RESEARCH ARTICLE

Building Information Modelling in Tertiary Construction Project Management Education: A Programme-wide Implementation Strategy

Perry Forsythe, Julie Jupp & Anil Sawhney

School of the Built Environment, University of Technology Sydney, Australia

Corresponding author:
Perry Forsythe, School of the Built Environment, University of Technology Sydney, Australia
Email: Perry.Forsythe@uts.edu.au

Abstract

This paper reports on the on-going development of teaching and learning supported by Building Information Modelling (BIM) in the undergraduate Construction Project Management Programme at the University of Technology Sydney. BIM is a model-driven approach to designing, constructing, operating and maintaining buildings and civil engineering facilities. The model that forms the core of the BIM approach is a smart, shared and computable three-dimensional model of the building or the civil engineering facility. At its heart, BIM and Virtual Construction Models (VCMs) are used to facilitate a more integrated and visual mode of teaching. The approach 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 enabling 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 on-going technology driven transformation happening in industry. The VCMs aim to be regularly used in various formats as students progress through their undergraduate degree programme – and we adopt the term 'vertical problems' to capture the way models and problem based learning are being utilised, where staff author 'sub-plots' that utilise information models in a way that best suits their specific subjects, e.g. cost, time, quality, sustainability subject areas. To this end, the article reports on findings from the research, development and early implementation stages of a programme-wide teaching and learning proposition supported by BIM. This includes a typology that helps target varying degrees of model utilisation and diffusion in given subjects and transitional requirements for both staff and students.

Keywords: construction project management, building information modelling, virtual construction models, project based learning

Introduction to Construction Project Management Education

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 architecture, engineering and construction (AEC) industry has relied on a process driven by two-dimensional (2D) paper based design documentation (Taylor & 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 three-dimensional (3D) object based Building Information Modelling (BIM). BIM is a model-driven approach to designing, constructing, operating and maintaining buildings and civil engineering facilities. The model that forms the core of the BIM approach is a smart, shared and computable 3D model of the building or the civil engineering facility that helps in overcoming the shortcomings of the 2D paper based approach. Among other things, it can have cost and work flow scheduling data linked to it. BIM is not simply a computer technology; it also involves strategies relating people and processes that allow the use of the technology.

The benefits to industry that BIM technology offers have been well documented in the literature (Eastman *et al.* 2008, McGraw Hill 2007, 2009, Allen Consulting Group 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 (Holness 2008, McGraw Hill 2009). 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 clear that there is a growing need for universities to provide their graduates with appropriate BIM-related skills in architecture, civil engineering, building construction and construction project management programmes. To realise the full potential of such new skills, a parallel shift is required in the way we teach because desired concepts such as collaboration and integration must be practised as well as preached.

Given the above discussion, it is proposed that BIM supported education, understood as a collaborative process – not simply a technology, has the potential to gradually evolve the industry towards improved efficiency, decision making ability, value generation and interdisciplinary understanding. Pursuant to this, BIM assisted pedagogy requires exploration and development in order to help the shift take place in an effective way. To this end, this paper:

- argues the pedagogical basis for utilising integrated models in construction teaching and learning;
- explores why a programme-wide approach is relevant;
- develops a programme-wide BIM implementation framework – based around an action research approach to curriculum development (Riding *et al*. 1995) linked with an active case study; and
- identifies practical considerations in the implementation of such a framework.

Research Method

The task of programme-wide implementation of BIM is complex, challenging and important. A careful design of the research method is therefore crucial. In addressing the issues above, the paper draws on the extant literature and experience of the authors to probe and develop pedagogical themes, and show why BIM can potentially assist student learning outcomes. It was clear from the beginning that a collaborative, reflective, accountable,

JEBE, Vol 8, Issue 1 (December 2013) doi:10.11120/jebe.2013.00003

self-evaluative and participative approach was the only way forward. These are all distinctive features of action research as quoted by Riding *et al.* (1995) from Zuber-Skerritt (1982). Action research has been deemed to be a successful strategy in pedagogical and curriculum related projects (Zuber-Skerritt 1982, McKernan 1996, Groves & Zemel 2000). We adopted this type of approach for the BIM adoption in the curriculum. Consultation with all stakeholders is therefore considered crucial. As explained in the next few sections, decisions pertaining to this curriculum initiative had input from various stakeholders. Further, to introduce the new curricular tools into the programme as the broader research was still underway, we adopted a case study approach. As described above, a case study approach (Yin 2009) is used to operationally address these issues – the paper involves the newly re-structured Construction Project Management Programme at the University of Technology Sydney. Figure 1 shows the overall methodology adopted in this project.

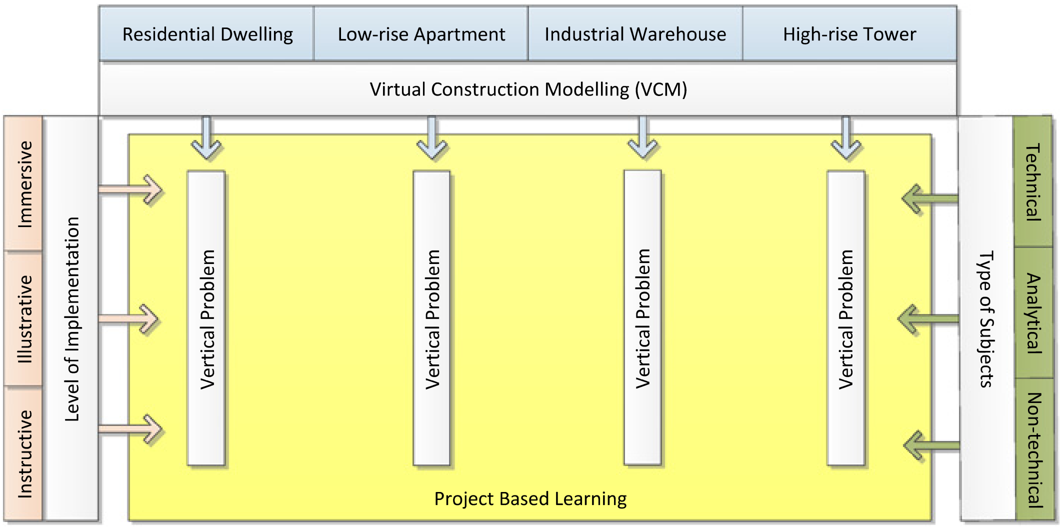

Figure 1 Schematic of Programme-wide implementation strategy.

As shown in the figure we adopted Virtual Construction Models (VCM) as the key drivers for this implementation. VCMs were contextualised within the dimensions of 'level of implementation' and 'types of subjects'. The intersection of these was merged with the project based learning approach to operationalise and develop curricular tools called 'vertical problems'. The issues relating to 'level of implementation', 'types of subjects' and 'vertical problems' are described in the following sections. Whilst the generalisability of findings will naturally be limited by programme specific context, many of the pedagogical issues dealt with in the paper have broad reaching applicability to built environment related education and include:

1. taking greater advantage of problem based learning in a way that provides greater linkages within stream based construction project management programmes;
2. creating a more visually oriented means of teaching and learning;
3. developing students' capability to work in dynamic industry style, knowledge networks;
4. encouraging decision-making in multi-dimensional project settings – in the face of opposing constraints;
5. intrinsically engaging students in the learning process;

6. improving linkage between separate subjects and assessment tasks, thereby taking a more integrated and developmental approach to learning and assessment, and
7. promoting a more holistic understanding of issues involved in built environment projects.

Traditional Construction Project Management Learning Environments

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 (Sawhney *et al.* 2001, Sawhney 2011). Still, many tertiary undergraduate construction project management programmes are based around teaching principles and practices that accentuate defined streams of study and are therefore limited in 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 subject intrinsically contributes to construction project management or how construction project management contributes to the overall objectives of the built environment. This has remained a dormant problem as long as the industry was not awakened to this type of fragmentation. As the industry moves towards more collaborative and integrative paradigms, the education sector needs to start shaping the 'pipeline' of graduates that can better fit the changes occurring in industry; requiring it to look closely at the programmes that are currently being offered (Sawhney 2011).

Delivery and assessment in construction project management 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 project management programmes (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 working in industry (Doloi *et al.* 2010).

Developing BIM-Supported Teaching and Learning Environments – A Programme and School-wide Context

The extent to which BIM should be used in teaching and learning is predicated by the context of a School's objectives and what it wants to achieve in student outcomes. Motivated by this potential, the University of Technology Sydney has embarked on an evolution of its teaching and learning model in the School of the Built Environment with the desire to achieve trans-disciplinarity and collaboration among the subjects taught, as well as other related programmes. Here, the School provides a mix of construction project management, property economics, urban planning, property development and project management programmes. Given this vertically integrated set of Built Environment disciplines, the School's aims are underpinned by the need to understand and assist the way different disciplinary values are successfully resolved and transformed into physical value – as realised in the built environment (Jupp *et al.* 2010). The information modelling, visualisation and collaborative abilities of BIM technologies (coupled with linked technologies such as GIS) provide a basis for achieving this goal. It is therefore 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 modelling and interdisciplinary decision-support as well as reflecting on its networked nature.

Drawing from experience elsewhere concerning education in sustainability, two distinct models of curriculum development and implementation were identified and used in considering the best way forward for the Construction Project Management (CPM) Programme. Originally propagated by Hungerford (Hungerford *et al.* 1994), these models have been adopted and adapted by many authors and institutions. Hungerford's Diffusion Model or Standalone Model (Hungerford *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 Hungerford'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 (Wals & Jickling 2002, Peet *et al.* 2004, Ceulemans & De Prins 2010). We adopted a hybrid approach in the CPM Programme. A layer of diffused subjects primarily supported by BIM were created. Surrounding this layer of subjects, core subjects received an infusion of BIM concepts. Figure 2 shows three models, (a) infusion model, (b) diffusion model, and (c) the hybrid model adopted at University of Technology Sydney (UTS). For example, as shown in Figure 2, 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 case for BIM from a learning theory perspective

Traditional concepts of learning come from behaviourism (Skinner 1984); cognitivist (Lilienfeld *et al.* 2010) and constructivism (Duffy & Jonassen 1992). Constructivism encourages students to undertake exploration within a given framework and more recent learning concepts that can be coupled to this and which are useful in the current study include networked learning, and multi-media learning.

Networked learning is 'learning in which information and communication technology is used to promote connections between one learner and other learners, between learners and tutors; between a learning community and its learning resources' (Goodyear *et al.* 2004, p1).

Multi-media learning is useful when information is remembered using visual images (Paivio 1971). 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 and Creative Services Australia 2007). This is still the predominant mode of learning in CPM programmes; 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 & Guo (2009) point out that this form of learning is believed to be eight times faster than auditory-sequential learning. Even so, it does not sit well alone. For instance Baddeley & Hitch (1974) proposed that visual and verbal information work in parallel and this allows simultaneous processing of information such that a learner is not necessarily

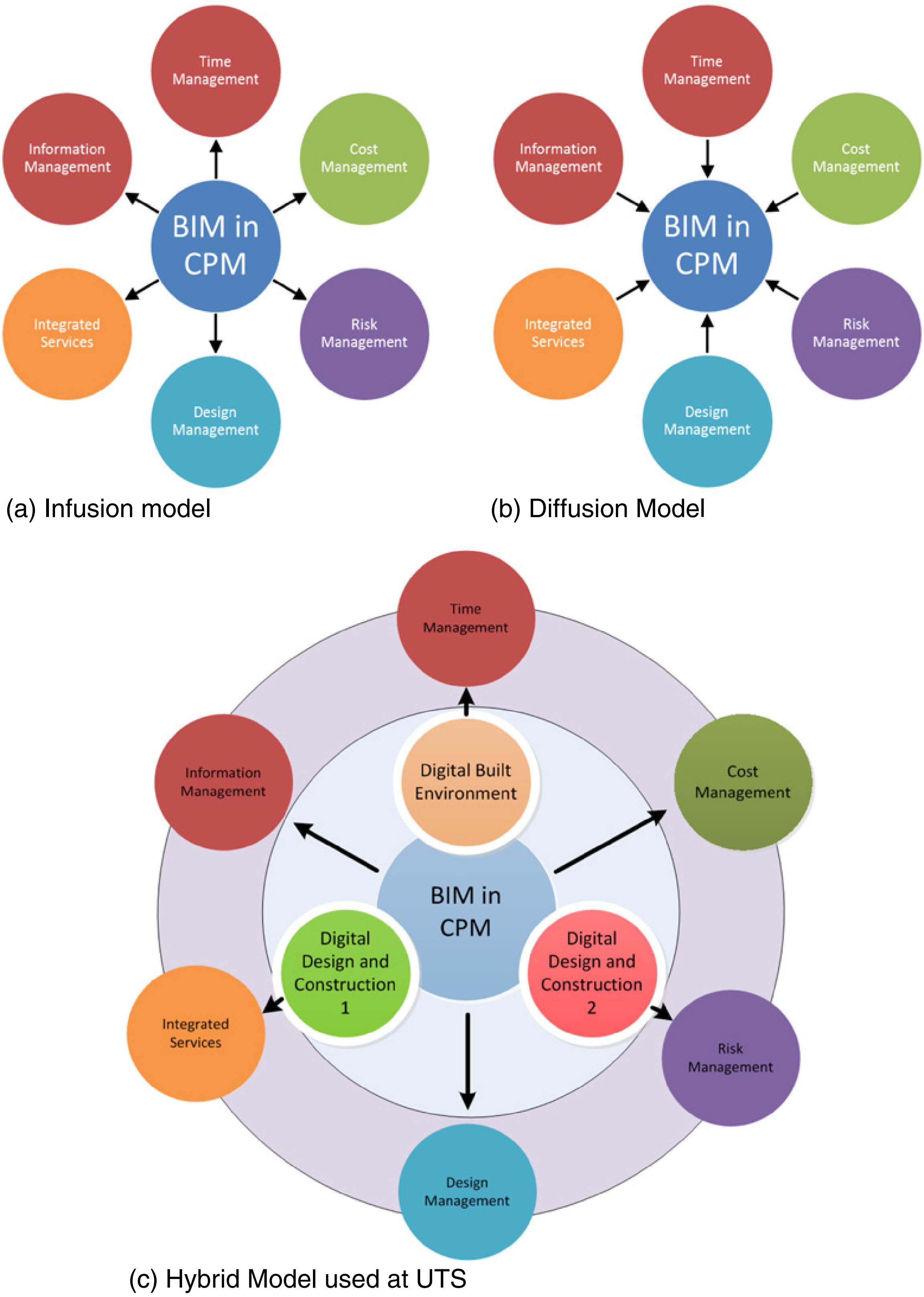

Figure 2 Hybrid model for University of Technology Sydney CPM Programme.

overloaded by multimodal instruction. Others such as Mayer & Moreno (1998) support this principle in their 'Cognitive Theory of Multimedia Learning'.

Given the above, BIM and the more specific concept of Virtual Construction Modelling has the potential to engender visually oriented multi-media learning and networked learning in the context of a common basis for collaborating among student-to-teacher and student-to-student groups. The fit between VCM and construction project management pedagogical objectives is obvious – VCM utilises 3D, real-time, dynamic and integrated modelling to construct a building virtually and visually, thereby leveraging opportunities to understand the likes of productivity and efficiency in design, construction and operation (Holness 2008). Using VCM offers 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 information models provide objects defined in the terms of building components and systems e.g. spaces, walls, beams, piles etc. The key generic attributes of these models include the following (Allen Consulting Group 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; and
- 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, the VCM can be rigorously analysed and simulations can be performed quickly, thus moving construction project management students from abstract concepts to more applied knowledge. Another one of the main benefits is the potential for more effective teaching, as information is more easily shared, contextualised, value-added and reused. Of note, the visual nature of the information in a VCM provides a more universal medium for understanding that is more quickly absorbed than words alone. More 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 programmes; 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 programme during the change.

Managing uptake and 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 programme if things go wrong;
- funding (an expensive) 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;
- changing shape of technology and the process of staying ahead.

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 CPM Programme, 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 aim was to shift the technology implementation from a push (in terms of adoption), to a pull (from staff who want the technology to improve and enhance the way they teach). Concurrent to this was the training of staff in BIM technology (which remains on-going), as well as the use of both outside experts to author the VCMs and appropriately skilled sessional staff from industry to help implement tutorial and studio teaching.

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 programme-wide 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 VCMs (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, shown in Table 1.

The typology facilitated application to a wide variety of subjects in the programme – where the School's staff members were able to nominate which level was appropriate for their subject in the coming year 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 programme, 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 Programme including:

- Technical support personnel: responsible for the maintenance of the hardware and software associated with BIM, plus assistance with the preparation of visually

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

Implementation Level	Purpose and Mode of Delivery	Implications for Teaching and Learning	Implementation Issues
Instructive	• Basic competency in BIM to establish overall modelling basis for other subjects • Subjects/lessons/tutorials/ self-learning to develop competency in targeted applications • Targeted at the front end of the entire programme • Important to separate model interaction skills from model authorship skills (low priority in CPM)	• 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 • Programme decisions about how much student and staff self-learning is realistic
Illustrative	• VCM is used as a visually descriptive means of assisting in teaching traditional construction project 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 should, where appropriate, use images generated from a VCM to add a visual dimension to the way they teach the subject – BIM technician support may be necessary to generate images • Only minor skills required as staff/students can download free 'VCM viewer software' to visually manipulate models • Use the same VCM in different subjects so that students build on their aggregated knowledge	• Only low lecturer software knowledge required – especially if BIM technician support provided • 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 means to assist problem solving and integrated decision making • Less lecture, more problem based learning • Less individual based and more group based • Initial subjects should include time, cost, sustainable design	• Lecturers who teach traditional construction subjects should develop parallel interest in utilising BIM systems to extend their ability to teach and involve students using an immersive studio approach • Lecturers should where appropriate: specify project sub-plots and problems for subjects (e.g. cost, time, quality) that involve students use of VCM to obtain a solution	• High teacher software knowledge required • High student software knowledge required • High levels of tutor assistance likely

oriented teaching materials such as variations to the core VCM image capture, simulations and other customisation. This latter aspect aims to help staff who are not strong in BIM software to incorporate visual teaching in a relatively low risk and low effort way. Clearly, this potentially carries significant implications for cost depending on the level of implementation across the Programme.

- Administrative staff: although unlikely to have much impact on the detail of the Programme, 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.

Mapping subject areas to implementation levels

In exploring the Construction Project Management Programme and mapping subject types to the levels of implementation in Table 1, the challenge for the Programme 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 the three areas of on-going curriculum development at the School, which also corresponded to feedback from UTS teaching staff.

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

	Instructive	Illustrative	Immersive
Technical/science-based		x	
Analytical/measurement-based	x		x
Non-technical, including human factors/organisational/process	x	x	x

The relationship matrix was used to harness teaching staff collaborations who were working in the similar or 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.
- 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 discussed issues, it was considered appropriate to adopt a more specific version of problem based learning which is particularly relevant to building and construction known as 'project based learning'. Thomas (2000) defines project based learning as organising learning around projects that encapsulate complex tasks and involve students in design, problem-solving, decision making, or investigative activities. Such projects provide relatively autonomous work over extended periods and culminate in realistic outcomes. Drawing on de Ureña *et al.* (2003) who summarise Thomas's (2000) five criteria for project based learning:

- projects are central, not peripheral to the curriculum;
- projects must drive students to encounter (and struggle with) the central concepts and principles of a discipline;
- projects must involve students in a constructive investigation that requires new knowledge (not only to use the things already learnt);
- projects are student-driven so teachers must to some extent renounce continuous supervision; and
- projects must be realistic, not school like for students to become deeply involved.

In the context of current construction project management programmes, project based learning 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. Project based learning 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 project based learning 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 programme-wide approach offers greater potential.

To address this, we introduce the concept of vertical problems as a means of obtaining programme-wide coverage of BIM-supported project based. The concept utilises the VCM 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 VCMs provides a key descriptive theme to begin the story line. The VCMs utilised encompass standard building typologies such as a residential dwelling, a low rise apartment building, an industrial warehouse and a high rise tower; the logic of the approach is shown in Figure 3.

The VCM 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 project based learning 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. For example, the residential BIM model (termed a VCM) is used as a vertical problem during all four years of the construction project management programme. During the autumn semester in year 1 of the programme instructors use this model in the Construction Technology I course in an illustrative format. Simultaneously the same vertical problem can be used in the Digital Design and Construction

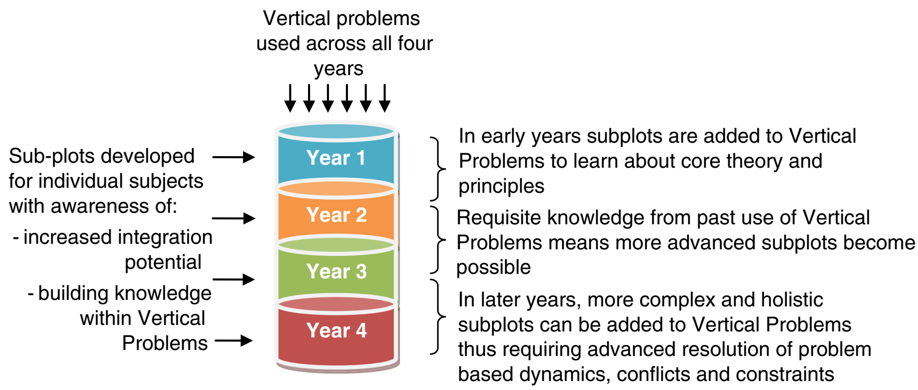

Figure 3 Vertical problems for BIM-supported project based learning.

I course to add details of the structure to the BIM model in an instructive mode. Each student then carries forward this enriched VCM to the next semester and uses it in the Cost Management 1: Measurement subject. The same project or problem continues along with the students to their respective semesters allowing them to evolve the VCM by integrating knowledge gained in the previous semester and making the problem more complex and realistic in the semesters to come. 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 later 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 Teaching and Learning at the University of Technology Sydney

Currently the Construction Project Management degree offers eight subjects (approximately 25% of the programme) 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. In addition, a further two subjects have been prepared for delivery in the coming semester and focus on greater illustrative use in Construction Technology 2 (low rise construction) and greater immersive integration of BIM in quantity take off measurement and time management.

Table 3 Construction Project Management subject offerings at UTS utilising BIM-supported teaching and learning approach.

Mainly Instructive	Mainly Immersive	Mainly Illustrative
Digital Built Environment (1st Year)	Digital Design & Construction 2 (4th Year)	Construction Technology 2 (1st Year)
Digital Design & Construction 1 (2nd Year)	Cost Management 3, Cost Planning (3rd Year)	Cost Management 2, Estimation (3rd Year)
Design Team Management (3rd Year)	Quality and Time Management (2nd Year)	

Case study of BIM-supported teaching and learning

To provide greater insight into the way BIM is being utilised in the Programme'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' – a project based immersive studio undertaken in 2010. The class introduced a variety of BIM technologies and processes to support students in their efforts to integrate three aspects of project management: project 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 project 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 (from the School of Architecture) 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 (refer to Table 4), 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.

Table 4 Software used in the Digital Design and Construction 2 subject 2010.

Groups	BIM modelling	Scope Management	Time Management	Cost Management	Model Integration & Clash Detection	Information Managemt &. Comm.
2010 Seven	ArchiCAD 13 Project Team	ArchiCAD 13 Vico Constructor	MS Project Vico Control 2009	Cost X Vico Estimator	Solibri Viewer Solibri Model Checker	ACONEX

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.

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 design management (2) BIM and preconstruction (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 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 programme, 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. Groups selected a hierarchical modelling approach by dividing the different components of the building into a product breakdown structure. Groups then assigned responsibilities between members to model the building based on the architectural and structural components of the product breakdown structure. 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 compensate for missing information in order to generate a complete 3D 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 4. 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 building model and were video recorded for assessment as shown in Figure 5.

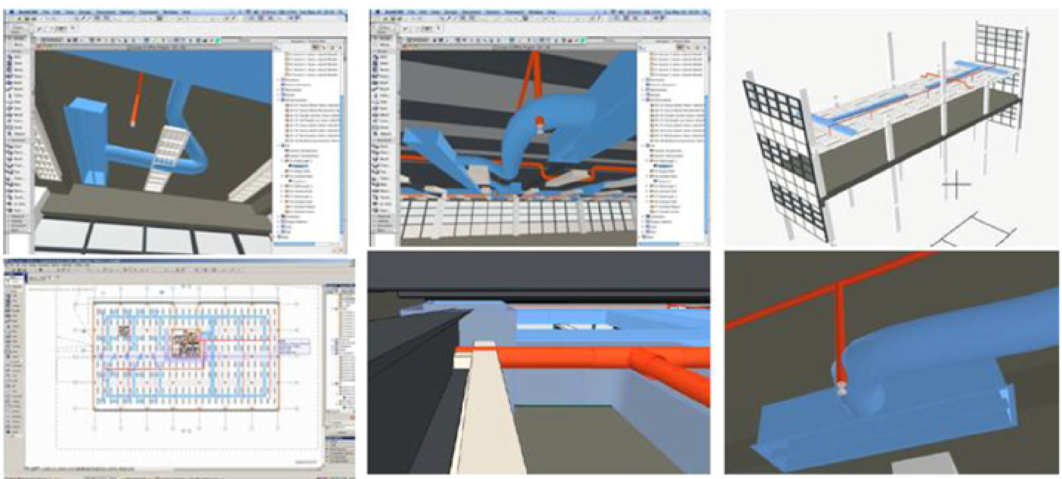

Figure 4 Student examples of BIM in design management and coordination.

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 programme into an overall project plan using digital technologies. In

Figure 5 Student groups participating in design review meetings.

this task, student groups were required to optimise for workflow, resource levelling, and duration. Students worked through these issues iteratively until an optimal solution was found. As has been reported by other researchers (e.g. Peterson *et al.* 2011), without the VCM the connection between the quantities and the schedule is lost, and the students would not have gained an understanding of the scope and time 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 subject's duration of thirteen weeks. Students utilised the BIM applications in the generation of the integrated project plan and reported that the 3D modelling process itself helped them to understand the important technical and geometric aspects of the building construction.

Discussion and Recommendations

Adoption of Building Information Modelling in the curricula provides numerous benefits to construction project management education. In addition to providing students with direct benefits of learning and acquiring skills that are rapidly becoming a norm in industry practice, BIM provides other benefits to the construction project management education ecosystem.

From a pedagogical perspective, its key benefit revolves around the ability to provide a more integrated approach to the teaching and learning of construction project management areas – one that encourages networked and multimedia learning. It provides 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.

Numerous design and implementation issues need to be addressed as was experienced during the implementation at UTS. Lessons learnt and strategic issues that were faced are discussed in the context of providing some guidelines for institutions going through this process and considering BIM adoption.

BIM is as much about people and process as it is about technology. Therefore, BIM in teaching and learning should ensure careful articulation of these three pillars – people, process and technology. Without appropriately and strategically considering these, it is likely to cause inefficiencies in a programme-wide adoption of BIM. Careful articulation of the message with internal and external actors is extremely important. At UTS it became clear that without internal discussions and subsequent buy-in of teaching and support staff the programme would have failed. During internal discussion articulation of the key issue centred on the perception that the programme was being geared to make radical changes and to produce graduates who are BIM experts and not construction project managers with knowledge of BIM. The UTS programme conveyed this message clearly that the main aim of the exercise is to strengthen the CPM programme by incorporating BIM and not change it into a BIM programme. This central question should be answered before a detailed implementation plan is made by any institution interested in taking this challenge.

Based on our experience we find that managing implementation risks becomes a crucial aspect of this challenge. Proper articulation of the message, overall objectives and possible risks need be delineated with internal and external actors. With sufficient initial understanding, determination of the implementation level of BIM in the curricula becomes the next important issue. To address issues pertaining to the implementation risks and level of implementation UTS found design charrettes with industry, staff and students to be a useful tool. Multiple events were held to determine implementation risks and to select the implementation level.

We envisioned and have early proof that for undergraduate construction project management programmes, the project based learning approach discussed in this paper is a suitable means to embrace the three pillars of people, process and technology in teaching, because project based learning enables students to contextualise theoretical and practical issues during their studies. In general, project based learning leverages the utility of a project and its associated contexts as a means for students to demonstrate enquiry, 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 project based learning in programmes that are stream based – as is the case in the Construction Project Management Programme at UTS. For years, construction project management have been criticised for providing fragmented learning experience and for failing to cross-pollinate learning from various subjects in any meaningful way. 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 offer, teaching 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 Project Management Programme 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 operationalise 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.

A clear and concise implementation plan that addresses the people, process and technology issues becomes a very important step in the adoption of BIM in any educational setting. 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 programme-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

Allen Consulting Group. (2010) *Productivity in the buildings network: assessing the impacts of Building Information Models*. Report to the Built Environment Innovation and Industry Council Report, Sydney, October 2010.

Baddeley, A.D. and Hitch, G.J. (1974) Working memory. In *The psychology of learning and motivation: advances in research and theory*. (ed. G.A. Bower) New York: Academic Press, **8**, pp47–89.

Berente, N., Baxter, R. and Lyytinen, K. (2010) Dynamics of inter-organizational knowledge creation and information technology use across object words: the case of an innovative construction project. *Construction Management and Economics*, **28** (6), 569–588. doi: 10.1080/01446193.2010.489926.

Ceulemans, K. and De Prins, M. (2010) Teacher's manual and method for SD integration in curricula, *Journal of Cleaner Production*, 10.1016/j.jclepro.2009.09.014, **18** (7), 645–651.

de Ureña, J.M., Menéndez, J.M. and Coronado, J.M. (2003) Project/Problem Based Learning in civil engineering: the Ciudad real (Spain) experience. *International Conference/Workshop on Engineering Education*, Texas A&M University, pp127–141.

Doloi, H., Sawhney, A. and Iyer, K.C. (2010) Benchmarking the versatility of construction management education with a global perspective. *Proceedings of the Australasian Universities Building Education Association (AUBEA) 35th Annual Conference, Melbourne*, (ed. P. Tombesi) pp1–3.

Duffy, T.M. and Jonassen, D.H. (eds.) (1992) *Constructivism and the technology of instruction*. Hillsdale New Jersey: Lawrence Erlbaum Associates.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008) *BIM handbook: a guide to building information modelling for owners, managers, designers, engineers, and contractors*. Hoboken, NJ, USA: John Wiley & Sons, Inc.

Gallaher, M.P., O'Connor, A.C., Dettbarn, J.L. and Gilday, L.T. (2004) *Cost analysis of inadequate interoperability in the US capital facilities industry*. Gaithersburg, Maryland USA: National Institute of Standards and Technology.

Gareau, S. and Guo, R. (2009) 'All work and no play' reconsidered: the use of games to promote motivation and engagement in instruction. *International Journal for the Scholarship of Teaching and Learning*, **3** (1), 1–12.

Gifted and Creative Services Australia. (2007) *Visual-spatial thinking*. Available at www.giftedservices.com.au/visualthinking.html (accessed 23 December 2010).

Goodyear, P., Banks, S., Hodgson, V. and McConnell, D. (eds.) (2004) *Advances in research on networked learning*. London: Kluwer Academic Publishers.

Groves, M.M. and Zemel, P.C. (2000) Instructional technology adoption in higher education: an action research case study. *International Journal of Instructional Media*, **27** (1), 57–65.

Holness, G.V.R. (2008) BIM gaining momentum. *ASHRAE Journal*, June 28–40.

Hungerford, H.R., Volk, T.L., Ramsey, J.M. and Bluhm, W.J. (1994) *A prototype environmental education curriculum for the middle school* (*revised*). A discussion guide for

UNESCO training seminars on environmental education. Paris, France: UNESCO-UNEP International Environmental Education Programme.

Jupp, J.R., Forsythe, P. and Sankaran, S. (2010) Towards a value-centric approach to education: implications of changing practices in construction project management. *Proceedings of the Australasian Universities Building Educators Association, University of Melbourne, Australia*, July 2010, ppA078-1–A078-18.

Lilienfeld, S.O., Lynn, S.J., Namy, L.L. and Woolf, N.J. (2010) *Psychology: a framework for everyday thinking*. Boston, MA: Allyn & Bacon.

Mayer, R.E. and Moreno, R. (1998) *A cognitive theory of multimedia learning: implications for design principles*. Available at www.unm.edu/~moreno/PDFS/chi.pdf.

McGraw Hill. (2007) *Interoperability in the construction industry*. SmartMarket Report. New York: McGraw, Hill.

McGraw Hill. (2009) *The business value of building information modeling: getting building information modeling to the bottom line*. SmartMarket Report. New York: McGraw, Hill.

McKernan, J. (1996) *Curriculum action research. a handbook of methods and resources for the reflective practitioner*. London: Kogan Page Limited.

Paivio, A. (1971) *Imagery and verbal processes*. New York: Holt, Rinehart and Winston.

Peet, D.-J., Mulder, K.F. and Bijma, A. (2004) Integrating SD into engineering courses at the Delft University of Technology – the individual interaction method. *International Journal of Sustainability in Higher Education*, **5** (3), 278–288. 10.1108/14676370410546420.

Peterson, F., Hartmann, T., Fruchter, R. and Fischer, M. (2011) Teaching construction project management with BIM support: experience and lessons learned. *Automation in Construction*, **20** (2), 115–125. 10.1016/j.autcon.2010.09.009.

Riding, P., Fowell, S. and Levy, P. (1995) An action research approach to curriculum development. *Information Research*, **1** (1). Available at http://InformationR.net/ir/1-1/paper2.html.

Sawhney, A. (2011) Learning construction project management using digital models. In *Proceedings of 2011 Project Management Research & Academic Conference (PMIREC 2011)*, 9–10th December, NICMAR, Pune, India.

Sawhney, A., Mund, A. and Koczenasz, J. (2001) Internet-based interactive construction management learning system. *Journal of Construction Education*, **6** (3), 124–138.

Skinner, B.F. (1984) The operational analysis of psychological terms. *Behavioral and Brain Sciences*, **7** (4), 547–581. Available at http://cat.inist.fr/?aModele=afficheN&cpsidt=9212556 (Accessed 14 July 2011).

Taylor, J.E. and Bernstein, P. (2009) Paradigm trajectories of building information modeling practice in project networks. *ASCE Journal of Management in Engineering*, **25** (2), 69–76.

Thomas, J.W. (2000) *A review of research on project-based learning*. San Rafael, California: The Autodesk Foundation.

Wals, A. and Jickling, B. (2002) Sustainability in higher education: from doublethink and newspeak to critical thinking and meaningful learning. *Higher Education Policy*, **15** (2), 121–131.

Yin, R.K. (2009) *Case study research: design and methods*. 4th ed. California: SAGE Publications.

Young, N., Jones, S., Bernstein, H.M. and Gudgel, J.E. (2009) *The business value of BIM: getting building information modeling to the bottom line*. SmartMarket Report: New York: McGraw Hill Construction.

Zuber-Skerritt, O. (1982) *Action research in higher education: examples and reflections*. London: Kogan Page Limited.

doi:10.11120/jebe.2013.00003