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BIM Collaboration in Student Architectural Technologist Learning

Malachy Mathews
Technological University Dublin, malachy.mathews@tudublin.ie

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Purpose – This paper is the result of a qualitative case study which investigated the influence of building information modelling (BIM) collaboration on the learning of student architectural technologists based around a studio group project. The purpose of the paper is to disseminate knowledge gained into a new learning environment facilitated by the collaborative properties of a BIM application.

Design/methodology/approach – A qualitative case study approach has been used to undertake the examination of the learners' experiences during the project. This approach allowed the author to map the complex interaction between the participants during the stages of the collaborative design project.

Findings – The paper provides evidence of a new learning environment created in the studio setting. This learning is facilitated by the creation of a single digital building model by a student group and then worked on by the group simultaneously using the applications collaboration toolset.

Research limitations/implications – The research was carried out on one group consisting of six student architectural technologists working with one practising architect over a twelve week period. The author was the single observer to the project.

Practical implications – This paper will support higher education institutions proposing to introduce collaborative BIM applications into a built environment curriculum and also may act as a catalyst to encourage educators to adopt a similar approach to teaching in a range of other professions.

Originality/value – This paper identifies a potential for higher level learning facilitated by collaborative BIM technologies and methodologies. It also supports the need in higher education to provide for transition from theory to workplace practice.

Keywords: Architectural Technology, BIM, Building Information Modelling, Collaboration, Education,

Article Type: Case Study.

Introduction

There is a growing demand for closer collaboration within the built environment. This demand needs to be reflected back into the teaching and learning practices of students in the disciplines of design and construction. Penttila and Elger, (2006), suggest that diverse multidisciplinary understanding and knowledge about various factors of design and construction will be essential in the near future architectural design profile and so to provide for industry, it will be incumbent on higher education institutions to break down silos of built environment education and provide opportunities for the development of collaborative skills for students poised to enter into the design and construction industry. A catalyst to bring about this change is the robust platform provided by building information modelling (BIM) technologies and the collaborative design opportunities it promotes. Bedrick and Rinella cited in Bedrick-Gerber et al., (2006) suggest that building information modelling technologies and methodologies are poised to revolutionize the construction industry because of its potential to radically improve collaboration among the wide-ranging expertise needed to design and construct a building and to increase efficiency.

If collaboration processes are reflected back into built environment education, a legitimate question arises as to the potential benefits for collaborative learning for the students whose discipline's fall within the design and construction industry. This research explores one case scenario that involved the collaboration of student architectural technologists with a practising architect using a BIM digital building model as the vehicle for the collaborative design process and as the delivery application for project documentation. A role previously achieved by group-work using a 2D computer aided design applications.

Architectural Technology is an emerging profession in the built environment industry. The role of the Architectural Technologist has changed and developed as building design and construction has become more specialized. The Royal Institute of Architects Ireland (2010, p. 4), regards “the professional Architectural Technologist as a technical designer, skilled in the application and integration of construction technologies in the building design practice”. Harty and Lang, (2010, p. 558) conclude that “Architectural Technologists are trained to know what each profession does and to know what each project needs from the other professionals. Architectural Technologists are equipped to adopt the role of manager in an integrated design and construction process”. Their core education is technical design and this gives them a skill set that allows them to communicate effectively with the other design disciplines to in effect provide a central point of co - ordination for building information. The Dublin Institute of Technology programme in Architectural Technology was established in 1963 and is the oldest programme of its kind in Ireland. Harty and Laing (2010, p. 548) refer to the Department of Architectural Technology ab-initio Level 8 BSc (Hons) in Architectural Technology addressing the educational needs of the professional Architectural Technologist. This new course had its first intake of students in September 2010.

Building upon a model of a constructivist learning environment proposed in a paper “Designing Constructivist Learning Environments” (Jonassen 1999, pp. 215-39), this research set out to observe and record a collaborative design project taught in the Department of Architectural Technology, in the Dublin Institute of Technology (DIT). Jonassen's model design puts the emphasis on providing learning experiences that facilitate knowledge construction and in meaning making. During the collaborative design process it became apparent that a strong learning dynamic had evolved, fostered by the collaboration tools of the BIM application. Using a single exploratory case study approach, the researcher has examined the strong learning dynamic and provided evidence of a new learning environment.

Review of Literature

Building Information Modelling (BIM).

The term building information modelling (BIM) is an extensive, wide-ranging term that covers technologies and methodologies based around the creation and co-ordination of digital building data that is visually represented in "three dimensions (3D)"on a computer screen. The subject is extensively reviewed in the *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors* by (Eastman C., Teicholz P., Sacks R., Liston K., 2008). BIM technologies and methodologies are central to integrated project delivery (IPD). The American Institute of Architects (2007, p. 1) defines IPD as “a project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harness the talents and insights of all project participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication and construction". A global information service provider McGraw Hill Company, produced a report in 2008 and followed this up in 2009, published the results of a state-wide survey in North America charting the rise of BIM in the AEC industry, A similar survey was conducted in Europe in 2010 focusing on the UK, France and Germany finding that the level of implementation might be higher in the North America but that Western European companies that have adopted BIM show a deeper commitment to BIM process's. These three reports appear to indicate, that BIM is on a rising trajectory in its use by AEC companies on both continents (McGraw Hill Construction, 2008, 2009, 2010). As a result BIM applications and methodologies are being increasingly taught in third level colleges across architectural, engineering, computer graphics and construction management courses see Barison and Santos, (2010, pp. 1-10) and Becerik-Gerber et al., (2011, pp. 411-32). "Over the last 5 years there has been a rapid movement from computer aided design (CAD) to building information modelling (BIM) by professional architects, engineers and construction managers and this has created several challenges and opportunities for AEC educational programmes" (Becerik-Gerber et al., 2011, pp. 411-32).

However, teaching BIM is not as simple as introducing the application within a module. BIM needs to be part of a holistic approach within technical design studio. Chistenson (2006, pp. 55-62) concludes that "the act of creating a parametric building model in Autodesk Revit, a BIM application, requires that a designer be able to intelligently define relationships between and within building elements". Chistenson also says that "the successful user of Revit, in addition to understanding how the software works, must understand construction technology sufficiently well in order to intelligently define such relationships". The growing number of architectural engineering courses in AEC education is testament to a need for a professional group to have a skill-set to marry the conceptual and practical. The development of the Architectural Technologist as a collaborative technical designer makes the professional Architectural Technologist ideally placed to fulfil this role.

Learning with BIM.

Fioravanti (2007, p 3) proposes "collaborative design as being the design method best suited to the challenges of our times". He suggests that the "fundamental components of these design problems lie in a low and selfish collaboration among actors", and to overcome this limitation he suggests that "higher education needs to deal with the lack of suitable education in cross-disciplinary collaboration and the lack of suitable ICT tools enabling collaboration to be practiced in the design of complex buildings". Denzer and Hedges (2008, pp. 1-11) investigated BIM in various classroom conditions and argue that BIM enhances group-based classroom management approaches of team learning. They use Bloom's Taxonomy (Bloom et al., 1956) as a benchmark to assess the student performance in a Design Studio Course. They conclude that BIM allows the students to reach the evaluation level of Bloom's Taxonomy in terms of cognitive skills development, (cited in Barison and Santos, 2010, p. 6).

Lonely BIM is a term used to describe a process where a BIM user works without collaboration deriving set benefits from this, but not achieving the full potential from the process. Becerik-Gerber et al., (2011) indicate that BIM implemented into the curricula will facilitate a multidisciplinary, approach that consolidates effort and enables more efficient collaboration and can also provide a platform for exploring new team structures and collaborations and realising improved student outcomes. Harty and Laing (2010, p. 548) refer to the "need to address the educational needs of the professional architectural technologist". In his authoritative work *Architectural Technology,* Emmitt (2002) states that "the technologist forms the link between conceptual design and production, translating design intent into physical reality". It is this "link" role that has the potential within a BIM process to elevate the architectural technologist into being the creator and curator of the digital model. The link being not only with the architect, the architectural technologist needs to develop the ability to collaborate with all the stakeholders in the design and construction process.

Learning spaces.

The studio has always been part of the educational experience of the student architectural technologist in DIT. The crucial difference between traditional classrooms and studios lies in the distinction between "learning about” and “learning to be” (Brown 2006, p. 5). The pedagogy of student-centred learning is well catered for in the open plan studio setting. Indeed this style of learning is rated highly in a paper “Designing new learning environments to support 21st century skills” (Pearlman 2010, pp. 123, 124). The open plan design is equipped with work tables on the inside allowing workspace for sketching, model-making and study. In Department of Architectural Technology in DIT where this research study was undertaken, personal computers were introduced into the studio in early 2000. This was facilitated by fixing benching to the exterior studio walls upon which the hardware was mounted and networked. The idea of keeping the personal computer within studio and not relegating it to a separate lab has made the integration of information communication technology into to the associated architectural technology course a smooth transition for the students. It is the replacement of the drawing board by the personal computer in the architectural technology studio as a main deliverable in terms of a learning tool, coupled with the collaborative methodologies of BIM applications that have led to the creation of a new learning environment explored within this case study.

Cognitive Learning in Architectural Technology.

The role of the AT is to solve technical problems within the process of delivering the architectural intent while conforming to statutory legislation. Emmitt (2002, pp. 32, 33) states that “creativity still takes place in the detailed design. This is a complex process full of reasoning about constraints, exploring fixes, resolving conflicts and searching for alternatives”. Jonassen (2011, p. 143) states, “constraints are rarely, if ever, identified completely at the beginning of the design process, as implied by the analysis phase at the beginning of the ADDIE model, (the ADDIE model being a generic term for the five-phase instructional design model consisting of Analysis, Design, Development, Implementation, and Evaluation), rather the beliefs and constraints emerge during each cycle in the design process”. Designers make decisions based on the constraints as they emerge.

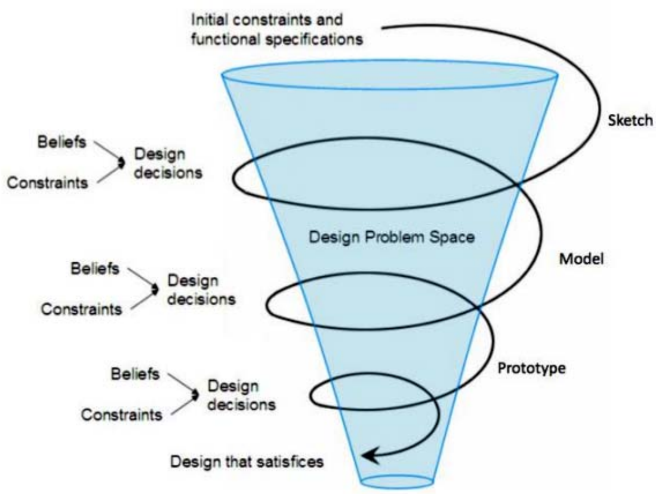

Figure 1 Iterative Design Process Model (Jonassen 2011, p. 144)

This iterative design process model aligns with the decision making process the architectural technologist faces when designing a technical solution to a design problem. Emmitt (2002, pp. 24, 25) writes that “It would be easy to conclude from the design methods literature that the conceptual design stage is where the creativity takes place, ceasing at the detail design”. For Emmitt (2002) this assumption would, however, be wrong as “creativity still takes place-indeed the best detailers can come up with creative solutions to very difficult technical problems-it just has to be constrained”. The BIM model contributes to this Iterative design process model, and can identify design problems in a way that working in 2D does not. BIM prompts students to ask questions about structures, material assemblies and detailing that requires the instructors to be relatively more agile in their ability to respond (Becerik-Gerber et al., 2011, p 9). These processes are also highly motivational to students as they engage collaboratively within their groups and with the architect on the design problem. The participation of the professional architect has the effect of provided scaffolding support to the students in this learning environment and help bridge the gap between student learning and professional practise. This enables the students to explore and learn the professional language of the industry and to communicate in the design collaboration.

A new learning environment for problem solving.

There has been considerable research around the creation of or what constitutes a learning environment, see for example Hannafin et al., (1999) and Wilson, (1995), "The case studio, studio team, studio group and problem based scenario are the main components of a Constructivist learning environment" (Ng, Fung Fai, cited in Barison and Santos 2010, p. 4). This aligns with Jonassen (1999, pp. 215-39) who proposes a model for designing a learning environment that has four aligned components. The first component is a problem, question or project that would be the focus of the environment. This is the goal that will drive the learning process. To provide a live brief for a project would sufficiently map Jonassen's (1999) three major components in the design of the problem. The brief must have context, it should provide description of the physical, organisational and socio-cultural elements of the problem. In this case study, the research is based around a brief to provide a new third-age centre and refurbish an existing senior citizens housing complex at Verschoyle Court in Dublin City centre. The live brief is therefore authentic and represents the same cognitive challenges as those in a real world setting. The real life setting is a challenge to the student and can be considered a meaningful and mindful activity where the manipulation space, in this case, the digital environment will visualise the students' argument to support their proposed solutions to the problem.

The second component from the model is related cases, representing a set of related experience. By the time the student AT has reached 4th year, they have completed an intense three year programme in building technology, environment, structures and materials aligned to their studio projects. The students are then encouraged to seek summer work in design practices. The third component from the model is information resources. This is well provided for as the student has access to the college library, the world wide web via the internet on the networked college personal computers. The final component is cognitive tools which, Jonassen (1999) states that "cognitive tools are computer tools that help visualize, organise, automate, or supplant thinking skills". A BIM application Autodesk, Revit, was introduced into the course in 2008 providing the innovative cognitive tool completing the four elements of Jonassen's model. In my observations of the collaborative design meetings and as outlined in this paper, it appears as though the collaborative properties of a BIM application, the studio setting, and a group project based around a live building brief, have combined to create the conditions for a new learning environment.

Research Methodology

The aim of this research was to explore potential benefits for learning to students through the use of collaborative learning supported by a BIM application. The author observed and recorded a studio based design and construction project that partnered a professional architect with 6 student architectural technologists. A qualitative case study methodology has been used to examine the learner's experiences during the project as "a hallmark of case study research is the use of multiple sources, a strategy which also enhances data credibility" (Patton 1990; Yin 2003 cited in Baxter and Jack 2008, p. 554). Potential data sources may include, but are not limited to, "documentation, archival records, interviews, physical artefacts, direct observations and participant observation" (Baxter and Jack 2008, p. 544). The author used six methods to capture data from the project, observation of the group collaborative design meetings, observation of the students working in the studio environment, reflective writing by the author, on line blogging by the students, students formative assessment from the project brief and project end interviews of the individual students. The research sample was drawn from a 4th year group of 18 students.

The class are separated into groups at the start of the first semester; they then work within these groups. The studio project is based around a live brief provided by a client in this case Dublin City Council Architectural Department. The student groups are each assigned a practicing architect with whom they will work in a collaborative design process for twelve weeks. The group the author used for research had decided from the outset to use BIM technologies as the main deliverable for their project. Their assigned architect was not familiar with BIM applications. The student group would be working collaboratively on the digital model using a BIM application in this case Autodesk Revit. The collaborative design process was observed by the author from start to finish over the period of 12 weeks.

The researcher selected Unit Four because of their commitment to work with a BIM application. Unit Four consisted of six students, five of the students had, the previous academic year, completed the NQAI Level 7 BSc in Architectural Technology. The sixth student had received his award the previous year. The six students had also completed two BIM projects as part of the Studio Cad element of their Technical Design Studio module and had a mixed ability from intermediate to proficient level of competence in Revit. The fourth year studio work in this study is based on the idea of a small architectural practice in the technical design studio module. A dateline for formative assessment of the group work and presentation of the design proposals to the client was set by the fourth year head of the course. The group had their first meeting with their architect in week two, the architect had received the brief the previous week. The architect had decided to take one typical building block consisting of eight senior citizens apartments on two levels with a space to the east gable end for a proposed tower block six stories high. The existing apartments are to be refurbished to meet current standards for accessibility, energy consumption and fire regulations.

The case study methodology allowed the author capture information through a range of data sources including;

Observation of group collaborative design meetings;
Four formal meetings were held with the design architect over the twelve week period. The author sat in on the meetings but did not contribute in any way, to avoid distorting the process. The first observed collaborative design meeting took place in week 2. The second observed collaborative design meeting took place in week 5, hand up of completed general arrangement drawings was on week 7 and the final observed collaborative design meeting was on the week 9. Presentation to the client of group work took place in week 12. The author took notes on his observations and photographed the group. This provided an insight into the thinking of the group. The author was able to observe the interaction, conversation and thought processes. It provided a timeline in the progress of the project.

Figure 2, Students first collaborative meeting

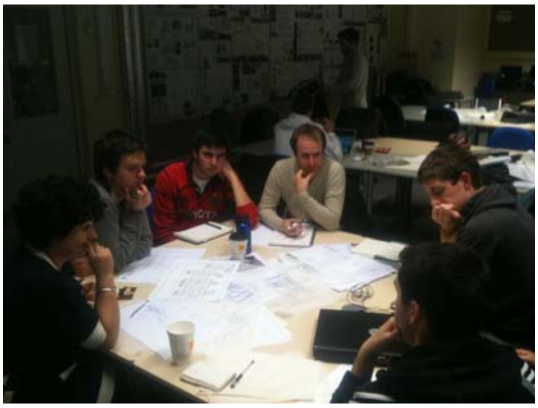

Figure 3, Students developing design through sketches

Observation of students working in studio environment;
The author setup the file based collaborative network and was in a position to observe the students working in the studio environment. The author took notes of the interaction between the students and saw the Revit collaborative application working.

Reflective writing by the author;
The author kept a reflective writing journal during the project and used this to put a rational on the different information coming from the data sets.

On line blogging by the students;
The author setup an on line blog to which the students had access. This allowed the students voice their thoughts during the project. The author prompted the students with open ended questions. The response to

the blog questions by the students was excellent and provided valuable insights to both the problems encountered and the type of learning the collaboration was promoting.

Figure 4, screen print of research blog.

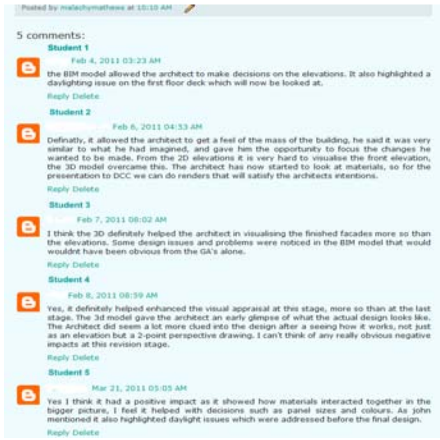

Figure 5, screen print of student response on blog.

Student's formative assessment from the project brief;
The students work was assessed as a group. They were to deliver a set of general arrangement drawings for the building project. This involved proposals for interventions into an existing block of apartments and a new build tower block. Unit 4 received the highest mark of the class for the work. The author made an assessment of the project work and concluded that the collaboration had been a great success in terms of meeting the project brief.

Project end interviews of the individual students;
These aural interviews were carried out after the collaborative project was completed. The author set three open ended questions designed to get the students to reflect on the experience of working in a collaborative group using BIM technologies. The author observed in each case a positive reaction to the collaborative working on the digital model.

Analysis of the data sets was carried out at project end. The data sets were mapped along a time line of the project and were compared, criticised and reflected upon. The data collected provided statements on the value of the new learning environment to the collaborative design process and the collaboration process on the learning of the students in unit four.

Findings

Stage one; problem solvers

The author took notes of his observations during the collaborative design sessions. In each of these session's the group sat around a large table in the students' studio where each member had a view of each other and were in a position to contribute verbally to the discussion. On the table were a large selection of hand sketches done in pencil and pen on light transparency paper. In the early discussions the researcher noticed that all the plans and elevations of the concept by the architect were in hard-line sketch format. The discussion was mostly initiated by the architect and covered an area of the project that required an intervention of an existing building. The student architectural technologists contributed as "problem solvers" at this initial phase. Information contributed to the collaborative design process (CDP) blog by the students indicates that they were already taking the architects 2D sketches and making 3D massing models. One of the group more advanced in Revit started to lay down a grid line and level framework to model the existing senior citizens block in preparation for the proposed refurbishment plans of the design architect. This was the start of the Revit model being used by the students to address the design problem.

Stage two; formulating collaborative skills.

In the next stage the architect continued a methodology of designing the concept solution through the use of hard-line sketches on butter paper (light transparency paper).The author noticed that when the architect was explaining an idea in relation to a portion of the building he used his hands to form 3D shapes and volumes to give expression the idea and to make it easier to understand and visualise. He also made use of overlays to co ordinate rooms sited directly above and below the four storey building, in effect simulating 3D. As the volume of sketches increased, problems started to occur in coordinating the information between plans, elevations and sections. Also locating sketches became difficult as the group had to shuffle through pieces of paper to locate a referred to layout. The author observed that the architect liked loose sketches at this early stage of the design as they allow for reflection and possible alternatives to come from this reflective process. The student group in these early sessions were also formulating technical questions as the design collaboration process continued. This had the effect of challenging their decision making skills and formulating their collaborative skills. They were also developing confidence through higher levels of involvement with the project.

Stage three; active collaboration.

By the end of week four the student group were contributing as collaborators in the design process with their increased commitment to and involvement with the project. They were re-presenting the design information to the architect with hard copies drawn from computer aided design formats. The architect continued investigating design changes through the use of transparency paper overlays and pencil sketching. It was noticeable however that the student group were taking ownership of the project as their involvement intensified and different areas of technical design work were delegated out to individual students' by group decision. These areas of responsibility were used later to form the Revit work-sets. Work-sets are a selected collection of building elements in the BIM model.

Although there were areas of the design still not fully resolved the students had a submission deadline for the end of week seven to submit general arrangement drawings for formative assessment on their project and the students decided it was time to initiate the BIM model. The students were setup with a shared drive space on the institutional network and each of the group needed access to this network storage area. One student had the basic framework of the Revit model constructed, so this was setup as the master copy. The building elements were grouped into work-sets with each student taking responsibility for a set. Unit four needed to work as a collaborative group, in order to make the deadline as they had five days to produce the general arrangement drawings a task that would take possibly three to four weeks working alone on a conventional 2D computer aided design application. The general arrangement drawings were handed up on time and following formative assessment by the 4th year studio staff unit four received the highest mark in class for their work.

Stage four; collaboration through the BIM model.

The final collaborative design meeting took place on the week nine and unit four presented the BIM model projected from a personal computer on to a screen to the architect. His reaction was surprise followed by acceptance that this digital model was what he had envisioned. He also commented to the group that this was not far off from his intended design. For the rest of the meeting the BIM model was used for design visualisation references. It was observed that the architects designer instincts almost immediately came into play as he initiated a discussion related to the external material of the lower two storeys of the tower block, and how these could be altered to give a "base" to the tower. This interaction and many other subsequent design decisions were taken all prompted by the visual observation of the BIM model.

The blog to which the student group contributed confirmed the facilitating role of the BIM model and the benefits to the project derived in terms of collaborative decision making but also in terms of improved decision making by the individual student. Student 4 states "that I learned in a different way. I learned through both individual research and group discussions". The BIM (model) also improved communication between all members of the design team. All the implications of design decisions were picked up on through the work-sharing feature and discussed before the project moved on. Student 1 responded that he "found the group did communicate much better while working in the collaboration mode of BIM, any important decisions to be made required us to discuss it as a group" Student 3 said "my decision making skills may have improved, but more so making decisions based on talking with others". The author has reflected on the timing of introducing the BIM model into the design process and concluded that this needs to be carefully considered. The model carries a strong visual representation, perhaps too strong for the architect in the early stages of the conceptual design, in that it could unduly interfere in the architects reflective thought process.

Figure 6, Students introduce BIM model to architect

Figure 7, Detail visualisation from BIM model

Discussion

The collaborative process involves creating a master copy of the model. This is housed on a networked server. The master copy is into divided up into work-sets. These work-sets are elements of the building for instance the external envelope, the internal walls, the stair-core, the floors, each of the students agreed to take ownership for an element and worked on this. The users synchronised with the master-copy on a regular basis. Each time a synchronizing happened all elements are updated and communicated to the group. This instant communication facilitated and prompted discussion amongst the students about the technical design proposal. The students were drawn into a conversation about the building elements and they would critically examine each other's work. Therefore, the BIM model provided enormous value in visualising the technical proposals and further enhancing the conversation. As a result of this, work was often, revised and re-visualised. The students were also teaching each other and seeing the immediate results of through the 3D visualisation of the BIM model. This was confirmed in interviews conducted with the students after the group part of the project had finished. The feedback received included the following statements:

Student 1 "Problem issues were much easier to see in the BIM model"
Student 2 "The use of BIM works well because you are not just drawing, you are building"
Student 3 "The model makes you think more of things on a macro scale"
Student 4"It was a totally different way of working"
Student 4"The model showed where things clashed; where you are drawing constantly in 2D you don't see these clashes"
Student 5 "Working on the model has changed the way one would think"
Student 1 "The model pushes you to collaborate more than one might do otherwise"
Student 6 "You will see what's wrong sooner when working on a BIM model"

The learning pyramid developed by the NTL Institute for Applied Behavioural Science ranks average retention rates against learning styles. The three highest rated learning styles on the pyramid are; discussion group, practice by doing and teach others with immediate use. The collaborative learning facilitated by BIM encompasses all three of these learning styles culminating in a new rich learning experience for the student group. This echoes Denzer and Hedges's (2008, pp. 1-11) use of Bloom's Taxonomy as a benchmark to assess the student performance confirming that BIM allows the students to reach the peak of Bloom's Taxonomy in terms of intellectual behaviour, "the evaluation level". From my observations, the work-set methodology further developed the collaborative process and contributed to a higher level of learning. For example, for a building element to interact with another from a different work-set, permission must be sought by the person wanting access to the element and permission must be granted by the owner of the work-set. This procedure facilitates a one on one conversation on how the elements will interact, resulting in a constant validation of the proposed technical design solution.


Figure 8, Proposed building visualised

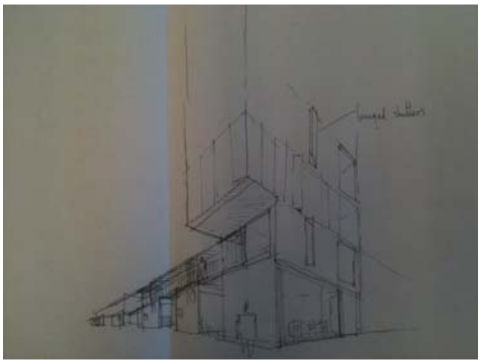
Figure 9, Architects early sketch proposal

The author observed continuous conversations during week seven while students were working on the BIM model and this resulted in solutions to technical design problems with deeper understanding of the technical detail as the problems were teased out by the group working in collaboration.

Conclusion

It is likely that the problems of the future, in this case building design, will have a cross-disciplinary approaches that encompass multiple areas of expertise and the ways of knowing will have to become the norm. People, in this case the stakeholders in the design and construction of buildings will need to be able to work in cross-disciplinary teams (Brown 2006). The DIT Architectural Technologist who is not burdened with the heavy weight of conceptual design can concentrate their learning on developing an understanding of the other disciplines in the design and construction of a building, not to become the expert in these roles but to have the ability to be the creator and co coordinator of the BIM and facilitate problem solving within the collaborative process. The complexities of modern design and construction lead the author conclude that no one profession has all the answers to all the design questions. As new processes bring new responsibilities, the degree of specialised expertise that goes into a modern building expands constantly. This new collaborative learning environment simulated through working with BIM has the potential to prepare and equip the student architectural technologist with the skill-set to be at the centre of the problem-solving collaborative process. Jonassen (2011, p. 146) also argues that although the ability to solve problems or to develop a methodology to address complex problems is something which requires practice. The creation of problem solving learning environments will address this. The fact that groups of students can collaborate together, simultaneously on a BIM model adhering to a well structured brief to propose a solution to a technical problem will give them practice that closely follows what they can expect in modern design construction workplaces. It is the author's opinion that this structured coordinated collaborative process is more efficient in terms of students reaching their deadlines for project delivery and also enables a higher level of learning and understanding of technical design for buildings. A modified version of this model could be introduced in year three of the course. This would provide further scaffolding to the students. They would learn the practicalities of how the collaborative tools work and this would have the effect of enhancing the collaborative project in year four allowing more time to spend on collaborative technical design. There is a challenge to take this model and extend it beyond the architect / technologist collaboration and open it up to include the other design and construction students and this can lead to further exploratory research in this area.

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