Workshop on BIM in Canadian Research & Education

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FINAL REPORT

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Executive Summary

Many researchers consider that changes in the industry are accelerating: the structures for the establishment of professional programs in universities do not offer the agility to adapt to the emerging needs in training of highly qualified staff to support this transformation of practices. Some consider that BIM technologies are disruptive and their adoption requires a paradigm shift in the way buildings are planned, designed, built and managed. However, unlike other countries such as France, Australia and Great Britain, in Canada there are no mechanisms that permit universities to rapidly adjust their undergraduate curricula in architecture and engineering. Professional associations are fragmented and don't have the resources nor can they count on research in the universities to update the bodies of knowledge in architecture or engineering. The industry is nonetheless moving forward in BIM and academia is lagging behind. An opportunity arises in new research approach promoting co-generation of knowledge, that is to say the industrial becomes a partner with the researcher to generate and formalize new practice knowledge. This approach is at the heart of the discipline of Construction Engineering.

The report outlines the principal outcomes of a strategic workshop that brought together key actors in BIM training, research and education as well as key players in industry from across Canada. The goals of the workshop were to identify challenges and needs regarding BIM research and education in Canada, look abroad for potential solutions and devise an action plan to establish a way forward. The report discusses the challenges and opportunities for Canada in furthering the development of its curriculum for professional, technical and academic sectors that were highlighted and discussed during the workshop. It also discusses how these efforts can align with similar efforts from around the globe. Finally, it presents a course of action to initiate and sustain the integration of BIM in current curricula.

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Introduction

The current trend towards the digitalization of the Architecture, Engineering, and Construction (AEC) industry, namely through the emergence of Building Information Modeling (BIM), is seen as a paradigm shift (Shelden, 2009). This shift is primarily being brought on by the transition from a 2D, representational approach to the development of project documentation and communication of design intent and technical information to a 3D, integrated digital repository containing both geometric and non-geometric project information (Eastman, Teicholz, Sacks, & Liston, 2011). The consolidating, linking and centralizing of asset information is transforming project actors' relationships all while providing considerable opportunity to leverage data to support evidence based decision making – the industry is trending towards "perfect project information" (Crotty, 2011). While industry is embracing the practical applications of BIM due to the many reported benefits of its use (e.g. Barlish & Sullivan, 2012), it still does not transcend nor does it pervade current practice (Forgues & Iordanova, 2010).

One of the core issues, highlighted in past research, is the disconnect between current curriculum being taught at the college and university level and the needs of industry regarding the new ways of working being driven by BIM (e.g. Cheng, 2006). There is an apparent and growing need to develop a tighter coupling between academia and industry to respond to emerging trends and new ways of delivering our built environment. The pace of technological change and the rate of innovation is growing and both academia and industry are having a hard time keeping up. The AEC industry has recognized the growing need for individuals with an expanded skillset upon graduation. For instance, a survey by the *Association des Architectes en Pratique Privée du Québec* conducted in the fall of 2016 indicated that 71% of respondents (n=210) agreed that BIM should be taught as part of the undergraduate degree in architecture. The issue however lies in the fact that "teaching BIM" is a far reaching and complex endeavour. Indeed, BIM is a multi-facetted and pervasive approach to project delivery and cannot be summarized to a single piece of software nor a single concept. Furthermore, while past work has considered the U.S. landscape (e.g. Becerik-Gerber, Gerber, & Ku, 2011)), little work has been done on investigating the challenges and the needs of the Canadian industry and academic community with regard to BIM and its impact on the current curriculum. To understand the implications of introducing BIM into the Canadian landscape of BIM in Research and Education, a workshop was held at the École de Technologie Supérieure (ÉTS) in Montreal, Quebec, Canada, that brought together key actors in BIM training, research and education from across Canada. The goals of the workshop were to identify the challenges regarding BIM research and education in Canada, look abroad for potential solutions and devise an action plan to establish a way forward.

The workshop highlighted several key challenges that must be overcome to help ease the transition. Namely, the workshop highlighted the divergent perspectives between academia and industry with regard to objectives and outcomes of initiating the transition to BIM: industry have an immediate need for skilled and capable professionals with an emphasis on technical proficiency whereas academics have to contend with saturated curriculum and a lack of incentives to undertake a reform of current programs. This results in academia lagging behind industry with regard to the uptake and integration of new practices. Moreover, a technical-theoretical dichotomy emerged in so much that while the immediate need for technical skills was recognized, the absence of underlying theory was seen as a hindrance to truly transition to BIM. Lastly, the interest and appetite of industry for research was a point of discussion, mainly around the immediate need for applicable results on the part of industry versus the longer-term objectives and need for rigor on the part of academics. This incompatibility exacerbates the fragmentation between industry and academia. This fragmentation is also recognized between departments and programs within academia, which is counter to this transition to BIM-enabled collaborative project delivery.

To overcome these issues, several actions were proposed:

- establish core learning outcomes that underlie the development of new educational content;
- create an on-line platform to connect industry and academic partners;
- share research results and educational materials, look outwards and learn from other countries' curricular frameworks;
- develop collaborative, multi-disciplinary studio projects with involvement from industry stakeholders that leverage BIM;
- jointly pursue grants that benefit a wider scale of proponents; and
- develop agile educational programs by layering shifting technical concepts of BIM onto core theoretical foundations.

Background

Research investigating the integration of BIM and other innovative approaches to project delivery into educational curricula is a growing trend. Abdirad & Dossick (2016) and Puolitaival & Forsythe (2016) both review prior research into BIM in education and highlight similar findings with regard to industry expectations, key challenges, formalizing core BIM competencies, pedagogical strategies and assessment methods. Industry expectations are divided between technical and non-technical aspects of BIM. From a technical standpoint, software skills and knowledge of processes and workflows are deemed important. However, as pointed out by Abdirad & Dossick (2016), socio-technical and non-technical skills were seen as being increasingly important. This was recognized by Cheng (2006) early on who stated: "Regardless of the magnitude of BIM's eventual of impact on the profession, its recent rise provides the ideal catalyst for rethinking architectural education. The level of expertise required to intelligently design with BIM is significant, and serious consideration must be given to how it can be taught." (p.9)

With regard to the progression of BIM into education, Becerik-Gerber et al. (2011) conducted a survey to understand the scale, the scope and the barriers at the undergraduate and graduate levels in U.S. based universities. The authors found that 56% of AEC programs in the US offered some form of BIM content or course in 2011 and that most of them introduced BIM between 2006 and 2009. The authors also found that 57% of programs that didn't offer any BIM content were planning to do so whereas 19% were not planning on developing any form of BIM content. This survey was replicated in Canada by Forgues & Farah (2013) who found that only 19% of AEC programs had integrated BIM content in 2012. Futhermore, the authors found that 38% of AEC programs did not intend to integrate BIM content any time soon (compared to 19% in the US).

Becerik-Gerber et al. (2011) also identified challenges to the integration of BIM into AEC curricula. Amongst the challenges identified, the lack of personnel qualified to teach BIM, inadequate resources to make curriculum changes, lack of room in current curriculum and the fact that BIM isn't an accreditation criterion ranked highest as reasons for not incorporating BIM in curriculum. Puolitaival & Forsythe (2016) similarly identified a series of key practical challenges in developing and implementing BIM curriculum in an Australian university. These challenges were:(1) finding the balance between theory and practice; technology and process; and traditional and emerging construction project management (CPM) methods, (2) facilitating for professional development of staff; and (3) availability of appropriate teaching and learning resources for BIM. These key challenges summarize those found elsewhere around training and up-skilling educators in both the software and on theory, finding a balance in subject matters, need for a more dynamic approach to curriculum development and diffusing BIM across programs and introducing it into core curricula.

Regarding program development, Cheng (2006) identified the need to focus on the core elements that sustain professional practice, namely "design thinking" and the underlying logic that support the development of technical capabilities and skills, rather than on the skills themselves, which can quickly become obsolete. In this sense, Kocaturk & Kiviniemi (2013) identify two areas where BIM will play a role in redefining professional curricula: (1) modelling and representation, and (2) collaborative working. According to the authors, BIM's impact will be felt "[…]to the extent to which the new technology and working methods will have an impact on the process of learning and development of both individual and distributed cognition." (p.471) Abdirad & Dossick (2016) found that between 2007 and 2015, research focus into curriculum development shifted from adapting standalone CAD courses to recognizing the need for integration of BIM into core curriculum, requires a shift towards multi-disciplinary collaboration and the power of BIM as an educational tool.

Other work has looked into developing structured approaches to education that is adapted to BIM-enabled collaborative practice. For instance, MacDonald (2012) developed the IMAC framework, a four-staged approach mapped to Bloom's taxonomy of learning. Forsythe et al. (2013) develop an approach to developing a programme-wide implementation strategy, with BIM supporting specific subjects according to the appropriateness of implementation. Puolitaival & Forsythe (2016) further identify a series of opportunities or measures to be taken to integrate BIM in current curricula based on their experience, including: (1) taking greater advantage of project-based learning (PjBL) to simulate real world projects; (2) creating a learning environment to support visual-spatial learning; (3) engaging students in the learning process; (4) finding a balance and a way out from a crowded curriculum; (5) developing new strategies for teaching and learning resource development; and (6) supporting staff in their professional development (p.357). The project-based learning approach is one that is supported and put forth by others such as Leite & Wang (2014) who develop a process-oriented approach to BIM education. Finally, Sacks & Pikas (2013) develop 39 knowledge areas or topics across three broad themes (Process, Technology, Application) as a foundation for BIM education requirements for CM.

Overall, the introduction of BIM in education has received growing attention over the years due to the recognition of the importance of training future professionals and giving them the skills and knowledge to enter a rapidly changing market. The needs and challenges are consistent across the literature surveyed, however the solutions put forth varying in their approach to overcoming these challenges. That being said, there is a general consensus on the need to not only develop technical skills but to increasingly focus on collaborative and multi-disciplinary behaviour. Many researchers also put emphasis on project-based learning as a way forward. Finally, there is consensus around the need to diffuse BIM and its core concepts across existing curricula and develop new programs to suit the shifting AEC landscape.

Workshop structure

The workshop was held on October 21st and 22nd, 2016 at the École de Technologie Supérieure in Montreal, Quebec, Canada. The goals of the workshop were to identify the challenges regarding BIM research and education in Canada, look abroad for potential solutions and devise an action plan to establish a way forward. Moreover, the following questions were addressed:

- How can we make academia construction programs agile enough to train students to the reality of an industry in full transformation?
- How do we align and integrate training efforts in college, university and continuing education for the production and transfer of new knowledge on emerging practices and technologies?
- How can we encourage and support learning and transdisciplinary research?
- How do we recruit and train the next generation of researchers and teachers in these emerging areas?
- How can we make the most agile certification programs to meet current and future needs?
- What can we learn and derive from programs supporting innovation and technology transfer as ones found in Scandinavia, Great Britain or Australia?

The workshop was divided into half days where a theme was addressed through visioning sessions and group discussions. Different groups were formed per background and discipline. Groups were changed throughout the workshop. Table 1 identifies the individuals in attendance at the workshop by discipline. Table 2 identifies the different themes for visioning sessions and group discussion. At the end of each session, the group would reconvene, present the outcomes of the discussion and would rank the items in order of perceived importance. Ranking was done through the online application *Mentimeter*. This was repeated for three of the five sessions. The following section presents the findings from the workshop.

Table 1 - Workshop attendees by discipline

	Industry		Academia		Total	
Owner	2	8%	0	0%	2	4%
Architecture	12	48%	15	56%	27	52%
Engineering	7	28%	12	44%	19	37%
Construction	4	16%	0	0%	4	8%
Total	**25**	48%	**27**	52%	**52**	100%

Table 2 - Themes for visioning sessions and group discussion

Session	Theme
Session 01	Defining BIM and identifying the needs in research and education
Session 02	Identifying the challenges to fulfilling these needs
Session 03	Defining a course of action to overcome these challenges
Session 04	Identifying priorities
Session 05	Developing partnerships, defining projects and identifying funding opportunities

Findings

The core of the workshop was focused around identifying the needs, challenges, and steps to be taken to progress the BIM agenda in the Canadian AECO industry, notably around supporting research and modifying the current curriculum to suite new ways of working adapted to the digitalization of the industry through BIM. The first session was aimed at developing a common understanding of BIM and identifying the needs in terms of research and education. Table 3 presents the outcomes from session 01 in order of perceived importance

Table 3 - Session 01 outcomes - ranked

Session 01: Identifying the needs in research and education	
Experiencing multidisciplinary collaboration & activities	17%
Teaching "theory of BIM", not one software tool	15%
Developing technical literacy: structured best practice learning BIM related tools	13%
Understand the big picture of project delivery (Technology-Organization-Process)	13%
Encouraging Industry interaction & engagement - coop programs / research / joint design studios	9%
New education stream programs: entire process, graduate attributes	9%
Understanding how BIM can support each aspect of the practice (business model)	9%
Teaching specific BIM uses: Representation, visualization, etc.	7%
Need for new spheres of specialization	6%
Distributing teaching responsibilities: who teaches what?	2%

Experiencing multidisciplinary collaboration & activities was perceived by workshop participants as the biggest need in research and education for students and practitioners alike. In fact, the concept of "learning by doing" and "learning how to learn" (or cognitive plasticity) came up often over the course of the workshop. The need to enhance the capabilities of individuals moving through the education system, mirrored by the identified need for increased interaction and engagement between academia and industry – both for research and education was high on the priority list. Another key need identified was to develop and teach a "theory of BIM", ie. the underlying models and frameworks which are prompted through BIM-enabled project delivery at the individual and collective levels. This was also reflected in the identified need to understand the "big picture" of BIM. The "theory of BIM" should pervade technical and professional educational curriculum – not be an "add-on". On the other hand, participants recognized the need to gain proficiency in software tools and in their use to be able to function in a BIM-enabled project delivery environment. Having a structured approach to the development of technical literacy was ranked high in this regard. Furthermore, developing capabilities, prior to entry into the workplace was seen as important by industry practitioners. This was directly related to the general sense that it is organizations in the industry that are bearing the brunt of the shift to BIM and are on the hook for the cost of training – an investment deemed risky by some given the high value of individuals with advanced BIM skills. The need to further develop spheres of specialization and delineating core responsibilities for the development of skills and capabilities, while identified as important, ranked less than the others mentioned above. That being said, the need for new educational streams came up and is discussed below.

The second session was aimed at identifying the challenges to fulfilling these needs. Groups were divided into academic and industry stakeholders. Table 4 presents the outcomes from session 02 in order of perceived importance.

Table 4 - Session 02 outcomes - ranked

Session 02: Identifying the challenges to fulfilling these needs	
Academia	
Legacy mindsets and structures: traditional teaching methods vs experiential learning	20%
Lack of resources: time, money, physical space. etc.	17%
Teaching novel workflows, fitting into existing	16%
Creating partnerships with industry to validate/develop learning outcomes	16%
Breadth vs depth of BIM education	8%
BIM is not a requirement from accreditation/certifying bodies	8%
Incentives to broaden scope are lacking	7%
Non-natural workflows	5%
Overcoming the BIM hype	3%
Industry	
Understanding a lifecycle BIM approach - optimizing information flows	13%
Lack of client understanding: FORMULATING asks & requirements	12%
Professional culture & ideology, and tradition: people set in their ways	11%
Lack of industry understanding & capabilities: DELIVERING on expectations	9%
Lack of capable/competent staff	9%
Lack of financial resources / incentives	9%
Legal aspects: ownership of BIM	8%
Lack of theoretical bases: management theory, design theory, etc.	8%
Developing reliable BIMs: towards a single source of truth	7%
Disconnect between academia & industry (delivery, profit, etc.)	7%
Technology: too many software choices + research for 'best' solution	5%
Difficulty for academia to understand the industry's needs	2%

From the academic participant's perspective, the biggest challenge in transitioning towards educating current and future industry professionals for BIM-enabled project delivery lies in the legacy mindsets and institutional structures currently in place. In fact, the four highest ranked challenges related to the significant effort and hurdles in developing new– and modifying existing curriculum to suite these new ways of working. In this regard, validating new curricula and learning outcomes was seen as a significant challenge due to the need for industry feedback. In parallel, it was stated by many that current curriculum is already saturated and that there was little room for new content. Indeed, Moreover, it was stated that Canadian accreditation and certification bodies currently do not require BIM to be part of any curriculum across most, if not all, disciplines. These three elements: effort required to change, the saturation of current programs and lack of requirements highlight the absence of incentives to broaden scope of the curricula across different disciplines. Another key challenge was the pace of technological change and keeping content up to date.

From the industry participant's perspective, the challenges were more in line with everyday practice and reflected challenges highlighted in prior research (e.g. (Azhar, Hein, & Sketo, 2008; Chien, Wu, & Huang, 2014; Davies & Harty, 2013; Hollermann, Melzner, & Bargstädt, 2012; Johansson, Roupé, & Bosch-Sijtsema, 2015; Korpela, Miettinen, Salmikivi, & Ihalainen, 2015; Mäkeläinen, Hyvärinen, & Peura, 2012). In this regard, challenges such as lack of market demand for BIM, change management, lack of incentives, reliability of the process and technological hurdles came up often. With regard to research and educational aspects, the first challenge identified by industry practitioners, understanding a lifecycle BIM approach - optimizing information flows, and the identified lack of theoretical bases touched on the need to develop and teach underlying theoretical notions and shift to a pervasive view of BIM across disciplines and programs. Interestingly, industry practitioners also identified a disconnect between industry and academia, however they viewed the disconnect at the level of framing research and fitting it into existing business processes without disrupting current workloads and workflows. Finally, industry practitioners also felt overwhelmed by the pace of technological change.

During the third session, participants were tasked to come up with concrete actions to fulfill the needs and overcome the challenges identified in the first two sessions. The outcomes of this session fed into the fourth session, which was aimed at identifying priorities and set courses of action. Overall, a tighter coupling between academia and industry was called for, which could take the form of research partnerships, co-op programs and internships. Moreover, more inter-disciplinary education was proposed in the form of integrated design studios. While this isn't a novel concept and has been done in other places around the globe, there was a general feeling that developing such a course in the Canadian context was challenging due to the departmental divisions found within Universities. In this light, new approaches were proposed, such as the possibility of creating a Canadian School of the Built Environment (which exists in the UK and the US) and a National Institute for the Built Environment. Identifying funding opportunities and considering all aspects of the project delivery lifecycle in the development of future curricula were also deemed a priority. Table 5 presents the outcomes from sessions 03 and 04 in order of perceived importance. The fifth and final session was aimed at developing partnerships, defining projects and identifying these funding opportunities.

Table 5 - Session 04 outcomes - ranked

Session 04: Identifying priorities	
Showcase collaborative studio projects (w/ industry partners & community stakeholders) that leverage BIM	24%
Develop an online knowledge-sharing "marketplace" to request & share curricular material	22%
Focus on studying lessons learned from other curricular frameworks developed overseas	19%
Pursue a CREATE grant (integrated design management & leveraging BIM in practice)	18%
Ensure the next step of virtual model to digital fabrication is included in the strategy	17%

Curriculum integration from around the world

Over the course of the workshop, academics from around the world were invited to present their approach to the integration of BIM within the curriculum at their institutions. They were asked to touch on three points during their presentations:

- Present your approach to BIM research and education,

- Discuss some lessons learned from your experience in developing and integrating BIM into your work as a researcher and educator,
- Identify your strategy to further this integration

Four academics offer their insight into this topic.

Arto Kiviniemi – University of Liverpool, Liverpool, UK

Present your approach to BIM research and education:

My teaching environment is a traditional School of Architecture, where I teach mainly in MSc BIM program which aims to give a thorough and deep understanding of BIM for specialists, who can work for example as project coordinators in integrated BIM projects or develop BIM strategies and implementation plans for companies. The program consists of four BIM specific modules (two 30 credits modules and two 15 credits module), two 15 credits modules shared with other architecture programs and a 60 credits thesis. The total duration is one year in full time mode

In addition, I give introductory lectures to BIM in several undergraduate and postgraduate programs mostly in the School of Architecture, but some also in our Civil Engineering department. I also teach BIM in one 3rd year undergrad module where the main focus is a general understanding of using BIM software in visualization and technical detailing. We are currently in the process to integrate BIM more closely in our traditional architectural education in all programs.

My research is mainly done with my PhD students whose research topics cover a very wide area, but all topics are related to BIM; for example, sustainability and energy efficiency, process and organizational challenges in BIM adoption, new business models, BIM-based risk management, use of BIM in retrofit projects. Currently I have nine PhD students, and three of them should graduate this year. We just started development of a BIM center in collaboration with our Civil Engineering department, which hopefully will lead to a larger research group and closer collaboration in teaching also.

Discuss some lessons learned from your experience in developing and integrating BIM into your work as a researcher and educator:

The main challenge in implementing BIM in education has been the lack of colleagues who are competent, or even interested, in BIM. Typically, all lecturers and professors have their own interest areas, where they are very competent. This makes them unwilling to move to new areas, and because BIM is still relatively new, most universities have very few people whose expertise is in that area. The traditional AEC education is also done in “silos”; there is very little if any collaboration between the disciplines, and efficient BIM implementation requires collaborative multi-disciplinary environment. The traditional teaching models are difficult to change, and there are also many practical challenges in multidisciplinary teaching; when should it start, how to build relevant content for all domains, how to assess team projects if some team members underperform and others are suffering from that?

The industry in the UK is currently very active in BIM adoption, but unfortunately the education seems to be lagging behind in most universities. I noticed the same phenomenon in Finland when the BIM adoption started, so it seems that the educational environment is slower to change when new disruptive technologies, such as BIM, come to the market. The change is happening, but much slower than it should, as in my opinion universities should drive the innovation, instead of being followers. The current situation requires strong connections with the leading companies and utilizing their knowledge and practices as a part of the teaching.

Identify your strategy to further this integration:

Closer collaboration between the different disciplines. We must get rid of the "silos" and start working together both in research and teaching. Ideally we should have a School of Built Environment rather that separate departments which in many cases are not even part of the same faculty.

Closer collaboration with the industry. As said we must have strong connections with the leading companies and use their knowledge and practices as a part of the teaching

More flexible program structures. Design and construction are becoming more and more complicated. BIM is not the only change we are witnessing. In the future we need a wide variety of professionals with different skills and competences, and instead of relatively fixed, static programs, we need more alternative combinations of the modules where students can build their learning portfolio based on their interests and industry needs.

Jennifer Macdonald – University of Technology Sydney, Australia

Present your approach to BIM research and education:

I have recently completed a PhD (CODEBIM: Collaborative Design Education utilising BIM Tools and Practices), which involved benchmarking current BIM practice in industry and academia, and the development of a framework to help academics develop collaborative, multi-disciplinary curricula, aided by BIM tools and processes. A central theme is the need to produce "T-Shaped" graduates, in other words, those who have a breadth of understanding of the roles and needs of their fellow AEC professionals, as well as depth of knowledge of their own discipline. The framework (called the IMAC framework) employs a constructivist approach where students build up their skills and knowledge in team working, various technologies and their own disciplinary studies, before coming together with students from the other disciplines to work on joint collaborative projects.

I used the framework to benchmark current practice in the Construction Project Management program at UTS and then to develop my own collaborative courses as a case study. One course (delivered to a large class cohort of approximately 100 senior year students) was delivered in "flipped mode" where students were required to develop their own materials ready to lead small group discussions each week, and the other course was delivered in studio mode, comprising 6 multidisciplinary teams of 4-6 students (from architecture, engineering and construction project management) working as Integrated Project Delivery (IPD) teams. The IPD teams were given a real project, and were required to produce various BIM deliverables for presentation to industry clients. My research showed that both course delivery modes improved the students' understanding of collaborative working practices and the needs of the other disciplines, though the IPD studio students showed a greater depth of understanding. Further research needs to be carried out to see if implementing the IMAC framework over entire degree programs results in greater improvements.

Discuss some lessons learned from your experience in developing and integrating BIM into your work as a researcher and educator:

My experience is similar to Professor Kiviniemi's and others' described in this report. The uptake of BIM by the education sector is a rapidly changing landscape, just as its adoption in the AEC industry is. Awareness and uptake of BIM in academia has increased over the past five years or so, and understanding of what it means to be 'doing BIM' has also changed. My research has shown that academic institutions are still lagging behind industry and struggling to supply graduates with the new skills required by industry, in terms of being able to work effectively in collaborative multi-disciplinary teams and harnessing the new BIM tools and processes. Engineering faculties (with the exception of some architectural engineering programs) are generally the furthest behind.

Some education is required in terms of persuading many academic institutions that the adoption of BIM actually provides a great opportunity to develop collaborative, multi-disciplinary approaches to educating our AEC undergraduates for a better industry future, rather than BIM just being seen as yet another CAD-type of software to be brought in as a stand-alone fix. Many educational institutions believe that they are 'teaching BIM' by introducing a single piece of BIM software to a single discipline course, rather than focusing on cross-discipline collaboration.

Some key requirements from industry include:

- The need for universities to demolish the current learning silos across the AEC disciplines
- The need for graduates to enter industry with a clear understanding of multi-disciplinary practice and team working
- Integration of BIM throughout AEC curricula, not just as stand-alone courses. BIM should be seen as key part of AEC curricula just as it has become a key part of industry practice
- Recruitment of faculty with the requisite skills to train undergraduates – this is a problem currently for academia as much as it is for the industry
- Greater integration between universities and industry – there is a wish to translate research into current practice and training
- Greater involvement of and support from the professional bodies

Some of the major barriers or obstacles identified, to the implementation of collaborative AEC education utilizing BIM tools and processes, include:

- Limited or inadequate faculty time and resources to develop new courses
- Not having faculty with the ability to "teach BIM"/lack of teaching assistant support/difficulties for faculty in keeping up with new technologies
- No room in the curriculum for new courses/limited number of courses available to complete degree program
- Lack of supporting resources such as textbooks or tutorial materials (however, this is improving as more free web-based training becomes available each month)
- Perceived complexity of BIM/uncertainty over which software tools to adopt
- Unwillingness to change curriculum
- Lack of support from colleagues/administration

- Lack of support from accreditation bodies/requirements for accreditation (so lack of incentive to change)
- Difficulty in scaling innovations seen in US programs (e.g. Penn State, CSU, Auburn) from class sizes of 25-40 to class sizes of 90-140 (UK/Australia)
- Finding suitable "Goldilocks" projects (not too complex, not too simple) for collaborative teams to work on and understanding how to set up projects so that all disciplines have something to do all the way through
- Managing workflows – the industry is currently struggling with interoperability issues so undergraduates will need to be supported in coming up with the inevitable workarounds etc.
- Dealing with varying levels of BIM competency across different disciplines, particularly as new courses are introduced and if there are students taking courses out of order.

From the case study collaborative multi-disciplinary courses I have run, some lessons learned are:

- Multi-disciplinary teaching requires much more preparation time than single-discipline courses. There is a need to work with the other instructors/faculties to coordinate timetables, syllabi, assessments, etc.
- Teaching and assessment strategies will need to evolve, but there is a great opportunity to use the new technologies to explore designs and analyse options (shifting the curve to the left into conceptual design).
- BIM should not be seen as a stand-alone specialist subject but should be integrated throughout AEC curricula as part of a toolkit for communication and collaboration. Students do not need to learn 2D CAD before moving on to BIM, and, in fact, the need to learn 2D CAD at all is questionable.
- Clear roles and responsibilities for multidisciplinary team members need to be defined at the outset. It is possible for successful Master-Protégé relationships to develop between more- and less-experienced students, but this should be planned for and assisted.
- Communication channels need to be clarified, particularly if relying on remote-collaboration. In this case, students should meet at least once, if possible, at the start of projects, in order to establish empathy. Instructors should provide guidance on best-practice communication strategies, with input from experienced industry practitioners if necessary.
- Software interoperability also needs to be considered, and assistance given to students in setting up their models/data for successful exchange.
- Careful thought should be put into the selection of projects and project models (if used) to be completed by undergraduates over one semester with a reasonable amount of guidance from tutors.
- Instructor ratios: my research suggests a maximum instructor to student ratio of around 1:25, with at least one instructor from each AEC discipline represented by the student teams. Something that needs to be considered as many universities are moving to large class sizes.
- There needs to be a clearly defined pre-requisite path. Many universities are moving towards flexible degree structures, with students taking courses out of sequence. This is to be discouraged if students are to be able to come together with their disciplinary peers – it is easier to instruct groups where all students have similar basic knowledge, particularly when using software tools.

Identify your strategy to further this integration:

My strategy is similar, again, to Professor Kiviniemi's, in that we need to have greater collaboration between industry and academia in developing and delivering curricula. My observation has been that this is encouraged in the US and South East Asia (e.g. Hong Kong) much more than it is in the UK and Australia, where academics often seem to be dismissed as "not living in the real world" by the construction industry – perhaps greater integration between industry and academia will assist in breaking down stereotypes. There is a great potential role for the professional bodies to support this integration. The professional bodies should provide support and encouragement to their members to engage with teaching and learning at universities, beyond the delivery of one-off guest lectures. This could provide multiple benefits to both industry and academia.

Some of the construction industry professional bodies have greater requirements for demonstrated multi-disciplinary team working skills than others. I would recommend that the professional bodies review some of these criteria and perhaps consider developing joint assessment criteria, thus modelling the collaborative behaviour they expect from their graduates.

I have started to publish some of my findings and tools on a website (codebim.com) in order to assist others in developing collaborative curricula and would be interested in receiving feedback and/or further examples to add to this.

David Beach – Drury University, Springfield, MO, USA

Present your approach to BIM research and education:

The Hammons School of Architecture at Drury University has applied Building Information Modeling (BIM) throughout its curriculum since 2006. We have evolved our curriculum to leverage BIM as both a mode of design research as well as a production tool for design expression. By building BIM curriculums around critical thinking we have been able to develop processes that push our student's design thinking building a more comprehensive understanding of architecture. The same process helps students to consider a modern toolset used by the profession (digital design and building information modeling) as an integral piece to the entirety of the design process.

Our initial move to a BIM curriculum was centered around three core concepts: First, we wanted to build a process where students could be iterative in their design explorations, building out multiple ideas with branching variables. This would help students learn to critically evaluate their own work through a process of both invention and editing. Second, we wanted to establish a workflow for our students leveraging a *single* BIM model as a *central* hub for multiple modes design exploration including predesign, design development, simulation, visualization/immersion, design documentation, and design fabrication. Finally, we wanted to develop a workflow where our students would be required to respond to both qualitative and quantitative data within their individual design process. This would allow our students to see design as a mode of research through experimentation, critical thinking, and project execution. To teach this process, our initial curriculum took a student's project from a previous studio and re-imagined the design through the development of a BIM model. While this engaged our pedagogical goals, and developed a sound process of teaching the toolset within a BIM program, it did not expand student thinking regarding the potential of digital design concepts. After allowing the curriculum to run through a course of three years we found students referring to BIM as a process of archiving their ideas, rather than generating new modalities of architectural exploration.

Discuss some lessons learned from your experience in developing and integrating BIM into your work as a researcher and educator:

The reason we were not moving forward with a more comprehensive digital design process utilizing BIM was placed politely atop the pyramid of Bloom's Taxonomy: Analyze, Evaluate and Create. Our thinking was well founded, that by repeating a project the student could be more concerned with learning the "how to" components of the software, while only making basic design decisions to modify an existing studio project. To teach mastery of a subject (the top level of Bloom's Taxonomy), a student needs to be able to analyze, evaluate, and *create*. With this understanding, we reshaped our digital design curriculum into a "studio light" format, where design decisions would be made in parallel with learning key components of BIM as a design process. This has led us toward two key understandings that are currently shaping our pedagogical approach of leveraging BIM as part of a critical thinking design process. First, the future direction of architectural practice requires fluency on the integration of technology based form building and design thinking. Second, tools need to be taught to continuously explore multiple scales of design engagement embracing the product, building, and urban scales as integrated elements of context.

Identify your strategy to further this integration:

Within the continual modification of our curriculum we find it critical not to add new classes, but rather to adapt the expectations and curriculums of classes running parallel to our studio experiences. This sets up the opportunity to build skills that are applied in practice within the design studio. Our key goals are to continually identify specific subject matters that can be enhanced by integrating technology and a capacity for rapid iterations to inform design thinking.

Jennifer McArthur – Ryerson University, Toronto, Canada

Present your approach to BIM research and education:

At Ryerson, we do not have any specific BIM courses, but have made Revit tutorials available to students to help them gain familiarity with the software starting in 2nd year, and have integrated BIM into the curriculum starting in 3rd year, specifically in the Integrated Studio (both terms), Project Economics course (fall term only), and (implicitly) in the Construction Documents course (winter term). In fourth year, students may also complement these skills with electives in digital fabrication and parametric design, the BIM integration is facilitated by a multi-media toolkit, consisting of a set of (captioned) interviews with architects and contractors, case studies of BIM use in various phases of the project (design, virtual construction scheduling, bid presentations, clash detection, etc.), and tutorials to support both typical studio activities (e.g. exporting files between Rhino and Revit) as well as a project in the Project Economics course, designed to complement Studio. This project is timed to coincide with massing and form generation in the studio course, and students are required to develop two alternate massings and test two envelope treatments (different percentages glazing, wall constructions, etc.) for each. Cost estimates are then undertaken using material take-offs (exported in CSV format) and a simple energy simulation (using Green Building Studio and prescribed settings) for each of the resultant four options. This activity is repeated within the studio both at the end of the first term (schematic design) and again the following term (design development) to help students both understand the financial and energy implications of form and materiality choices, but also to gain further comfort and proficiency with both the BIM software and these two particular uses. Implicit in this exercise is a requirement for students to develop precise models, in order to obtain realistic results. BIM is also integral to the Construction Documents course, where teams of six students work together to advance a project from schematic design through complete construction documents. Each student team is provided with a folder on a Revit server and is presented a short tutorial on worksharing, worksets, central vs. local files, and other key concepts necessary to collaborate on a BIM project. This term I am hoping to pilot a tutorial on simple uses of Dynamo for file management (generating drawing lists and updating title blocks) to support this course.

In my research, I focus primarily on developing new methods of using BIM to support facilities management, particularly in existing buildings where limited as-built information is available and there is limited appetite for investment. Working with the Ryerson Facilities Department for the last three years, my research has focused on three key areas: (1) developing a low-cost approach for BIM in FM; (2) automated generation of BIMs for existing buildings; and (3) integration of data analytics and streaming with BIM for visualization ("BIM Analytics"). This research is applied in nature, working either on the Ryerson Virtual Campus Model (the model of the full campus integrated with FM data, providing a testing and demonstration sandbox for new BIM applications for the Facilities Department) or on a BIM-enabled FM Visualization tool with an industry partner, in collaboration with Computer Science researchers and Data Scientists. Insights from this research, as well as new automation tools and approaches developed by my students are both presented in context to the students, and in many cases (because my research students are primarily Masters or undergraduate) are adapted and brought into Studio projects by the students themselves.

Discuss some lessons learned from your experience in developing and integrating BIM into your work as a researcher and educator:

I have found that my students (I teach in both studio and the Project Economics course) have responded well to the multimedia approach to BIM, particularly the cost/energy simulation project, and this has affirmed my belief that experiential learning is a highly effective means to teach BIM, particularly within the context of design. I have found that the integration of Data Science with BIM has been highly beneficial, resulting in both significant new collaboration and funding opportunities, as well as new insights on the underlying structure of BIM models and how those might influence my future research.

I have found industry to be extremely supportive of efforts to enhance BIM teaching in the curriculum, and had input from nearly 15 firms for the BIM Curriculum toolkit.

Identify your strategy to further this integration:

There is not yet any dedicated fourth-year or graduate course on BIM or VDC, which would provide opportunity for both a much more comprehensive teaching of BIM theory (information structures, model management, BIM Execution Planning) as well as experiential practice, which I have found particularly effective, as noted above. I do feel it's necessary to "not teach Revit", in part because while used extensively for multi-disciplinary design coordination, it is rarely used in design authoring and form generation (Rhino+Grasshopper and CATIA are preferred by architects) and it is important that approaches developed are flexible enough to work within any BIM context.

Sheryl Staub-French – University of British Colombia, Vancouver, Canada

Present your approach to BIM research and education:

I teach BIM/VDC within the undergraduate Civil Engineering Program and the graduate Project and Construction Management program. Within our undergraduate program, we try to incorporate some BIM/VDC in every year starting in year 2. In the second year, we incorporate conceptual modeling within a core project-based course where students have to develop conceptual 3D models for a pedestrian overpass. In the third year, students in the core 3rd year course on project and construction management must develop 3D and 4D models for a small building project as part of their course project. In the fourth year, students can take a technical elective focused on BIM/VDC that is also a core course in our Project and Construction Management graduate program. This is the most extensive course on BIM/VDC that we have in the program. This course covers four modules: BIM fundamentals, organizing BIM projects, planning BIM projects, and executing BIM projects. Students explore these topics through a case study project for a 'real' building based on the project requirements established by UBC. Students create a new conceptual 3D design, a cost estimate, a construction schedule, and a 4D model.

In my research, I have a very applied approach and work extensively with industry partners to study real projects. I have studied numerous BIM project and worked with numerous organizations throughout the project supply chain. My research approach investigates BIM from three distinct perspectives: Technology (what modeling tools are used, what level of detail are models developed, etc.), Organization (how are project teams organized, when are specific disciplined brought on board, etc.), and Process (what level of BIM execution planning taken place, what coordination processes have been developed, etc.). My research focuses on the development of new tools, techniques, and knowledge about how to represent, coordinate, share, and use BIM as part of a collaborative model-based project delivery process. I collaborate extensively with faculty researchers in Computer Science, Architecture and Community Planning, and have strong connections with industry that have allowed my research team to collect extensive data through long-term field studies of BIM projects. I acquired a 'BIM Trailer' and deployed it on many construction sites to facilitate this research. The lessons learned from my research are incorporated into the teaching of my BIM/VDC course.

Discuss some lessons learned from your experience in developing and integrating BIM into your work as a researcher and educator:

The collaborate nature of my research is both rewarding in challenging. I believe students working in this multi-disciplinary and applied setting makes them much more prepared to work in industry and become catalysts for change. I also believe the results of my research is also of benefit to industry, which furthers the impact of this type of work. In terms of my teaching, I believe that students benefit from the multiple perspectives on BIM that are presented in the class focusing on the technological, organizational and process-based issues of BIM implementation. There are challenges, however. In terms of teaching, it is difficult to teach BIM/VDC as part of a large class (our undergraduate classes can be almost 200 students), and with a large program it can be difficult to teach this course as part of a multi-disciplinary teaching team (with architects, mechanical and structural engineers, etc.). In terms of research, collaboration with industry can be difficult to fund and more time-consuming to execute as it involves significant coordination.

Identify your strategy to further this integration:

There needs to be more flexibility collaboration within academia to advance BIM education and train the next generation of industry practitioners. In the current system, architects and engineers typically are educated in silos with almost no interaction between the students. Similarly, industry engagement with teaching and research has been limited. Industry practitioners need to recognize the importance and value of academic research and they need to engage with academia to better inform how and what students in these different disciplines are taught.

Discussion

From the findings, it becomes apparent that workshop participants identified the same needs and challenges that were highlighted in past research (Abdirad & Dossick, 2016; Puolitaival & Forsythe, 2016; Sacks & Pikas, 2013). This is encouraging to the extent that possible solutions have already been identified and that they simply require adaptation to the Canadian context. Accordingly, this was one of the questions formulated at the onset of the workshop (*What can we learn and derive from programs supporting innovation and technology transfer as ones found in Scandinavia, Great Britain or Australia?*) and highlighted as one of the courses of action to be taken: *focus on studying lessons learned from other curricular frameworks developed overseas*. In this sense, adaptation of the IMAC framework (Macdonald, 2012) or another could serve as a good foundation.

Another area of focus was around adaptation of current curricula, integration of BIM into existing programs and creation of new multi-disciplinary, collaborative programs. The question of agility came up often and was seen to pose a serious threat to future AEC training and education programs. Indeed, a workshop question was formulated in this sense: *How can we make academia construction programs agile enough to train students to the reality of an industry in full transformation?* A partial answer can be found in the past literature around project based learning and encouraging tighter couplings between industry and academia. However, in the Canadian context, this was also seen as a challenge. One course of action developed was identifying and applying for funding and grants which cover industry-academic partnerships and encourage co-generation of knowledge. Further to this, laying out core learning outcomes relating to BIM and multi-disciplinary practice, that should be integrated into existing programs or serve as a foundation for new training and education programs was seen as crucial. This is consistent with findings by Sacks & Pikas (2013) and Forsythe et al. (2013), among others.

Regarding certification and assessment, workshop participants were asked: *How can we make the most agile certification programs to meet current and future needs?* This was a difficult question to answer and no consensus emerged around it resolution, although a tighter coupling between industry and academia could help ensure relevance and rigor of certification and assessment process. Additional questions formulated for the workshop were: (1) *How can we encourage and support learning and transdisciplinary research?* And (2) *How can we align and integrate training efforts in college, university and continuing education for the production and transfer of new knowledge on emerging practices and technologies?* It was suggested to create an online platform or "market place" to co-develop and share lessons learned and resources, instead of expecting every program to reinvent its own material.

Forsythe et al. (2013) and Puolitaival & Forsythe (2016) both identified this as a challenge and proposed approaches to overcoming it. Alignment of training efforts is also a challenge that resonates with the technical-theoretical dichotomy that has been identified in the workshop and in prior research. Some approaches, such as the one developed by Kocaturk & Kiviniemi (2013) warrant further investigation in the Canadian context. There is also a need to focus on the academic "supply chain" to see what catalysts exist or which are required to initiate change to highlight responsibilities and uncover new roles which may clash with the more traditional and institutional mindsets that exist.

Lastly, questions around *How do we recruit and train the next generation of researchers and teachers in these emerging areas?* also mirrored the challenges identified by others such as Becerik-Gerber et al. (2011), Puolitaival & Forsythe (2016) and Abdirad & Dossick (2016). Again, greater integration between industry and academia was seen as a possible solution path, ie. having individuals from industry more involved in teaching BIM and involved in research projects. While this is already happening to a certain extent, there is increasing opportunity for industry practitioners to play a hybrid role in academia: expert, teacher and student.

Conclusion

Researchers have been increasingly studying how BIM and integrated, multi-disciplinary practice gets included into AEC training and education programs. The recognition by most that BIM is a disruptive and transformative innovation in the AEC industry has led many to question how students are educated and how professional get adequate training. Some have called for a complete rethinking of the current AEC curricula, yet many barriers stand in the way of such a reform. The findings of the workshop presented in this paper set the course for action to begin rethinking the way Canadian AEC stakeholders are trained and educated. Findings reflect conclusions made in prior research that the integration of BIM into existing programs is challenging yet it can be done. The importance of tighter couplings between academia and industry were also highlighted in that there is a need to ensure the relevance of what is being taught at both a technical and theoretical level. Consistency is also seen as an important part of the transformation effort and in this regard, the creating of a learning outcomes framework, currently undertaken by buildingSMART Canada, and the networking and sharing of methods and resources is seen as an important step. Finally, agility and the promotion of "design thinking" is key to this integration effort: recognition that the tools may change, but the underlying theory remain somewhat stable is paramount in the development or transformation of AEC educational and training programs.

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