DIGITAL INNOVATION IN EUROPE: REGIONAL DIFFERENCES ACROSS ONE INTERNATIONAL FIRM

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Comparing the implementation of Building Information Modelling (BIM) across geographies has emerged recently as an important discussion area, but it has been rarely researched. Research of BIM maturity across countries is vital for observing similarities and differences in adopting innovations and establishing strategies to transfer lessons across national boundaries. This is addressed by comparing BIM implementation in 146 projects of seven European countries: Denmark, Germany, Ireland, Italy, the Netherlands, Poland and Spain (respectively 2, 21, 70, 11, 13, 15, 14 projects). These projects were from one international firm that works on different aspects of the built environment. A BIM maturity assessment, the BIM Maturity Measure (BIM-MM) was applied on these projects. Findings show that in overall, BIM maturity is the highest in Spain, followed by the Netherlands. However, when looking individually at the measured criteria, it has been observed that regions tend to do better than others in certain areas. Denmark and the Netherlands, for instance, have the highest percentage of projects with high maturity levels in 'Open Standard Deliverables'. Therefore, the various digital artefacts that fall under the umbrella of BIM, are adopted at varying levels across countries. It is hoped that this study will deepen the understanding of BIM maturity across regions and influence new research and policies that build a collective approach to explore digital innovation in Europe.

Keywords: Arup, BIM, Maturity Measure, Europe, regional studies

INTRODUCTION

There has been a considerable interest in studying how different regions adopt and implement digital innovations, such as tools, technologies and processes (Smith, 2014, Cheng and Lu, 2015). In the Building Information Modelling (BIM) literature, the field of regional performance measurement has focused on several themes. These include an analysis of noteworthy BIM publications in multiple countries (Kassem *et al.,* 2015), comparison of the BIM adoption status across continents (Jung and Lee, 2015) and countries (Gerges *et al.,* 2017) and exploration of the critical initiatives to implement BIM across regions (Wong *et al.,* 2010). However, little research has been based on quantitative methods to map how different regions are implementing BIM and digital innovations in projects, moving beyond studies on BIM adoption. Comparative approaches are of vital importance to create a comprehensive account of

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how BIM is applied on a country level and how countries could transfer knowledge and learn from the successes and challenges of each other.

Policy work to drive BIM innovation have been developed across countries. In 2011, the UK's Government required a fully collaborative 3D BIM as a minimum for all Government projects by 2016 (GCCG, 2011) A BIM Task Group was established to raise awareness of BIM in the Architecture, Engineering and Construction (AEC) industry. In Europe, a similar approach has been followed where a BIM Task Group was formed to encourage the common use of BIM, as 'digital construction', in public works with the common aim of improving value for public money, quality of the public estate and for the sustainable competitiveness of industry (EUBIM, 2016). Despite this wide strategic approach in Europe, countries also create own BIM mandates. For instance, the German government will request a mandate for public infrastructure projects by 2020. Spain has a BIM Commission sponsored by the Ministry of Public Works to implement BIM in buildings in 2018 and in infrastructures in 2019 (McAuley *et al.,* 2016). Denmark will have a mandate for all projects in 2022.

Targets, mandates and strategies on national and regional levels have led to an increased interest in BIM Assessment Methods (BIM-AMs). Over the last decade, researchers and professionals have developed seventeen BIM-AMs globally to assess BIM in projects, organisations, individuals and teams (Azzouz *et al.,* 2016). However, the introduction of these methods has failed, in most studies, to compare country-to-country evaluations. BIM is not only software; however, due to their development years ago, some BIM-AMs fail to capture fully all functionalities and artefacts of BIM-based process and technologies. This paper, addresses these knowledge gaps by applying the BIM Maturity Measure (BIM-MM) to 146 projects in seven European countries. It aims to deepen the understanding of digital capabilities across countries through the lens of one international company. In particular, this comparison will focus on the 'hard' aspects of BIM, such as the use of Common Data Environment (CDE) and the Virtual Design Reviews (VDRs) rather than soft skills, e.g. leadership and collaboration, because they are easily captured through quantitative analysis.

Digital Innovations Diffusion and Implementation

3. BIM as a digital innovation

Innovation entails a new product, service or process (Abernathy and Clark, 1985) and is usually observed in projects (Shenhar and Dvir, 2007) BIM has evolved through decades of push and pull strategies and efforts to standardise the representation of building information (Papadonikolaki, 2017). Thus, it is not entirely novel as it has evolved from efforts for structuring and representing information about buildings, a predominant line of thought in the 1970s (Eastman, 1999). These advancements in building product modelling shaped a long-standing debate on the computerisation and construction digitalisation (Eastman, 1999). Nevertheless, BIM could still be seen as an innovation because the associated processes and methods to implement it are novel and challenging and require change at both organisational and institutional levels.

BIM is at the forefront of construction digitalisation. Apart from digital representation of buildings, BIM relates to artefacts that affect the processes that technologies are adopted and implemented through. BIM is a multifunctional set of instrumentalities for specific purposes (Miettinen and Paavola, 2014: 86) and affects various actors across the AEC, while policies, processes and technologies interact to generate a digital building (Succar *et al.,* 2012) BIM is a set of existing and new digital technologies for generating, controlling and managing building information. Various digital artefacts such as CDE, BIM-specific contracts, BIM Execution Plans (BEP) and so forth could form criteria to evaluate the extent to which digital innovation is used.

4. Diffusion of digital innovation

BIM diffusion studies facilitate better understanding of how BIM innovation unfolds across contexts and whether it is evolutionary or revolutionary (Burns and Stalker, 1961). In Europe, to control the various nuances and artefacts of BIM and prescribe BIM implementation to reap its acclaimed benefits, various initiatives from the government and professional industry associations suggest quasi-contractual means of BIM-related agreements among actors. For example, pre-contract BIM Execution Plan' (CPIc, 2013) under the efforts of the UK BIM Level 2 mandate and 'BIM Protocol' Norm issued by the Dutch Government Building Agency (GBA) (Rijksgebouwendienst, 2012). Both are inspired from the Norwegian 'BIM Manual' (Statsbygg, 2011). Also in the UK, many mandates in the form of Publicly Available Specification (PAS) have been issued to prescribe BIM use in project delivery, such as the family of PAS 1192.

At the same time, a European BIM Task Group is working on developing policy and advising countries on BIM adoption (EUBIM, 2016). The work of the EU Task Group has been published in a handbook with a conclusion on the need to harmonise a European wide common strategic approach of BIM and a recommendation that encourages government policy and public procurement as 'powerful tools' for this (EUBIM, 2016: 16). As noted in the report, without this top-down leadership, the sector's low and uneven adoption of information technology is likely to continue which would limit its opportunity to improve significantly productivity and value for money.

Scholars have acknowledged the need for evaluating digital innovations across geographies to improve BIM capabilities. According to Kam (2015: 278) international comparisons shed light on the sophistication of BIM implementation and challenges encountered by those regulating or purchasing BIM-enabled services. A comparison of several countries also helps to define the capability development, research and development, procurement and project delivery of those providing services.

Kam (2015) carried out research on country level BIM use by applying the Virtual Design and Construction (VDC) scorecard to 130 projects in over thirteen countries. The VDC Scorecard is a BIM-AM developed by researchers at Stanford University (Kam *et al.,* 2013). The VDC Scorecard has four categories of comparison: planning, adoption, technology and performance. The study, however, did not explain in detail how different countries implement BIM but only provided a snapshot of top ranking countries per category. For instance, Singapore is leading in 'planning' and Finland and Norway have general attainment of best practice status in deploying 'technology'.

Another study that focused on technology diffusion and adoption across geographies is by Jung and Lee (2015). They studied the status of BIM adoption across the six continents (Jung and Lee, 2015). Findings were built upon an online survey with total of 150 valid responses from countries, for instance in Europe, responses were received from 17 countries. The survey is built on four main set of indexes. One of them was concentrated on hard aspects of BIM; the *'use frequencies of BIM services'* in each continent that included seven criteria: 3D coordination, cost estimation, existing conditions modelling, design authoring, structural analysis, maintenance scheduling and building system analysis. The study attempted to establish a global survey of BIM status, but one of its main limitation is the small number of collected responses.

5. Implementation of digital innovation

Greenhalgh *et al.,* (2004) distinguish four categories of innovation in service firms: diffusion, dissemination, also referred to as adoption, implementation and sustainability, until the innovation becomes mainstream. Drawing upon this, research on digital innovation from BIM unfolds in three wide categories:

1. Adoption of isolated firms, based on individual perceptions of employees;
2. Implementation in projects, from case study analyses of projects and
3. Diffusion at a macro-level, by targeting specific professions or countries.

Scholars on the geography of BIM tend to focus on how nations or regions adopt BIM, yet they rarely investigate the 'project' as a unit of analysis, which this paper will address. Naturally, in innovation adoption studies ‘soft’ aspects, such as leadership and communication activate socio-technical processes to align actors and information (Liu *et al.,* 2016, Papadonikolaki, 2016). In projects with various BIM-using firms, implementation varies, as firms display various BIM capabilities, due to heterogeneity in service and size (Succar *et al.,* 2012, Succar and Kassem, 2015). Even within the same country, BIM implementation also might vary due to the different levels of adoption of the various associated digital innovations and artefacts, such as BEP, CDE and virtual design reviews (VDR). At a project-level though, these ‘hard’ aspects, such as the implementation of specific processes, use of sophisticated tools and methods could be considered measurable criteria and easy to capture. Therefore, there is room still for understanding how various countries implement digital innovation after adopting BIM. This paper addressed the question: how do countries implement the various digital artefacts and functionalities of BIM innovation?

RESEARCH METHOD

A comparative case study research has been selected to demonstrate how BIM is implemented in different countries in Europe. For this, the BIM Maturity Measure (BIM-MM) (Schofield, 2015) was applied to 146 projects in seven countries: Denmark, Germany, Ireland, Italy, the Netherlands, Poland and Spain (respectively 2, 21, 70, 11, 13, 15, 14 projects) BIM comparison in regions was conducted for two reasons. First, most studies on BIM maturity models tend to introduce new models or apply them to a small number of case studies. However, they rarely explore how artefacts of digital innovation, e.g. tools, processes and technologies are adopted and applied. Second, this paper attempts to not only compare the overall BIM maturity but also operationalise it through the use of multiple BIM criteria with an emphasis on the hard aspects of BIM. Such comparisons are crucial for professionals, scholars and policy-makers to better understand similarities and differences of BIM implementation and how, accordingly, knowledge, lessons and successes can be transferred across regions.

Because the implementation of BIM and digital innovation across regions depends on both institutional and organisational aspects (Papadonikolaki, 2017) the study uses a single case of an international firm. This firm employs around 13000 staff based on 38 countries. This firm is a multi-disciplinary design, engineering and management consultancy, employing staff across a number of disciplines. The organisational culture of a multinational firm varies (Kostova and Roth, 2002) as firms adjust their corporate culture across contexts (Schneider, 1988). To this end, to explore how countries implement digital artefacts associated with BIM innovation, data were collected only from countries where BIM use is not mandated and thus more organically developed. Data from the UK are purposely excluded from the sample, as the British BIM implementation practices are heavily tinted by the public mandates.

Quantitative data

Currently, there are 16 BIM Assessment Methods (BIM-AMs) developed by scholars and professionals (Azzouz *et al.,* 2016). These methods measure BIM in terms of projects, organisations, teams or individuals. The BIM-MM was chosen as it measures BIM in 'projects' and developed inside the firm where the projects were undertaken (Schofield, 2015). The BIM-MM measures two parts: 'project' and 'disciplines', to assess how the varied disciplines use BIM. This study focuses only on the assessment of the 'project' part through 11 criteria. These criteria are formed by the existence of the following artefacts: (1) BIM Design Data Review (BDDR) (2) BIM champions (3) Common Data Environment (CDE) (4) BIM Execution Plan (BEP) (5) Document/Model referencing and version control (6) knowledge sharing (7) Open Standard Deliverables (OSD) (8) Virtual Design Reviews (VDR) (9) BIM contract (10) Employers Information Requirements (EIRs) and (11) Project Procurement Route (PPR). Among those, only the 6 'hard' criteria were included in the quantitative analysis, as leadership (BIM champions) knowledge sharing, procurement, contracts and employers' requirements are not compatible with quantitative data collection and analysis and could in the future form part of a future mixed methods study.

The study builds upon a quantitative approach and uses descriptive statistics. Through the BIM-MM, each assessed project gets an overall BIM score. This score is extracted from the weightings scored in the 11 criteria, 6 are used at the second part of data analysis. To complete the assessment, key project actors, such as the project or the BIM manager, assign maturity level from 0 to 5 to each criterion. Maturity Level 0 is when a criterion is not applied and Level 5 when the criterion is most advanced. It is important to note that numbers of projects measured in each country vary based on the available ongoing projects of the firm in each region at the time of the study.

Data Presentation and analysis

4. Overall BIM maturity scores across Europe

Regional comparisons of BIM provide a comprehensive snapshot of how digitalisation in construction is applied, in countries that have varied policies and diverse social and cultural contexts. An initial analysis of the data shows that average overall scores of BIM maturity vary across regions, as illustrated in Figure 1.

The data from Table 1 show that maturity levels are the highest in Model Referencing and Version Control as 79% of projects in Europe have maturity levels 2-5. Over three quarters of projects use good practice of file naming, version control and comply with requirements. Another highly applied criterion in Europe is BEP, which is used to formalise goals and specify roles and information exchanges. The data shows that advanced BEP Levels 2-5 is used in 45% of projects in Europe. BEP is mostly applied in Denmark, where all 2 projects used it and Spain where 93% of projects used it.

Highest BIM maturity level is found in Spain and the Netherlands. These are followed by Italy and Germany that have similar overall BIM maturity scores. Lowest scores are seen in Ireland and Poland. Due to data sensitivity, the average scores per country are kept confidential.

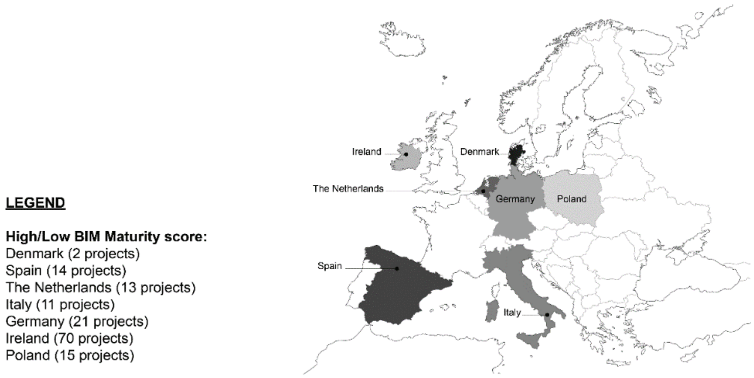

Figure 1: Overall score of BIM maturity across countries.

Apart than looking solely at the overall BIM maturity scores, a more focused analysis can demonstrate how countries apply different digital artefacts of BIM. Therefore, in each country and for each criterion, an average score is calculated on the percentage of projects that are allocated a maturity between Levels 2-5. BIM maturity Levels 0-1 are excluded from the analysis, because they indicate criteria not applied at all or applied on rudimentarily. Levels 2-5 maturity levels have been chosen instead as they represent advanced implementation of the digital artefacts of BIM. Table 1 presents the six out of the eleven criteria of the BIM-MM, which represent the hard aspects of BIM. Soft aspects as leadership and knowledge sharing were the focus of this study.

Table 1: Percentage of projects with Level 2-5 maturity in each criteria across each country.

Country	CDE	BEP	VDR	OSD	Model Referencing	BDDR
Denmark	50%	100%	50%	100%	100%	50%
Germany	29%	29%	67%	52%	71%	24%
Ireland	26%	46%	24%	26%	79%	16%
Italy	36%	45%	27%	36%	82%	9%
Netherlands	38%	54%	69%	69%	77%	15%
Poland	27%	7%	27%	40%	73%	13%
Spain	57%	93%	29%	36%	93%	29%
% in Europe	32%	45%	36%	38%	79%	18%

5. Spotlight on digital artefacts of BIM across countries

The maturity of the digital artefacts of BIM will be explained next to identify trends and patterns across their use in Europe. Namely, BEP, CDE and VDR will be analysed in higher detail. These three artefacts were selected for being relevant to the whole project team, whereas model referencing, OSD and BDDR relate to information exchange. Although Table 1 and the previous analysis focused on mature Levels 2-5 of using BIM, this sub-section will unpack the data for all maturity levels to identify missed opportunities and room for improvement. All criteria, are assessed through six maturity levels ranging Level 0-5, where 5 is when the criterion is most advanced.

BEP is a document that prescribes how project teams work together and how data is shared. For example, BEP Level 0 (**L0**) is when there is no BEP in the project, BEP Level 1 (**L1**) is when a traditional 2D drawing management plan is used. BEP Level 2 (**L2**) is when a BEP created and used by designers, BEP Level 3 (**L3**) is when a BEP used by whole project team. BEP Level 4 (**L4**) is when a project-wide BEP is driven by the client and BEP Level 5 (**L5**) is when a project-wide BEP is driven by client and the team collaboration needs. Table 2 shows the levels that projects apply BEP. Over half of the projects in Europe do not apply BEP; 74 projects have BEP Level 0 where the criterion is not applied. The rest 72 projects have BEP but most of them are allocated to BEP L2, which means it is used mainly from the design disciplines.

Table 2: Number of projects allocated to BEP maturity levels across countries

Country	BEP L0	BEP L1	BEP L2	BEP L3	BEP L4	BEP L5	Total
Denmark				1	1		2
Germany	14	1	4	1	1		21
Ireland	35	3	18	7	3	4	70
Italy	5	1	4		1		11
Netherlands	6		4	1	2		13
Poland	11	3	1				15
Spain	1		5	5	3		14
Total	74	10	42	15	11	4	146

Following a similar logic to define the maturity levels of CDE and VDR, Tables 3 and 4 contain how these digital artefacts are used from project teams across Europe. CDE is an online platform for storing, exchanging and managing digital information among the project team, where all actors can have access. Table 3 shows that typically around half of projects do not use it. The outlier of this is Spain, where all projects used CDE.

Table 3: Number of projects allocated to CDE maturity levels across countries

Country	CDE L0	CDE L1	CDE L2	CDE L3	CDE L4	CDE L5	Total
Denmark	1				1		2
Germany	14	1	1	5			21
Ireland	32	20	1	8	2	7	70
Italy	2	5	1	2		1	11
Netherlands	5	3	1		4		13
Poland	6	5	1	3			15
Spain		6	2	4	2		14
Total	60	40	7	22	9	8	146

Table 4 shows the data about the maturity levels that VDR are implemented across countries. VDR is a session where different disciplines come together to digitally view, collaborate and coordinate their designs and optimise their work. The data on VDR maturity is evenly distributed and show that around two thirds of projects use VDR. In Germany and the Netherlands more than half projects are L2 to L5 mature.

Table 4: Number of projects allocated to VDR maturity levels across countries

Country	VDR L0	VDR L1	VDR L2	VDR L3	VDR L4	VDR L5	Total
Denmark		1			1		2
Germany	5	2	10	3	1		21
Ireland	30	23	8	6	2	1	70
Italy	3	5	2			1	11
Netherlands	3	1	5	1	2	1	13
Poland	5	6	2	2			15
Spain	2	8	4				14
Total	48	46	31	12	6	3	146

DISCUSSION

Assessment of BIM maturity across geographies has been increasingly the focus of growing attention from academia and industry. Studies have contributed significantly to BIM assessment literature (Wong *et al.,* 2010, Davies *et al.,* 2015). To further this contribution, there is need to move beyond evaluating BIM adoption. The paper added to knowledge by operationalising BIM and highlighting its digital artefacts and functionalities for construction digitalisation and how these are used across countries.

Regional studies on technology adoption and diffusion observe how technologies and processes are applied and how regions respond to the dynamics and changes affecting AEC. Scholars explain that the differences are due to institutional forces such as national policies (Kam *et al*., 2013, Papadonikolaki, 2016). For instance, Kam (2015) explained that Singapore's leading position in 'planning' is largely due to an architectural BIM e-submissions programme which is 'one of the strongest BIM mandates in the world' . Similarly, the maturity of the Netherlands in BEP and OSD could be attributed to recommendations of their GBA (Rijksgebouwendienst, 2012).

The data showed that digital functionalities of BIM innovation, such as model referencing, which are related more to information exchange are implemented to an advanced level (Table 1) as opposed to BEP, CDE and VDR. These three digital artefacts and functionalities relate to the whole project team, as BEP is a document plan, CDE an online exchange platform and VDR a session for virtual coordination. Although these criteria are at the heart of multi-disciplinary collaboration that BIM and digital work requires, are not used at an advanced level (Tables 2-4). Namely, around half of the sampled European projects do not use BEP and CDE, whereas VDR is not used from one third, which clearly reflects common practice in regions.

The practical implication is that it reveals that in some regions BIM and digital are still approached as software, rather than as an additional novel digital collaborative process. Whereas this study set out to explore the extent to which countries implement the various digital artefacts and functionalities of BIM, it focused only on the 'hard' and measurable criteria, omitting the influence of soft factors, such as knowledge sharing, leadership and procurement schemes. It is thus concluded that even the 'hard' criteria such as BEP, CDE and VDR are challenging to implement as they need engagement and coordination by the whole project team; they are thus socio-technical.

In addition to the above socio-technical reasons for low digital maturity, it is vital to acknowledge the influence of project type, budget and clients. This limitation was addressed by sampling from a single firm to ensure consistency among the assessors of BIM maturity, as they had shared organisational culture and same briefing and training on BIM-MM. As stated in the methodology, culture in multinational firm varies due to the influence of context and national policy (Schneider, 1988, Kostova and Roth, 2002). However, the data showed clear associations between digital maturity and institutional context. Naturally, addressing these limitations can show the path for further research and validation and enrichment of the existing findings.

CONCLUSIONS

Digital innovation across different geographies has emerged as an important theme in research. This is due to the popularity of BIM and digital innovation in construction as well as driven by a need to attain results by exploring state-of-the-art across regions. Industry players, policy-makers and users are keen to learn from one another and transfer lessons to improve their productivity. This study compared digital maturity in BIM use across seven European countries and revealed two important findings. First, this study operationalised digital innovation through various digital artefacts and functionalities that are of both 'soft' and 'hard' nature, the latter of which was quantified and studied further. Second, when assessing digital maturity, project teams tend to use only some digital artefacts and functionalities, e.g. model referencing, more than others, such as BEP, CDE and VDR (Table 1) which are paramount for multi-disciplinary digital coordination and work. It appears that even these 'hard' aspects of digital innovation are applied in an advanced manner only in half to two thirds of projects and thus, require additional engagement and are of socio-technical nature. Further research will delve into a larger sample using mixed methods to define the relation between context and BIM maturity and how it can be accelerated.

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