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BIM in Tertiary Construction Project Management Education: A Program Wide Strategy

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ABSTRACT
This paper reports on the ongoing research and development of teaching and learning supported by Building Information Modelling (BIM) in the undergraduate Construction Project Management (CPM) Program at the University of Technology Sydney (UTS). At its heart, BIM is used to facilitate a more integrated and visual mode of teaching. It provides a new basis for developing problem based learning – one that has the potential to allow students to aggregate their learning around a central project whilst allowing problems to be scaled at different levels of complexity. This approach aims to better integrate and link individual subjects together as well as improve the development of core student attributes such as communication, understanding, decision making, collaboration and information gathering skills; very much mimicking the ongoing BIM driven transformation happening in the industry. The BIM models aim to be regularly used in various formats as students progress through their undergraduate degree Program – and we adopt the term “vertical problems” to capture the way BIM models and problem based learning can be utilised throughout the Program. Here, lecturers are able to author ‘sub-plots’ that utilise BIM models in a way that best suits their specific subjects, e.g. cost, time, quality, sustainability subject areas. To this end, the paper reports on findings from the research, development and early implementation stages of a program wide teaching and learning proposition supported by BIM. This includes a typology that helps target varying degrees of BIM utilization and diffusion in given subjects and transitional requirements for both staff and students.

KEYWORDS
construction project management, building information modelling, project-based learning

INTRODUCTION
Designing and constructing the built environment is a creative and collaborative process; making it knowledge intensive and generative (Berente et al. 2010). Marred by tradition and intense fragmentation the AEC industry has relied on a process driven by two-dimensional paper based design documentation (Taylor and Bernstein 2009); a process
that largely flies in the face of creativity and collaboration. Recently realising the impediments of this traditional approach - characterised by a 20% decline in productivity compared to other industries and approximately 30 % waste in processes and delivery methods (Gallaher et al. 2004) - the industry has slowly started embracing advanced digital technologies such as those that support 3D object based Building Information Modelling (BIM).

The benefits to industry that BIM technology offers have been well documented in the literature (Eastman et al. 2008, McGraw Hill 2007, 2009, BEIIC Report 2010), including: (1) improved information sharing; (2) time and cost savings that can be directly translated into productivity gains; (3) improved quality; (4) greater transparency and accountability in decision making; (5) increased sustainability; and (6) labour market improvements. International studies indicate that BIM adoption is likely to accelerate over the next few years (McGraw Hill 2009, Holness 2008). In the US in 2009 it was reported that 50% of the industry was using BIM products; representing a 75% increase in two years (Young et al. 2009). Though uptake in Australia is slower, the same trends are expected to gain traction. From an educational perspective it is proposed that there is a growing need for universities to provide new professionals with appropriate BIM-related skills.

In exploring the nature of this proposition in industry, much research has been dedicated to the identification of barriers to the adoption of BIM (Lamb et al. 2010, Becerik-Gerber and Rice 2010, Taylor and Bernstein 2010, McGraw Hill 2008). There are a range of structural, cultural and technological challenges. Such issues are symptomatic of a more general lack of integration between data sets generated by the various AEC disciplines. This has been identified to be a major cost factor for the construction industry through the introduction of inefficiencies, errors and lost opportunity (Gallaher, et al. 2004). Further to this, the AEC Industry is broadly organised into professional silos which does not assist the aim of obtaining improved efficiencies through improved collaboration. It is therefore also proposed that BIM supported education, understood as a collaborative process - not a technology, has the potential to gradually evolve the industry towards improved efficiency, decision making ability and value generation through a more integrated and collaborative approach.

**CONSTRUCTION PROJECT MANAGEMENT LEARNING ENVIRONMENTS**

In addressing the above propositions, the present approach to education within most design, building and construction schools reflects the very same fragmentation which has been identified as problematic in the context of the industry. Still further, many tertiary undergraduate construction project management programs are based around teaching
principles and practices that accentuate defined streams of study. Though common and used for a wide variety of reasons, such programs lack the extent to which problem based learning can be applied. Subsequently, construction students do not necessarily recognise how the separate streams of knowledge fit together at the time they undertake individual subjects. In a combined sense, there is limited understanding about how each respective subject intrinsically contributes to construction management or how construction management contributes to the overall objectives of the built environment. This remained a dormant problem as long as the industry was not awakened to this fragmentation. Now as the industry is moving towards more collaborative and integrative paradigms the education sector needs to start shaping the “pipeline” of graduates that can better fit the changing industry.

Delivery and assessment in this discipline has traditionally been driven by didactic, “chalk and talk” teaching which has not necessarily led to appropriate knowledge transfer and learning outcomes. At its core, many traditional approaches to setting assessments in construction management programs (for example, exams, essays, reports, calculation sheets) involve isolated, static and individual learning, often seen as ‘boring’ by students or of limited relevance to their intended career paths. As a result, these approaches to assessment tend to only attract minimal student motivation and therefore limited learning potential for they do not involve students in the complex dynamics of running real projects or the need to make decisions involving potentially conflicting variables, even though that is what they will likely face once they start working in industry.

**BIM-SUPPORTED TEACHING AND LEARNING AT UTS**

Motivated by its potential, UTS has embarked on an evolution of its teaching and learning model in the School of the Built Environment. The School provides a mix of construction project management, property economics, planning, property development and project management programmes. Given this vertically integrated set of Built Environment disciplines, the School’s aims are predicated by the need to understand and assist the way different disciplinary values are successfully resolved and transformed into physically realised value (Jupp et al. 2010). The information modelling, visualisation and collaborative abilities of BIM technologies provide a basis for achieving this end. Here it is considered that curriculum development be based on an understanding that BIM is not a separate set of technologies across design, planning, property economics, and construction project management, but a means of facilitating integrated decision-support systems and reflecting its networked nature.

Drawing from experience in implementing sustainability across programs globally the program at UTS used a hybrid model. Two distinct models of implementing sustainability
in the curriculum exist. Originally propagated by Hungerford (Hungerford et al. 1994), these models have been adopted and adapted by many authors and institutions. The Hugerford’s Diffusion Model or Standalone Model (Majumdar 2007, Hungenford et al 1994) simply takes the sustainability topics from various subject areas and creates a standalone sustainability course that diffuses the ideas into one common subject. In Hugerford’s Infusion Model sustainability topics are embedded into the various conceptual subjects without the creation of a new standalone course on sustainability. The pros and cons of both these approaches have been documented in the literature (Peet et al. 2004, Wals and Jickling 2003, Ceulemans, and De Prins 2009). We adopted a hybrid approach. A layer of diffused subjects primarily focusing upon BIM were created. Surrounded by this layer of subjects, core subjects received an infusion of BIM concepts. Figure 1 shows three models, (a) infusion model, (b) diffusion model, and (c) the hybrid model adopted at UTS. For example, as shown in Figure 1, the Digital Design and Construction sequence of subjects are primarily the diffused content pertaining to BIM. Once students have gained the explicit knowledge of BIM they are then exposed to the core subjects in which issues of digital modelling, collaboration and integration are addressed within the context of the subject.

The newly re-structured Construction Project Management Program has been targeted by the School as the first to implement BIM-supported teaching and learning. This paper therefore takes a case study approach (Yin 1994) to reporting the core reasoning and implementation involved in this endeavour. It aims to assist other programs interested in adopting similar modes of teaching and learning. Some key aspects of this approach include the design of learning opportunities so as to:

1. Take greater advantage of problem based learning within stream based construction project management programs;
2. Create a more visually oriented means of teaching and learning;
3. Develop students’ capability to work in dynamic industry knowledge networks;
4. Intrinsically engage students in the learning process;
5. Improve linkage between separate subjects and assessment tasks, thereby taking a more integrated and developmental approach to learning and assessment, and
6. Promote a more holistic understanding of issues involved in building projects.
Figure 1 – Hybrid model for UTS CPM program

(a) Infusion Model

(b) Diffusion Model

(c) Hybrid Model Used at UTS
The case for BIM-supported learning in construction project management

From a learning theory perspective, BIM engenders visual-spatial learning and a common basis for collaborating among student-to-teacher and student-to-student groups. However of note, visual-spatial learning differs from the more common form of hearing and language based learning known as auditory-sequential learning. Those partial to auditory-sequential learning respond to “progression from simple to complex, organisation of information, and linear deductive reasoning” (Gifted & Creative Services Australia 2007). This is still the predominant mode of learning in construction project management programs; however it does not necessarily work well for visual-spatial learners - learners who are present across the built environment disciplines. These learners by definition think in terms of visualisation, images and an awareness of space - they are able to simultaneously process concepts, apply inductive reasoning, and generate ideas by combining existing facts - a benefit of this is that learning is said to be permanent once the student is able to fit the information into the context of what they already know (Gifted and Creative Services Australia 2007). Gareau and Guo (2009) point out that this form of learning is believed to be eight times faster than auditory-sequential learning.

The fit between BIM and construction management pedagogical objectives is obvious - BIM utilises three-dimensional (3D), real-time, dynamic modelling softwares to construct a building virtually, thereby leveraging opportunities to understand the likes of productivity and efficiency in design, construction and operation (Holness 2008). The virtual building model is called a rich model because all objects in it have properties and relationships, and based on this, useful information can be derived by simulations or calculations using the model data. This is much more advanced than 2D CAD which is limited to independent plans, sections and elevations and limited graphical entities such as lines, arcs circles, etc. In contrast, the intelligent semantic objects of BIM models provide objects defined in the terms of building components and systems e.g., spaces, walls, beams, piles etc. The key generic attributes of BIM models are (BEIIC Report 2010):

- **Robust geometry** - objects described by faithful and accurate geometry, that is measurable
- **Comprehensive and extensible object properties that expand the meaning of the object** - any object in the model has some pre-defined properties, or the Industry Foundation Class (IFC) specification allows for any number of user or project specific properties.
Semantic richness - the model provides for many types of relationships that can be accessed for analysis and simulation e.g. is-contained-in, is-related-to, is-part-of etc.

Integrated information - the model holds all information in a single repository ensuring consistency, accuracy and accessibility of data

Life cycle support - the model definition supports data over facility life cycle, from conception to demolition, extending current emphasis on design and construction phase.

Given the above, buildings can be rigorously analysed and simulations can be performed quickly, thus moving construction project management students from abstract concepts to more applied knowledge. Another of the main benefits is the potential for more effective teaching, as information is more easily shared, can be value-added and reused. Other specific benefits that BIM offers to education include engagement and exploration of teamwork, collaboration and continuity across multiple construction stages; defining responsibility, ownership and exchange of information; exploration of design management tasks and core tasks such as construction scheduling, trade coordination, assembly and manufacture and cost and life-cycle analysis.

IMPLEMENTATION STRATEGY

In acting on the potential benefits of BIM in education, there is a continuum that must be considered: at one end is the introduction of small elements of BIM through discrete subjects that operate at the periphery of existing programs; at the other end is the fully integrated BIM enabled degree involving students in the resolution of problems through close to real world experience. As mentioned previously, we support the latter but from an implementation point of view the critical challenge that remains is how to make this significant shift, whilst still providing a high quality of educational program during the change.

Managing risk in BIM-supported teaching and learning

The temptation may be to implement BIM technology as a heavy handed symbol of change. From a risk management point of view, there is much to be considered here:

- Technology failures and glitches.
- Over-worked/ over-stressed academics.
- Poor student experiences as they feel like guinea pigs while staff build new competencies and problem-shoot implementation issues.
- Maintaining political support for the program if things go wrong.
- Funding capital infrastructure to enable the use of BIM in education.
• Threat to accreditation if student experiences are inadequate.
• Ability to source and train appropriate staff.

Thus, the counter argument to a heavy handed approach is that a lower risk approach would enable some of the softer issues to be addressed before significant technological implementation. A critical challenge here continues to be the level of comfort among staff where moving from a more traditional didactic education model to a digitally mediated problem based learning model. The movement from one to the other is substantial, but can be done across the existing curriculum with staged use of technology.

In the Construction Project Management Program targeted staff took responsibility for convening and maintaining an overview of how different subject areas integrated BIM in relation to teaching modes, content and digital capacity. The movement from one to the other is substantial, but can be done across the existing curriculum with staged use of technology.

Managing levels of implementation

It is worth highlighting a more conceptual understanding of how BIM-supported teaching and learning has and will continue to take place in terms of a program wider implementation. A structured approach was considered important in order to avoid unnecessary, undirected, or premature use of BIM technologies. There was also the practical need to consider different staff capabilities and motivations for utilising BIM (including differences between permanent versus sessional staff, and early versus late adopters of BIM systems). For these reasons, we have developed a simple typology for BIM-supported teaching and learning that defines different levels of implementation.

The typology shown in Table 1 was applied to all subjects in the program – where the School’s staff were able to nominate which level was appropriate for their subject in the coming year (2011) and potential options for upgrade in subsequent years. Here, it is pertinent to note that while the ‘instructive’ level may, by necessity, dominate first year subjects in a program, and the ‘immersive’ level may dominate in latter year subjects, it is probably better to think in terms of the chosen classification representing a bias (i.e. “mainly instructive” or “mainly immersive”) rather than a strict delineation of the approach taken.

In addition to teaching staff, a number of other actors were identified as being integral to the implementation of BIM-supported teaching and learning in the Program including:
• **Technical support personnel:** responsible for the maintenance of the hardware and software associated with the BIM. This potentially carries significant implications for cost depending on the level of implementation across the Program.

• **Administrative staff:** Although unlikely to have much impact on the detail of the program, they will need to field information requests and have an understanding of responsibilities within its operation.

• **External actors:** Accrediting bodies and other regulatory agencies will also have an environmental influence on the adoption of BIM within the course.

Table 1 – Levels of implementing BIM-supported teaching and learning

<table>
<thead>
<tr>
<th>Implementation Level</th>
<th>Purpose and mode of delivery</th>
<th>Implications for T&amp;L</th>
<th>Implementation issues</th>
</tr>
</thead>
</table>
| Instructive          | ● Basic competency in BIM to establish overall basis for other subjects.  
● Subjects/lessons/tutorials/self learning to develop competency in targeted applications  
● Targeted at the front end of the entire program.  
● Important to separate model interaction skills (low) from model authorship skills (high) | ● Lecturers who have a core interest in BIM technology to teach and or supervise these subjects.  
● Finer student skill development supported by on-line tutorials, forum groups and self-learning | ● Strong teacher knowledge of targeted applications  
● Tutors required to assist instruction  
● Program decisions about how much student and staff self learning is realistic |
| Illustrative         | ● BIM is used as a visually descriptive means of assisting in teaching traditional construction management subjects.  
● Best applied to subjects which benefit from constant graphic reference to a 3D building model such as construction technology and site establishment.  
● Also useful in design related subjects such as structural appreciation and environmental design.  
● Students can easily use the same model as the one that lecturer is using. | ● Lecturers who teach traditional construction subjects should where appropriate.  
- Use BIM to add a visual dimension to the way they teach the subject.  
- Only minor skills required as staff/students can download free “BIM viewer software” to visually manipulate models  
- Use the same BIM in different subjects so that students build on their aggregated knowledge | ● Only low lecturer software knowledge required  
● Only low student software knowledge required  
● As a minimum, most subjects should be able to adopt this level of BIM usage |
| Immersive            | ● Staff set problems and students are actively and experientially involved in using BIM as a tool to assist problem solving. | ● Lecturers who teach traditional construction subjects should develop parallel interest in utilising BIM systems to extend | ● High teacher software knowledge required  
● High student software |
• Less lecture, more problem based learning.
• Initial subjects should include time, cost, sustainable design.

<table>
<thead>
<tr>
<th></th>
<th>their ability to teach and involve students using an immersive studio approach.</th>
<th>knowledge required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Lecturers should where appropriate:</td>
<td>• High levels of tutor assistance likely</td>
</tr>
<tr>
<td></td>
<td>- Specify project sub-plots and problems for subjects (e.g. cost, time, quality) that involve students in using BIM to obtain a solution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Merge traditional and BIM based methods for best overall affect</td>
<td></td>
</tr>
</tbody>
</table>

Mapping subject areas to implementation levels

In exploring the Construction Project Management Program and mapping subject types to the levels of implementation in Table 1, the challenge for the Program was to develop and adapt it to the unique set of capabilities of the staff and student body. From this perspective, three main types of subjects were characterised:

• Technical/Science-based subject areas
• Analytical/Measurement-based subject areas
• Non-technical, human factors/organisational/process/policy subject areas

Table 2 presents an example relationship matrix illustrating the links between these two aspects of ongoing curriculum development at the School.

Table 2 – Relationship matrix linking types of subjects with levels of implementation

<table>
<thead>
<tr>
<th></th>
<th>Instructive</th>
<th>Illustrative</th>
<th>Immersive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical/Science-Based</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analytical/Measurement-Based</td>
<td>X</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Non-technical, including human factors/organisational/process</td>
<td>X</td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

The relationship matrix was used to harness lecturers working in the same types of subjects to further develop the way they utilised BIM for teaching purposes. For example:

• Technical/Science-based subject areas – curriculum development is currently focusing on the use of BIM technologies and models as graphical teaching aids. e.g., the School’s suite of Construction Technology subjects (1-4).
• Analytical/ Measurement-based subject areas – curriculum development is currently focusing on the utilisation of BIM technologies and processes for the execution of domain specific activities. e.g., cost and time management subjects.
• Non-technical/ human factors/ organisational/ policy subjects – curriculum development is currently focusing on the use of BIM technologies and processes in a studio environment using problem-based learning as the foundation to help students understand BIM as a system in construction and aspects of interdisciplinary collaboration and project integration. e.g. Project Management Integration subjects.

This simple approach was designed to promote the new direction of teaching and learning to staff within the School and establish a basis for communication between lecturers in a way that was mutually beneficial. To develop these linkages further the School has begun the implementation of two important concepts: project-based learning and ‘vertical problems’.

PROJECT-BASED LEARNING AND ‘VERTICAL PROBLEMS’ CONCEPT

In responding to the above, it was considered appropriate to adopt a more specific version of problem based learning which is particularly relevant too building and construction known as “project-based learning” (PBL). Thomas defines PBL as:

‘Project-based learning is a model that organizes learning around projects. ... projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentation’

(Thomas 2000).

Thomas (2000) goes on to specify the five criteria for effective PBL. De Urena et al. (2003) summarise his position.

‘First, PBL projects are central, not peripheral to the curriculum, so PBL must be a decision of the whole institution, not just some teachers experiencing on their own. Second, PBL projects are focused on questions or problems that drive students to encounter (and struggle with) the central concepts and principles of a discipline. Third, projects involve students in a constructive investigation. New knowledge is necessary to solve the problem (not only to use the things already learnt), so students are responsible for reaching new skills and understandings. Fourth, Projects are student-driven to some significant degree and teachers must renounce continuous supervision and leave some freedom and autonomy to the
student to lead their own work. Finally, Projects must be realistic, not school like.
If projects are real, students will be deeply involved and their results will be better
as they feel solving a real problem’. (de Ureña et al. 2003)

In the context of current construction project management programs PBL represents a
radical departure from conventional discipline specific approaches to teaching and
learning, which involves teaching staff in the use of a very different set of skills and
practices. PBL implies a shift to a student focused approach to learning and is generally
framed by constructivist principles of learning. In the case of BIM-supported teaching
and learning, adoption at an individual course level will not place PBL at the centre of the
curriculum and will likely lead to a fragmented and inconsistent approach as different
lecturers, with different backgrounds and teaching and learning approaches, apply
potentially contradictory methods. Subsequently, a program wide approach offers greater
potential.

To address this, we introduce the concept of ‘vertical problems’ as a means of obtaining
program wide coverage of BIM-supported PBL. The concept utilises the virtual building
model as the problem’s core so as to provide a multi-layered vehicle for student and
teacher engagement that can be progressively used from early to latter years of learning.
At all levels, the base problem embedded in pre-made BIM models provides a key
descriptive theme to begin the storey line, conveyed using a BIM model that may
describe a number of standard building typologies such as a residential dwelling, a low
rise apartment building, an industrial warehouse and a high rise building; the logic of the
approach is shown in Figure 2.

![Figure 2 – Vertical problems across a four-year Construction Project Management
program](image-url)
The virtual building model and its site provides the context of the problem and establishes the framework of the vertical problem for ‘sub-plots’ to be built in to, so that specific PBL situations are defined to suit areas of learning – be it construction technology, structures, quantity take-off, risk management, project planning and so on. Subplots can therefore be developed to help in-class teaching and/or for assessment. Lecturers of individual subjects and subject areas therefore have considerable control over content, and simply make use of the vertical problem as a means of conveying the principles and methods in an integrated and/or visually applied way.

In this way, students are able to enhance their understanding (and that of others) by solving project based activities that require detailed insight and analysis; hence students in the early years of their degree can gradually build their knowledge under the auspices of a common theme, and in latter years by embedding their learning in multidimensional, practice based problems that capture the complexities of dynamic systems in the Built Environment.

**STATUS OF BIM-SUPPORTED T&L AT THE SCHOOL**

Currently the Construction Project Management degree offers six subjects (approximately 20% of the Program) that utilise BIM-supported teaching and learning to various degrees. These subjects can be categorised into two of the previously discussed modes of teaching and learning - instructive and immersive, and are shown in Table 3.

**Table 3 – CPM subject offerings at UTS utilising BIM-supported teaching and learning approach**

<table>
<thead>
<tr>
<th>Instructive</th>
<th>Immersive</th>
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<tbody>
<tr>
<td>• Digital Built Environment (1st Year)</td>
<td>• Digital Design &amp; Construction 1&amp;2 (2nd &amp; 4th Year)</td>
</tr>
<tr>
<td>• Design Team Management (3rd Year)</td>
<td>• Time and Quality Management (2nd Year)</td>
</tr>
<tr>
<td>• Cost Management 2, Estimation (3rd Year)</td>
<td>• Cost Management 3, Cost Planning (3rd Year)</td>
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</table>

**Case study of BIM-supported teaching and learning**

To provide greater insight into the way BIM is being utilised in the Program’s approach to teaching and learning as well as the way BIM systems are taught, this section provides a more detailed view of the subject ‘Digital Design and Construction 2’ – taught as a project based learning studio in 2010. The class introduced a variety of BIM technologies and processes to support students in their efforts to integrate three keys aspects of project management: scope, team collaboration and management, and project planning. By simulating a construction project that closely resembled realistic conditions, students
were asked to explore current technological possibilities for integrating project management data by learning the functionality of BIM software applications and applying them when executing a variety of management tasks.

During the Autumn 2010 class, students successfully undertook digital design and construction management tasks for a four storey open-plan office building, including a lower level basement, located in North Ryde, Sydney. A detailed brief was provided and the project was in close proximity to the University which allowed students to visit the building site to obtain location-specific site information. The lecturer provided the students with the complete set of design and bid documents for this project as the information basis for generating the 3D model and subsequent management tasks. Therefore, we can state that the class project resembled real-world conditions closely.

Overall 39 Construction Project Management and three Architectural Design undergraduate students participated in the class. For the course assignment, the lecturer divided students into seven groups of students. In the class, the lecturer introduced the students to the concept of BIM and tutorials were provided in a number of software applications, with the onus put on the student groups to continue the development of their skills. Design and construction modelling exercises were undertaken using digital teamwork functionalities and model serving capabilities. Following this a number of BIM-based project management applications were introduced. Students were exposed to a variety of software as shown in Table 4, and with the exception of Cost X and Vico Estimator all software listed was utilised in the studio.

<table>
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<tbody>
<tr>
<td>2010 Seven</td>
<td>ArchiCAD 13 Project Team</td>
<td>ArchiCAD 13 Vico Constructor</td>
<td>MS Project Vico Control 2009</td>
<td>Cost X Vico Estimator</td>
<td>Solibri Viewer Solibri Model Checker</td>
<td>ACONEX</td>
</tr>
</tbody>
</table>

At the beginning of each week, the lecturer addressed various aspects of BIM, integrated project delivery, and BIM management during a one hour lecture prior to studio commencement. These lectures presented students with concepts, theories and materials covering BIM in relation to people, processes and technologies, and was structured according to four themes: (1) BIM and preconstruction, (2) BIM and design management, (3) BIM and construction, and (4) BIM and updates.
In the first three weeks of the course, studio sessions were used to provide individual support in generating 3D building models and researching the building’s construction sequence and scheduling (4D) from project drawings and specifications. Once the basic virtual building model had been produced and familiarity with the various software applications was acquired, studio sessions were used to undertake three separate tasks. In the remaining ten week program, students undertook three phases of exercises: *Phase 1* - defining project scope, *Phase 2* - undertaking a series of management tasks that characterise digital collaboration and coordination, and *Phase 3* - developing an integrated project plan.

In the first phase, each student group was required to define the project scope using the information from the 3D and 4D information modelling stage. The construction project scope defined by student groups described the 3D items and structures that would be built and the expected roles of everyone involved with the project. Each group’s construction project scope also defined the construction delivery method and provided time estimates for project completion. Group’s selected a hierarchical modelling approach by dividing the different components of the building into a product breakdown structure (PBS). Groups then assigned responsibilities between members to digitally model the virtual building based on the architectural and structural components of the PBS. All groups reported struggles with missing details in the 2D drawings and lack of specification details. This forced groups to make assumptions about project scope and needed to compensate for missing information in order to generate a complete virtual building model.

In the series of exercises that were targeted in the second phase – typical BIM management tasks – students undertook a number of exercises in digital model integration and coordination using Solibri Viewer and Solibri Model Checker. One example of these digital management tasks included clash detection, where student groups were given an industry pre-made 3D MEP model to embed in their 3D building models. The MEP model contained over 400 legitimate and often occurring clashes. Student examples are illustrated in Figure 3.
Here, groups were required to represent the interests of five disciplines in structured review design meetings, including architectural, structural, building services, quantity surveying, and construction. In these simulated review meetings role playing was introduced to explore these diverse interests. Review meetings were held in a round table format using digital projections of the virtual building model and were video recorded for assessment as shown in Figure 4.

The main objective of the final phase – the development of an integrated project plan – was to assess how well the students could integrate project management concepts covered across their four year program into an overall project plan using digital technologies. In this task, student groups were required to optimise for workflow, resource levelling, and duration. They iterated through these three optimisation foci until changes were negligible. Without the virtual building model the connection between the quantities and the schedule and from the schedule to the costs would have been lost, and the students would not have gained as holistic an understanding of the scope, time, and cost relations.
Furthermore, in studio sessions tutors were able to challenge students by testing how well each group was able to quickly change any of the integrated aspects of scope, or time and determine the effects of changes on one of these aspects on the other two.

At the end of the class, the students incorporated a number of changes into their final building models (based on outcomes of Phase 2) and to their integrated project plans. In summary, each of the seven groups was able to cover all three phases and most significantly develop an integrated project plan within the class duration of thirteen weeks. It is questionable whether the students would have been able to generate the integrated project plan without the help of BIM-based applications in the first place.

Students reported that modelling the project in BIM helped them to understand the important technical and geometric aspects of the building. This hints towards the possibility that the structured way of modelling a project using BIM systems supported students with their efforts to understand project drawings and specification at the start of a class project.

**DISCUSSION AND RECOMMENDATIONS**

BIM is as much about people and process as it is about technology. Therefore, BIM in teaching and learning should ensure these three pillars—people, process and technology—are appropriately and strategically considered in a program wide adoption.

Of note, its key benefits revolve around the ability to provide a more integrated approach to managing project variables, a more visual basis for understanding and analysis, and the related ability for visual content to provide a common, collaborative and dynamic basis for dialogue between teacher-student and student-student.

We envision that for undergraduate construction project management programs, the PBL approach discussed in this paper is a suitable means to embrace the three pillars of people, process and technology in teaching, because PBL enables students to contextualise theoretical and practical issues during their studies. In general, PBL uses the project as a means of requiring students’ demonstrate inquiry, research and information synthesis in a meaningful way, thereby developing understanding, knowledge and analytical abilities. The concept of vertical problems is thought to be the best way of implementing PBL in programs that are stream based – as is the case in the Construction Project Management Program at UTS. Here, vertical problems act as a means of binding individual subjects taught throughout the degree. With the new opportunities that 3D, 4D and 5D digital modelling offers, staff are now able to flexibly write their own “sub-plots” that tap into vertical problems in a way that enhances rather than destabilises existing subject content.
In meeting the above initiatives there is a parallel need for staff buy-in, particularly in the use of BIM tools. Here, some staff represent early adopters but others are not as quick in taking up the technology. A pathway forward – and the one used at UTS - is for the Construction Management Program to provide a structured approach that utilises different levels of implementation across instructive, illustrative and immersive levels. In this way, subject lecturers identify their chosen level of implementation and write “sub-plots” to operationalize an approach suitable to their competencies. Those working in specific subjects areas (e.g. technical, science-based, measurement, analytical, etc.) are encouraged to work in groups to aid systematic adoption of BIM within a given area. As this degree of collaboration matures, the potential emerges to provide harmony, learning efficiency and removal of unwanted overlaps between subject areas and spend more time exploring complexities of dynamic systems in the Built Environment.

Whilst the above concepts and steps are currently in process within the School of the Built Environment, there is still a considerable path to travel regarding Program wide implementation of BIM-supported teaching and learning. Of note, this will include the need to systematically monitor and evaluate teaching and learning outcomes.

REFERENCES


