage of BIM technology experts [23, pp.25].	Construction is one of the sectors where Australia led in physical capital investment in the year 2010 [35]; this may be attributed to its significant lags in knowledge capital investment. However, with clear record of capital investment in engineering and some sectors, Australia is considered medium amongst its counterpart in innovation [36].
BIM Initiation and Adoption Method	**Policy/Process**	BIM adoption in the USA started as middle-out diffusion process, driven by Architects. BIM adoption initiated by Architects and then followed by the US government initiatives for the BIM technology deployment and Building Energy Performance (BEP). The BIM diffusion in the USA market has changed from Top-Down to **Middle-Out** dynamic running concurrently with a Bottom-Up dynamic [12].	BIM adoption in the UK started as a bottom-up diffusion process, driven by designers. The UK government initiated BIM adoption journey back in 2010; and the subsequent release of the BIM level 2 mandate (in 2011) on all public projects by 2016. The BIM diffusion dynamic within the UK market has changed from Bottom-Up to **Top-Down** dynamic and now changing to Middle-Out.	BIM is being move by both the government and industry stakeholder; the move is in collaboration between the government and non-profit organisations through the development of national specification (NATSPEC) in 2011 and the subsequent released of first BIM framework in 2014 by ACIF-APPC. No mandate in general, however there is a restricted one from New South Wales' Health on project in excess of $30 million and the effort by Australian Department of Defence as well.

				The BIM diffusion dynamic in the Australian market is currently **Bottom-Up** diffusion dynamic.
Development and Challenges	**Process**	BIM started developing from professionals in the industry and the states before the federal government. The industry is facing challenges of regulation and standards where multiple agencies having their own rules and requirements.	The BIM development in UK is an exclusive commitment of the UK government. An extension to the digitalisation process of the country's systems. Absence of defined opportunities of adoption of BIM in the UK policy is one of the considered a barrier to its adoption [25]. Moreover, lack of clear understanding of BIM by clients and BIM experts' deficit were amongst persistent challenges of BIM utilisation.	buildingSMART Australia was the motivator, buildingSMART organised a workshop for the industry stakeholders to accelerate the BIM adoption in Australian AEC market. Standards and guides were developed and available for use. However, there is significantly low adoption by SMEs who are about 98% of the construction sector and more than 70% of them are non-adopters [25]. Mostly due to lack of investment cost and lack of evident ROI.
Policy Initiative and Standardisation	**Policy**	National 3D-4D BIM policy program was initiated in 2003, and mandated on government projects in 2007. There are standards published by National Institute of Building Sciences (NIBS). Various government departments are producing standards and publishing them in NIBS, and these are independently used on projects – opened BIM standard. Thus, no unified standard adopted and imposed at national level.	There is comprehensive government policy; mandate released in 2011 to be complied in 2016 for all public projects in excess of £5m. UK is widely recognised as a world leader in BIM standards and guide. In 2007, BSI together with business organisations, researchers and industry bodies embarked on the development of BIM standards as well as necessary guidance to implement the BIM [23]. These include the following development: BS 1192:2007+A2:2016; PAS 1192-2:2013 PAS 1192-3:2014; BS 1192-4:2014 PAS 1192-5:2015; BS 8536-1:2015 and PAS 1192-6:2018.	The Australian BIM initiative lack policy backing for now as there is a heating scrutiny on plans to pursuing a BIM mandate [33]. National BIM guide was first published in 2011, reviewed and reconfirmed in 2016 based on NATSPEC construction information. There are also standards for all the professional parties including the client (NATSPEC construction information). buildingSMART Australia committed to ensuring the development of some specifications like: IFC (ISOPAS 16739), IFD (ISO 12006-3:2007) and IDM (ISO/DIS 29481-1).
Technology (Infrastructure, man-power and accessibility)	**Technology**	USA may be considered as a centre for Technology development; the availability and affordability of technology made their public and even	The technology infrastructure supporting digital processes is readily available in the UK; having digitally transformed many sectors of the	Australia is considered medium amongst its counterpart in innovation [36]. There was a great move in BIM technology accessibility and its

		private sector top in the world. This is what brings about competitiveness and enormous development in all sectors. The availability of technology infrastructure is moreover facilitated a quick development, adoption and implementation of BIM within the industry even before the government mandate in 2007 [17].	economy and services [21]. The technology infrastructure and their accessibility are magnificent for usage; without doubt, '*UK continues to be an innovative developer and adopter of technology*' [23]. These kind of system has been in use within UK public sector, such as planning portal, OCG procurement systems and paperless open borders systems were since deployed (for more than a decade) [18]. However, in construction industry digitalisation process, deficit of BIM technology experts is considered amongst the barriers to the speedy adoption BIM [23].	development by buildingSMART. "Open BIM Alliance of Australia" was established by buildingSMART and is amongst its great roles that brings alliance with software vendors who promoted "Open BIM" concept [10].
Education, Training and Research	**Policy**	Educating students on BIM in the US began since 2002 when many countries hasn't built up awareness on BIM even at industry level. Morses [18] carried out a survey on USA Academic Institutions that indicated 82% providing formal teaching in BIM. As for researching, GSA collaborates with International Real Estate Organisations, CAD/BIM Technology Centre and Construction Engineering Research Laboratory to support open standards and guide for BIM software and system.	BIM Academic Forum (BAF) was establishment in the late 2011, this was considered very promising seeing its mission to develop and promote teaching and learning with research aspect of BIM. The forum serves as a conduit between industry's needs and BIM training in higher institutions. Succinctly, the forum is for the promotion of academic prospect of BIM in the UK [27]. There are some educational programmes plan for BIM training in the UK, this include BIM for education and BIM for SMEs. On the other hand, there is overall low levels for BIM maturity awareness within the entire disciplines thus, higher education institutions (HEIs) are generally underperforming [27].	The Australian Government Office for Learning and Teaching (OLT) supported a project on BIM technologies known as 'collaborative design education - CODE BIM' that engages three universities (University of South Australia, University of Newcastle and University of Technology Sydney). A clear framework was developed to help Academics implement BIM training. On another effort, the Australian Institute of Architecture (AIA) and Consult Australia established an industry - academia BIM working group in 2011; it was on this base that a foundation was formed with series of Noteworthy publications in 2012. Subsequently, a joint research centre for BIM was formed for sharing knowledge amongst researchers, engineers and innovators to be achieved

	Consequently, resulted in shortage of BIM experts in the market [23] this is reported as a top ranked barrier to utilising BIM [23, pp.25]. Some organisations and professional bodies are offering BIM training. BRE [28] discovery reveals that higher education is not producing skilled candidates on BIM as needed by the industry.	through collaboration between Huazhong University of Science and Technology and Curtin University.

414 **Table 2. BIM Adoption guide and standards by the USA, UK and Australia**

	Organizations	Role and year
United States of America	General Services Administration (GSA).	Formation of National 3D-4D BIM Program in 2003. General guidelines for GSA associates and consultants engaging in BIM practices (2010). Sets requirement of BIM in all final concept approval for all major projects and the development of BIM Guide Series in 2007.
	AGC - Consensus Docs 301 BIM Addendum.	Development of standard contract documents for legal and administration issues associated with using BIM (2006).
	USACE, BIM Project Execution Plan, ver 1.0	Protocols for implementing BIM in the U.S. Army Corps of Engineer's civil works and military construction processes with a focus on operation phase (2006)
	National Institute for Building Science (NIBS).	Development of National Building Information Modelling Standard (NBIMS) on Building Energy Performance as well as publishing BIM standards from various government departments.
	States Protocols and Guidelines.	State of Ohio developed BIM general guidelines for building owners (requests for qualifications, agreements, bidding requirements, and contracts) in 2010. And, New York city council developed basic guidelines for use of BIM for the municipal agencies in 2012.
United Kingdom	UK government	Development of BIM level 2 mandate on public projects in 2011 and the committed to the achievement recorded in the 2016.
	BIM Task Group	Provision of support and assistance in the BIM adoption journey. Presented the utilisation of Information sharing environment known as Construction Operations Building information exchange (COBie) in 2011.
	AEC (UK) committee.	Integrated standard for the AEC industry CAD & BIM in the UK
	British Standards Institute (BSI).	Development of Information sharing standards created (i.e. PAS 1192:2, PAS 1192:3, BS 1192:4, PAS 1192:5 etc.). BSI started developing BIM standards since 2007.
Australia	Built Environment Industry Innovation Council (BEIIC).	BEIIC is responsible for National Building Information Modelling initiative since 2012.
	CRC-CI national guidelines for digital modelling.	Guidelines for creation, maintenance, modelling procedures and implementation on large projects (2009).
	Department of Planning, Transport and Infrastructure (DPTI)	Developing guidelines for government agencies, consultants and contractors
	NATSPEC.	NATSPEC developed National BIM Guide in 2011.
	Australian Construction Industry Forum (ACIF).	Development of BIM Knowledge and Skills Framework in 2014.

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416 ## 4. STRENGTHS AND WEAKNESSES OF BIM EFFORTS BY USA, UK AND AUSTRALIA

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418 Several common drivers ease innovation adoption for these three countries. For instance,
419 technology infrastructure, availability of software and hardware as well as enabling policies to speed
420 up the diffusion are quite clear in context. These set of advantages utilised by the countries are
421 important backbone to soften resistance and key factors to drive and move the industry together.
422 Availability of NBPs also played a significant role in providing awareness and streamlined guide

across all professionals wish to adopt BIM in these countries. The NBPs aimed to encourage BIM understanding, regulate its implementation or mandate, and they are develop by:

- government agencies (i.e. USA, UK)
- government mandate (i.e. UK)
- industry/professional organisations (i.e. Australia and USA) or
- academic entities (i.e. USA, UK and Australia).

Nonetheless, there are some dissimilarities amongst them in terms of guide by countries. Open guide is demonstrated in the USA where agencies use or develop their guides; and this allows flexibility and speedy adoption/implementation. On the contrary, UK demonstrated closed guide that facilitates substantial number of NBPs from the government but with less adoption rate. Despite the low adoption rate compared to the USA, this strategy positioned the UK at world leadership stage in providing standards, guides and protocol to adopt BIM. While Australia demonstrated a combination of the two above strategies. Government and non-profit organisations deliver standards and guidance on BIM, and this provides a balanced of flexibility and government input while maintaining a partial (restricted) mandate.

5. CONCLUSIONS AND RECOMMENDATIONS

This paper focuses on comparing both the process and legislative efforts of USA, UK and Australia in BIM adoption and implementation within their respective construction markets. Considering the huge literature availability and NBPs, it is evident that these countries are leaders in the BIM implementation. The generated middle-out diffusion dynamic by the USA shows proactive nature of their construction industry and the government flexibility as to adoption of innovation. On the other way, UK and Australia begun with bottom-up diffusion dynamic due to level of control by the government on innovation adoption. The UK subsequently changed as the mandate came into play in 2016 to top-down dynamic. Although the dynamic is changing to middle-out as bigger firms are taking the lead. A multiple and concurrent diffusion dynamics reveals higher diffusion and adoption rate.

Despite similarity in availability of technology infrastructure, hardware and software (BIM tools) between these countries, availability of experts still differs. As such, there is variation in BIM experts' availability within these countries. Similarly, developing teaching in BIM is one of the keys to its acceptance, thus USA takes that advantage, as such built-up the man power against experts' shortfall and possible resistance. Architects are in the forefront of BIM adoption and even training across countries. Government involvement is playing a key role in BIM adoption, and most importantly enacting a policy (mandate) on its usage. Despite BIM development in Australia, the adoption is still not as wide as USA and the UK hence, mandate may play role to wider BIM adoption and acceptability. Mandating BIM can go a long way to integrating country's construction market to the rest of the world in market and technology.

It's recommended that, the new adopter countries acquire appreciable technology infrastructure, hardware and software availability to drive the adoption effectively. Mandating BIM to particular level speed up adoption and alleviate education and training challenges. A multiple and concurrent diffusion dynamics is also recommended especially at early stage.

COMPETING INTERESTS

All Authors declared no competing interests exist.

ETHICAL APPROVAL (WHERE EVER APPLICABLE)

No ethical issues regarding this piece of work.

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