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HOW UNIVERSITIES ARE TEACHING BIM: A REVIEW AND CASE STUDY FROM THE UK

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SUMMARY: *Growing industry demand and the United Kingdom (UK) government's 2016 'BIM deadline' have provided a clear impetus for enhanced BIM teaching in UK Higher Education institutions. This paper reports on the strategic approach taken in a large multi-disciplinary School of Civil and Building Engineering. From a number of options suggested by literature, the approach to embed BIM into existing modules was chosen and three categories of BIM Learning Outcomes (BIMLOs) were identified including: knowledge and intellectual aspects; practical skills; and transferable skills. A three-year implementation plan (2014 – 2016) was developed in which 26 priority modules had their existing learning outcomes upgraded to meet the BIMLOs. Three new modules had to be introduced to cover new concepts and processes that required special attention, including: model coordination and clash detection/avoidance; as well as use of common data environments (CDE) which is a pre-requisite for Level 2 BIM. The contents of the BIMLOs were influenced by partnership with BIM technology providers, practicing professionals, contemporary and research-driven topics as well as UK BIM guidance and strategy documents e.g. BS1192-2007, the PAS1192 series, BIM Protocol and Government Soft Landings. Many priority modules were taken by mixed cohorts of students drawn from various programmes, so group work via problem-based coursework was typically used for assessment. Guided self-learning through web-based video tutorials was adopted across the School using commercially available and in-house produced content. These have helped students with problem-solving and modelling skills. There were differences (such as background skills and future interests between local undergraduate students and international postgraduate students) and these differences influenced how they approached group working and the tasks they could effectively carry out. The approach adopted by Loughborough University for teaching BIM required long-term vision, leadership, BIM championing and the cooperation of academic peers who were extensively consulted. A feedback mechanism was put in place to capture students' experiences regarding BIMLOs, access to computing facilities and effectiveness of video tutorials. Recommendations are made to other institutions considering wide scale multi-disciplinary embedding of BIM into their curriculum.*

KEYWORDS: *Multi-disciplinary cohorts; Embedding; BIM Learning Outcomes; Streamed video tutorials; New BIM-focused modules; BIM champion; Multi-media Feedback.*

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1. BACKGROUND: BIM IN THE UK CONTEXT

Various BIM implementation and regulatory bodies shape the policy, technology and process aspects of BIM in different countries. Wong, et al. (2010) have reviewed and classified the roles of such bodies for six countries namely: Denmark; Finland; Hong Kong; Norway; Singapore and USA; and it is crucial for universities to work in tandem with the aspirations of such bodies. In the United Kingdom (UK) for instance, the BIM Task Group is a principal interest group comprising of experts drawn from the public sector, industry and academia. Its remit covers building the capacity of the public sector to deliver Level 2 BIM by 2016 as part of the Government Construction Strategy (Cabinet Office, 2011). The BIM Task Group (2014a) has acknowledged that BIM is *"such a wide open subject with interpretations differing throughout the supply chain that we could have spent a year just trying to define BIM*". This suggests that seeking a universal approach to teaching BIM could be unrealistic, even in the same country, hence, common ground would be required to accommodate differing perspectives or interpretations of BIM. The BIM Task Group also implies that digital-tool sets (e.g. authoring and collaboration software), are necessary to implement BIM, and from the UK's perspective, there are four different levels of implementing BIM (Fig. 1). These are summarily described as: Level 0; Level 1, Level 2 and Level 3 (RIBA, 2012). Of immediate interest in the UK is Level 2, where models are created in BIM applications by specific disciplines before deployment in a common data enviroment (BSI, 2013; BSI, 2007), with Construction Operations Building Information Exchange (COBie) output being mandatory. The deadline for implementing Level 2 BIM is 2016, for all centrally procured projects (CIOB, 2011; HEA, 2013).

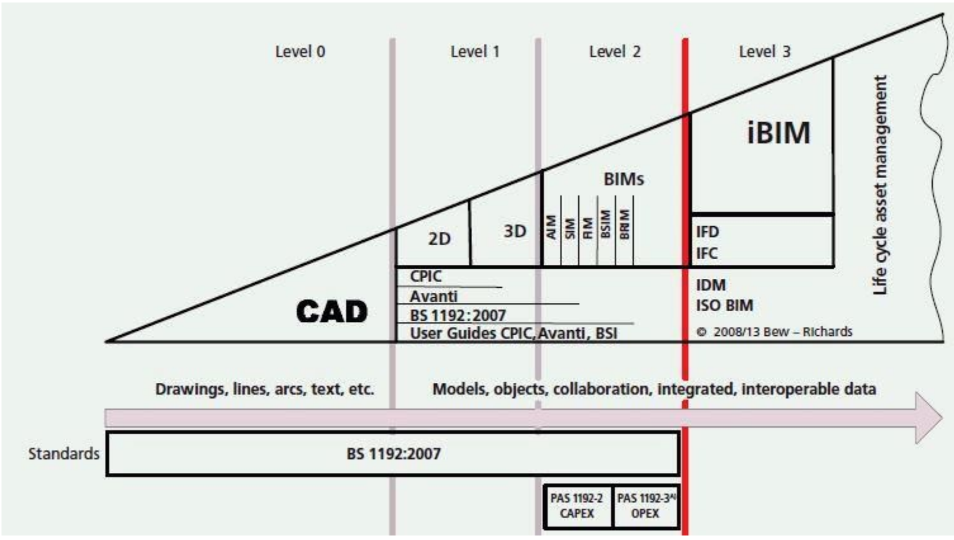

FIG. 1: The BIM Maturity Diagram (Source: BSI, 2013)

However, the UK Government's engagement with higher education institutions (universities and colleges) towards operationalising the 2016 deadline could be regarded as passive. Despite the efforts of the BIM Academic Forum (HEA, 2013) in bringing together academics voluntarily, there is evidence that a lot of focus on 2016 readiness in the UK is on professionals working in industry. Although SMEs are getting attention and support for training (Mellon, et a. 2014) this sub-sector is beset by problems where many SMEs are relying on free training events, hence only 10% of them have plans to invest their own money in training and 27% are not planning to train at all (NFB, 2012). The general desire by the wider construction industry to be ready for 2016 (Ganah and John 2014; Ngo, 2012) is aided by desire to upskill and acquire professional certifications that would drive organisational change and lead to career progress (Khosrowshahi and Arayici, 2012). Overall, it can be said that the focus on 2016 BIM-readiness for the professional AEC industry is somewhat to the detriment of sustained engagement with universities and academics that are arguably well-placed to help train a new generation of professionals. This is especially important given that cost of resources and training are major barriers to implementing BIM (Eadie, et al. 2013; Azhar, et al. 2011; Yan and Demian, 2008) – whereas colleges and universities are often able to get BIM-related technology (e.g. from Autodesk) for free or at reduced price.

2. TEACHING BIM: OVERVIEW OF THE GLOBAL AND UK POSITIONS

2.1 Global perspectives on teaching BIM

An example of a contemporary approach to planning a BIM curriculum can be found in Barison and Santos (2010a) who reviewed AEC undergraduate programmes in 25 universities, most of which were in the USA. They deduced that BIM was taught by six universities at an introductory level, by 12 universities at an intermediate level, and by seven universities at an advanced level. BIM at the introductory level did not require any pre-requisites (not even CAD) or high level of computing skills, making it suitable for first year students. Barison and Santos (2010b) also suggested that there are schools which teach BIM via distance collaboration, the idea being to simulate real-life collaborative working amongst geographically dispersed students in different institutions. They gave examples of universities that have implemented this approach as University of Nebraska-Lincoln (Architecture) and University of Wyoming (Architectural Engineering). Another US example involved senior level undergraduate or postgraduate level students at Virginia Tech and University of Southern California who collaborated on the platform of a Construction Engineering Management course (Becerik-Gerber, et al. 2012). A similar multi-institutional (but international) exercise has been carried out by Loughborough University (UK), Coventry University (UK) and Ryerson University (Canada), through the 'BIM-Hub' initiative (Poh, et al. 2014).

For a subject that is open to various interpretations, teaching BIM has its challenges and opportunities. Becerik-Gerber, et al. (2011) studied over 100 US-based AEC programmes and found inconsistencies in how BIM was adopted and accepted by many institutions, based on cultural, economic and academic differences. There can also be obstacles to BIM integration due to inflexible or tight curricula that cannot withstand elective courses; there can be constraints due to graduation requirements and even lack of reference materials for teaching (Sabongi, 2009). A BIM capstone dissertation can however, give valuable and in-depth skill sets to undergraduate students (Azhar, et al. 2010). On the basis of industry needs, Pikas, et al. (2013) identified 39 key topics or BIM competencies that should be acquired by construction management students for industry application. The process-oriented approach taken by Wang and Leite (2014) for teaching BIM to graduate students is an interesting example that covers many fields such as: Cost Estimating; Scheduling and 4D Simulation; MEP Design Coordination; 3D Point Clouds; and Energy Simulation. It is also evident that due to its revolutionary technologies (Hardin, 2009) BIM is creating new types of activities and protocols that are not only re-defining traditional AEC roles, but creating new career opportunties like: 'Model Manager' (RIBA, 2012); 'BIM Manager' (Barison and Santos, 2010a); as well as 'BIM Coordinator' and 'BIM Engineer' (Wu and Issa, 2013). These new career opportunities have to be considered and exploited in the training of AEC students and there is so far, no evidence that separate degree programmes are required for these new BIM-specific 'professions' – except perhaps at the MSc level where many UK schools (see Table 1) have BIM specialisations. Nevertheless, embedding BIM into existing degree programmes could lead to similar professional titles.

Generally, effective learning by students requires a combination of methods, including lectures, 'isolated drill and practice', cooperative learning, use of narrative videos as well as problem-based and guided self-study, according to Bransford, et al. (2000) who discussed the principles of 'how people learn'. Hence, learning BIM can be achieved via teacher-led instruction in traditional lectures and/or lab tutorials, problem-based projects/coursework and use of web-based tutorials for acquiring practical skills in BIM technologies. Videos offer better student learning experiences than possible from text-based hand-outs because they: aid metacognition (Wouters et al., 2007); support problem-based learning (Chan, et al. 2010); and increase the stimulation, knowledge retention and satisfaction of students (Choi and Johnson, 2007). By encouraging guided self-learning through video tutorials, students could acquire BIM skills on their own, with knock-on effect on computer lab sessions that can then focus on problem-solving. This approach should eventually speed up the Kolb Learning Cycle (Kolb, 1984). Examples, case studies and best practices of teaching BIM can be helpful in this regard, but they are currently scarce. The 9th BIM Academic Symposium and Job Task Analysis Review (7th-8th April 2015, Washington DC) has therefore led to a global consortium of academics (the Academic Interoperability Coalition) seeking to delineate global standards and best practices to BIM education.

2.2 Teaching BIM in the UK

Compared to North America, there is a relative shortage of pedagogical literature and case studies about curriculum development and teaching experiences regarding BIM in UK higher institutions. There are some exceptions like McGough, et al. (2013), where a two-staged approach was used to integrate BIM into the Civil

Engineering, Architecture and Building Department of Coventry University. This approach involved the implicit introduction of collaborative working skills to first year students, with a reorganisation of a third year integrated project module. Eadie, et al. (2014) argued that the preferred mode of delivery of BIM knowledge/skills in a multi-disciplinary department is via standalone modules which are linked to other AEC courses where both theory and software-related aspects of the built environment are taught. The BIM Academic Forum (BAF) is nevertheless playing an important coordinating role through its BIM Academic Framework with membership from over 30 UK universities. One of its key outputs is a report on the embedding of BIM in taught programmes, sponsored by the UK's Higher Education Academy (HEA, 2013). This report overviewed the impact of BIM on the needs of students, the expertise of staff as well as essential BIM learning outcomes. The report outlined three types of intended learning outcomes (ILOs) for BIM which are: knowledge and understanding; practical skills and transferable skills. These categories of learning outcomes are supported by Ghosh, et al (2013) who argued that for effective BIM implementation, the pedagogical approach should cover theory, practical experience and use of technology-driven collaborative environments.

The HEA report is however silent on some issues which have practical bearing on successful integration of BIM. For example, the steps to be taken to infuse the ILOs of BIM into the specifications of existing modules require a mapping process, if embedding is indeed the preferred approach. Without careful planning (e.g. through a toolkit), duplication of ILOs, over-assessment of students (Boud and Falchikov, 2007) or inconsistencies with accreditation requirements could occur. Additionally, the HEA report does not discuss role-playing amongst multi-disciplinary cohorts of students as a specific pre-requisite to teaching and learning knowledge and skills aimed at Level 2 BIM. The sequential order of professional tasks associated with collaborative work via BIM modelling (Shafiq, et al. 2013, Gu and London 2010) should be adopted by students in the form of role-playing as exemplified in Becerik-Gerber et al. (2012). Such role-playing would be helpful towards acquiring the range of skills necessary for efficient and effective collaboration with respect to UK's Level 2 BIM ambitions.

Teaching BIM generally requires that the subject is considered in the contexts of sustainability and whole life-cycle performance of buildings. There are examples of approaches for integrating BIM into the AEC curriculum include (Zhang, et al., 2016; Luo and Wu, 2015) as well as industry-based perspectives on the subject (Azhar, 2010 and Azhar and Brown, 2009). With respect to the UK, it is necessary to frame and teach BIM with respect to the 2025 targets set out in the Construction 2025 strategy document (Cable, et al. 2013) of achieving 50% reduction in greenhouse gas emissions and 33% reduction in whole-life cycle cost. It is also helpful to consider the principles of the Government Soft Landings (GSL), aimed at easing the transition between the design/build or capital expenditure (Capex) phase with the post-occupancy or operational expenditure (Opex) phase (BIM Task Group, 2014c). The GSL powered by BIM is intended to lead to better outcome for built assets and requires data collected over a mandatory three-year post occupancy evaluation (POE) to be fed into asset information models (AIM) - with ambitious consequences for computer-aided facilities management (CAFM). Therefore, there is need to train a new generation of professionals that consider POE and aftercare issues including: measuring performance; feeding back to designers; continuous improvement; as well as bridging the gap between predicted targets and actual outcomes (BIM Task Group, 2014c). The GSL framework is hence a unique BIM supplement for extracting value from publicly procured projects. The requirement for a 'GSL champion' in each government department is another example of new job opportunities created by BIM, at least in the UK.

2.3 Postgraduate and distance learning in BIM

The most visible/publicised BIM programmes in UK universities' websites are Postgraduate (MSc) taught programmes. It is not clear why there are not many undergraduate AEC programmes that market the 'BIM' aspects of their curriculums, but it may be that BIM (as a specialization) is more marketable given the findings of Khosrowshahi and Arayici (2012), i.e. the demand for upskilling and professional certifications that would drive organisational change and lead to career progress. The risk in this approach, however, is that BIM will (at least in the near future) be regarded as a 'specialization' and not the fundamental process of collaborative design, construction and operation of buildings, which is arguably what it is. Those universities that publicise such postgraduate BIM programmes generally appear to offer a focused specialisation (Table 1), with evidence of distance learning being a popular (and sometimes only) mode of delivery. Possibly, such MSc distance learning approach are the best or most preferred routes for practicing AEC professionals wanting to up-skill themselves in BIM in order to make career progress, as suggested by Khosrowshahi and Arayici (2012). It is likely, therefore, that universities offering such modes of learning are adopting some form of 'disruptive innovation in teaching' (Arnett, 2014; Christensen, et al. 2008). Disruptive innovation in teaching is aimed at remote students who benefit from flexibility in when and how learning content is delivered to them; perhaps in addition to the affordability of such disruptive models in higher education (Christensen, et al. 2011). The studies which looked at remote learning of BIM in academic settings (e.g. Poh, et al. 2014; Becerik-Gerber, et al. 2012; Barison and Santos, 2010b) have not specifically linked their approach to disruptive innovation, but this can be inferred. The distance learning model used by Middlesex University (London) for its MSc Building Information Modelling Management is a unique example of a (purely) distance learning degree. The programme prides itself in being the "only work-based MSc in BIM" because it is aimed at "practitioners in full-time employment". The programme is based on three 60-credit modules, which are: a first module on Technical BIM Management (with an exit option of Postgraduate Certificate); a second module on Operational BIM Management (with an exit option of Postgraduate Diploma); attendance of a summer school between second and third modules; and a third module on Strategic BIM Management (for a thesis-based MSc degree). These modules are heavily supported by online presentations done by academics and industry experts, and students are expected to engage them in discussions.

TABLE 1: Overview of BIM-related MSc programmes in selected UK universities (as of Dec 2014).

University Name	Programme title	Duration / Mode of Study	Delivery format
Westminster	Building Information Management	1 Year (FT);	Campus only
Middlesex	BIM Management	1 Year (FT); 2 Years (PT)	Distance learning only
Salford	BIM and Integrated Design	1 Year (FT); 2.5 Years (PT)	Campus, Distance Learning and International Distance Learning
Liverpool (in London)	Building Information Modelling	1 Year (FT)	Campus only
West of England	BIM in Design, Const. & Operation	1 Year (FT); 2-3 Years (PT).	Campus only
Northumbria	Building Design Mgt. and BIM	3 Years	Distance learning only
South Wales	BIM and Sustainability	1 Year (FT); 3 Years (PT).	Campus only
FT = Full Time; PT = Part Time.			

Web-based disruptive models of learning are not without challenges and universities considering this model for BIM-based courses/programmes would want to consider 'persistence': a pedagogical phenomenon that describes the skills, behaviour and attitude required for a student to complete (and succeed) in an online based course (Hart, 2012). Among the popular models of disruptive innovation in higher education is the Massive Open Online Courses (MOOCs) that are compelling universities to re-think their modes/approach to learning due to the 'momentum' that MOOCs give to distance learners (Kartensi, 2013). MOOCs have many other benefits such as: enabling participants to acquire autonomous learning abilities and computer skills; empowering mature learners with capacity to engage in a fast changing information technology driven world; and allowing universities to test the popularity of new course content or curricula (Kartensi, 2013).

Although there is often a 'belittling' of online learning this can be traced to its asynchronous mode and the distance involved (Christensen, et al. 2011). Perhaps this is also linked to concerns that if the quality of online teaching does not match what is obtained in 'real universities' then MOOCs could inherit the 'stained reputation' of old fashioned 'correspondence courses' (Kartensi, 2013). However, given that in the US for instance, the fraction of students that took at least one online course was 10% in 2003, rising up to 30% in 2009 with a projection of up to 50% by 2014 (Allen and Seaman, 2010) then evidently, the disruption in the higher education sector is not to be ignored. In addition, many studies in the last decade (e.g. Woodall, et al. 2014; Obermiller and Atwood, 2011, Lomas, 2007) have looked into students' increasingly customer-like behaviour, particularly with respect to the perceived value of their university experiences. The recent rise in tuition fees in the UK is for example, an important criterion used by prospective students to select a university (Dunnett, et al. 2012). There is evidence indicating that this is leading to 'changing behavioural dynamics' to the extent that UK students are considering more options, such as: studying within or outside the UK; in public or non-profit institutions; and even within or outside formal higher education (Dunnett, et al. 2012). Hence, if the rising popularity of MOOCs is contrasted with higher cost of degrees, these studies suggest the need for reflection on the future of BIM education, especially at the postgraduate level where mature students are likely to: (a) be in paid employment and would desire flexible learning; (b) be willing to consider alternatives to traditional campus-based learning; (c) urgently need up-skilling in order to acquire BIM skills for career progression, particularly against the backdrop of the 2016 BIM deadline; (d) exhibit more consumer-like approach to their learning experiences than perhaps undergraduate students.

3. TEACHING BIM AT LOUGHBOROUGH UNIVERSITY: A CASE STUDY

Although many UK universities have invested in MSc programmes on BIM, the teaching of BIM at the undergraduate level is arguably where long-term investment and impact will be most effective. The rationale for this is that BIM fundamentally applies to all aspects of a building's life-cycle, hence training a new generation to view and utilize BIM as a modern process of working is helpful – and not necessarily a 'specialisation' to be acquired at postgraduate level. Additionally, the lack of funds for training and upskilling has been identified as a barrier to BIM adoption (Eadie, et al. 2013; Azhar, et al. 2011; Yan and Demian, 2008), whereas universities often have free access to training/technology of BIM), then it is economically sound to invest in undergraduate students who will 'be BIM-ready'. This is the position taken by Loughborough University, where the School of Civil and Building Engineering (SCBE) has four undergraduate degree programmes (and up to five postgraduate taught programmes) requiring BIM upgrades. The undergraduate programmes include: Architectural Engineering and Design Management (AEDM); Civil Engineering (BEng/MEng); Construction Engineering Management (CEM) and Commercial Management and Quantity Surveying (CMQS). The postgraduate (MSc) programmes include: Construction Management; Construction Management; Low Carbon Building Design and Modelling; and Low Energy Building Services Engineering. The co-location of these programmes in one School has traditionally allowed the optimisation of multi-disciplinary teaching and learning, and project-based group working is often used to achieve learning outcomes. The effectiveness of project-based student-centred learning has shown (Wu and Luo, 2015; Bas 2011), and this is a pedagogical approach that suits the collaborative aspects of BIM. Nevertheless, embedding BIM into such a wide array of programmes had logistic implications, requiring coordination and consistency in approach. The leadership of the School therefore identified and empowered a BIM champion (lead author) to facilitate the required changes. The exercise began with a comprehensive review of literature and extensive consultation of academics about their needs, expectations or concerns, leading to the identification of key modules requiring BIM upgrades. This was the foundation upon which changes to the curriculum was possible. In order to ease the transition and minimise disruption to the curriculums of the affected undergraduate (four in number) and graduate programmes (four in number), a phased approach was adopted. The phasing would also give academic staff time to upskill and prepare required BIM learning and support resources accordingly. These phases are summarized below.

3.1 Phase 1: Embedding BIM in identified priority modules

The goal of the first phase to identified the relevant modules that would be: (a) given priority in terms of resources; (b) mapped with existing frameworks; and (c) ensure a spread across the years of study and across the various programmes. The BIMLOs recommended by BAF (HEA, 2013) were mapped and cross-referenced with the ILOs of 26 existing undergraduate (Table 2) and five postgraduate modules identified for priority embedding (Table 3).

TABLE 2: Priority undergraduate (UG) and their implementation semesters

Phase 1	**Semester 1: 2013/14**	**Semester 2: 2013/14**
	CVA028 (Const. Comm. Mgt 1) - UG	CVB026 (Construction Tech. Management 2) - UG
	CVC037 (Pre Const. Est. Plan) - UG	CVA011 (2D CAD & BIM)* - UG
	CVB033 (Health and Safety) - UG	CVA030 (Methods of Measurement) - UG
Phase 2	**Semester 1: 2014/15**	**Semester 2: 2014/15**
	CVA014 (Construction Tech. Management 1)* - UG	CVA027 (Graphic Communications)* - UG
	CVC022 (3D CAD Modelling) - UG	CVB005 (Construction Management) - UG
	CVC039 (Arch. Design Project) - UG	CVC045 (Collaborative. BIM Design Project)** - UG
	CVB037 (Measurement and QS) - UG	CVA026 (Building Production) - UG
Phase 3	**Semester 1: 2015/16**	**Semester 2: 2015/16**
	CVB042 (3D BIM Auditing and Coordination)** - UG	CVC019 (Project Management) - UG
	CVC024 (Architectural Detailing) - UG	CVC033 (Maintenance, Repair and Refurbishment) - UG
	CVC030 (Advanced Mechanical Services) - UG	CVC037 (Pre Const. Est. Plan) - UG
		CVC028 (Construction Economics) - UG
	* In phase three, this module was absorbed into a new mega-module taught across two semesters ** brand new modules on specific BIM specializations	

Other modules not on the priority list were expected to change but not necessarily within the three-year plan. The criteria developed and applied for prioritising an existing module for BIM embedding include: (1) it is taken by a multi-disciplinary cohort of students; (2) it primarily teaches building design and/or construction; (3) it has an inherent focus on ICT applications: i.e. computing or modelling; (4) it is at a critical stage of learning (i.e. first year or final year). These BIMLOs also served as a guide in the development of new BIM-specific or BIM-relevant modules introduced to a programme.

TABLE 3: Priority postgraduate (PG) modules and their implementation semesters

Phase 2	**Semester 1: 2014/15**	**Semester 2: 2014/15**
	CVP320 (ICT for Construction) - PG	CVP335 (Federated Build. Info. Modelling)** - PG
Phase 3	**Semester 1: 2015/16**	**Semester 2: 2015/16**
	CVC005 (Design Project) - PG	CVD003 (Teamwork Design Project) - PG
	CVD004 (Design Project Management) - PG	
	** brand new modules on specific BIM specializations	

In addition to customary texts on BIM which provide theories, conceptual backdrop and collaboration processes, there are important documents that provide crucial content to the learning outcomes of BIM in the School. These include: regulatory guidelines like BS1192-2007 (BSI, 2007), PAS1192 (BSI, 2013) and the CIC BIM Protocol (BIM Task Group 2014b); and Government Soft Landing (BIM Task Group, 2014c). There are also industry frameworks such as Royal Institute of British Architects (RIBA) BIM Overlay (RIBA, 2012), and Royal Institution of Chartered Surveyors' (RICS) New Rules of Measurement (Wu, et al. 2014). Other sources of BIM knowledge and understanding come from case studies by industry professionals who give presentations on how BIM has been used in real-life projects. Depending on the programme and its focus, the acquisition of various practical skills is achieved through: data generation (e.g. modules dealing with 3D BIM design such as CVA019); data interoperability (e.g. IFC export in CVC045); model coordination and auditing (e.g. clash detection exercises in modules like CVB005 and CVB042); information management and collaboration through shared workspaces (e.g. use of Viewpoint 4Projects in modules like CVC045 and CVP335). Assessments of these skills are done via coursework done in groups which typically consist of a cohort of four or five students drawn from several programmes.

Across the School, a typical undergraduate student is expected to go through four stages of BIM education (Fig. 2). In the first year, his/her focus is on fundamental principles and concepts of BIM, awareness and basic use of basic BIM technologies and appreciation of collaboration and interoperability issues. The second year is dedicated to BIM protocols/standards, production of multi-disciplinary design information, coordination of models and generation of COBie datasets. In the third year, students are typically on industrial placement where they are expected to appreciate industry needs and utilization of BIM, fine-tuning of practical skills, engagement in professional development and getting first-hand experience of the opportunities and barriers to BIM adoption. A final year student is expected to apply BIM to his/her specialist area (including dissertation and final design projects), setting up and managing a common data environments (CDE) and acquire knowledge of strategic delivery of BIM for construction projects as well as its place in modern AEC organizations.

The core BIM technologies adopted by the School include: Revit suite of products for 3D BIM (Architecture, Structure and MEP); CSI-SAP2000 (Finite Element Analysis); Candy (costing); Navisworks and Solibri Model Checker (clash detection and auditing); as well as 4Projects (Viewpoint 4Projects, 2014) for CDE. In this regard, long-term partnerships with technology providers are essential. For the Civil Engineering (BEng/MEng) programmes accredited through the Joint Board of Moderators (JBM) framework, BIM was made a distinct 'thread' or 'theme' separate from existing JBM threads namely: Design, Health and Safety Risk Management and Sustainability. This enabled clarity in delivery of BIMLOs for these programmes, providing transparency to the accreditation body and industrial sponsors who have been keen to see BIM in the curriculum. Other programmes in the School have also strived to involve their accreditation bodies and industrial sponsors, and a BIM implementation group was also formed in the School.

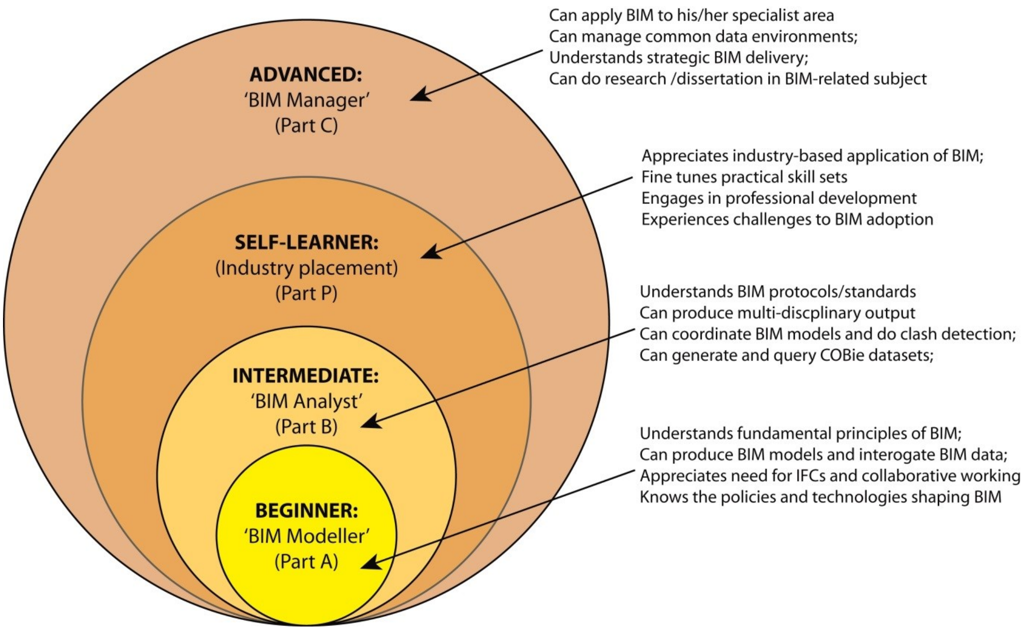

FIG. 2: Typical BIM capacity for an undergraduate student at Loughborough Univeristy: following the model of Barison and Santos, (2010a)

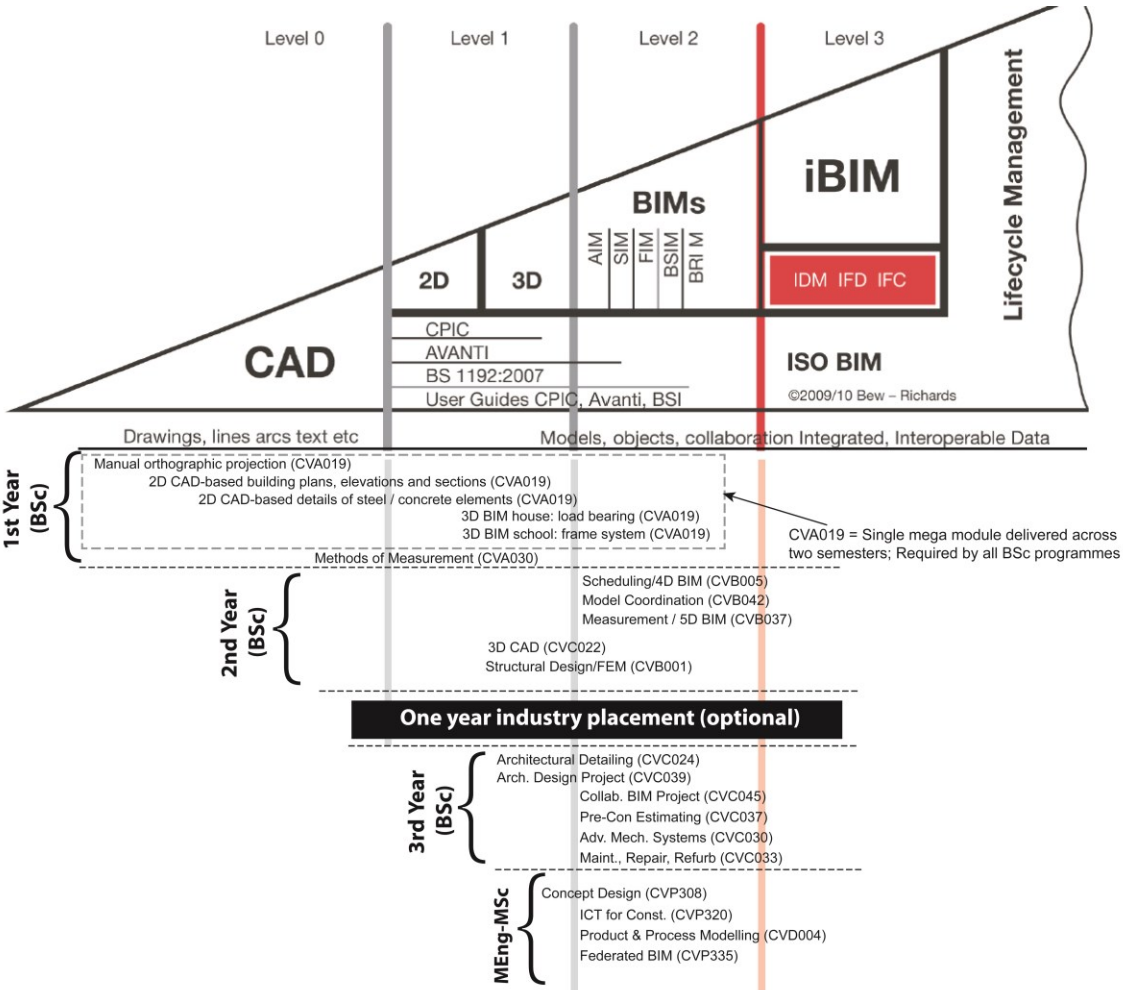

FIG. 3: Selected priority modules sequenced against the BIM Maturity Diagram (Source: Authors).

The priority modules have also been mapped against the BIM Maturity Diagram (Fig. 3). The intention is to demonstrate the progressive nature of the learning experience, particularly in the first year (BSc) where a single (two semester) module has learning outcomes that transcend Level 0, Level 1 and Level 2 BIM. From individually assessed manual orthographic projection and 2D CAD components in Semester 1, students conclude with a group-based design project (of a frame building) by end of Semester 2. A few second and third year BIM modules overlap Level 1 and Level 2 BIM outcomes, but this was inevitable given the embedded nature of the transformation exercise carried out. The long-term vision is to progressively de-emphasise Level 0 and Level 1 learning outcomes from these modules. Three brand new BIM modules had to be developed because their ILOs could either not be covered sufficiently in existing modules or their scope is based on entirely new concepts (e.g. clash detection/avoidance and use of common data environments).

3.2 Phase 2: Mission BIMpossible (a five-day workshop) and video tutorials

The goal of the second phase was to raise awareness amongst students, examine the practicalities of implementing various teaching resources as well as the appraise the requisite BIM technologies that would be taught. This phase (2013/14) began with a 5-day extra-curricular workshop on BIM. The workshop was aimed at final year students and those about to go on industrial placement, particularly because these students would miss parts of the planned changes. The workshop provided over 100 of these students with essential knowledge and skills in BIM, but it was also used to achieve other goals, such as evaluating various BIM software being considered for teaching, e.g. Navisworks vs. CATO for cost estimating / 5D BIM quantity takeoff, based on the following criteria: cost per annum; number of available licenses; compliance with new rules of measurement - NRM1 and NRM2 – standards; free personal/laptop installations for students; 3D model comparison / version checker; working with IFC data (import/export); working with COBie data (import/export); use of BIM Collaboration Format (BCF) messaging schema; availability of structured video tutorials; availability of standardised textbooks; free training for staff (up-skilling); and wide-scale adoption in AEC industry (UK). There were similar evaluations done for Navisworks vs. Solibri Model Checker (for 3D BIM coordination of multi-disciplinary models). The workshop provided opportunity to network with experts from industry for case studies (morning sessions) and site visits; and importantly to pilot the use of video tutorials (InfiniteSkills.com)[1] for acquisition of various modelling skills. Other freely available video resources were used such as those from B1M (B1M, 2015). Over Easter holidays, participating students were able to acquire enough practical skills (afternoon sessions) to collaboratively re-create the Sir Frank Gibb Building, a composite (steel and concrete) three-storey building using 3D and 4D BIM technology. This group work was supported by as-built CAD drawings and walk-through audits. Completion of this group modelling was a key pre-requisite for a student to obtain a certificate of attendance. The success of video tutorials during the workshop provided the confidence needed for their adoption as a formal teaching and learning resource in the School. The workshop also increased awareness and momentum about BIM in the School of Civil and Building Engineering. The confidence and employability of participating final year students was positively affected by the workshop, in agreement with findings by Eadie, et al. (2014) who carried out a study on BIM in a multi-disciplinary department.

Following the workshop, customised in-house video tutorials were produced for demonstrating the link between Revit and SAP2000. This was primarily because the Structural Engineering academics were not keen on switching to Robot (Autodesk's finite element analysis tool). Computer-based structural (FEA) analysis has always been taught in the School using SAP2000 and given the preference of module leaders to this application over Revit's Robot, reliability of data exchange between Revit and SAP2000 was identified as essential. Although CSI has documented the desired workflow and identified some issues between both applications (CSI, 2014), a student-led project funded by Engineering and Physical Sciences Research Council (EPSRC), was undertaken to explore the import/export process of data interoperability. The project investigated the quality and quantity of important data that would be transferred or lost between SAP2000 and Revit Structures using a plugin (CSiXRevit). The outcomes of the project included production of training materials (handouts and screen captured video tutorials) on best workflow practice for 3D BIM and FEA using Revit and SAP2000 respectively.

The data exchange exercise revealed that exporting models from one application to another was mostly flawless (for all section geometries and their materials) but naming of concrete and wood families within Revit needed to be done carefully for the export process to work well. Steel sections did not pose any such challenge but the orientation of some concrete elements could change when data was exported from SAP2000 to Revit. While this

[1] http://www.infiniteskills.com/

could easily be corrected in Revit, students might struggle to make multiple changes in complex structures that have many of such disoriented concrete elements. Gridlines were not exported/imported between these applications, but all loading-related information (i.e. load cases, combinations, line loads and point loads) were exported and imported flawlessly. This exercise was based on Revit 2014 and SAP2000 and similar tests have not been carried out on newer versions of these tools. There was a recommendation to consider switching from SAP2000 to ETABS (also by CSi) because the latter software was thought to integrate better with Revit.

The commercial and in-house videos can be consulted by students (e.g. during tutorials on desktop computers, or streamed into laptops and mobile devices) at their convenience. In the first year of implementation, data was collected on the opinion of students sampled from three programmes about these videos. Respondents were drawn from the following programmes: AEDM (Part A = 20% and Part B = 34%); CEM Part C (21%) and Civil/MEng Part D (23%). These students were targeted based on recently taken modules where substantial use of BIM technology was required. Students were asked to rank the helpfulness of the videos, their confidence after watching the videos as well as the range of topics covered and quality of streaming (Fig. 4).

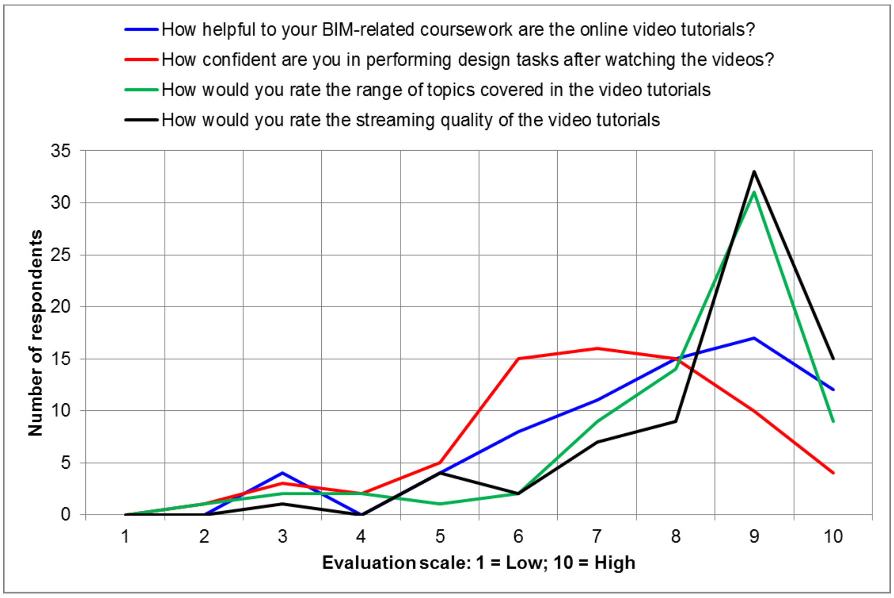

FIG. 4: Students’ evaluation of video tutorials based on recent coursework

Students surveyed stated that they would have to watch a specific video clip twice before properly understanding the task involved. Only 21% would watch a video clip once, but up to 24% will need to watch a video clip a few times. The MEng students were found to typically spend longer time (45 minutes to 1 hour) watching these videos than AEDM and CEM students (15 to 30 minutes), but this could be due to the complexity of the MEng coursework. Only 11% of students thought paper hand-outs were a better way to learn BIM software, 72% thought videos were better while 17% were undecided (Fig. 6). The use of video tutorials is still being monitored for long-term impact, but initial reports from a Staff Student Committee (SSC) meeting suggested that first year students might prefer to be given specific step-by-step handouts on paper. This is in contrast to final year students who (being more independent learners) asked for more videos (e.g. the Revit-SAP2000 data exchange videos) in the same meeting. There also appeared to be a general lack of awareness about which computer labs had BIM software installed on campus. This may however, be linked to the fact that 63% of respondents would rather watch the videos (and perhaps do their coursework) on personal laptops.

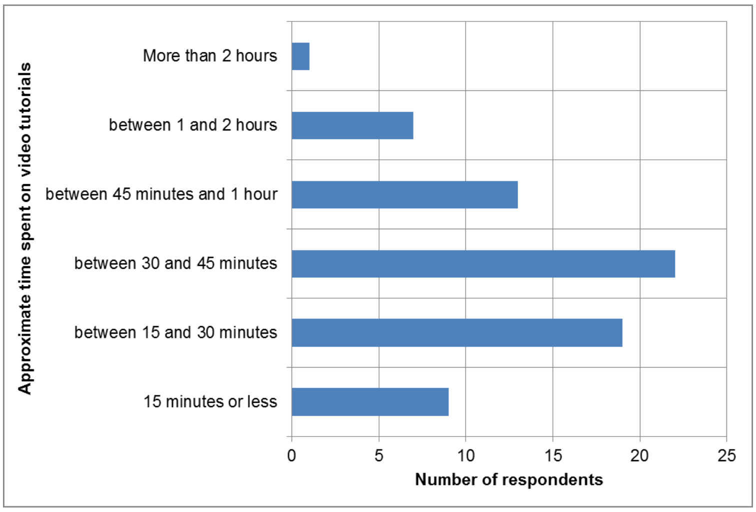

FIG. 5: Approximate time spent watching video tutorials per sitting

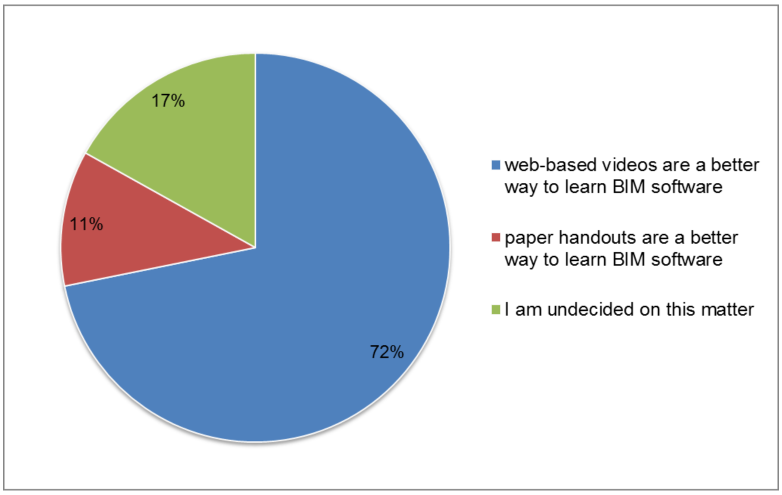

FIG 6.: Students opinion on preferred mode of learning BIM software

3.3 Phase 3: New BIM-dedicated modules

The third phase was dedicated to the creation of new BIM-dedicated modules that would cater for the specific aspects of BIM that could not be embedded, either due to tight curricula constraints or due to their uniqueness and required depth. For instance, the mandatory requirement to use common data environments was a specific learning outcome that was too complex to embed in an existing module. In addition, the coordination and auditing of BIM models was viewed as being too complicated to introduce in design modules. These are examples of specific requirements of Level 2 BIM that could not be integrated into existing modules without losing focus or sacrificing existing ILOs.

Three new modules were developed by the lead author for BSc and MSc programmes: a BSc module on coordination of 3D BIM where database driven auditing of BIM data as well as clash detection and clash avoidance are covered; and two (BSc and MSc) modules that combine digital (paperless) workflow with collaborative role-playing. The digital workflow modules are unique because their learning outcomes and assessments are aimed the multi-disciplinary use of common data environments for Level 2 BIM as required in the UK starting from 2016. The specific BIMLOs include: (1) acquiring the specific knowledge of the principles of Level 2 BIM; (2) adherence to BS1192-2007 and PAS1192-2 standards for file/folders and their naming conventions; (3) access rights and security of data; (4) quality of single and aggregated BIM models with IFC and COBie outputs; (5) team-based response to requested design changes and proper data archiving; (6) task delegation, quality of comments and discussions using communication tools within 4Projects.

These new modules were designed to be taken by a cohort of students drawn from various disciplines and in the case of CVC045, final year BSc students from AEDM, CMQS and MEng programmes were involved. Students from BSc Construction Engineering Management (CEM) are expected to join the module starting from its second year of offering (2015/16). For CVP335, the typical cohort of students comprises of international postgraduate students drawn from two MSc programmes: Construction Management and Construction Project Management. Although the aims were largely similar, the MSc version was pitched to higher intellectual and skill level. In both modules, the specifications have learning outcomes that seek to unify two types of BIM technologies: design content authoring applications (i.e. 3D, 4D and 5D BIM); and collaboration applications (4Projects). To simplify the design cycle, the coursework brief was based on re-modelling of a given commercial building design. Students had freedom to choose how 5D data was created: i.e. either through spreadsheets generated from Revit schedules or by exporting 3D models to CostX or Navisworks for automated take-off of quantities. Local students taking CVC045 were perceived to be better at role playing because of their different backgrounds (academic programmes) and their prior knowledge and skills in BIM. The international students largely comprised of students with Civil Engineering background as well as a handful of architects and quantity surveyors, often lacked fundamental BIM knowledge/skills particularly on 4D and 5D BIM. Hence, while the BSc students were able to focus on the process of arriving at a collaborative solution to the given design problem, the international students were generally interested in acquiring technology skills. In addition, the more mature international students tended to have some years of industry experience, compared to the undergraduate students who only had a year of industry placement experience. The learning experiences of both sets of students were therefore remarkably different.

Students typically worked in a team of four people (BSc) or five people (MSc) whereby three/four members produce the ‘raw’ design data (i.e. from sketches to final design with cost information). The fourth/fifth person plays the role of information (BIM) manager, who coordinates the flow of information and the aggregation of structural and architectural models in 4Projects. All other roles were self-assigned and negotiated by team members. Students were encouraged to patronise the UK’s National BIM Library (NBL, 2015) to download products and components that met specific client criteria and comply with National Building Specifications (NBS) standards. The production of custom families was discouraged in order to shift focus on existing content and collaborative working.

For CVC045, two responsible examiners played the role of clients, who are given read-only access to each team’s private workspace (Client Shared Folder) so that feedback and ‘requests for changes’ can be made at specific periods. The requests for changes are intended to make students to collaboratively produce revised versions of their models and to archive the superseded versions in accordance with PAS1192-2. Each team’s output was assessed electronically, through the common data environment and no paper-based submission is allowed. A written ‘Client report’ component requires students to reflect on their experience and demonstrate understanding of Level 2 BIM and any limitations of the common data environment or work flow processes. The BSc students were also asked to maintain a critical reflection diary using ‘wikipost’ through which they captured their collective experiences at the start and end of the module, as well as during a typical (face to face) team meeting.

The views of both sets of students were jointly captured in a web-based questionnaire survey and the qualitative data was analysed using Semantria, an Excel plugin for sentiment analysis (Semantria, 2015). From a total of 38 BSc/MEng and 25 MSc students only 24 students (38%) participated in this post-module survey: 12.5% for BSc AEDM; 16.7% for BSc CMQS; 29.2% for MEng Civil; 25% for MSc Construction Management; and 16.7% for MSc Construction Management. Data was extracted based on positive, neutral or negative sentiments associated with keywords, themes or user categories. The most common keywords (facets) that emerged include: Module, BIM, Knowledge and Software with mostly neutral connotations, except for knowledge which appeared six times with a strong positive facet, while two keywords (‘model’ and ‘able’) appeared in negative contexts (Table 4).
Some of the features students thought could help improve a CDE and (4Projects in particular) included:

- “viewing and mark up of 3D models / View and markup of Revit models in 4Projects”;
- “In Revit, you can 'Link Revit File' so that when changes are made to one model, these changes are automatically transferred to the other model. However, this does not happen with files saved in 4Projects. As such, an additional facility to enable this function would assist clients in achieving Level 3 BIM”. *Note: Level 3 BIM was only mentioned in brief as a concept during lectures.*

- “I would like to have an instant messaging functionality. also, whenever I login, I would want to see a notification pop up besides the folder where certain new activity happened instead of looking within folders and not knowing where the newly updated file is”.
- “advice within 4 projects as how to use it best to comply with BS 1192 and PAS 1192”;
- “Automate the CDE. Approved files in the WIP should automatically move to the shared folder with the click of a button Improvements in the communication tool. Design disciplines should be able to communicate between each other in a more flexible way like WhatsApp”.

TABLE 4: Sentiment analysis of the module feedback based on keywords (Facets)

Facet[1]	Facets Count	Positive Facets	Neutral Facets	Negative Facets	Attribute[2]	Attributes Count
module	15	1	14	0	BIM	2
BIM	7	1	6	0		
hand	7	0	7	0	final	2
knowledge	7	6	1	0		
software	6	1	5	0		
discipline	5	0	5	0		
file	5	0	5	0		
model	5	0	4	1		
able	4	0	3	1		
change	4	0	4	0		
Revit	4	1	3	0		
understand	4	0	4	0		
work	4	0	4	0		
design	3	0	3	0		
focus	3	0	3	0		

[1]Facet = keyword;
[2]Each attributes describe a corresponding facet

Some of the interesting themes that have emerged include: hands (on) experiences; job prospects; and moving files (Table 5).

TABLE 5: Themes extracted from survey data

Theme	Themes Count	Theme Sentiment Score
construction industry	5	0.1066
hand experiences	4	0.0951
job prospects	2	0.1915
Moving files	2	0.0000
structural engineer	2	0.1415

- “I think that instead of having a discussion forum, there should be an instant messaging service available. The discussion forum is good and we utilised it thoroughly but with 4Projects being as advanced as it is, I think a discussion forum is not the best form of communication because essentially it is the same as sending an email”.
- “There needs to be some form of data compression, especially on site where Internet speeds can be very slow, it often took 30 minutes to download a drawing schedule with the associated drawings slowing down my day to day productivity”.
- “To be able to incorporate a central file to enable more than one person to work on a model at any given time. I spend a few hours trying to achieve this for the module, but I believe 4Projects could not handle this”.

4 DISCUSSION, REFLECTIONS AND LESSONS LEARNED

The embedding of BIM led to the merger of modules which used to be taught alone, and perhaps not in the best possible sequence. A two-semester first year module (Fig. 3) has now combined graphic communications (manual and CAD) with aspects of building materials and construction systems at an introductory level. This seemed logical given that a BIM model contains: graphic information about 3D objects at various level of definitions, (LODs); the associated data on the objects such as materials, finishing, fire rating, u-values, etc.; as well as the construction assembly for the entire building (e.g. load bearing or frame systems). In other words, the learning and experience students used to get from three modules can now be acquired in one module which starts from basics (Level 0) to the peripheries of Level 2 BIM. A new module that was introduced to the AEDM students is 3D BIM Auditing and Coordination which has thrown challenges for teaching clash detection and/or clash avoidance. While there is wealth of knowledge and a lot of tools for clash detection, there is lack of adequate clarity and exemplars in literature about how clash avoidance can be achieved either as suggested by 'volume strategy' in PAS1192-2 (BSI, 2013), or by pull scheduling (Tommelein and Gholami, 2012). Nevertheless, the concept of clash avoidance is discussed in theory and with analogies on its application in manufacturing and retail industries. There is also a surprising turn of events with regards to dissertation or final year projects related to BIM. Azhar, et al. (2010) had argued that a BIM capstone thesis can provide useful knowledge and skills to undergraduate students. In the School's BSc programmes, there has been a decrease in the ratio of dissertation titles which were explicitly aimed at BIM (inferred by their titles) over three years. The decrement was from 9.5% in 2013/14 session to 5.5% in both 2014/15 and 2015/16 sessions. In the MSc programmes however, there has been a slight increase: from 17.6% in 2014/15 session to 21% in 2015/16 academic year.

For the modules aimed specifically at Level 2 BIM and CDE, the BSc students largely respected their roles in CVC045 while many MSc students were keen to learn or advance their 3D/4D/5D skills as well as explore the functionalities of 4Projects - sometimes to the detriment of their assigned roles. The international postgraduate students were also not as multi-disciplinary as the undergraduate cohort as they were largely comprised of Structural/Civil engineers. For CVC045, we were able to attract a balanced number of students from three different undergraduate AEC programmes. The use of digital processes and tools such as 4Projects has also raised awareness on the security or vulnerabilities of digital assets. Security consciousness and standard practices for IT-based working is therefore something universities have to consider exposing their students to, if they are to be well-prepared for a digital future. The release of PAS1192-5 (BSI, 2015) was intended to address this matter.

Feedback between teacher and student can be dynamic and the students of CVC045 and CVP335 made some interesting observations or 'wish list' of features they thought would improve 4Projects application. Some notable commentaries include: students wanting 4Projects to allow the "Linking of Revit files" (as done on desktop software) "for Level 3 BIM" and being able to "view and mark up of 3D models". There appears to be some impact of social media on how students prefer to use BIM technology, for example, a few students wanted "instant messaging functionality" within 4Projects. A previous study on remote modelling through desktop-sharing (Adamu, et al. 2015) found similar interests in the use of instant messaging for collaboration. Students in this case, argued that "a discussion forum is not the best form of communication" because essentially, "it is the same as sending an email". This is similar to another comment: "design disciplines should be able to communicate between each other in a more flexible way like WhatsApp" and we need "improvements in the communication tool". There was advice for 4Projects to also "Automate the CDE" so that "approved files in the WIP" (folder) "should automatically move to the shared folder with the click of a button" . There is perhaps a need for "4Projects (to guide users on) how to comply with folder structures of BS1192 and PAS1192-2"; as well as a "need for data compression, especially" due to "internet speeds".

From the teaching perspective, assessing students' work 4Projects has provoked a need to reflect on the appropriateness of traditional (paper based) feedback practices. When used appropriately, feedback improves student learning (Gibbs and Simpson, 2004; Black and William, 1998), but effective feedback is one that can be acted upon by students (Orsmond, et al. 2005). Irwin, et al. (2013) argued that students can benefit from guidance and tools which enable them to engage with the feedback and learn from it. The traditional approach to coursework feedback in the School is through written documentation accompanied by the assessed item (e.g. printed reports, CD/DVDs, etc.) with grades/marks. Verbal feedback is often used to supplement the written feedback. For CVC045 and CVP335 modules however, audio-visual feedback will in future, be included based on the success of a pilot study. In the absence of hard-copy submissions, screen capturing of each team's 4project workspace will be done using Camtasia Studio (Techsmith, 2015). The resulting multi-media video clip should make it easier and intuitive to either pinpoint and discuss errors or showcase/display exceptional outcomes in ways not previously possible with written documentation. The documents and model can be viewed and interrogated in detail with voice-over narrative. The resulting video clip(s) can be emailed to students (individually or in groups) or deposited in a secure downloadable webpage. Based on the piloted multi-media feedback, the time taken to assess student(s) work is longer (+ 15 minutes) since there is additional editing of the recorded video clip in Camtasia Studio. However, given the preliminary reaction of piloted students (who received such video clips) it would seem worthy of consideration.

Feedback from external examiners on CVC045/CVP335 has also been positive and although hard copy samples of (printable aspects of) students work were made for evaluation requirements, the examiners were also given access to 4Projects for first hand appraisal of students output. This is in the spirit of digital practices that BIM promotes. A recent JBM accreditation visit also complimented the progress made in adoption of BIM across the school.

In our experience, the choice and role of BIM technologies to be taught should not be underestimated because the production and sharing of object-oriented models through digital applications is critical to BIM, regardless of the country-specific protocols, policies and professional processes. Contextualising BIM within the wider sustainability agenda is also crucial for students to appreciate its broad potentials. Accreditation of AEC programmes will also need to be considered when reconciling BIM learning outcomes with the expectations of professional societies. In our case, merging graphics, design and construction modules into a single mega-module delivered across two semesters has the advantage of taking first year students on a 'BIM maturity journey', i.e. from individual learning of manual orthographic projection on paper (described as Level 0) to project-based group design of a frame system in 3D BIM (required for Level 2). As a result, the logistical and manpower implications of teaching three different modules were simplified leading to a more integrated learning experience for students. Further merging of modules is likely going to be explored in future. We also found that some BIM concepts and process might be better off taught in stand-alone dedicated modules and in the case study described, clash detection/avoidance and use of common data environments could not be embedded into any existing module.

In order to avoid overwhelming students with too many types of BIM technologies, it is helpful to adopt a restricted suite of applications, even though IFC concepts are stressed. For the School, one of the advantages of adopting Autodesk solutions lay in its popularity in the UK, where 66% of all CAD/BIM applications are based on its products (NBS, 2013). In addition, there is wide availability of teaching and learning resources (textbooks and video tutorials) on Autodesk applications. Sometimes, it can be helpful if not necessary to produce special purpose in-house video tutorials as in the case where a student-led project produced valuable workflow tutorials on data exchange between Revit and SAP2000. The availability of these supporting resources is important to academics. The use of video tutorials has in particular helped to deliver training on practical BIM skills to students and has eliminated the need for academics to develop and update hand-outs for computer lab sessions. Just as BIM is changing the professional AEC landscape, the electronic submissions of students in BIM-focused modules may dictate that assessment and feedback of BIM is done with audio-visual feedback methods.

5. CONCLUSIONS AND FUTURE OUTLOOK

Given its various interpretations, the teaching of BIM could be approached in many ways and there are a number of options that can be pursued as suggested in existing literature. This study is aimed at providing an overview of the implicit and explicit consequences of introducing BIM in a multi-disciplinary School. Guidance was sought from many sources and the most detailed studies on curricula implications of teaching BIM are based on North American institutions and their degree programmes. In this regard, distance collaboration by geographically dispersed North American undergraduate students has found similitude with MSc programmes in the UK that often have distance learning options. In the UK, teaching BIM ought to be shaped by Level 2 expectations and standards like BS1192-2007/PAS1192-series along with political deadlines for implementation of BIM for public projects have been crucial. Where multi-disciplinary degree programmes are offered in a School or Department, embedding BIM into ILOs of existing modules has advantages and opportunities. Loughborough University's School of Civil and Building Engineering adopted a three-year implementation plan, culminating with the deadline for Level 2 BIM in 2016 based on external pressures and internal ambitions. It is doubtful that any BIM-embedding template can be satisfy the unique ILO needs of different universities due to administrative, programme, curricula or cultural differences. However, the guidance provided by the BIM Academic Forum

(BAF) (HEA, 2013) is a good place for UK-based institutions to start. The 9th BIM Academic Symposium in the US has also embarked on a similar exercise, with a more global perspective. Loughborough University has benefitted significantly from such efforts. Concerning the individual module-level ILOs of BIM, unless a university decides to treat BIM as a postgraduate specialization, then it is probably desirable to infuse or map the BIM-specific learning outcomes with existing ILOs. It would be crucial to ensure that accreditation requirements are not sacrificed or compromised in the process.

The positive feedback on students' experiences and career prospects that began with the BIM workshop can only be sustained through regular monitoring and update of BIMLOs the curriculum. Such monitoring can however, be complicated by the continuously evolving BIM **technologies**. Nevertheless, the **policies** that govern BIM (at least Level 2 BIM in the UK) have largely remained consistent, even if the **processes** are also improving with the evolving technologies. The fast pace of technological growth implies that academics need to constantly re-appraise their BIMLOs for relevance to professional practices and industry needs.

Some academics might take a view that BIM '*should be taught by a BIM expert… on a specific BIM module*'. However, for proper integration into multiple AEC programmes, the case study described suggests no single person or module can satisfy the multi-faceted scope of BIM. It may be reasonable and practical to have a BIM champion coordinating the learning and teaching of BIM in order to ensure consistency, integration and perhaps oversight. BIM champions are also found in industry as exemplified by the GSL champion who oversees the transition from design to post-occupancy. All AEC academics should be capable of situating BIM in their courses/modules. This may require continuous learning and up-skilling without which, BIM capacity will remain in the hands of select few or worse, BIM will be viewed as 'something someone else should teach'. The inadequacy of examples of best practices from other institutions embarking on such wholesale changes to the taught components of their curriculum was an initial drawback, but this led to a bold and ambitious approach. The initial drawback was not been helped by the lack of specificity from accreditation bodies and professional societies, who simply "*want us to teach BIM*". For example, no accreditation body has specifically asked us to produce "Level 2 BIM graduates" but surely this is something the industry is working towards and any guidance would be helpful. There are also matters related to traditional accreditation requirements like the need for students to know how to 'draw' which ought to be replaced by ability to 'model' buildings and their components. In addition, although the BIM Academic Forum has brought together interest groups from many UK universities, it appears that the Government's priority has been to upskill industry professionals, while universities (and indeed diploma awarding colleges) have been left to educate the new generation of professionals in BIM. However, greater impact can be made if academia, industry and governments work together on a common agenda and understanding of the complex field of BIM in order to achieve mutually beneficial goals.

Based on our learning, six key considerations for a university thinking of embedding BIM are:

1. **Plan, phase and prioritise:** It is crucial to have a vision upon which a plan can be developed for bringing BIM into the curriculum. As part of the plan, a quality assurance (QA) framework should include the phase introduction of BIM over two to three years, depending on the size of a department/school or the number of modules identified for priority upgrade. In identifying these modules, extensive consultations (individually or groups) should be done for academics and sponsoring/partnering companies. New BIM-focused modules may be necessary to teach concepts and skills like coordination of multi-disciplinary 3D BIM models and role-playing within shared workspaces (CDE).

2. **Create an ecosystem of BIM technologies:** It would be helpful to identify, evaluate and select the technologies that would support the teaching of BIM processes. The barriers and pathways to data exchange should not be taken for granted. The two kinds of BIM technologies should be considered include: (a) software for authoring BIM content/data, i.e. for 3D, 4D and 5D BIM; and (b) collaborative working technologies that are helpful for role-playing often called shared workspaces or common data environments, e.g. Autodesk Vault; 4projects, Asite, etc.

3. **Identify learning outcomes and industry needs:** A matrix or map of BIM intended learning outcomes (BIMILOs) that would overlay existing learning outcomes should be created to: identify the changeable and

non-changeable outcomes; avoid duplication of BIMLOs; serve as an auditable and transparent toolkit for the entire process. The learning outcomes should be guided by national BIM standards and clarity of expectations should be sought from accreditation bodies and professional societies. In the UK for example, it is logical to teach BIM with the aim of producing graduates that are Level 2 BIM ready, but this cannot be achieved without engaging with industry. Regular guest lecturers from industry can help make this connection. The knowledge and skills required for Level 2 BIM should be taught in increasing complexity from first year to the point of graduation. In the case study described, modules were mapped against the BIM maturity diagram to provide a progressive learning experience from Level 0 to Level 2 BIM in a sequence starting from first year to final year (Fig. 3).

4. **Get teaching and administrative support:** It may be necessary to upskill a significant proportion of staff whose modules are identified for priority embedding. In the UK, the building research establishment (BRE) has some BIM training courses that can be helpful to academics. A BIM workshop can be held for staff and/or students on general contemporary topics or on specific professional themes. Appointing an ad-hoc BIM champion or BIM implementation group (with industry and student representatives) can be helpful for quality control (QC) and monitoring. It is important that the leadership of the department/school as well as higher level institutional management are interested and committed to the vision and planned changes.

5. **Develop student-centred learning methods:** Consider the potentials of using in-house or commercially made video tutorials. Ideally, these should be provided free of charge to staff and students. There are also plenty of free professionally made video series such as those made by The B1M, which can help provide additional learning content. Where BIM is considered at the postgraduate level, distance learning can be an attractive option due to its cost-effectiveness, the geographical spread of students and for purposes of implementing work-based learning. Another important learning approach is to create two-semester modules which could result from a merger of two or more single semester modules. This has potential to reduce the 'silo' approach to learning when students focus on specific modules or fail to transfer knowledge and skills into other modules.

6. **Form university coalitions for multi-disciplinary learning:** A department/school that does not offer multi-disciplinary programmes (for role-playing by students) should consider forming long-term coalition with other institutions that have complimentary programmes. The coalitions can jointly deliver modules/courses through cloud-based distance collaboration (see Poh, et al. 2014 and Becerik-Gerber, 2012). This approach can be challenging because it requires proper planning, management, alignment of learning outcomes, marking schemes, and even time zones. However, it can be enriching for the academics and students involved.

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