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METHODS FOR EVALUATING 3D VIRTUAL WORLDS IN DESIGN EDUCATION

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1. Introduction

Design education is concerned with learning theory and its applications in the design of artifacts that are essential to our society. Technologies have always played an important part in revolutionising design and design education. For example in architectural education historically institutes taught "descriptive geometry", based on a Euclidean understanding of form and space. The revolution of the paper technology in the 15th century can be considered as the "application" that enabled "the intellectualisation of buildings", leading the notion of architecture as it is currently understood [Kvan et al. 2004]. As an ongoing process, today the information and communication technologies have brought both new opportunities and challenges to design and design education, requiring us to address the new pedagogical approaches that employ these emerging design medium [Gu et al. 2007]. Innovative approaches to design education have demonstrated the impact of these new technologies in terms of creating new ways of designing [Kvan et al. 2004], new design contexts and possibilities [Gül et al. 2007, Kvan et al. 2004], as well as new core skill sets [Gül et al. 2008].

3D virtual worlds are multi-user online environments developed by applying the metaphor of places. 3D virtual worlds have the potential to make a major contribution to design education as a new teaching and learning environment, supporting synchronised communication and 3D modeling; as well as encouraging students to explore creative design by responding to the new design contexts and opportunities as exhibited in these virtual environments. One of the successful applications of the technologies in design education is Virtual Design Studio [Gu et al. 2009, Maher 1999]. Considering this changing trend, we have been employing 3D virtual worlds in the design curriculum since the past decade, allowing students to design and collaborate by immersing in virtual worlds such as Second Life (www.secondlife.com) and Active Worlds (www.activeworlds.com). 3D virtual worlds as new teaching and learning environments are full of potentials, yet there is a general lack of formal methods and evidences for design academics and practitioners to understand the effectiveness and full impact of 3D virtual worlds in design and design education.

This paper presents three categories of formal methods we have adopted for evaluating 3D virtual worlds in design education. Our evaluations concern two specific issues: the support of 3D virtual worlds for collaborative design; and the support of 3D virtual worlds for creative design. The application of each method presented in the paper is exemplified through a case study. The paper concludes by evaluating the effectiveness of the different methods through comparison and discussion The paper shows that the three evaluation methods have their own advantages and limitations, it is important to understand these advantages and limitations and select the suitable evaluation methods or combination of methods for specific purposes.

2. Methods for Evaluating 3D Virtual Worlds in Design Education

To understand the effectiveness of 3D virtual worlds in design education, in particular for supporting students' development of collaborative design and creative design, we have adopted a wide range of evaluation methods in our current and past teaching. These methods for evaluating 3D virtual worlds in design education can be grouped into three main categories: (1) methods for the direct evaluation of various features in 3D virtual worlds for supporting design and design education; (2) methods for analysing students' design outcomes as a measure for evaluating 3D virtual worlds in design education; and (3) methods for understanding the behaviours and perceptions of the participants (designers and design students) as a measure for evaluating 3D virtual worlds in design and design education.

2.1 Category One

The first category refers to the methods that enable researchers and educators to directly evaluate various technical features in 3D virtual worlds for supporting design and design education. One of the most common methods of such is based on the affordance theory [Gül 2008, Dickey 2007] for examining 3D virtual worlds as constructivist design learning platforms, where learning is facilitated through "doing". Dickey (2007) points out that affordance theory has relevance when examining learning environments. In the context of the constructivist concept, the affordances and constraints of the learning environments affect the opportunities for construction [Dickey 2007]. The use of the affordance theory is demonstrated in the following case study where we aim to evaluate the design and collaboration features in 3D virtual worlds for supporting constructivist learning. Constructivism can be employed as a design teaching approach which includes the facilitation of the emerging information and communication technologies.

2.1.1 Case study

Between 2001 and 2006, we taught the Designing Virtual World course to postgraduate design students from the cross-disciplines of architecture, design computing and digital media, at the University of Sydney, Australia. The design of the course has been based on the concept of 3D virtual worlds as constructivist learning environments. As a part of the evolving pedagogical theories, constructivism has been employed as a design learning approach that includes the facilitation of information and communication technologies. It characterises how individuals construct their own understanding and knowledge, through experiencing and reflecting on those experiences [Huitt 2003, Mahoney 2004]. According to the constructivist view, the learning process involves the followings: knowledge is obtained and understanding is expanded through active (re)constructions of mental frameworks [Abbott and Ryan 1999], and learning is an active process involving deliberate progressive construction and deepening of meaning [Spady 2001]. An awareness of these patterns helps to anticipate and respond to students' understandings. Our development of 3D virtual worlds for constructivist learning in the course has applied Winn's approaches of constructing knowledge in computer-supported education [Winn 1993] to emphasise the use of 3D virtual worlds as *environments* for design and learning, by integrating design and learning resources and tools, assessment and feedback, as well as providing the opportunities to interact within the environments.

Prior to the restructure of the course in 2008, a comprehensive course evaluation was conducted. A main part of the evaluation focuses on the design and collaborative features in the range of 3D virtual world platforms we have previously adopted, in relation to the support of constructivist learning. The evaluation method is based on Dickey's views on affordance theory (2007). As discussed about, in the context of constructivist learning the affordances and constraints of the learning environments affect the opportunities for construction [Dickey 2007]. Affordances theory was initiated by Gibson (1977) who suggests that humans "perceive" in order to operate on the environment. Perception is designed for action that is called "the perceivable possibilities for action affordances" [Gibson 1977]. Gibson (1977) claims that people perceive affordance properties of the environment in a direct and immediate way, for example, as suggested by Norman (1988) surfaces for walking, handles for pulling, space for navigation, tools for manipulating, and so on. Norman (1988) believes:

"[…] that affordance results from the mental interpretations of things based on our past knowledge and experience applied to our perception of the things about us" [p.219].

Gül (2008) points out that different virtual environments provide different affordances that can have an impact on users' behaviours. Particularly, the experience of being immersed in a virtual world while designing is very distinct from interacting with real-world artefacts. By following this established framework and combining with our observations on and discussions with the students in the course, we identified the affordances and constraints of 3D virtual worlds for supporting design and collaboration during the course. The main evaluation aspects are listed below. During evaluation, each aspect is investigated in terms of its affordance and constraints to understand the effectiveness in facilitating design and design education. More details of the evaluation results can be found in Gül et al. (2008).

- 3D design and modelling features: this aspect of the evaluation firstly characterises different design and modelling methods in 3D virtual worlds, and their impacts on students' design outcomes and their design and modelling skill building. This aspect also concerns the way designers and design students interact with different 3D design and modelling features, such as the use of different viewpoints during the modelling process and so on.
- Collaborative design and workspace awareness: 3D virtual worlds as multi-user online places enable designers and students to work collaboratively without being located together physically. This aspect of the evaluation mainly assesses and compares the different supporting features in 3D virtual worlds for collaborative design and learning. Issues investigated include the support for communication and team activities, model sharing and management, awareness of self, others and the work environment.
- Programming and scripting for interactivity: one of the focuses of our course is for students to explore the new contexts and opportunities as exhibited in the 3D virtual worlds for exploring creative design. Comparing to the physical world, 3D virtual worlds are highly interactive and the main method for achieving interactivity is through programming and scripting. This aspect of the evaluation analyses the effectiveness of different programming and scripting features in 3D virtual worlds and their different levels of technical demands on designers and design students.

2.2 Category Two

The second category refers to the methods that enable design educators and researchers to directly compare and analyse design outcomes as a measure for evaluating 3D virtual worlds in supporting design and design learning. The development and adoption of these methods often involves the design and application of a formal framework or matrix comprising of relevant criteria for categorising and evaluating the designs. The development of the actual evaluation criteria for the formal framework or matrix can differ from case to case as the purposes of the evaluation vary. The following case study describes a framework we developed in 2007 based on the key principles of designing and learning in 3D virtual worlds. The framework has been applied for understanding the impact of 3D virtual worlds on contemporary architectural design education, where virtual worlds have been gradually establishes as a design discipline in its own right.

2.2.1 Case study

3D virtual worlds as an emerging technology for collaborative design and education in general have been well explored. For example, Kvan (2001) argues that while design teaching has traditionally focused on the product, virtual design studios allow students to learn more about the design process. Dickey (2005) suggests 3D virtual worlds like Active Worlds can provide "experiential" and "situated" learning. Clark and Maher (2005) examine the role of place in virtual learning environments that encourage "collaboration and constructivism". However there is a general lack of research and practice in exploring and teaching designing 3D virtual worlds as a design discipline in its own right. In 2006, in order to recognise this significance, the "Designing Virtual Worlds" course was structured as a design subject focusing on exploring the design potentials in 3D virtual worlds beyond being a technical tool for simulation and collaboration. To evaluate the effectiveness of 3D virtual worlds in this regard, we develop and apply a framework based on four categories of design and learning

principles in 3D virtual worlds, for analysing the student design outcomes and our supervision and assessment strategies. During the course evaluation, evidences were collected and investigated in terms of these four aspects in order to understand the effectiveness of 3D virtual worlds in facilitating design and design education. These principles are briefly discussed below. More details of the evaluation results can be found in Gu et al. (2007).

- Design metaphor: this aspect of the evaluation aims to understand and analyse the role of the place metaphor in students' design development, as we know, without the use of this metaphor, most design issues of 3D virtual worlds such as layout, virtual object design and navigation problems all become irrelevant. However, in order to explore the design potentials of 3D virtual worlds, designers need to think beyond principles of physical places. As shown in the course, the different uses of design metaphor can lead to significantly differences in students' design developments and outcomes.
- Design approach: this aspect of the evaluation concerns both the conceptual approaches and technical approaches to design development in 3D virtual worlds. In this particular case, the conceptual approaches has been narrowed down to two: the metaphorical approach and the virtual approach. The metaphorical approach has an influence from built environments, for example, designs that mimic or are inspired by physical forms and physical experience. The virtual approach has a focus on the unique qualities of 3D virtual worlds, for example, designs that explore interactions and experiences that are not readily available in built environments. As shown in the course, adopting different design approach can also lead to significantly differences in students' design developments and outcomes.
- Skill and assessment: this aspect of the evaluation concerns the effectiveness of the strategies we have adopted in developing and utilising different design and technical skills through project and group formation, and assessment design.
- Design and learning within the design: 3D virtual worlds are constructivist and process-oriented in nature, which combine both design and learning resources in an integrated environment. This aspect of the evaluation aims to understand the characteristics of such and their impacts on students' design development.

2.3 Category Three

The final category refers to the methods that enable researchers and educators to evaluate 3D virtual worlds by understanding the perceptions and behavioural changes of the participants (designers and design students) in 3D virtual worlds. The most common methods of such are questionnaires and interviews that survey the subjects' preferences and expectations based on their design experiences in 3D virtual words. However, to conduct an in-depth investigation of the impacts on the participants often apply the method of protocol analysis [Cross et al. 1996]. In the following case study protocol analysis has been applied as the behavioural measures to investigate the ways in which designers perceive and interact with the design environments and representations while working in 3D virtual worlds. The understandings of such are essential for the development of the design and learning environments in 3D virtual worlds for design education.

2.3.1 Case study

Protocol analysis has been accepted as a research technique allowing for the clarification of designers' cognitive abilities [Cross et al. 1996]. In the late 1980s, a rapid change occurred in the protocol studies by extending single-subject design activity to the team's design activity [Cross et al. 1996]. Cross and Cross (1996) state that a team's design protocols resemble the "think aloud" method, since a joint task seems to provide data indicative of the cognitive abilities that are being undertaken by the team members. Consequently investigating the team's design protocol has not been substantially different from investigating single-subjects' design thoughts.

In this study, two architects' design actions and communications are video-taped, transcribed, segmented and then encoded by using a specific coding scheme that has been developed for the study. The study is conducted based on a comparison of four design environments which are (1) the baseline study in which designers use pen and paper, (2) the remote sketching in which designers use Group Board with digital pen-based systems, (3) 3D modelling (3D) in which designers used Active Worlds,

and (4) 3D modelling with sketching (3DS) in which designers used a virtual world prototype, Design World [Gül 2007]. During the data analysis, patterns emerge to provide insights into designers' behavioural changes when changing from conventional design environments to 3D virtual worlds for design and communication [see Gül 2007 for more details of the experiments and analysis].
The results of this case study show that collaborative 3D virtual worlds have the potential to change the ways in which designers communicate and work. Different virtual environments provide different affordances that have an impact on designers and their activities. The key evaluation aspects that have incorporated for developing the coding scheme are listed below. More details of the evaluation results can be found in Gül (2007).

- Visuo-spatial reasoning: this aspect of the evaluation concerns how designers perceive and react to the visuo-spatial properties of a design representation either in 2D or in 3D representation modes, in order to understand if designers may behave differently when switching from the conventional sketching environments (2D) to 3D virtual worlds (3D). The visuo-spatial properties of a design artefact include spatial properties (concerning spatial adjacency, arrangement, position, and etc.) and visual properties (concerning size, form, colour and material). In addition to the above visuo-spatial properties of a design artefact this aspect of the evaluation also concerns with the dimension of the design artefact, i.e. 3D or 2D. The connection of the dimension and visuo-spatial properties of a design artefact is explained as 2D and 3D representations install slightly different mental models.
- Engagement within the design environment: This aspect of the evaluation characterises and evaluates how the designers engage within the 3D virtual worlds including navigation features of the environment, interface and the simulation quality of the design representations.

3. Discussion and Comparison

The three categories of methods as presented above can serve different purposes for evaluating different aspects of 3D virtual worlds in design and design education. Their strength and common usage are highlighted below. These issues should be considered when applying the methods for evaluating 3D virtual worlds in design and design education.

- The first category of the evaluation methods provides the direct indication of how effective the different features of a 3D virtual world facilitate the design and learning activities. The 3D modelling and visualisation features of the virtual worlds are often the most important elements during the design and learning activities. However what is missing in these evaluation approaches is that the design educators and researchers are not able to take into considerations of the designers' or students' design performance and their preferences for particular design features, when utilising the analysis of the range of 3D virtual world features for design and design education.
- The second category of the evaluation methods on the other hand provide extensive information and understanding relating to the quality of the design outcomes. The performance of the virtual worlds is evaluated indirectly via the assessment of the design outcomes produced from the virtual worlds. However these evaluation approaches do not enable us to understand designers' and students' perceptions of applying 3D virtual worlds in design and learning. In addition, another weakness of these approaches is the lack of understanding of the effectiveness of 3D virtual worlds during the design process because the evaluation focuses on design outcomes only.
- The final category of evaluation is focused on the perceptions and behavioural factors of the designers and students. These methods of evaluation provide us extensive knowledge and understanding of how designers and students think and employ the diverse range of 3D virtual world features whilst involved in the activity of designing and learning. However the limitation of this study is that the key elements of the evaluation may be restricted due to the limitations of the measures of the coding scheme or the questionnaires.

As discussed above, different evaluation methods have their unique strength. To gain a more thorough understanding of the process as well as the outcome of the design activities, often requires the use of combined methods or a multiple perspectives to the assessment. The following is an example of such

an assessment for 3D virtual worlds involving multiple evaluation methods. The assessment concerns an international virtual design studio, established in Second Life in 2008. Students enrolled in the studio were required to collaborate with overseas partners to develop a "virtual home" project collaboratively in multi-national teams utilising Second Life as the design domain or context. We firstly surveyed the design students who participated in the collaborative studio, utilising questionnaires to gain an insight into their perceptions of 3D virtual worlds in supporting design and collaboration. We then developed and applied a matrix to critically evaluate the student design outcomes from the collaborative studio to compare and rectify the results. The questionnaire design and the evaluation matrix are described below. Further details of this study are available in Gu et al (2009).

The questionnaire consisted of three parts, which incorporated 34 questions in total. These three parts are:

- Technical features (answered on a five-point Likert scale): part one of the questionnaire aimed to evaluate the students' perceptions of the performance of the range of technical features provided in Second Life which support the collaborative design and learning activities involved in the project. These are comparative in relation to other synchronous and asynchronous communication tools.
- Teamwork skill development (answered on a five-point Likert scale): part two of the questionnaire focuses on surveying students' awareness and perception of teamwork skills they developed through the application of Second Life in the design activities.
- Open questions: the survey concludes with a set of open questions with the purpose of developing a more in-depth understanding of students' perceptions and expectations of 3D virtual worlds in supporting collaborative design learning. Participating students reported and discussed the evaluation, preference and expectation of various key issues, ranging from communication, design representation, design documentation, project management, to conflict resolution and other teamwork skill development in 3D virtual worlds.

To provide a full understanding of the impacts of 3D virtual worlds on the students and the course, after the analysis of the questionnaire, a direct analysis on the design outcomes of each student groups is followed. Selected student designs are illustrated in Figure 1, each of which represents a different approach to virtual world design. We briefly summarise each of the selected design as followed:

- "Sky Garden": the design explores the idea of a "virtual home" as series of relaxing gardens. This design is most similar to real-world designs.
- "Archi-Bio": the design is inspired by bio-mechanisms and transforms those dynamic and growing "virtual homes" into their virtual home in Second Life.
- "Metamorphosis": the concept mainly revolves around Krishnamurti's philosophy of Living without Conflict where materiality of the physical world conflicts with a person's inner self. The design shows different levels of sub-consciousness through different layers of underwater rooms with familiar artefacts but aims to create ambient environments that depict different emotions in the "virtual home".
- "Floating Cubes": the group presents a "virtual home" as series of floating cubes that shift the occupants from one activity to another and from one mind set to another.
- "Zero Gravity": virtual worlds have no physical constraints such as gravity but still support various activities. This design uses (non) gravity as the design trigger to challenge the constraint of gravity and to have different spaces hanging upside down within a "virtual home".
- "})i({": The name of the group is a representation of a butterfly - a symbol of "freedom" - that you cannot verbally "say" it. The "virtual home"here is a place of communication inspired by poetry.

The main categories of the evaluation matrix we developed and applied for categorising the final student designs are discussed below:

- *Degree of realism in form*: the designs applying dominantly the simulated forms from the physical world are classified as "realistic". The designs adopt mainly forms that are

imaginative and are classified as “non-realistic”. Finally the ones that use a combination of both are classified as “semi-realistic”.

- *Degree of abstractness in concept*: the design has a more profound concept behind its implementation is classified as having a higher degree of abstraction. For example, a design that aims to simulate a physical environment literally is considered as non-abstract, while a concept of depicting different “emotions” of spatial experiences is considered as more abstract.
- *Design approach*: two different design approaches have emerged from the studio in 3D virtual worlds. The first is the “form-based approach” where students start with the exploration of interesting forms, then adopt or sometimes even “create” a concept afterwards. The second is a “concept-based approach”, in which students firstly explore, develop and agree on certain concepts at quite a deep level, and then realise the concepts through 3D models.

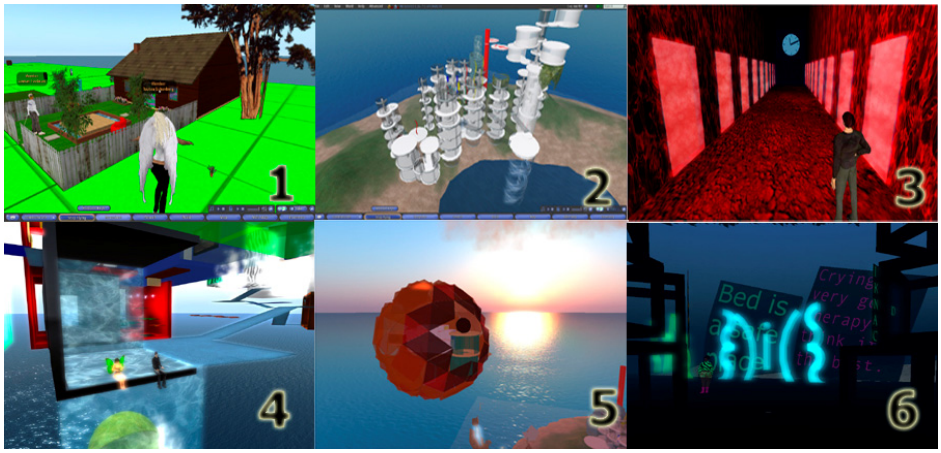

Figure 1. Selected student designs

A combination of “degree of realism in form” and “degree of abstractness in concept” assist us in understanding different designs evolved from the collaborative studio. Non-realistic and more abstract designs often receive higher recognition in the studio as they often represent a novel approaching to design and emerge to break from conventional designs with innovative and challenging solutions. They most often lead to more interesting outcomes, encouraging students to explore different design possibilities during the collaborative process rather than repetition of how they would approach in a conventional design studio. It is noted that the groups who adopted the “form-based approach” can often quickly reach certain design solutions and move on to detailed design and documentation, as their design begins with form making and detailed modelling. Students adopting the “concept-based” approaches often progress slowly especially in the early stage of the collaboration compared to the groups that have adopted the form-based approach. However, their design outcomes are often more sophisticated and providing more interesting and diverse ideas.

In our experience, the combined evaluation methods have been effective in gaining a broader understanding of the use of 3D virtual worlds in the virtual design studio. After the analysis of the questionnaire, we discovered the polarisation among students over the user perception and tool preference during the design collaboration in 3D virtual worlds. The results together with our observation on and discussion with the students unveil some challenging aspects, especially the issues related to the affordance of new technologies and the management of teamwork, when applying 3D virtual worlds for collaborative design learning. They have also directly impacted on the overall satisfaction of students. The analysis of the design outcomes then provide a different layer of understanding which clearly indicate that the students are able to develop, collaborate and implement designs in 3D virtual worlds to a very competent level. However, the questionnaire results show that students have been frustrated with various issues emerging from the collaboration including: lack of design support in 3D virtual worlds; inability in teamwork management; delay in responses from collaborators; language barriers; cultural differences; lack of shared design understanding; and lack of

common goal in collaboration. Without the use of the combined methods, the evaluation would have been concluded from a rather limited perspective.

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