Infusing Research Know-How into the Construction Sector: Pedagogies to Support Digital Construction in Ireland

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Keywords

BIM, Digital Construction, AEC, Building Information, student research, academic research, knowledge generation

Building Information Modelling (BIM) and BIM Management (BIMM) support digital construction and have the potential to revolutionize the construction industry. In countries where BIM has been most readily adopted, and national supports and mandates put into place, the use of these digital construction methodologies is yielding results. National governments work in various ways to encourage and support the use of BIM, and research is an important part of moving ahead the knowledge base, usability, and uptake of BIM. This paper focuses on the use of BIM in Ireland, the role of education in the shift toward digital construction, and the value of research conducted in one higher education institution (HEI) in Ireland. This HEI, the Technological University of Dublin, has become a leader in BIM education and research. With hundreds of academic research papers having been produced at TU Dublin at the Bachelors, Masters, and Doctoral levels, the authors believe it is time to review the storehouse of publications to assess its range, quality, and value to the Irish construction sector.

This paper explains existing strategies for the implementation of BIM at national levels, and pedagogies that can be used to support this shift toward digital construction. The paper starts by discussing BIM adoption globally, the increasing use of BIM in Ireland, and the need for BIM education in Ireland. It then explains why research is needed to move the adoption of BIM forward and how student research can support implementation of BIM in industry. It proceeds to describe TU Dublin's stepped and scaffolded approach for supporting student researchers, and then propose a plan for a study that will systematically map, critically analyze, and systematically review the results of BIM-related research generated at TU Dublin since 2020. The paper concludes with implications for future research.

Strategies for National Implementation of BIM

BIM signifies a digital representation of the physical and functional characteristics of a building – using both graphic and textual data – to help plan, design, construct, and manage buildings and infrastructure. An even more integrated approach, BIMM, can support more efficient and effective building operation and maintenance while it is in use, although the terms are often used interchangeably. BIM and BIMM can potentially improve project efficiency, reduce construction waste, and improve collaboration and communication among stakeholders [1]. Although many

large companies in the Architecture, Engineering and Construction (AEC) industry are using BIM to streamline their work, BIM tools and practices are not yet well-infused across the sector. Many small firms lack the resources and/or capabilities to use BIM effectively. Small to Medium-sized Enterprises (SMEs) face many barriers concerning legal context, attitude and market perceptions, education, knowledge and learning, technical challenges, and software financing issues [2]. Understanding where and how BIM is being used well, what challenges and gaps persist, and how to conduct research in a responsive, iterative, and informative way can help. Upskilling the overall industry and its people will require providing education in technologies, processes, and communication standards and building research capability. To achieve this, the education system faces challenges regarding educators' knowledge base and skills (which may be lacking in BIM), the financial and physical resources available, and general resistance to change by educational institutions and the people who teach in them [3].

Global leaders in BIM adoption

Recent research has identified countries at the forefront, globally, of BIM adoption. Current levels of BIM adoption vary across the world, but countries with a well-established construction industry and government support – like the United Kingdom (UK), Australia, Canada, and the jurisdiction of Hong Kong – are now recognized as leaders in BIM implementation [4]. The UK is seen as a leader in BIM adoption due, in part, to a government mandate for the application of BIM on all public sector construction projects [5]. Nordic countries, such as Sweden and Norway, have also been leading in BIM adoption, due to their early adoption and integration of BIM into public and private sector construction processes [6]. The growth of BIM adoption in different countries has been driven by factors that include agreed recognition of its benefits, government supports, and the development of national BIM standards and guidelines [7].

The increasing use of BIM in Ireland

In Ireland, the use of BIM has been increasing over recent years, leading to significant improvements in the construction industry. Academic studies have been conducted to examine the adoption and implementation of BIM in Ireland; they highlight the benefits and challenges associated with the use of BIM in the construction industry. Researchers studying BIM’s use on public projects in Ireland have noted its potential to improve collaboration and communication among stakeholders, increase project efficiency, and reduce construction waste [8].

Although BIM adoption is increasing in Ireland, and more firms are incorporating BIM into their work processes, there is a need for further training and education to increase its uptake in the country [9]. Primary challenges confronting Irish AEC firms wanting to use BIM include a lack of trained personnel, a lack of standardization, and resistance to change [10]. Moreover, the use of BIM in public projects appears to have been limited by a lack of awareness of its benefits [11]. A recent push by the Irish government is evident in the Build Digital Project, which aims to transform the Irish AEC sector by enabling all stakeholders, particularly SMEs, clients, and suppliers, to develop, maintain, and continuously improve their capabilities as digitally enabled, standards-based, agile, collaborative, and sustainable participants in the delivery of Project Ireland 2040 [12]. Nevertheless, a 2021 report by the Expert Group on Future Skills Need [13] emphasized that 16% of organizational respondents report a specific difficulty in hiring BIM operators/experts within Ireland. This claim was reinforced through a recent vacancy report by

the report National Skills Bulletin 2022 [14] and another by Solas that found 26% of organizations reporting difficulty sourcing BIM professionals [15].

The need for BIM education in Ireland

By increasing BIM use in Ireland, the construction industry can benefit, but further education and training, standardization, and a willingness to adopt new technologies will be needed to fully realize the benefits. Researchers evaluating BIM maturity and the diffusion of BIM knowledge in Ireland have recommended integrating BIM into the education system, providing BIM training to students and professionals, and promoting collaboration between government, industry, and academic institutions [16].

Irish scholars reviewing the practices and prospects of BIM in the country's construction sector have recommended adopting national and international BIM standards, providing training and education, promoting collaboration and information sharing, and encouraging innovation and research [11]. They argued that addressing these issues is crucial to ensuring the continued success and growth of BIM within Irish construction. There is a need for professionals in the construction industry to be trained in using BIM techniques and tools.

Assessing the contributions that Irish universities are making in the uptake of BIM, scholars [17] mapped recent research conducted on the island.

They analyzed five years of academic research on BIM in Ireland related to implementing and adopting BIM in the country's AEC sector. They found that the research helped increase the understanding of BIM in Ireland and its potential benefits in the construction industry. The results advocated that BIM can be central in addressing current challenges in Ireland, including the country's housing and broader climate crises.

Overall, to overcome the current lack of standardization, limited training and education opportunities, and resistance to change and innovation among some members of the construction industry, researchers [11, 16, 17] have recommended doing more to provide BIM training and education, promote the adoption of national and international BIM standards, encourage both innovation and research, and promote collaboration and information sharing between industry, government, and academic institutions.

Why research is needed to move the adoption of BIM forward

Despite BIM's potential to improve the AEC industry, its adoption has been slow globally; in most places, adoption has been even slower than in Ireland. To move the adoption of BIM forward, and to address the challenges and barriers to BIM implementation, much more research is needed.

At a global level, scholars have been investigating *why* research is needed and *what type* of research should be done. In assessing why New Zealand had been slow to implement BIM, one research team found "an urgent need for a joint research programme in NZ to develop a Kiwi-oriented knowledge base on BIM" [18, p. 66]. They said the program should focus on construction management processes related to BIM, including procurement, contract and

information management, and post-construction aspects like facility management. These findings are likely transferrable to Ireland and many other countries as well.

A systematic review conducted in 2021 found little research existing "on the dynamics of the change environment and AEC organizations' corresponding ability to influence and manage BIM adoption and implementation within organizational settings" [19, p. 412]. The review noted that the topics of BIM expertise, support from upper management, and education and training have often been studied together, but research investigating BIM enablers collectively is lacking. The researchers could not find an analysis of stakeholders alongside risk-benefit analysis or change agents (two known BIM enablers). In looking at the state of research and current gaps in knowledge regarding enablers for BIM adoption at the organizational level, Abbasnejad et al [19] identified the lack of a clear, shared definition of BIM across the industry. Having a weak definition hinders the quality and reliability of research, resulting in a lack of clarity about BIM leadership competencies, mechanisms for facilitating change within organizations, and mechanisms for diffusing BIM knowledge. Empirical research is needed regarding best practices in BIM training, "particularly with respect to intervention design and delivery aspects from the perspective of different construction supply chain disciplines" [19, p. 429].

Other researchers investigating factors affecting the adoption of BIM in India [20], found an organizational framework was needed, as well as an overall plan for BIM implementation, to provide guidelines and methods of standardization, and to build skills in collaboration. Other barriers identified in India included limited in-house BIM modeling expertise and additional training costs.

When considering the complex challenges of implementing BIM globally, it becomes clear that both education and research are crucial. Research can help address major barriers and understand key enablers to BIM adoption. We know what many of the barriers are. For instance, six major barriers to BIM implementation, identified in a study of 31 contracting firms in the United States [21], were: (1) learning curve and lack of skilled personnel, (2) high implementation cost, (3) stakeholder (e.g., architect, engineer, contractor) reluctance, (4) lack of collaborative processes and modelling standards, (5) interoperability and (6) lack of legal/contractual agreements. What is less known is how to overcome these barriers. Key factors include BIM vision and leadership from management, training to develop new skills, government support, inter-enterprise structure, corporate culture, corporate strategy, infrastructure, data exchange, construction methods, socioeconomic environment, and technological environment [22]. Research on the best ways to leverage these enablers is urgently needed.

How student research can support the implementation of BIM in the industry

Teaching students to do research can have knock-on benefits in the overall effort to implement BIM across the AEC industry. By engaging in research projects related to BIM, students can develop deeper understandings of BIM technologies and their potential benefits, learn how to collaborate effectively across sub-disciplines of AEC, and identify and address some of the challenges faced by the industry when adopting BIM. For students working in the AEC industry while they study, it is possible to immediately apply their new knowledge in practice and share it with colleagues.

This section examines the role of student research in supporting the implementation of BIM in the construction industry in Ireland. The systematic mapping proposed later in the paper will review research conducted by BIM students and will assess the impact of students' research on the industry. In this paper, we identify student work already presented and published at professional conferences in Ireland and beyond.

We see student research as supporting the implementation of BIM in the Irish AEC industry and encourage integrating student research projects into the education and training of construction professionals. By equipping our BIM students with research skills such as problem framing, literature review, and synthesis, we aim to develop future leaders for the field of BIM.

Stepped and scaffolded approach for supporting student researchers

Teaching students to conduct publishable research studies to enhance the AEC sector in Ireland is a focus of the BIM courses at the Technological University Dublin (TU Dublin), formerly Dublin Institute of Technology (DIT). We aim to help students produce publishable research studies of use to the Irish industry.

TU Dublin has operated a Master of Science (MSc) degree program in applied Building Information Modeling and Management (aBIMM) since 2015. The university's suite of Level 9 BIM modules provides three possibilities. A student can exit after one year at Level 9 with a Post-Graduate Certificate in BIM (with 30 ECTS credits), after an additional year with a Post-Graduate Diploma in BIM (with 60 ECTS), or after a third year (a total of 90 ECTS credits) with a Master of Science (MSc) in aBIMM.

Building on that program's success, the university launched in February 2020 its Bachelor of Science (BSc) in BIM (Digital Construction) and Postgraduate Certificate in Digital Construction Analytics / Engineering Analytics. The BSc (Hons) degree is a one-year part-time re-skilling program that addresses a significant market deficit for construction professionals by providing them with the ability to use BIM technologies in discipline-specific modelling and multidisciplinary coordination contexts. Students in our BSc (Honours) BIM program, as a result of our masters, have a scaffolded pathway leading to a level 9 qualification in BIM.

The BSc (Honours) and MSc programs require students to conduct research in the form of a dissertation and capstone project, respectively. The significant collection of documents produced by students and teachers in these programs includes BIM-focused conference publications, industry reports, and research thesis papers published at the BSc (honours), Master's, and Ph.D. levels.

BSc research at TU Dublin typically provides a synthesis of existing publications on a topic of relevance in Ireland. The final output is a research paper to a "starter" conference paper standard.

The MSc capstone experience aims to facilitate learners in synthesizing and integrating knowledge and learning acquired in all previously completed modules through a task that addresses a current, programme-related, and possibly ill-defined problem or issue-based in practice predominantly within Ireland. The final output is to produce a draft research paper to conference paper standard.

Both the BSc and MSc levels emphasize relevance and usefulness to the student's career development and the needs of these students' industry and government employers. Much of the work is funded by grants from the Irish government.

The format of the BSc and MSc theses/dissertations mirrors conference papers for the Construction Information Technology Alliance (CitA) BIM Gathering. This Gathering is a bi-annual conference with international attendance; several of the students' papers have been presented at this and similar conferences.

The degree courses, now housed within the School of Surveying and Construction Innovation, use a scaffolded approach to support students in learning research skills. Typically, registrants in these courses are mature students who are studying part-time while simultaneously employed in industry.

TU Dublin is known for its tradition of providing stepped education – it is seen as an institution where a student can enter at an apprentice (Level 6 on the Irish education framework) and proceed, rung by rung, up the educational ladder. Students can enter at any level and are presented with straightforward paths. At Level 6 are apprenticeship programs. Level 7 provides "ordinary" three-year bachelor's degrees. Level 8 "honours" bachelor's degrees require doing self-directed thesis research. The Level 9 post-graduate degrees and Level 10 doctoral degrees require the same standard of research and writing required globally for such degrees. Here, the BSc and MSc degree designations and the PhD in BIM and Digital Construction all require research outputs and the mastery of established standards of knowledge generation, reflective practice, and project management.

The MSc and BSc (Honours) research projects expect students to implement a proposed solution to an industry-relevant context(s) or setting regarding their organization, if possible. For the BSc (Honours), both Work Based Learning and Research modules enable the students to develop a research industry-defined problem within their organization that can be explored at the dissertation level. This ensures that research output is relevant to that organization and can have a lasting impact. The MSc takes a similar approach, where students will develop a research proposal before commencing their capstone, which is required, where prudent to be organization specific. Students are not confined to researching within their organization, but it is promoted that this approach may yield a greater impact for them regarding career progression.

The MSc research is published on TU Dublins research repository Arrow which brings together all of the University's research under one umbrella, with an aim to preserve and provide access to that research. This repository enables one to track their paper downloads and access their impact. Based on the latest figures, the MSc capstone papers have been downloaded over 6000 times, with multiple downloads in the United States, United Kingdom, India, Russia, Netherlands, Canada, China, and Australia.

It is worth noting that although academic teaching staff at this institution have not, up until now at least, been contractually required to conduct or publish research, many have taken the lead in generating research in this realm. Moreover, the MSc has produced many publications with

further development to its capstone outputs [10, 23-32]. Impressively, three studies produced by BSc students have been reported and published in conference proceedings [33-35].

A plan for mapping research

To address our own desire to produce increasingly valuable research, in addition to fostering individuals' skills to develop it as a natural course of professional practice across the AEC industry in Ireland, we now plan to conduct a structured, comprehensive mapping of research produced at our university in recent years (framing the period of January 2020 - January 2023 would make sense). We believe that now, with TU Dublin's BIM programs firmly in place and producing graduates, it is an optimal time to study and assess the quality and usefulness of our research outputs. (The quality of the teaching is, of course, rigorously evaluated by internal and external quality assurance practices.)

We herein propose to critique and summarize progress made via BIM knowledge generation in our research courses. This study will map and summarize the landscape of research produced over the past three years, ranging from conference papers and journal articles by academic staff, and including work published by PhD researchers and students in degree courses dedicated to BIM and Digital Construction.

The systematic mapping will involve the identification of major themes across the work. Then we will expand this into a systematic literature review (SLR) by critiquing the quality and depth of the overall body of work, summarizing key findings, and generating recommendations for the discipline moving forward at this institution – regarding both student-generated and staff-generated research. The systematic mapping and subsequent SLR will use best practices identified by Booth and Grant [36] and by Saunders-Smits and Cruz [37] who assessed their applicability to engineering (and BIM) education. A systematic mapping of literature involves using a structured approach to identify, categorize, and analyze all the existing research on a particular topic.

The mapping and SLR process begins with defining the research questions. For us, these research questions will include: *What themes exist across the work produced in this university? What key findings have emerged through this research activity? To what degree is this work contributing to progress in the Irish AEC industry? What recommendations can be made for future research in the country and within this university?*

The next crucial step in a systematic mapping is to put forward clear criteria for inclusion/exclusion of studies. We will include capstone dissertations and subsequent academic papers, by students and/or staff at this institution. This is followed by an extensive search of various databases and sources to collect relevant publications. For us, the university's library repository, digital archives for external examination, and other engineering-related databases will be searched.

Following standard procedures, after removing duplicates and screening articles based on predetermined criteria, data is extracted and analyzed in a systematic manner using various methods, such as content analysis or citation analysis. The results are then presented in a visual

map or table, providing an overview of the research landscape in the field, identifying knowledge gaps and areas of potential future research. We look forward to conducting such a study, so we can learn and grow as a BIM and AEC community.

Conclusions

We believe that research and reflective practice are crucial for evolving the field of digital construction. We believe that research generated by students and academics at TU Dublin is helping improve the knowledge base in Ireland. The research that is available via the university's digital repository is helping the TU Dublin community share knowledge with others, as are the students and teachers who prepare and deliver conference papers and presentations. It is worth noting that today, searching arrow.tudublin.ie for the term "BIM" yields 288 results, and this does not include the bachelor's level thesis papers produced here.

We believe that learning to conduct research – to generate questions, to seek answers by consulting reliable sources, to synthesize and interpret existing research – is helping make our students more effective practitioners. Our students are gaining new skills, developing confidence in their research abilities, visualizing themselves as leaders and change agents, and making increasingly valuable contributions to their companies and the overall practice of construction in Ireland.

The proposed study represents one way for us to gauge the value and impact our community's research efforts are having. Implications we have identified for future research include the systematic review outlined above, perhaps supplements with a survey of past student or analysis of the downloads of our institution's BIM publications from the university's digital repository, as evidence of impact.

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