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AN INNOVATIVE LEARNING MODEL FOR TEACHING ARCHITECTURAL TECHNOLOGY USING BUILDING INFORMATION MODELLING: A QUEENSLAND UNIVERSITY OF TECHNOLOGY PERSPECTIVE

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Abstract

In architecture courses, instilling a wider understanding of the industry specific representations practiced in the Building Industry is normally done under the auspices of Technology and Science subjects. Traditionally, building industry professionals communicated their design intentions using industry specific representations. Originally these mainly two dimensional representations such as plans, sections, elevations, schedules, etc. were produced manually, using a drawing board. Currently, this manual process has been digitised in the form of Computer Aided Design and Drafting (CADD) or ubiquitously simply CAD. While CAD has significant productivity and accuracy advantages over the earlier manual method, it still only produces industry specific representations of the design intent. Essentially, CAD is a digital version of the drawing board. The tool used for the production of these representations in industry is still mainly CAD. This is also the approach taken in most traditional university courses and mirrors the reality of the situation in the building industry.

A successor to CAD, in the form of Building Information Modelling (BIM), is presently evolving in the Construction Industry. CAD is mostly a technical tool that conforms to existing industry practices. BIM on the other hand is revolutionary both as a technical tool and as an industry practice. Rather than producing representations of design intent, BIM produces an exact Virtual Prototype of any building that in an ideal situation is centrally stored and freely exchanged between the project team. Essentially, BIM builds any building twice: once in the virtual world, where any faults are resolved, and finally, in the real world. There is, however, no established model for learning through the use of this technology in Architecture courses.

Queensland University of Technology (QUT), a tertiary institution that maintains close links with industry, recognises the importance of equipping their graduates with skills that are relevant to industry. BIM skills are currently in increasing demand throughout the construction industry through the evolution of construction industry practices. As such, during the second half of 2008, QUT 4th year architectural students were formally introduced for the first time to BIM, as both a technology and as an industry practice. This paper will outline the teaching team's experiences and methodologies in offering a BIM unit (Architectural Technology and Science IV) at QUT for the first time and provide a description of the learning model. The paper will present the results of a survey on the learners' perspectives of both BIM and their learning experiences as they learn about and through this technology.

Keywords - Building Information Modelling (BIM), Architecture, Construction Technology, innovative teaching & learning, Computer Aided Drafting (CAD), building industry.

1 INTRODUCTION

Until very recently, Brisbane's built environment was expanding at a phenomenal rate, and as such Architecture, Engineering and Construction (AEC) practitioners were extremely busy and in high demand. This scenario has substantially changed as a direct result of the World Financial Crisis. In this changed environment, only AEC practitioners with proven work records and competitive skills are still in demand. In an attempt to gain an advantage in this highly competitive environment, AEC practitioners are currently looking to software's' and process to achieve efficiencies. Building Information Modelling (BIM) is one such revolutionary technology that promises to achieve efficiency.

Queensland University of Technology (QUT) is a premier tertiary education institution in the Brisbane region that prides itself with close ties to industry. In an attempt to both acknowledge industries desire for BIM skills and 'lead' industry rather than to 'follow' industry, QUT's School of Design has recognised the need to offer BIM education.

This paper seeks to present the innovative changes to teaching and learning in the final unit of the Architectural Technology and Science subject stream at QUT. The paper is contextualised around fourth year architecture students and their use of BIM. It outlines the current role of BIM in the AEC industries as well as the process of introducing BIM at QUT. Also included are the student's evaluation of this new tool and the results of their first assessment.

2 BUILDING INFORMATION MODELLING

Traditionally, buildings and the wider urban environment has been designed, constructed and operated through the communication of intent. This intent originates from practitioners, owners and operators and generally takes the form of industry specific and abstract paper documents or representations (plans, schedules, specifications, etc.). The production of this intent has traditionally been accomplished by either the hand draughting of documentation using either the drawing board, or alternatively, using software that mimics this hand draughting process i.e. Computer Aided Design and Drafting (CADD or simply CAD). The major problem with these paper based technical representations is that they rely on drawing conventions that are somewhat flexible, primarily two dimensional (2D) in nature, and their application and subsequent interpretation is intended primarily for the initiated i.e. the actual information being communicated is open to a degree of interpretation.

In response to this information *vagueness* BIM, currently regarded as one of the most promising developments in the AEC industries [1], has been developed. BIM operates on the premise that you build any building twice: Firstly, as a single information rich optimised digital model in a virtual environment, and secondly, you transfer this *tested* information into the *real* world. BIM, on one level operates much like traditional CAD, in that it represents the objects or geometry of a building; however on a higher level these objects be they walls, columns or ceilings are also enriched with theoretically infinite amounts of information. A wall, now far from being an abstract representation, knows it is a *wall* as it contains information about its material, construction, placement, relationships, etc. (see Fig. 1). Objects in BIM are considered as parametric as they are determined by both parameters and rules.

At this point, it is important to note that BIM apart from being a technology is more importantly a process [1]. Typically the process of designing, documenting, constructing and managing buildings has been highly fragmented, hierarchical, adversarial, and litigation prone. BIM, on the other hand, proposes a process that is essentially the inverse of this traditional mode; here the process is theoretically monolithic, integrated and cooperative. According to Robinson, "BIM is a collaborative tool used by any member of the AEC industry based upon a number of soft solutions. BIM incorporates all the building components (or objects), including their geometry, spatial relationships, properties and quantities, including all the services and equipment information for the full life cycle management of the building and even its demolition." [2]

BIM is, however, not a new concept. As a pure technology or process it has been in development since the mid 1990s [1][2][3]. Alternatively, it can be considered as having been in development for nearly 30 years; being a natural evolutionary process from 2D CAD, to three-dimensional (3D) CAD, to object orientated CAD and finally BIM. BIM essentially adopts the Virtual Prototype methodology that has become prevalent in the automobile and aeronautical industries in the last two decades.

BIM in essence communicates optimised actual information about a particular building, rather than abstract, industry specific representations. This communication of information makes it easier to detect errors and facilitates the correction of these errors at documentation stage instead of at the construction site. With BIM corrections need to be made only in one place and automatically accepted and copied to the entire project. In addition, the information in the model can be accessed by all project team members regardless of time and place. This is not to argue that industry specific representations will altogether disappear from the AEC industries. What will change about these representations is the accuracy and consistency of the communicated information.

It has been acknowledged that the major emphasis in the training of architects has been on aesthetics, theory, history and building technology and construction [4]. It could be argued that aesthetics, in the form of architectural design, constitutes the major focus of an Architect's training and practice. One of the most common misconceptions of the application of BIM amongst practising architects is that it is a technical production tool like CAD, rather than a holistic process that fundamentally includes design. This misconception is possibly reinforced by the fact that most BIM software is limited in its ability to model forms other than rectilinear ones. This is seen as a major restriction in the architectural design process. BIM not only makes it possible to visualise and speedily evaluate various design proposals, albeit mostly rectilinear proposals; it also contextualises and supports these various design proposals with structural, mechanical, electrical and fabrication information.

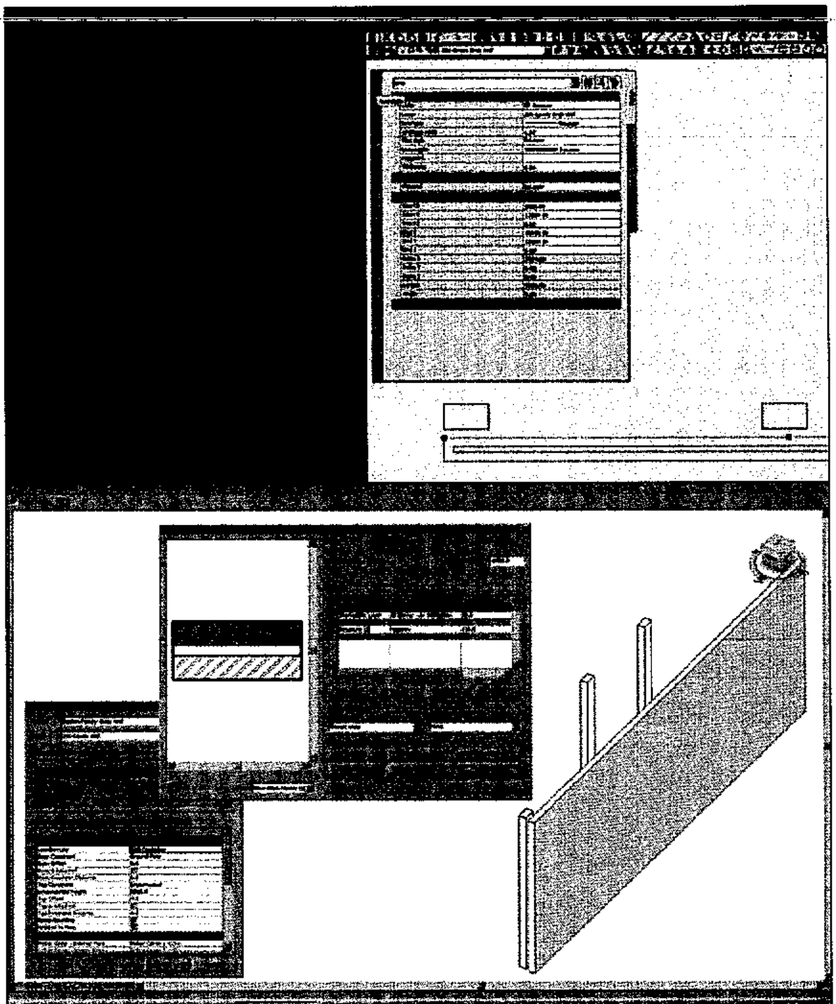

Fig.1. (Clockwise from top left and indicated in red.) The first image illustrates a hand drawn representation of a 280mm Cavity Wall. As it is an industry specific representation, only those initiated into the industry would potentially understand it as a 280mm Cavity Wall. The second image represents the same wall but drawn in CAD. The properties shown describe layer, line weight, colour, etc. and tell the viewer little or nothing of the walls construction. CAD is a computer based drawing board, it represents the same information as the hand drawn example; essentially *dumb* representational lines. The last image is a BIM representation. Here, instead of drawing lines, you draw an 'actual' 280mm Cavity Wall. This wall can theoretically contain an infinite amount of information that describes it construction, fire rating, thermal performance, relationships, etc.

Some authors attribute the early success of BIM to enhanced capacity of personal computers [5]; while others attribute BIM's recent popularity to the marketing strategies of the major software vendors. [6] Nevertheless, a recent success for BIM is Swire Properties One Island East project in Hong Kong. In this project, numerous clashes were discovered and resolved in the BIM model even before the construction started, thus avoiding costly errors, rework delays and requests for information. It is estimated that the BIM process saved 10% of the cost of this US $ 500 million project. [7]

The findings of a Stanford University Centre for Integrated Facility Engineering's study on 32 major projects using BIM point to: A 40% elimination of unbudgeted change, cost estimation accuracy of 3%, an 80% time reduction in the generation of cost estimates, a saving of 10% of the contract value through the use of clash detection, a 7% reduction in project time, and a return on investment (extra investment required to produce the BIM model) of between 5-10 times. [8]

This is not to say that BIM is the proverbial *magic bullet*. Contextualised within its embryonic status, BIM still has numerous significant challenges namely: Interoperability, or data transfer, between different software packages, inability to model complex geometry, turning the *marketing hype* into reality and wider industry acceptance - especially by all AEC professionals.

The challenge from a teaching and learning perspective is to identify an appropriate learning model to facilitate student's engagement with this new technology. Integrating students' use of this tool, as part of a design and communication process, is a major educational challenge.

3 BACKGROUND TO TEACHNING SCIENCE AND TECHNOLOGY TO QUEENSLAND UNIVERITY OF TECHNOLOGY ARCHITECTURE STUDENTS

The focus of this paper is a unit from the Bachelor of Architecture (B-Arch) degree at QUT. A B-Arch is the globally accepted qualification for Architects, and generally comprises a four or three year undergraduate degree, followed by a two or one year postgraduate degree. QUT's B-Arch comprises a '4+2' year mode that distinguishes itself by mandating a period of student employment in architectural workplaces. At QUT, each year of the B-Arch comprises two semesters with four units (or subjects), per semester. Technology and Science, or alternatively Architectural Technology, is one of a number of core programmes in QUT's B-Arch curriculum; the other cores' being design, theory and history. QUT's B-Arch Technology and Science curriculum comprises seven units that all occur at undergraduate level. Students acquire knowledge and skills in environmental issues concerning climate, energy and conservation, the mechanical, electrical and hydraulic services used in building and the construction and structural issues associated with a wide range of domestic, industrial and commercial buildings. In the final Architectural Technology unit, the students have previously been required, to produce a set of generally 2D drawings that explicate particular technical aspects of their current major design project. These 2D drawings are generally accomplished using traditional CAD.

With dramatic local and international changes to both the workplace and academic structure of architectural qualifications, coupled to a subsequent realignment of priorities within these newer courses toward sustainability and digital tools, an innovative approach to the teaching of Architectural Technology needs to emerge. A process that offers this potential is BIM.

3.1 Integration of Building Information Modelling in the teaching of architectural science and technology

As BIM is both a revolutionary technology and process, it offers massive potential to change both the students and the wider profession through challenging the design process and furthering the ability for different professional groups to collaborate. Using BIM, students can now model and visualise actual construction elements and the parametric relationships between these objects, rather than approximating abstract representations. Students can make a paradigm shift from working with unconnected 2D representations, to a 3D 'actual' construction. Using BIM, the proposal is that students can more readily comprehend the results of their inputs. This shift from 2D to BIM presents an opportunity for students to acquire skills that are both digital and that closely mimics the experiences that they will have in industry.

It is expected that the students in their fourth year of architectural studies have attained a sound knowledge of architectural Technology and Science that enables them to produce a set of drawings to adequately explain the technical aspects of a building. In the second semester 2008 the focus of this final unit in technology and science changed from 2D CAD to the creative application of this prior knowledge using BIM. This is the first time that BIM was applied to the architecture curriculum at QUT.

The aim was to develop knowledge and skills in BIM that would equip the students with expertise needed to adapt to the rapid changes taking place in the AEC industries. By their fourth year of study, architecture students at QUT already have a reasonable competence with CAD, gained through their experiences in the workplace. The purpose of this unit was not about teaching of software packages; it was about the creative exploration of the potentials of BIM. It was expected that on the completion of this unit the students should gain a range of communication skills at a professional level. Furthermore, it was anticipated that proficiency in BIM, which is progressively superseding traditional CAD, will give QUT graduates a greater advantage in the workplace.

4 THE UNIT

This unit was delivered over a thirteen week period in Semester two of 2008 and was officially designated Architectural Technology and Science 6 (ADB026). Each week, formal contact time consisted of a one hour lecture, generally by industry specialists, followed by a two hour tutorial. In the tutorial students explored the creation of an actual BIM model with assigned tutors. This formal contact time was additionally supplemented by student self directed learning. The students' performance in this unit was measured against two projects assessed according to Criterion Referenced Assessment (CRA) standards. This paper focuses only on the first project.

4.1 The project

The first project was a group exercise that required the production of a BIM model of a particular building design. The selected building designs were projects completed in the preceding semester by senior fifth year students. The intention of assigning design projects completed by other students, rather than the accepted mode of students working on their own designs, was done to closely mirror the reality in the workplace. The five chosen projects had design merit, technical robustness, and no prior BIM modelling. 'Technical robustness' should be further explained. These five designs originated from a process for the conceptualisation of an Australian National Sustainability Initiative (ANSI) complex. The fundamental requirement for this ANSI project was that sustainable technologies would be used. As such, designs produced were outside the scope of traditional or accepted construction technologies. Students undertaking the BIM modelling of these designs had to effectively adapt to BIM as well as innovative construction technologies. This methodology helped students to 'abandon' accepted modes of practice. Each of the five hosen ANSI projects required more than one unit group to complete the BIM exercise. Therefore, groups working on a particular ANSI project were required to negotiate a fair and equitable portion of their allocated ANSI project with the other groups. Thus no one group did less or more than the others in the unit. The reality of more than one group working on any one design was intended to further enhance collaboration.

The project required students to form skill based groups of five, that would emulate the professional skills required in an architectural practice: Students adopted the roles of either a Project Architect who assigned and directed work flows within the group, a BIM Manager who had reasonable exposure to BIM software's and thus was able to offer technical assistance to all other members of the group and three Technical Architects who did produced the actual BIM model. The Technical Architects were generally students who had little or no exposure to BIM. The driving force behind the need for these three main personalities was to ensure that all groups had the fundamental capacity to organise, produce and learn. A total of twenty groups were formed by the one hundred and two students enrolled in the unit.

The BIM model produced by the group was expected to fully and competently represent both the 'fabric' and 'structure' of the allocated ANSI portion. The students were also required to include all the site and landscape elements. The groups had the choice of selecting the software for completing their BIM models from either Autodesk's Revit or Graphisoft's Archicad.

As the majority of the experiences within this unit were largely self-directed and exploratory, the 'process' was obviously of vital importance. The groups were required to exclusively use the Blackboard wiki for all aspects of the project including, the process, submissions, assessment, group discussions, issues arising, etc. The use of Blackboard was intended to simulate a real environment and processes of digital collaborative design. For this project the students were required to submit a group submission via the Blackboard wiki that included the following items:

1. The process in accomplishing the final BIM.
2. Representations of the individual group BIM as a series of 3D images. The number of images was entirely a group decision.
3. The actual BIM computer files, in both proprietary and Industry Foundation Class (IFC) 2x3 formats.

As such, the learning model adopted in this unit has 4 distinctive characteristics:-

1) Apprenticeship and modelling – as fourth year students took fifth year student designs and used BIM to represent these designs, the design skill sets of later year students are modelled to them. Fourth year students are also put in a position of critiquing the work of their later year peers through identifying problems with the design through the use of BIM.
2) Collaboration – since each project is to big to be completed by any one person, the students must work in teams. This not only mirrors the reality of the workplace, but also provides them with further opportunities to learn from other student peers.
3) Sustainability – as students were required to resolve sustainable solutions, they are tackling emergent real-world problems that are of significance to both the wider AEC industries and the community as whole.
4) Experiential and work-based skills – students can utilise their experiences from industry to inform their design solutions and to capitalise on their existing skills in using BIM (if they are employed prior to starting the unit.) Where they do not have these experiences, they are exposed to them through the skill sets of other students.

4.2 Assessment

Based on CRA, a group mark was awarded for this assessment that included the following items:

1. Application of BIM technologies: The production of a BIM model representing both the structure and fabric (including site and landscape) of the ANSI example.
2. Communication: The communication of the process that was followed to create the BIM using the wiki.
3. Accuracy: The BIM model produced should be an accurate representation of the original design intent.

4.3 Analysis of student performance related to assessment

Students were assessed as having preformed well. (For examples of student submissions see Fig.2-4). Of the 20 group projects submitted, three groups have scored in excesses of 85% but less than 90%; these three projects being considered as excellent and outstanding in their address of the three criteria above. The bulk of the submissions, namely 10 groups, scored between 75-84% in the assessment. These 10 submissions have been evaluated as being very good. The remaining seven groups scored between 65-74% and are considered as good in their ability to address the criteria.

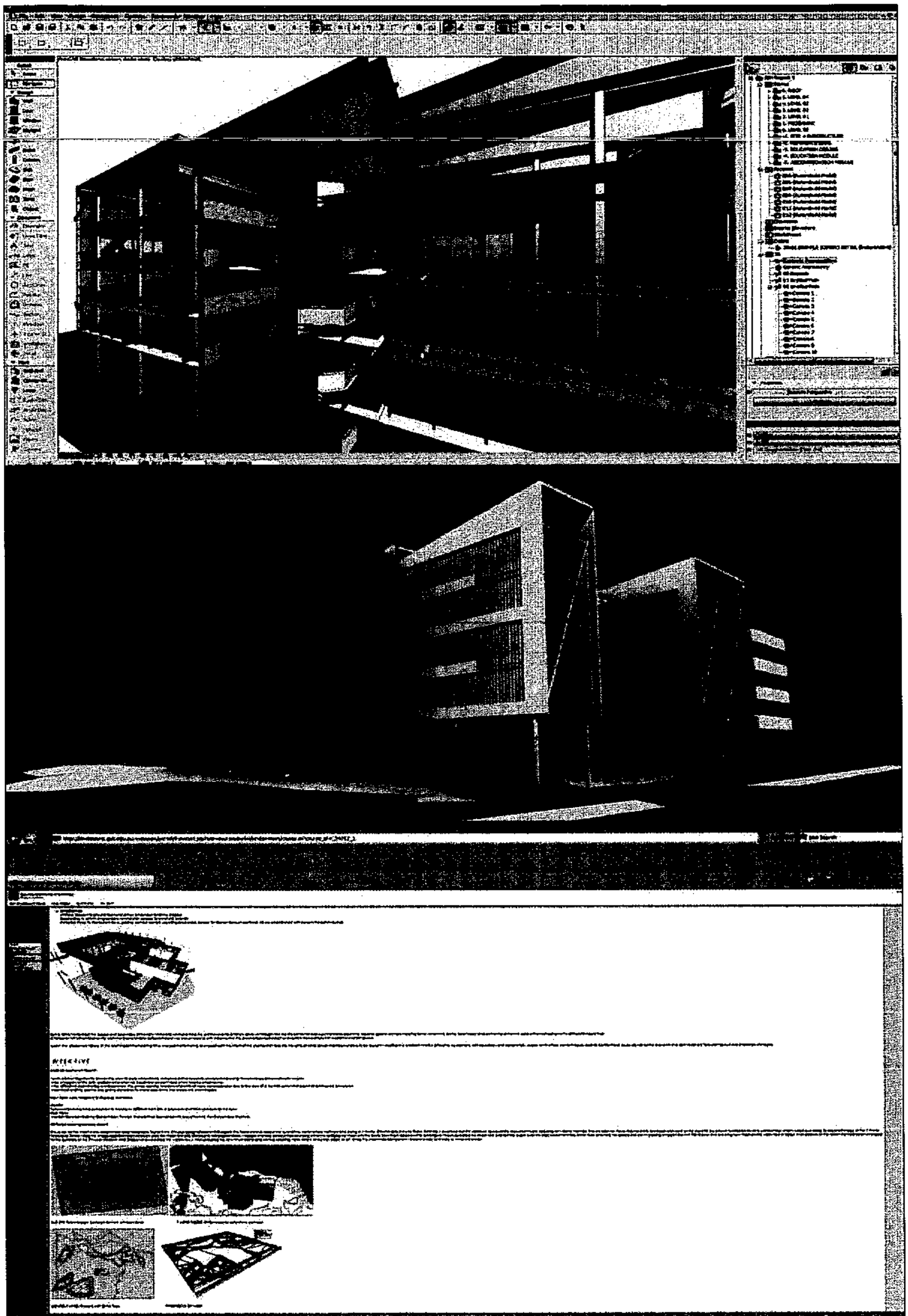

Fig.2. Group 17 - *Team A-Z*: Christopher Rawlinson, Shaun Purcell, Allison Hume, Allison Hortz and Zachary Marshall.

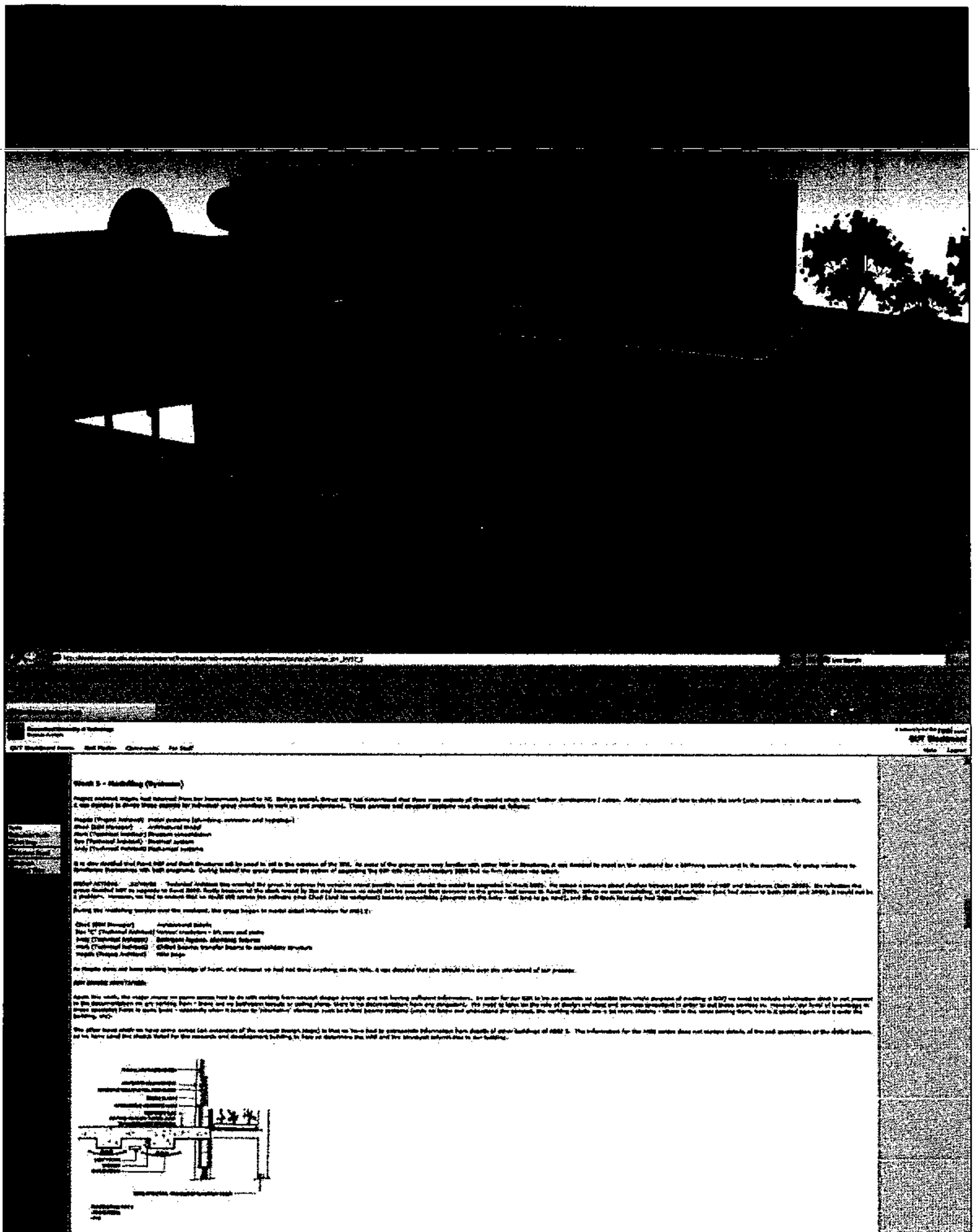

Fig.3. Group 5 – *Kitty Kat:* Magda Kowalik, Cahd Middlemis, Mark Andrew, Sze Suen and Andrew Hui.

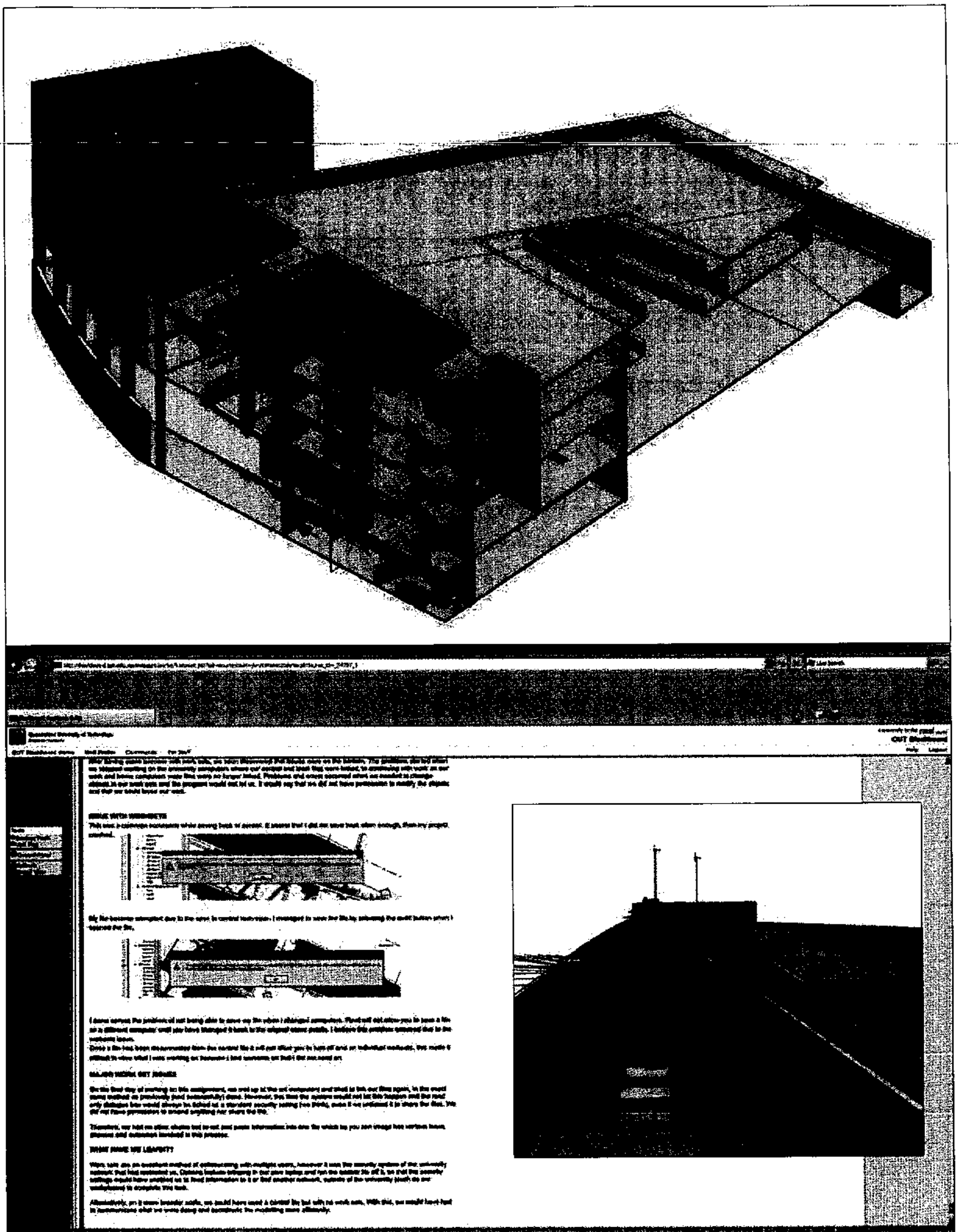

Fig.4. Group 14 – BIMit: Luke Nuske, Jeremy Gilmore, Heidi Clem, Roxanne Harris and Amanda Greene.

5 LEARNERS PERSPECTIVES

5.1 Survey method

A paper survey consisting of three distinct sections was conducted to gauge student perspectives. The first part asked students about their use of BIM in the workplace, the second part focused on their use of BIM during their studies and the third part looked at how this might impact on their and their cohort's employability. In total 47students (out of 102) completed the survey which consisted of 10 items (Fig.5.), representing a response rate of 46%.

Questions to students:

1. Are you currently working in an architectural practice? Y / N

2. Do you use BIM in your workplace? Y / N

3. If not would you strongly recommend BIM? Y / N

4. How would you rate your application of BIM in this unit?

   Excellent / Good / Average / Poor

5. Which software package did your group use:

   a. ArchiCad b. Revit c. Other (specify)

6. How would you rate your knowledge and general understanding of BIM gained from this unit?

   Excellent / Good / Average / Poor

7. Do you think the knowledge gained in this unit will be useful for your career as an architect? Y / N

8. Do you think BIM should be an important component of the education and training of architecture students? Y / N

9. Do you think this educational experience will enhance your employability in the future? Y / N

10. Do you recommend BIM as a tool teaching and learning architectural Technology & Science? Y / N

Fig.5. Student survey.

5.2 Survey results

Just over 93% of the students surveyed were working in an architectural practice and 50% of these students used BIM in their workplace. The remaining students either didn't use BIM (47%), or the question was inapplicable (3 students). When asked if they would recommend the use of BIM, 57.5% of students responded that they would, 17% said that they would not and 25.5% gave no reply. The no-reply responses to this last question might indicate a level of uncertainly regarding the exact nature of BIM.

When asked about their use of BIM software as part of their studies, 4.25% rated their skills as excellent, 63.8% rated their skills as good, 21.25% rated themselves as average, 4.25% as poor, and 6.4% gave no reply. 42.5% of students used the Archicad software while 53.2% used the Revit software and 2.12% used an unspecified BIM software application, 2.13% used both ArchiCad and Revit. When students were asked to rate the knowledge that they gained of BIM through their study of the unit, their responses were: 4.25% rated their knowledge as excellent, 68% rated their skills as good, 21.25% rated themselves as average, 4.25% as poor and 2.12% gave no reply. There was a strong correlation between student responses to this question and their response about the use of BIM software.

87.23% thought that the knowledge gained would be useful to their careers as Architects (8.51% did not and 2.13% gave no reply).

Over 93% of students thought that BIM was an important part of the education and training of architecture students. 74.5% thought that their educational experiences in this unit would enhance their employability, 17% did not think their employability was enhanced and 8.5% gave no reply. 93.6% would recommend the use of BIM in the teaching of the Architectural Technology and Science.

5.3 Queensland University of Technology's Learner Experience Survey

The Learner Experience Survey (LEX) is the online institutionalised measure of student satisfaction of the learning experience. Of the 23 students (out of a possible 102) who completed the LEX survey: 60% proposed that the unit 'often' helped develop their skills and knowledge, 87% were satisfied with the assessments' 'relevance to topic' and 65% were satisfied with the assessments' 'level of difficulty'. Positive student comments generally revolved around the use of the Blackboard wiki, informal learning of BIM software, flexibility in formation of groups, and relevant information delivered in lectures. Negative comments generally identified a student desire for formal BIM software training, and students not seeing the relevance of a BIM subject as many may have been using BIM in their workplaces.

6 CONCLUSIONS

This research indicates that BIM has merit in an architectural teaching and learning context. Interpretation of the data indicates that the majority of students support the use of BIM in the workplace. Additionally and unsurprisingly, there is a correlation between using BIM in the workplace and this preference for recommending its use. Students also rate their proficiency with BIM as above average (in the context of its use within their studies); and a substantial majority report that the knowledge of BIM gained through study of the unit will be beneficial to their transition to professional practice. Each of these key findings will now be explored in more detail.

Although the majority of students would recommend the use of BIM in the workplace, nearly 1/5 said that they would not. Further research should investigate why students would not recommend the use of BIM in the workplace. It may be that students' technological literacy is challenged by the use of the software and that they feel they are insufficiently prepared for professional practice. This may be particularly so for those students who do not already use BIM in the workplace, or who are not currently employed in an Architectural practice. There is anecdotal evidence to support the notion that this view is correct; for instance, several students made unsolicited extended comments requesting that BIM should be introduced earlier in the Architectural Technology strand of their studies and that they should be given more explicit instruction on how to use the software. Given the increasing prevalence and role of BIM in the architectural industry, it is advisable to address these student concerns with more opportunities for developing their technical proficiency. It also needs to be clarified whether the reluctance to use BIM is based on a lack of awareness about the benefits it provides to team communication and project completion.

The majority of students also rated their skills as average or above average. Whilst it would appear counterintuitive that the majority of students could rate their skills as above average, given that half of the surveyed students have experience using BIM in the workplace, this is not so surprising. It also coincides with the grades that students received as part of their assessment with all students achieving credit or higher grades. It would be interesting to correlate overall qualitative evaluation of assessment with students' familiarity and self rating of their BIM proficiency. It may be that those who are more proficient are achieving the higher grades and producing higher quality projects. Additionally, it may be that there is a degree of informal learning taking place, where students are teaching each other how to use BIM and shifting the skill level of all students higher. If this is the case, it would support the success of the current learning model and promote its adoption as one method of addressing the need to develop higher level technical competencies for students that are in demand by industry and that may enhance their employment opportunities.

Whilst the majority of students rated the knowledge gained as helpful to their careers, approximately 10% did not. This may be due to the fact that about half the student cohort have already been exposed to the use of BIM in the workplace and may feel that their skills have not been expanded through completion of the unit. It is not possible to state whether this is the correct interpretation of this finding without additional qualitative research. However, it may also be the case that the current learning model does not facilitate students learning from each other as much as was intended. This warrants further investigation through focus groups or interviews with students using this technology in other units.

Further research should be conducted with students using in-depth qualitative techniques such as focus groups or interviews to examine these issues. An additional extension to this research could be to ask employers about proficiency with BIM in the workplace.

Overall, the student feedback and staff observations on how students responded to the challenge of using BIM supports the learning model adopted in this unit.

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