RELEASING THE POTENTIAL OF BIM IN CONSTRUCTION EDUCATION

JOHN BOON
jboon@unitec.ac.nz

CHRIS PRIGG
cprigg@unitec.ac.nz

Unitec Institute of Technology
New Zealand

Abstract
When setting out to teach a group of construction students the lecturer is faced with a class who have a variety of learning style preferences and have brains with a variable ability to process information and that ability varies further with the type of processing required. They also come to the class with varying previous experience and knowledge and with varying social skills. In order to facilitate the learning the students need to be actively engaged in a task designed to cause them to interact with the information they are supposed to be learning. However learning is a complex process that requires considerable management. BIM has the potential to assist construction education in this as it can make information available in a manner that is much more accessible to visual and kinaesthetic learners (the majority of learners). It is not in itself a universal panacea to the problem of teaching construction students. The challenge for construction educators is to use this new form of information provision to enable us to move away from lecture formats and reshape our teaching delivery to a format that is better aligned with the learning styles and processes that suit most learners.

Keywords: Construction education, learning styles, learning processes, Building Information Modelling.

INTRODUCTION

For the purposes of this paper the American General Contractors (2006) definition of BIM has been adopted:

> Building Information Modelling is the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model is a data rich, object oriented, intelligent and parametric representation of the facility from where views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and improve the process of delivering the facility.

The generally accepted convention of describing construction assembly and time related modelling as 4D and cost related modelling (including the quantification of work for estimating purposes) as 5D has been adopted.

BIM at least in the sense of 3D modelling is fast becoming a reality in the commercial world (McGraw Hill 2008) including New Zealand (Boon 2009). It also has the potential to become a powerful tool in the world of construction education. At its simplest it enables construction students to see in a 3D virtual model how buildings are assembled. This in itself is a considerable advance on trying to get students to learn building construction through interpreting 2D information. Beyond this BIM has the potential to allow faculty to radically rethink the teaching and learning process for construction students. If the BIM models provide information, that is readily understood by the student, as to how buildings are assembled, faculty should be able to spend less time "telling" students about construction detailing and thereby create more time for the students to learn by interacting with BIM models in the processes of construction planning, measurement and estimating.

This paper explores this issue by firstly looking at how people learn and then considering how BIM can be used to enhance the students learning experience in construction education. The latter is done firstly from a theoretical perspective and then by way of case studies of the authors own experiences.

EDUCATIONAL THEORY

This section is written from the perspective of a construction educator attempting to understand the process they are engaged in rather than as an expert in teaching and learning. MacKeracher (2004) makes the point that *"Learning is something done by the learner rather than something done to or for the learner. Learning proceeds independently of (and sometimes in spite of) education and schooling"* (p5) Understanding how learners approach learning and process information is therefore critically important. This brief review of literature is broken into three sections, learning styles, brain styles and the learning process.

Learning Styles

There is general agreement in the literature that learners vary in the way they approach learning. How such variation is categorised to form a typology of learning styles differs between authors.

MacKeracher (2004) refers to Curry's (1983) three layer onion metaphor as a way of analysing students approach to learning. The outer layer is composed of behaviours that are more observable, less stable and more easily influenced by external conditions. The middle layer is concerned with information processing styles that are less directly observable although modifiable by the learner adopting new strategies. These information processing styles can be categorised using tools such as the Grasha-Rechmann Student Learning Style Scale (Grasha ,1993) which measures three paired styles: social (competitive / collaborative) emotional (avoidant / participatory) and the needs for structure (dependent / independent). The third inner layer is concerned with cognitive personality styles affecting an individual's approach to adapting and assimilating information. Styles in this layer can be assessed using instruments such the Myers-Briggs type indicator (Myers 1985).

MacKeracher (2004) also refers to Suessmuth (1985) typology of personal learning style preferences:

1. *Language learners* prefer to hear (auditory) language or see (visual) language. They are best at remembering information in word form.
2. *Numerical learners* prefer to hear (auditory) or see (visual) numbers. They are best at remembering and using information in numerical forms.
3. *Auditory – visual – kinaesthetic (AVK) learners* prefer to learn through personal experiencing and need sensory stimuli. They need to manipulate material and be totally involved; they may become distracted if not entirely involved. (p81)

Materna (2007) refers to the work of a number of authors to present a three part model:

1. *Auditory learners* who learn best by listening. Such learners are comfortable with traditional lectures and learn best if they have listened to information before reading about it.
2. *Visual learners* who needs to see information before they learn well. The learning of this group is greatly aided by pictures, diagrams, flowcharts as well as text information.
3. *Kinaesthetic – tactile learners* who learn best by doing. They need to be actively engaged in experiments, exercises or preparing their own material in order to learn.

Materna (2007) acknowledges that learners are capable of using more than one style and in some cases are skilled "combination learners" capable of using all three styles. However she quotes a number of authorities to suggest that "40 – 65% of learners are visually dominant, 20 – 30% are primarily auditory and 5 – 15% are primarily kinaesthetic learners" (p49).

Intelligence

Theories concerning learning styles only help to explain the manner in which a person prefers to approach the learning experience. They do not explain how the brain processes information or the nature of intelligence that enables the learning process.

During much of the 20th century theorists tended to view intelligence as a singular or general thing. The IQ test being an example of a means of measuring that singular intelligence. However in the latter part the century theorists developed the concept of multiple intelligences. Notable work includes Howard Gardiner's eight intelligences. Gardiner defined intelligence as "the capacity to solve problems or fashion products that are values in one or more cultural settings". His eight intelligences are:

1. *Logical-mathematical* the ability to compute and apply mathematical concepts and logic to complex situations.
2. *Linguistic* the ability to use language to describe, express, develop arguments, persuade and influence.
3. *Musical* the ability to understand, interpret, create and perform music.
4. *Spatial* the ability to visualise and perceive through the use of hands and other body parts. The ability to interpret and graphically represent ideas.
5. *Interpersonal* the ability to perceive emotions and respond accordingly.
6. *Intrapersonal* the ability to have personal insight and understand own emotions and responses.
7. *Bodily-kinaesthetic* ability to use parts of the body
8. *Naturalistic* the ability to understand and classify patterns in the natural environment. (adapted from Materna 2007).

Within the context of this paper the concept of spatial intelligence is particularly interesting. It is this type of intelligence that students need to develop in order to be able to interpret drawings and understand how building components fit together. Materna (2007) makes the point that within the education system generally we have promoted the development of the first two intelligences to a much greater degree than the others.

Whilst agreeing with the concept of multiple intelligences Sternberg (1988) does not classify them in terms of specific abilities in the way Gardiner does. Sternberg argues that successful intelligence is a mixture of analytical, creative and practical thinking behaviours. He defines these as:

1. *Experiential intelligence (creative)* the ability to deal with different situations and develop new ideas for dealing with situations

2. *Componential intelligence (analytical)* the ability to process information effectively using abstract thinking and logical reasoning.
3. *Contextual intelligence (practical)* the ability to adapt to the environment, street smarts and ability to change behaviours in a new environment.

Sternberg's analysis seems to provide a different perspective. It can be argued that in order for a person to be competent in the area of construction technology they need to bring all three dimensions of Sternberg's intelligences to apply to develop their spatial intelligence in Gardiner's terms.

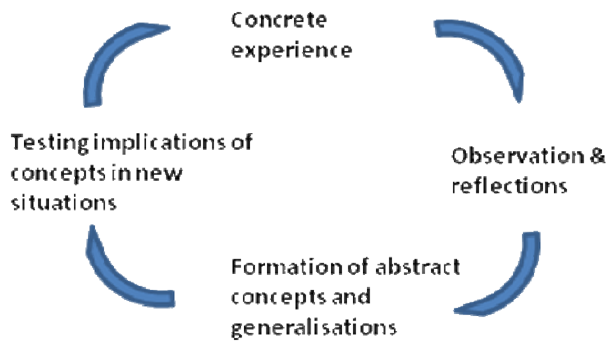
Materna (2007) also refers to the work of Perkin's (1995) who supports the concept of multiple intelligences but focuses on three dimensions.

1. *Neural intelligence:* Efficiency and precision of the neurological system.
2. *Experiential intelligence:* Accumulation of life experiences in different areas.
3. *Reflective intelligences:* Metacognitive abilities or personal strategies for problem solving and self management.

This analysis provides additional insights into the learning process as it identifies both that learners bring all their past experiences to the process and that the learner needs to process the information in accordance with their own reflective intelligence abilities and preferences.

The Learning Process

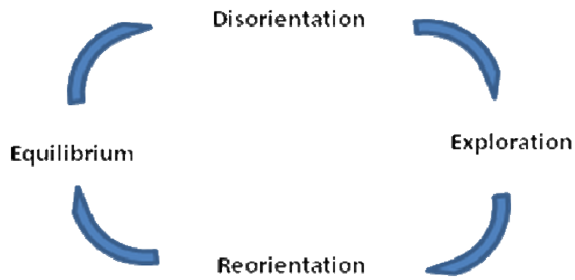
There seems to be a reasonable consensus that learning is an iterative (or circular) process. Authors such as Mackerchar (2007) refer to the "Kolb Cycle" although David Kolb (1984) refers to the "Lewinian experiential learning model "(p21).



The Lewinian Learning Cycle from Kolb 1987 p21

The implications of the model include that the learner needs some kind of experience as a start point which they can move on from, to reflect on and then conceptualise in an abstract sense and then further experiences in increasingly challenging situations in order to test and affirm their concepts and generalisation. Kolb is of the view that as part of the learning process the experience and the observations and reflections should be shared with others.

Taylor (1987) provides a useful alternative that aligns with the author's own experiences. She argues that the experience can start with *disorientation and confusion* when the learner is confronted with a new situation. This can result in a loss of confidence and unless the learner can find a way forward (with or without assistance) they may stay in that situation for a protracted time. If successful in moving forward the learner enters what Taylor calls the *information phase* within which the individual becomes engaged in searching for information to solve the problem. Taylor argues that when learners have gathered enough information they usually withdraw to think things over. Following this period of reflection Taylor says the individual enters a *reorientation phase* within which they synthesize and make sense of ideas. It is in this phase that the learner is engaged in the act of learning. They are then able to proceed to the *equilibrium phase* within which they refine and elaborate on their understanding. It is normally necessary to engage in discussion with others in order to complete this phase.



Taylor's learning Cycle (adapted from Taylor 1987)

Gavin and Taylor (1992) have elaborated on the dangers of the learner struggling in the disorientation phase and suggest that the learner may instead of moving forward enter a "decremental cycle of learning" in which they will seek to blame others, build a case to support their negative feelings and may even exit the learning process altogether, rather than seek to understand the disorientation they are experiencing and enter the exploration phase.

Cross (2009) acknowledges that learning is not necessarily a linear process. Some people learn in an incremental (step by step) process whilst others may appear to make no progress and then move forward in large and apparently unpredictable ways.

Learning as a Social Constructivist Activity

The final piece of theory of relevance to this paper is the notion of learning as a social constructivist activity. Within educational theory there are two schools of thought; objectivist and constructivists. Feyton and Nutta (1999 p50-51) summarise these as:

> *The objectivist (also known as behaviourist, instructivist, rational, or directed learning) viewpoint assumes that the role of the teacher or instructor – is to transfer or transmit knowledge to a student, who is a more or less passive recipient. In this model, the content of "what is to be learnt' is considered to be a stable entity that can be organised into a structure involving a series of steps or subcomponents that are often followed in a sequence. The teacher – directs the process of transmitting the sequence of structured content.----*
>
> *In contrast, the constructivist approach incorporates the notion that learners build a knowledge base through personal experience. Knowledge is not viewed as something to be poured into an empty vessel. Constructivists maintain an emphasis on learning by problem solving and apprenticeship in real-world contexts (Brown, Collins and Duguid 1989).*

Cross 2009 describes constructivist's theories as being concerned with "knowledge creation within individual minds and through social activity" (p31). In order for the learner to learn they have to actively reconstruct the knowledge in their own minds. Cross uses the work of Vygotsky to look at the social aspects of learning, suggesting that when a learner interacts with a "more knowledgeable other" progress can be made with a task that is beyond the current ability of the learner. However Cross extends beyond interaction with the expert to emphasise that the "social" dimension of "social constructivism" includes the need for other people interacting with the learner to observe in action, engage in discussion or provide emotional support. Cross uses the metaphor of scaffolding to support the learning activity in progress (the authors of this paper, as members of the construction industry feel "propping" would have been a better term). Learning is seen by Cross as a transition that needs support. Once the new knowledge is integrated into an existing framework of knowledge in the learners own mind the scaffolding can be removed.

Cross (2009) describes the role of the teacher within the concept of social constructivism as being to design tasks and activities, integrate appropriate assessment, provide relevant feedback and act as facilitators of dialogue during the learning process.

Summary of Educational Theory

This overview of education theory suggest that when setting out to teach a group of construction students the lecturer is faced with a class who have a variety of learning style preferences and have brains with a variable ability to process information and that ability varies further with the type of processing required. They also come to the class with varying previous experience and knowledge and with varying social skills. In order to facilitate the learning the students need to be actively engaged in a task designed to cause them to interact with the information they are supposed to be learning. The task should enable them to move through the type of cycle described by Kolb (1984) and Taylor (1987). This cycle includes a period of reflection that each student will hit at a different time and need a different period of reflection. Repetition through the cycle with increasing levels of complexity is necessary. As they move through the cycle the learner needs some (but a varying) degree of interaction both with people with expertise (the lecturer) and fellow students. If the task is too challenging the students may experience disorientation and if not able to move out of this situation (with or without assistance) may become negative and even withdraw. How students engaged with the learning experience presented to them depends on their earning style, past experiences and prior knowledge. If they succeed in moving through the learning cycle they will learn something but not necessarily what the lecturer intended.

EXPERIMENTS IN USING BIM IN THE LEARNING PROCESS

From the theoretical discussion above it is possible to conclude that an ideal process for learning construction subjects such as technology, scheduling and measurement should:

- Present the subject matter in a visual manner with some verbal explanation but allow those who wish the freedom to explore for themselves.
- Should be delivered in an environment that allows social (informal) interaction, student – teacher and student – student.
- Allows students to proceed at their own pace.
- Gives the teacher the ability to identify those experiencing disorientation and time to work with them to move them to the next phase.
- Gives students time to reflect when they need to.
- Provides repeat experience.

To a certain extent construction subjects have always allowed elements of this approach. Technical subjects are inherently visual and students learn by doing (drawing, scheduling, measuring etc). BIM has the potential to improve this process particularly in regard to the first bullet.

At Unitec we have been teaching our architectural technology students drafting of 3D models for about five years. However it was only in early 2009 that we started to take a serious interest in the wider issues of BIM and consider its potential as a teaching tool for construction management and quantity surveying students.

In order to build our understanding of the potential of BIM beyond basic 3D models we formed a small development group of recent graduates and senior students and tasked them with:

1. Creating some 3D models
    a. A very detailed model of a house
    b. An industrial building
    c. A four storey teaching block. In this case separate architectural, structural and services models were produced.

    These were created by obtaining 2D drawings and redrawing them as 3D models.
2. Learning to connect the 3D model to a M.S. Project schedule to produce an animation of the construction sequence (basic 4D modelling).
3. Use additional software to compare the architectural, structural and services models for the purposes of coordination and clash detection.
4. Use software to measure and estimate in accordance with quantity surveying practice and rules, directly from 3D models (5D).

From this exercise we gained:

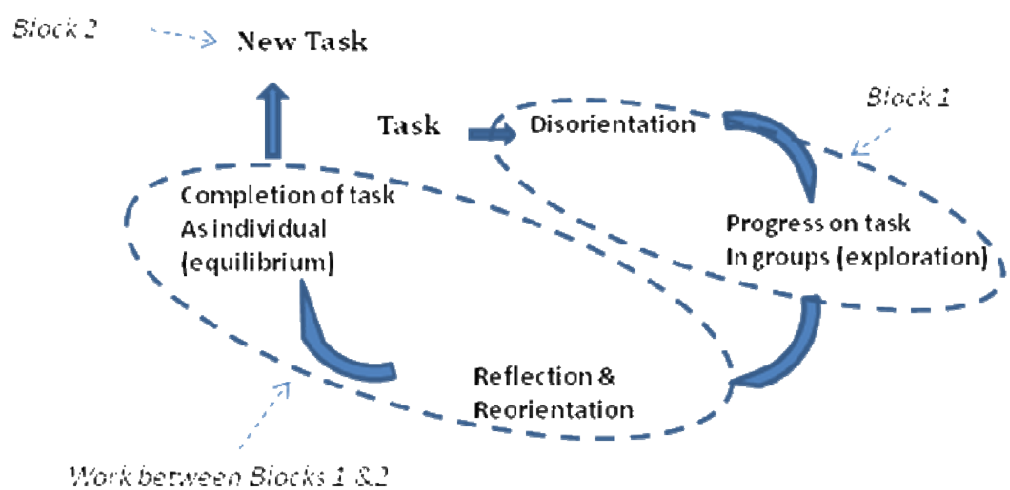
1. An initial stock of 3D models to use as teaching tools
2. Confidence that it was possible for the students to integrate the models with limited assistance.
3. An understanding of how to link model to schedule and produces a sequence animation.
4. Confidence that students would be able to use software to measure from 3D models.

From this exercise we also learnt that what was possible to achieve by way of scheduling and measurement was limited by the way the 3D model was built, by the information that had (or had not) been placed in the drop down boxes that are associated with each object in the 3D model and the limitations of the interrogating software both integrating software and 5D software, to read the information in the boxes. Our learning caused us to undertake substantial rebuilding of the 3D models.

In parallel with the activities described above we experimented with the use of 3D models to assist a year one measurement class. In this case the students were required to measure from simple 2D drawings (as in previous years) however a 3D representation of the drawings was also prepared and set up to run as a rotating model on the projector in the classroom. It was also made available to students through our online teaching support system (Blackboard). This seemed to significantly enhance the students understanding of and ability to interpret the 2D drawings and enable them to make progress with their measurement (avoid disorientation). Whilst this experiment barely tapped into the potential of BIM it did make us realise just how much students struggle with understanding 2D drawings.

Our second experiment was with third year construction economics students on the Bachelor of Construction programme. The aim of the course is to teach students measurement and pricing of building services. We decided to incorporate the use of measuring and estimating software that extracted information directly from 3D models for the first time, thereby introducing the concept of 5D modelling into the programme. The course is a final year course delivered as a Block course in two blocks each of two days mainly to part time students. It was delivered in a computer lab to approximately 25 students. To assist in delivering the course we obtained the assistance of a specialist from the software company and staff from a QS practice with expertise both in services and the software.

We have been teaching block courses for a good number of years now and have evolved a pattern of delivery that was influenced by an interest in "problem based learning" based on the work of authors such as Boud and Feletti (1997) and Savin-Baden (2004). The pattern has many individual variations dependent on the subject matter and inclinations of the course lecturer however its generic form is as illustrated below. This seems to accord with much of the educational theory presented above, providing for loop learning, social interaction, and engagement through a variety of learning style preferences etc.



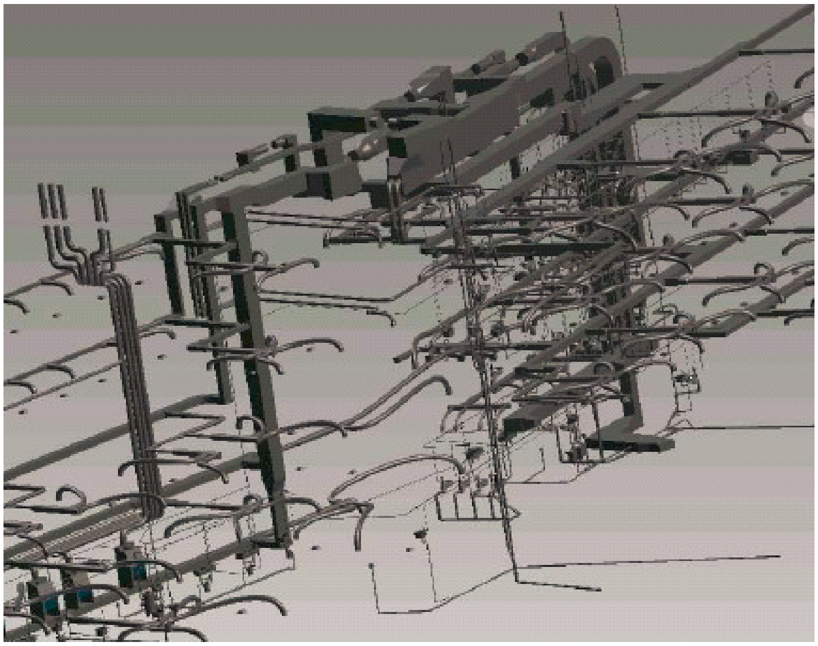
Generic format of block course delivery used by authors with reference to Taylor's (1987) learning cycle

The building used for the course assignments was the four storey teaching block which we had modelled in 3D described above. Most of the students were already familiar with the building and the 3D model as it had been used in a services technology course they had taken the previous semester. This course had also included a site visit. This coordination with the previous course and 3D model reduced the possibility of the students becoming disoriented through being unfamiliar with the services they were required to measure and price. It was also their third course in measurement and pricing so they were familiar with the basic approach and processes.

Delivery of the course was designed around a 3 part assignment requiring the students to:

1. Produce an early stage estimate based on gross floor area
2. Produce an elemental cost plan
3. Produce a schedule of quantities based on the New Zealand standard method of measurement and an estimate of the cost of the work.

Designed in this way the assignment provided three learning loops with increasing complexity. The first was done entirely within day one of the first block and enabled the student to become familiar with using the software. The second was started within block 1 and completed as an individual assignment before block 2. The third was started in block 2 and completed before the end of the semester. Students also had to complete an end of semester examination.



Screen shot of 3D model of services

The first block started with a short formal teaching session on using the software. The students were then required to work at their own pace working in collaborative clusters as much as it suited them. The lecturer and industry experts circulated and coached the students through difficulties as they encountered them. From time to time presentations were made to the whole class on common difficulties. The industry people also gave short presentations on issues such as dealing with inadequate and inaccurate information, quality assurance and sources of pricing information.

Overall the course went well. Significant student collaboration was observed particularly they helped each other when they become stuck (typically with the use of the software). Their interaction with the industry people increased as they became more familiar with them. Two students displayed noticeable symptoms of disorientation as they struggled to master the software. One worked their way through the difficulties and successfully completed the course. The other entered a decremental cycle and did not.

There were significant issues with the 3D model. Some confusion was created where we had used generic models of objects such as pumps, heat exchanges, sanitary fittings etc, taken from an object library, which were not a good likeness to the actual equipment specified. This problem will be overcome in the future as more manufacturers provide online libraries of their equipment as BIM objects. In addition the model had errors in it and little specification information had been entered into the drop down boxes (equipment type, capacity, etc). Whilst it can be argued this represents a ‘real world experience” (the drawings are always incomplete and contain mistakes at the time of estimating) it does increase the learning challenge to students. They have to struggle with the “what” as well as “how” to measure and price. This must increase the chances of disorientation and therefore seem desirable to avoid. To improve this situation it is necessary for us to embed in the model significant amounts of specification information that currently resides in a separate specification document. Whilst the process of entering the data into the drop down boxes that are associated with each object in the 3D model is straight forward it is labour intensive and for a resource lean academic institution provides considerable challenge. However once this is done it is easy to envisage that the students will have the ability to better connect in their own minds text based specification information (contained in the drop down boxes) with the 3D object they are looking at.

A further noticeable impediment to the students understanding was the issue that whilst the literature on BIM tends to imply there is one single model, whereas at the current stage of evolution of BIM there are in fact several models. The students therefore had significant difficulty in understanding where in the building (as depicted in the architectural model) the services (contained within a separate model) were actually located. These difficulties were at a fundamental level concerning issues such as whether the piping was in an exposed situation, contained in a duct or run between ceiling and floor slab. This limited their ability to describe the difficulty of installation and reflect that in their estimating. Until BIM models become fully integrated, this problem will remain with us.

CONCLUSION

Learning is a complex process that requires considerable management. BIM has the potential to assist construction education in this as it can make information available in a manner that is much more accessible to visual and kinaesthetic learners (the majority of learners). It is not in itself a universal panacea to the problem of teaching construction students. The challenge for construction educators is to use this new form of information provision to enable us to move away from lecture formats and reshape our teaching delivery to a format that is better aligned with the learning styles and processes that suit most learners. Specifically BIM models if constructed in sufficient detail and they contain sufficient embedded specification information, can empower the student to visualise the building component they are attempting to understand and then access specification information relevant to that component. If this is done successfully much of the disorientation that can occur in the early part of the learning process arising from not understanding the building components they are dealing with can be avoided.

Moving beyond the experiences we have described here we see the next step is for us to use BIM's 4D capabilities to enable to students to better understand the assembly process through the production of assembly animations. We envisage that in time this will extend to include temporary work such as formwork, propping etc.

References

American General Contractors (2006) *The Contractors Guide to BIM*; Association of General Contractors of America; Arlington.

Boon, J. 2009 Preparing for the BIM Revolution. In *Proceeding of 13th PAQS Congress* Kuala Lumpur, 33-40.

Boud, D.J. & G.I.Feletti (1997) *The challenge of problem based learning (2nd ed)* Krogan page; London.

Cross, S. (2009) *Adult teaching and learning: Developing your practice;* McGraw Hill; London.

Curry, L. (1983) An organisation of learning style theory and constructs. In L. Curry (ed) *Learning style in continuing medical education* (pp115 -230 Ottawa.

Feyton, C.M. & J.W. Nutta (1999) *Virtual instruction;* Libraries Unlimited; Santa Barbara, CA.

Grasha, A.F. (1993) *Teaching with style*; Alliance; Pittsburgh.

Kolb, D.A. (1984) *Experiential learning*; Prentice Hall; New Jersey.

MacKeracher, D. (2004) *Making Sense of Adult Learning (2nd ed);* University of Toronto Press; Toronto.

McGraw Hill. 2008. *Smart Market Report on Building Information Modelling*, McGraw Hill Construction; New York.

Materna, L. *Jump start the adult learner;* Corwin Press Thousand Oaks CA.

Myers, L. (1985) *Gifts differing (7th ed.)* Consulting Psychologist Press; Palo Alto.

Perkins; D. (1995) *Smart schools: From training memories to educating minds*; Free press New York.

Savin-Baden, M. (2004) *Foundations of problem based learning*. McGraw Hill; Maidenhead U.K.

Sternberg, R.J. (1977) *Intelligence, information processing, and analogical reasoning: The compontial analysis of human abilities*; Erlbaum; Hillsdale, NJ.

Suessmuth, P. (1985) *A learning styles inventory*; Training Ideas, 44, 2-20.

Taylor, M. (1987) Self directed learning: More than meets the observer's eye. In D. Boud & V. griffins (eds) *Appreciating adult learning; From the learners perspective (pp179-96).* Kogan Page; London.