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EVALUATING THE MODES OF COMMUNICATION: A STUDY OF COLLABORATIVE DESIGN IN VIRTUAL ENVIRONMENTS

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SUMMARY: *With the recent developments in communication and information technologies using Collaborative Virtual Environments (CVEs) in design activity has experienced a significant increase. In this paper, a collaborative learning activity between the University of Sydney (USYD), and the Istanbul Technical University (ITU), Global Teamwork, is presented. This paper explores the use of asynchronous and synchronous communication modes during design activity in a remote context. The paper continues with an evaluation study of the Global Teamwork based on the students' comments and a protocol study, focusing on the communication modes provided by the CVEs used. The paper concludes with insights into the applications of virtual environments in collaborative design teaching.*

KEYWORDS: *Collaborative design; collaborative virtual environments; collaborative design teaching and learning*

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1. INTRODUCTION

With the recent progress in information and communication technologies, using Collaborative Virtual Environments (CVEs) in design activity has experienced a remarkable increase. Collaboration in geographically distant locations using information and communication technologies has become the new way in which architecture firms and other related parties practise and communicate (Maher 1999; Çağdaş, Kavakli et al. 2000; Kvan, Schmitt et al. 2000). As a result, design curricula have been changing to accommodate this new trend around the globe. In design education, web-based tools (Craig and Zimring 2000), virtual design studios (Maher 1999; Çağdaş, Kavaklı et al. 2000; Kvan, Schmitt et al. 2000) and 3D virtual worlds (Gu, Gül et al. 2007; Gül, Gu et al. 2007) have been widely used, especially in the form of online design studios. In this context, students

have been sharing the learning environments, which offer participation, shared knowledge, and shared understanding of the design goal. In addition, another key element of collaborative learning is the consensus through cooperation by group members, instead of competition (e.g. Loeffler 1993).

Collaborative design teaching using different communication modes and virtual environments attracted little attention. Researchers have been investigating the differences of synchronous and asynchronous communication predominantly through comparing face-to-face communication with computer-mediated communication for collaborative design tasks/activities (Kvan, West et al. 1997; Gabriel 2000). The contribution of the research work presented in this paper is to fill this gap by comparing students' design protocols in an online design studio context. Particularly, the paper compares synchronous and asynchronous mode presenting collaborative design process.

This paper is motivated by the challenge of new emerging educational paradigms of using CVEs into design education and explores its pedagogical implications on design learning. In this paper we present a collaborative learning activity between the University of Sydney (USYD), and the Istanbul Technical University (ITU): Global Teamwork. The intentions to set up the Global Teamwork are to:

- Establish a collaborative teaching activity employing the emerging technologies in design learning,
- Understand and experience the communication and design technologies in a remote context, and
- Understand and apply the principles of designing of collaborative virtual environments, which facilitates collaborative design, information sharing, communication, management and participation.

In order to establish a collaborative learning platform, understanding the essence of design communication in a remote context is necessary. The focus of the paper is to investigate two modes of communication: asynchronous and synchronous in computer mediated design context. The paper continues with an evaluation study of the Global Teamwork based on the students' comments and a protocol study, focusing on design and communication activities. The paper concludes with insights into the applications of virtual environments in collaborative design teaching.

2. RELEVANT WORK OF COLLABORATIVE VIRTUAL ENVIRONMENTS IN EDUCATION

Collaborative Virtual Environments (CVEs) clearly have the potentials to enable innovative and effective teaching, which involves debate, simulation, role-playing, discussion groups, brainstorming, and project-based group work, etc. The emphasis can be placed on the human-to-human interactions as common understandings are negotiated and developed among people with different knowledge, skills and attitudes.

CVEs for education have been explored in many disciplines. While advanced multi-user educational CVEs are still mostly speculation (Okada, Yamada et al. 2003), simpler CVEs based on standard technologies have been in existence for some time such as the CVE developed by (Gül, Gu et al. 2008). Different applications of virtual environments for educational purposes are being investigated by different institutions. For instance, CVEVM (Kirner, Kirner et al. 2001) was developed as part of the Virtual Museum Project and focused on learning in a constructivist way. The philosophy behind is that through creating the world in a collaborative manner, users could learn about the different objects, which form the world. The DeskTOP CVE (Hara, Bonk et al. 2000) was developed to support and promote collaborative learning in universities. It aims to create new possibilities for communication between users and increasing the awareness that users have of each other. The DigitalEE (Yang 2007) project aims to use a CVE for environmental education. The system is meant to support discussions and information exchange between different users, and create a space where knowledge can be recorded. The system also makes experiences of certain natural environments and processes possible through Virtual Reality, and adds to the experience of real nature by making use of augmented reality.

Flexibility in time and place by CVEs allows learners individually and collectively to construct solutions to problems and negotiate differences in their points of view (Yang 2007). Previous studies showed that learners could participate more actively over time (Hara, Bonk et al. 2000). How teamwork enhances collective learning

has also been investigated (Salter 2006; Goodyear 2005). Two major transformations in collaborative learning are identified and highlighted:

- Shifting towards learner-centred knowledge construction in which the importance of active learning in participation, interpretation and collaboration are emphasised (Yang 2007), and
- Placing of much wider responsibilities and control over the process of learning and teaching on both teachers and students (Goodyear 2006).

2.1 Design teaching in collaborative virtual environments

The emergence of communication and collaborative technologies presents many opportunities for design collaboration which are not available before. In design education, these technologies have formed new design platforms for collaborative learning as students can now collectively develop and document design ideas when they are in remote locations. In design education, web-based tools have been widely used (2005), such as online design studios. Broadfoot and Bennet (2005) defined online design studios as a web-based studio, which is a 'networked studio, distributed across space and time'; such that the participants of an online design studio may be physically located in different locations, handling design communications via computers. Recently, virtual design studios (2006) have been set up by several architecture and design schools around the globe (Kvan, Schmitt et al. 2000; Schnabel, Kvan et al. 2001; Dickey 2005).

CVEs could combine ideas from socio-cultural theories of learning that are facilitated by information and communication technologies. Gül et al. (2008) pointed out the affordances of CVEs as constructive learning platforms aiming to provide a shared "place" where distant design collaboration, synchronous and asynchronous communications and design activities can take place. The affordance of CVEs provides the availability and possibility of new ways of designing (Gül, Gu et al. 2008), allowing significant time-space independence for learners and teachers (Hara, Bonk et al. 2000), and facilitating the learning activity focused on the production and the use of shared content (Yang 2007).

One of the advanced CVEs is 3D virtual worlds which are multi-user online environments developed by applying the metaphor of places. Through the use of the metaphor of architecture, virtual environments can inherit many characteristics from built environment. While teaching in 3D virtual worlds, design knowledge, which typically forms the construction of buildings and places, and the issues such as layout design, navigation design and virtual object design, needs to be obtained (Gu, Gül et al. 2007). For example, the most popular interactive online games and the emergent agent-based intelligent worlds have been leading the area of interaction and experience design. Once mediated with software agents, 3D virtual worlds become intelligent and responsive to their inhabitants (Gu, Gül et al. 2007). In fact, 3D virtual worlds create places that users experience just as they are immersed into a virtual world (Bolter and Gromala 2003). The forms of virtual design studios vary from the very early approach of digital design data sharing to the more recent 3D virtual world approach in which the design artefact and learners are simulated and represented. This new phenomenon has caught the attention of many design academics.

Over the years, design educators have explored different applications of 3D virtual worlds in design learning and reflected on their experiences. For example, it is argued that virtual design studios allow students to learn more about the design process, while the traditional design education has focused on the product (Kvan 2001); 3D virtual worlds can provide "experiential" and "situated" learning (Dickey 2005); The role of place in virtual learning environments can encourage "collaboration and constructivism" (Clark and Maher 2005); The use of 3D virtual worlds can support social awareness when students from different cultural backgrounds design and learn collaboratively (Wyeld et al. 2006). The effects of CVEs on learning processes, creativity and quality of the design solutions and design process are currently hot debates in academia.

2.2 Communication in collaborative virtual environments

Gaining the core communication skills are essential in design teaching in CVEs. Bellamy et al. (2005) identified the following core skills for designers effectively participate in collaborative design. First, leadership is important because it decides the balance of relevant skills and contributions required from team members. Team leader(s) need to be able to create a dynamic team that is able to identify the important "social links" between team members (Baird, Moore et al. 2000). Second, co-ordination and structuring skills are required for team

members to work collaboratively in a virtual environment (Lahti, Seitamaa-Hakkarainen et al. 2004). Third, feedback abilities are also important skills for team members (Bellamy, Williams et al. 2005). This is crucial because large amounts of information often need to be validated in virtual worlds (Baird et al, 2000). Fourth, interpersonal relationships between virtual team members can affect the team's ability to provide a satisfactory product. In addition, social collaboration appears to play an important part, especially when there is a need to understand the given problem and its limitations. Finally, trust is not easily built in a computer-mediated environment, especially when team members have no prior experience with each other. Commitment could foster trust, but such trust may not reach its highest level until the end of a task (Jarvenpaa and Liedner 1998).

In general, communication imposes a challenge in virtual environments. A number of factors constrain the interaction in virtual environments. The lack of visual cues and auditory input might affect the quality of shared understanding. Even when visual cues are used (e.g. augmented with video conferences or web cameras) team members' abilities to communicate through non-verbal interactions (such as body language) can be inhibited (Hoyt 2000). The technology does present some advantages when communicating over distance as they often allow more focused and concise information exchange between team members (Gabriel and Maher 1999; Maher and Simoff 2000), and assist team members keeping to their task (Cleland and Ireland 2002). In addition Baird et al (2000) find that the virtual environment may not foster skills such as feedback. Furthermore, Williams and Cowdroy (2002) note that communication is easier if team members have previously worked together. Gabriel and Maher (1999) pointed out that simply mimicking co-located settings such as teleconferences may result in fewer social interactions between team members as well as difficulties in sharing visual information.

Our previous studies also pointed out that communication channels have an impact on the development of the core communication skills (Gül, Wang et al. 2008). Students reported some difficulties in working with a new partner in distance and lacking physical contact. The students experienced problems in building trust and social communication as well as receiving and giving timely feedbacks. Thus, students are encouraged to employ all available communication channels during the projects. In the study, each team were required to submit weekly collaborative design journals and online meeting records as assessment items to reinforce the collaboration and to exercise the core skills.

2.3 Communication modes

In general, the term mode refers to communication. As Martin (2001) explains, "...mode reflects a strong concept of contextual dependency: As language moves away from the events it describes, and the possibility of feedback is removed, more and more of the meanings a text is making must be rendered explicit in that text if they are to be recovered by a reader, no matter how well informed" (Martin 2001, p. 159). In other words, mode determines the way communication occurs. If a face-to-face mode is adopted, instant feedback is available and this may enhance the effective understanding between all parties. If another mode such as online communication is the option, then the absence of a shared physical environment makes it vital to provide complementary contextual information to enable participants to understand the message being communicated (Yang 2007). Gabriel et al. (2000) compared the effectiveness of different communication channels in collaborative design context underlining differences of the channels. He reported that communication channels should be selected on the basis of the type of communication considered being the most effective for the stage and task of the design project (Gabriel 2000).

For learning in virtual environments, the concept of mode is relevant to the following two key concerns:

- The key elements of face-to-face communication and interaction should be supplemented with well-designed task specifications and well-chosen learning materials;
- The material used for learning in virtual environments needs to be adapted to suit this mode of learning (Steeples, Jones et al. 2002 as cited in Yang, 2007).

Two types of design communication modes have been investigated: synchronous and asynchronous. Synchronous collaborative working means that all members of a team are working on the same product at the same time simultaneously to search for new innovative design solutions or routine design solutions (Scherer 2004). Asynchronous collaborative working means that each team members can provide and contribute a part, which is necessary for solving the problems without direct and immediate communication in a formalised way by exchanging the ideas and suggestions (Scherer, 2004).

Asynchronous communication has many advantages of enabling distributed collaboration, whereas prolonged response and weak awareness of people and events make the teams hard to build quick trust (Gül, Wang et al. 2008). Synchronous collaboration seemed to have benefits to overcome the above mentioned difficulties, but in a distributed working situation, it is often not easy to overcome the problems caused by time differences. Based on the above framework of collaborative design learning in virtual environments, it is worth the research efforts on how design teaching and group efficacy differ and develop in the online learning platforms that are supported by different communication technologies. In virtual group contexts, people interact with each other by means of different sophisticated technologies.

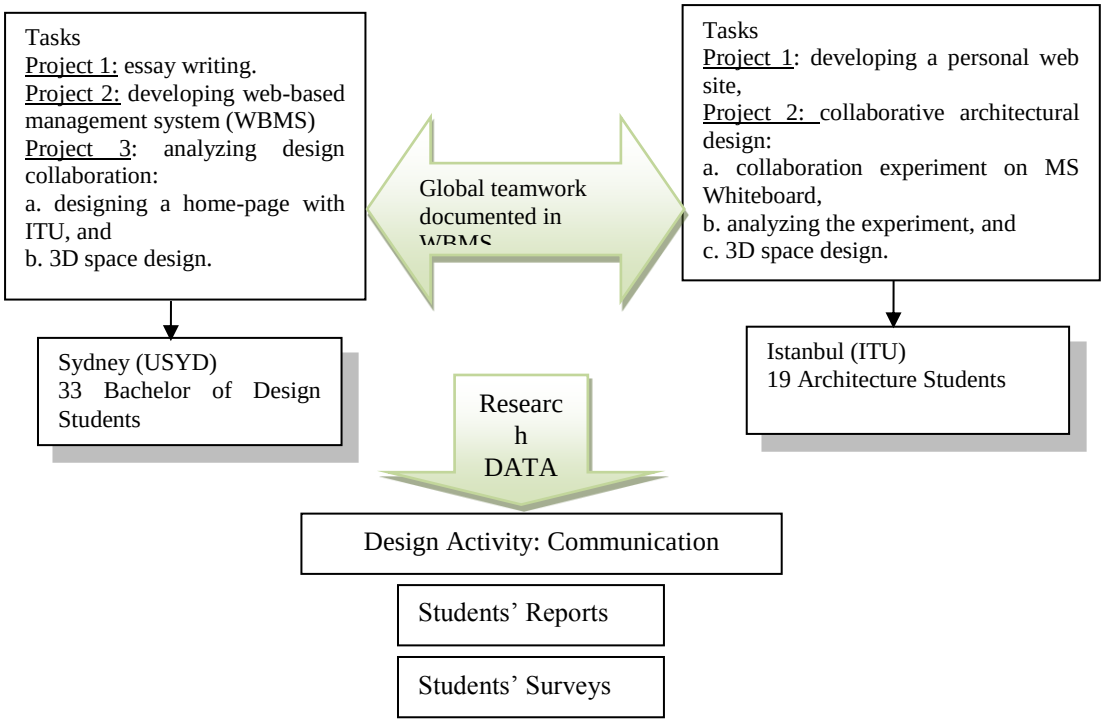
In this paper, the students' collaborative design activity was investigated in two comparative conditions: asynchronous and synchronous modes of communication.

The comparison focused on the following questions:

- What is the impact of communication modes into the students' collaboration and design processes?
- What is the impact of communication modes into the students' design exchanges?
- What is the impact of communication modes into the student's communication skill development?

3. GLOBAL TEAMWORK BETWEEN THE UNIVERSITY OF SYDNEY AND THE ISTANBUL TECHNICAL UNIVERSITY

The collaboration attempt in two graduate courses was established between the University of Sydney (USYD) and the Istanbul Technical University (ITU) in 2007. In this collaboration study, a total of 52 students, geographically separated, collaborated on a joint-design project over several CVEs and designed 2D and 3D places. Both universities currently administer design curricula that are reinforced by the emerging field of CVEs in design education. The structure of the Global Teamwork is shown in **Napaka! Vira sklicevanja ni bilo mogoče najti.**. The USYD course DECO 2010 Collaborative Virtual Environments course had 33 design students, and the ITU course MIM 344 Information Technologies in Architecture course had 19 students who participated in this study. 52 Students formed into eleven groups which had three design students from the USYD and two or one architecture students from the ITU. In order to communicate over the CVEs, the students are provided several tutorial sessions which taught variety of communication technologies. Then for the group projects, the students had given flexibility to choose a suitable medium for design collaboration. Students in the



USYD are asked to develop a web-based management system (WBMS) which was the project 2, as shown in

ITcc FIG 1. Framework of design collaboration project between the USYD and ITU

Fig. 1. They were also asked to utilise this system for the project 3 with collaboration of the ITU students. The collaboration between the two universities took place final 5 weeks. Following the completion of the project 3, the students in the USYD analysed their group's collaboration process using protocol analysis method and submitted a reflective report. Moreover the students in ITU were given the questionnaires to reflect their opinion about the course. In this paper, we discussed some of the findings from the reflective reports, the questionnaires and our observations during the Global Teamwork.

3.1 The 'designing collaborative virtual environments' course

The DECO2010 "Collaborative Virtual Environments" was offered as a full-semester (13 weeks) unit in USYD. The weekly format includes a 1-hour lecture and a 2-hour design studio. This course attracted 33 undergraduate students from the discipline of design computing, to explore how to design in and of CVEs. The aim of this unit is to teach to students an understanding of the similarities and differences of computer mediated and face-to-face communication and to develop the skills in the use of collaboration tools such as email, shared white boards, bulletin boards, video conferences and shared online design environments.

Course objectives and structure: The course content was structured so that the students could gain an understanding of the basic principles of designing CVEs, communication issues and the skills for the implementation of the CVEs. In order to develop the understanding of CVEs, firstly relevant literature, issues and problems in collaborative design and design examples were introduced and discussed through lectures. Secondly, the students were instructed to use a wide variety of collaboration tools and applications, and they reported in an essay to reflect their learning outcomes. In order to gain adequate design knowledge and technical implementation skills, three design projects were scheduled as the major submissions for the course, as shown in Fig. 1. On the successful completion of this unit of study, students will have demonstrated:

- An understanding of synchronous and asynchronous communication technologies through the collaborative project report;
- An understanding of communication and representation of design data in a computer mediated collaborative design project in the development of the collaborative project report; and
- The skills in using collaborative technologies in the tutorial exercises.

Design projects: With structured design supervision and technical tutorials, three projects were assigned, as shown in Fig. 1. The first project was an essay writing task which aims: to develop an insight into the technical issues involved in CVE for collaborative design, and an evaluation/critiques of the effectiveness of using a particular existing CVE system or method in the area of design. The aim of the first project is to gain students the current knowledge about the use of technology supporting collaborative work.

The second project included developing a web-based project management system (WBMS) which was utilised during the collaboration project with the ITU students (project 3, as shown in Fig. 1). The WBMS included the collaboration tools (blog/forum, calendar, schedules, task allocations, meetings, document links, etc.), the member's personal web-space links and the documentation of the design and design process. The students in the USYD and ITU used this space for the collaboration for the project 3 which was the designing of a 3D space in a virtual world.

Third design project included designing two virtual places (a home page and a 3D place in Active Worlds) using 2D and 3D based CVE design tools (shared white-board and Active Worlds) with the collaboration of the ITU students in Istanbul. The final project provided opportunities for students to:

- Develop an understanding of the asynchronous and synchronous collaboration;
- Develop an understanding of design collaboration processes and activities involved; and
- Identify issues/problems in collaboration (conflict resolution, time management, task monitoring, project management etc.).

The project two and three also includes developing of the design-related skills (place design, web page design, and interaction design), digital design skills (modelling, image editing, scripting, and html) and generic design skills (decision-making and problem-solving). In terms of the assessment of the students' learning, the multi-criteria that cover different design and technical aspects were applied.

3.2 The 'information technologies in architecture' course

The MIM 344 "Information Technologies in Architecture" , course was programmed as a full-semester (14 weeks) class for undergraduate architecture students in ITU, as illustrated in Fig. 1. It aimed to introduce the students of the cutting-edge technologies on the Internet for architecture in relation to collaborative design environments and communication techniques. The format of the course included lectures and design studio. In the spring semester of 2007, 19 students from the ITU Department of Architecture were signed to take this course.

Course objectives and structure: The content of the course was structured around small tasks that allow the students to exercise on every topic that was discussed in the lectures. The students were first introduced to concepts and methods and then asked to complete an assignment in order to gain hands on experience about the subject. Since the students taking this class had no computational background, the exercises were particularly selected from those that require no programming and technical implementation skills. Students were expected to use their architectural design skills in computer mediated environments. In order to gain a better understanding collaborative design methods, the students were also asked to collect and present other examples of collaborative architectural design.

The objectives of the course were to:

- Introduce students to the alternative design environments;
- Present web page development concepts and techniques for effective communication;
- Develop skills for managing a computer-mediated collaborative design project; and
- Gain an understanding of the changes in the architectural practice through the use of information technologies.

Design projects: In order to reach the course objectives, students were required to complete three different design projects through the semester, as shown in Fig. 1. The first project focused on the basic Internet technologies. Then the students developed their own web sites for introducing themselves to their partners in the USYD. The aim of the first project was allowing students to explore various methods for publishing and communicating on the CVEs and to gain some familiarity with the CVEs. The students were expected to experiment on different web design and navigation schemes to best represent their content. This project was completed individually.

The second project was about discovering several modes of collaborative design. In this project students worked in groups of two. Their first task was designing a small housing unit for 15 students using only MSN Chat and Whiteboard. This task was completed in three hours. Then, the students submitted a report on how this remote design experience was different from conventional design methods and tools. After this task, students were asked to collect examples of virtual collaborative design examples and present them in the class comparing the utilized methods and procedures. This project was concluded by designing a 3D place in Active Worlds using both asynchronous and synchronous collaboration techniques. The students were expected to gain an understanding of the issues and activities involved in collaborative design and identify the strategies to properly manage a collaborative design project.

The third design project is completed in collaboration with the USYD students. In this project, the students were asked to design a memorial artefact for representing the collaborative study between USYD and ITU. The designed projects were varied from a web site logo to urban furniture. This project aimed to carry the students' experience on collaborative design to a new level and allow them to test the core communication skills with a partner coming from a different culture and using a second language.

The design projects were designed in a way that students could compare different modes of communication and the role of using CVEs in collaborative design. The first project required individual work while the second and third projects provided an opportunity to work in groups.

4. STUDENT DESIGNS AND OBSERVATIONS

The students in the USYD submitted 11 group designs of CVEs in Active Worlds (www.activeworlds.com) and 11 web-based management systems (WBMS) and home-page designs. The students worked on the projects using both communication modes: synchronous and asynchronous. Synchronous collaboration generally occurred during allocated meetings in remote locations and studio. The students reported that they used - Active World's communication tools, which are mainly text-based. Students reported that other synchronized platforms such as Microsoft MSN and Skype were also used. The common communication method was the text-based communication. Asynchronous collaboration generally occurred during the design development phase when students separated and worked on their individual parts. The most common asynchronous communication tool which the students used was email. Based on the two communication modes of the distributed teamwork, we summarise the following observations:

Asynchronous collaboration: The analysis of the student works showed that the teamwork between the students in USYD and ITU occurred asynchronously most of the time. The main reason for this might be the time difference, that is, Istanbul is seven hours behind Sydney. Thus the students tended to utilise such computer-based communication tools as email, offline MSN Messenger, blog and live-journal to manage the collaborative design process. The students also reported that the task allocations and being aware of each other's responsibilities during the project were essential to achieve a better outcome.

To maintain and monitor the progress of collaborative design, we encouraged them to use their groups' web-based management systems (WBMS) in which each member can upload information and documents. The analysis of the student reports demonstrates that the students experienced several issues related to the maintenance of the collaborative activities. They pointed out that the distributed team collaboration requires a structured design progress monitoring mechanism and a thorough documentation mechanism of the development of the design product. Both of demands are offered by WBMS. Fig. 2b shows one of the WBMS layout design with the logo on top of the screen which is designed by the ITU students (Fig.2a). The WBMS has the following features: navigation bar, collaboration tool (including applets for meetings, documents, calendar, transcriptions of previous meetings, file upload, download, etc.) and member links. Fig 3. shows some examples from the profile pages of the WBMS design.

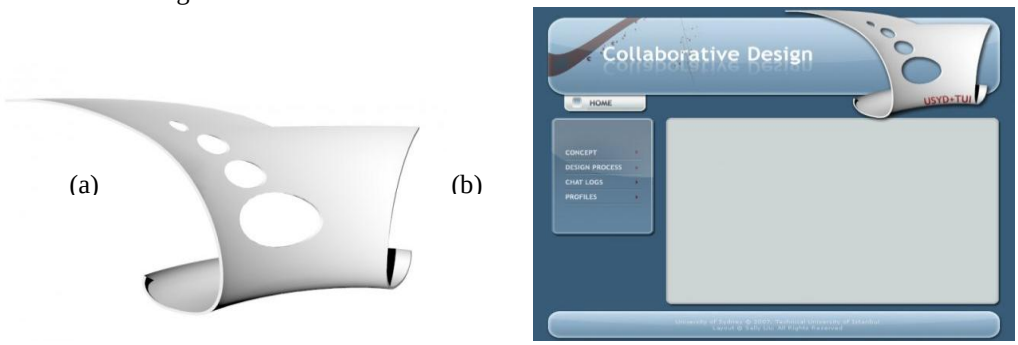


FIG 2. Design outcomes of asynchronous mode (a) and (b) WBMS layout including the logos

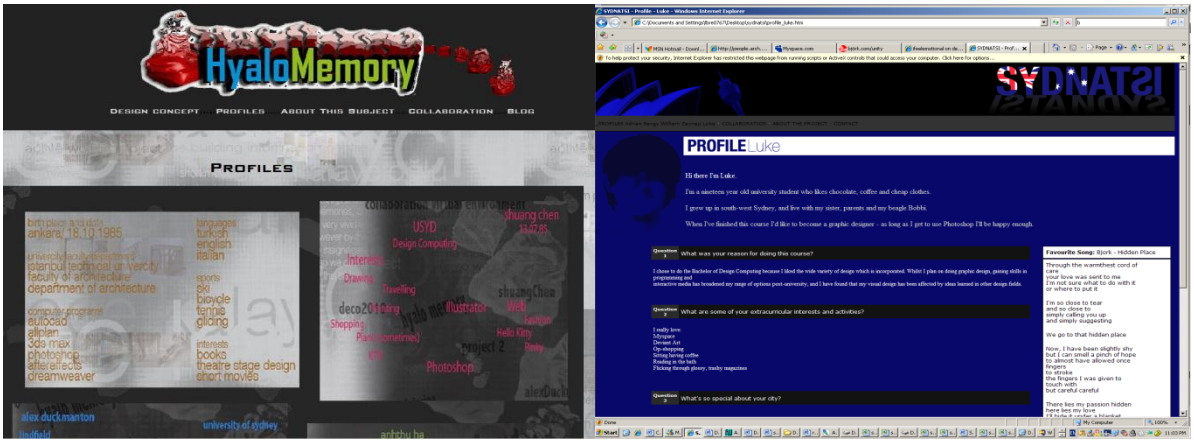


FIG 3. Design outcomes of asynchronous mode, profile pages

Synchronous collaboration*:* The students reported that they worked synchronously for the place design task most of the time while using Active Worlds. Most of the design concept discussions took place in the tutorial sessions where the students were virtually located in the virtual design studio. The students reported that they had some face-to-face discussions at the early phase of designing in which they found more effective for having the brain-storming session.

The design tasks include the modelling a 3D place which represents the group's identity. The 3D place could occupy different functions. Since the virtual world allows using in-built object to model, most of the designs in the world have this 'Active Worlds look'. Active Worlds also allow importing outside objects with the server upload, but we prefer not to encourage the students for this. Fig. 4 illustrates a garden design in Active Worlds which used the in-built features of the virtual world such as waterfall, flower pots and clouds etc. Fig.5 illustrates an exhibition space named as 'HyaloWorld' where the users record their memories to be exhibited. Students also reported that MSN messenger and several white-board applications have been used for as supplementary tools for communicating designs ideas and solutions with each other.

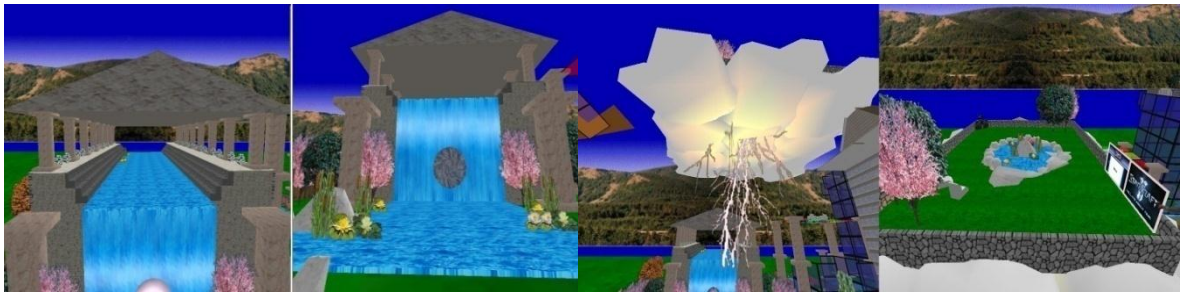


FIG 4. Design outcomes of synchronous mode. 3D place design in Active Worlds, students designed a garden

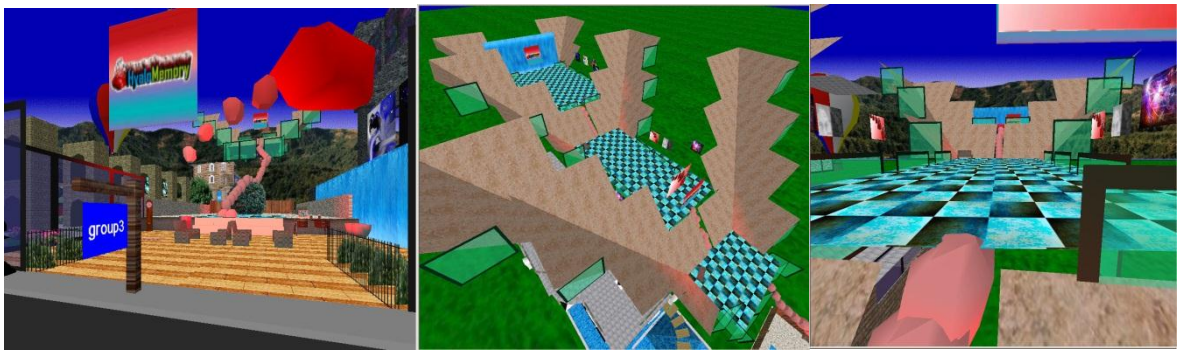


FIG 5. Design outcomes of synchronous mode. 3D place design in Active Worlds, students designed a HyaloWorld as an exhibition space

5. DATA COLLECTION AND PROTOCOL ANALYSIS

During the implementation of the project, the students recorded the design communication protocols which are later analysed using protocol analysis. The analysis was the final phase of the student's project submission including the reflective report. Once we collected all the student's reports including the protocol analysis, we combine all of the data into one set and calculated the occurrences of each coding categories. In addition, the students in ITU are asked to answer the questionnaire following the submission of their project. The data includes the communication transcripts, meeting minutes, team calendar, student's blogs, visual materials (sketches, models, etc) and the protocol analysis.

Protocol analysis, which was first adopted by Eastman (1968) to study design cognition, has been accepted as a research technique allowing for the clarification of designers' cognitive abilities (Cross 2001). The method has been widely used by researchers in the field of collaborative design (Kvan, West et al. 1997; Gabriel 2000; Maher, Bilda et al. 2006; Gül 2007). The protocol analysis has soft and hard techniques that are included in this

paper: the soft technique refers to interviews, questionnaires or the observation of design activities, and the hard technique refers to coding and analysis mechanisms (Oxman 1995).

The protocol analysis allows us to measure the changes that can be counted by a coding scheme. Purcell et al. (1996) presented that there were three approaches to developing the structure of a coding scheme: the theory based, externally derived and data-generated structures. In the development of the coding scheme, the last two approaches are applied in this paper. As mentioned earlier, the following aspects are focused in the comparison of the communication modes:

- the impact of communications modes into collaboration and design process;
- the impact of communications modes into design exchanges; and
- the impact of communications modes into collaboration skill development.

We analysed the collections of communication transcripts based on the expected result of the study, that is, different communication modes will have an impact on the ways in which the students collaborate and design. Thus, measuring the changes in (1) the collaboration and the design process, (2) the design scope (exchanges), and (3) the coordination of the activities are necessary.

5.1 Collaborative design coding scheme

We review existing coding schemes in the design studies, and then borrow and adapt the categories to measure the changes in the above aspects. Thus the initial coding scheme evolves through the analyses of data. In conclusion, a coding scheme that classifies the design information into four main categories is developed, as shown in Table 1.

The first category, ***collaboration process***, is derived from Kvan et al.'s (1997) cognitive model of collaborative design. Kvan et al. (1997) pointed out that collaborative design consists of parallel expert actions, each of short duration, bracketed by joint activity of negotiation and evaluation. In this view, designers work separately to solve the problem and come together for meta-planning, negotiation and evaluation. The first step is a meta-planning process that is concerned with the management of the design process. This part of the process includes discussions about how to break down the problem into individually manageable units as well as about how and when the collaborators should come together to integrate their individual efforts. Meta-planning does not deal with the design problem itself but only with how to approach dealing with it collaboratively. The meta-planning is followed by a joint decision-making process, a negotiation process that deals with specific aspects of the design problem. Following an initial negotiation each participant works separately in routine problem-solving, guided by the meta-plan that was agreed upon and controlled by the jointly made, task-specific negotiated decisions. When designers have finalised their agreed-upon components, they evaluate the outcome together and are then either finished or iterate through the steps again (Kvan et al. 1997). This is a process of identifying the approach of collaboration (who is doing what), identifying key problems (problem analysis) and proposing (generating new ideas) and evaluating design alternatives. Based on the cognitive model of collaboration, the category has four codes: meta-planning, negotiation, individual design work, and evaluation. In Kvan et al.'s (1997) cognitive model, meta-planning, negotiation, and evaluation are considered as cooperative steps whereas individual design work is not.

The second one, ***design process,*** is based on the studies (Rittel and Webber 1984; Cross 1999) which define design as a different kind of problem-solving activity that is ill-structured and iterative in nature. This category also shares the characteristics of Maher et al.'s design process actions (2005) and Gero and McNeill's (1998) process-oriented design coding scheme. The design process category includes the problem-understanding and the solving strategies, which are the set-up goal, proposing ideas, the problem analysing, the synthesising, and the clarify/restate codes.

The third category, ***design scope*** is adapted from Gül (2007) and Vera et. al.'s (Vera, Kvan et al. 1998) two types of design exchanges. Vera et al. (1998) defined four design activities: digesting the information given, gathering and reading facts and determining the data at hand. These were called the task-focused activities, and consisted of two types of design exchanges (Gül 2007): high-level design and low-level design. In high-level design exchanges, the designers plan solutions and make broad decisions which would affect significant aspects of their later decisions. These activities included planning the site, laying out major components and identifying primary routes. Once these have been completed, low-level design activities could be expected to start, such as placing

individual elements such as trees, benches and parking places into the framework set by the high-level design actions, resolving issues of drafting (for example, line type) and drafting actions (Vera, Kvan et al. 1998). The design scope category has two codes; the low-level and the high-level design exchanges, as shown in Table 1.

The final coding category, ***design task management***, is adapted from Gabriel's (Gabriel 2000) design task coding scheme. The category has three codes, as demonstrated in Table 1. The focus of the category is to capture the discussions that are related to the coordination of activities during the design process, this can be also considered as the sub-category of the meta-planning activities.

TABLE 1 Design communication coding scheme

Collaboration Process	(based on Kvan's model of collaborative design (Kvan, West et al. 1997)
Meta-planning	Co-ordinating the activities of the collaborators, task allocations, management of the process
Negotiate	Negotiation regarding specific aspects of the design problem/joint interactive decision-making
Individual Design work	Working individually on the design problem
Evaluation	Evaluate and explore design idea
Design Process	
SetUpGoal	Assigning task
Proposing ideas	Proposing new ideas
AnalyseProb	Analysing the problem space
Synthesise	Synthesising the solution space
Clarify/restate an idea	Clarifying or restating a concept previously introduced by another individual or by self and questions by others
Design Scope	(based on (Gül 2007)
Low-level design	When students discuss individual elements, discussing colours etc.
High-level design	When students make broad decisions which affect significant aspects
Design task management (based on (Gabriel 2000)	
Brief	When students discuss about the design brief
Schedule	When students discuss about time management
Task/instruction	When students discuss about task allocation and instruction, and monitoring activities

5.2 Segmentation

Following the cleaning up the collected data and having the transcripts of the communication protocols, the next step is segmentation. During segmentation, the design protocol excerpt is divided into smaller units. In order to investigate the design protocols of each of the teams in the collaborative design context, we segmented the protocols using the utterance-based segmentation method as used in (Gabriel 2000; Maher, Bilda et al. 2005).

6. RESULTS AND DISCUSSIONS

6.1 Protocol Analysis

The encoded protocols were compared to understand qualitative differences between the communication modes. Encoded protocols represent the context of collaborative design, the way students collaborate, design and communicate, and the kinds of interactions they have in the virtual environments.

Collaboration and Design Processes Evaluations: Fig. 6 shows the percentages of the occurrences of the collaboration process actions. In the synchronous communication mode, the negotiation action is higher, followed by the evaluation, meta-planning actions (22.5%). The percentage of the individual work action is lower (16.5%) in the synchronous communication mode. However, in the asynchronous communication mode, the percentage of the meta-planning action is higher (32%), followed by negotiation and individual work. The percentage of the evaluation action is lower (18%) in the asynchronous communication mode.

This result shows that in the synchronous communication mode, the students were working together with their peers for the development of the design ideas staying in joint decision-making mode of negotiation and evaluation. In the asynchronous mode, the same students spent most of their time for coordinating their collaborative activities for effective time management and task monitoring.

The result suggests that working in synchronous communication mode encourage students to work collaboratively on the development of the design ideas. Being present in the meeting and having instant feedbacks and online synchronous communication encourage students to discuss design issues and evaluate the

design ideas and artefacts. On the other hand, asynchronous communication mode encourages students to plan and structure the collaborative activities, monitor the processes and work on their individual parts.

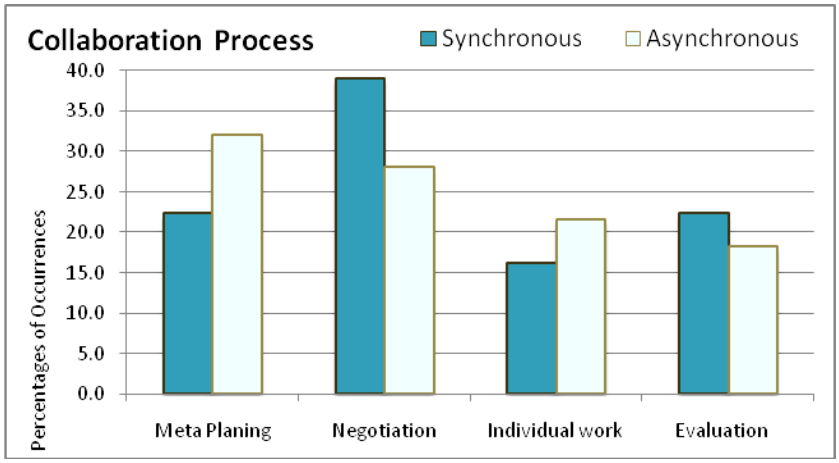


FIG 6 Occurrences of Collaboration Process actions

Fig. 7 shows the percentages of the occurrences of the design process actions. Although it is hard to define a pattern in the design process actions, the overall percentages of the design process actions are higher in the synchronous communication mode in most cases, except the percentages of the set-up goal actions are higher in the asynchronous communication mode, as shown in the Fig. 7. The result shows that the asynchronous communication mode encourage the students to assign design tasks to each other, this results are also compatible with the findings of the collaboration process actions showing the meta-planning activities are higher in the asynchronous communication mode (see Fig. 6). The result also shows that the students proposed more design ideas in the synchronous communication mode. The students also spent more time analysing the design problem and clarifying the design concepts in the synchronous communication mode. The same students spent more time on the discussions that are related to setting-up goals to each other in the asynchronous communication mode.

This result suggests that students manage to work productively together with their group members in the synchronous communication mode having more proposed ideas and the analysis of the ideas. As most brain storming sessions shows that timely feedback and fast response are essential in the idea development in which the synchronous sessions supported. It can be speculated that the synthesizing of a design idea would require more time or thorough thinking, so the students performed more synthesizing of actions in the asynchronous communication mode. This claim needs a detailed analysis which is worth to study.

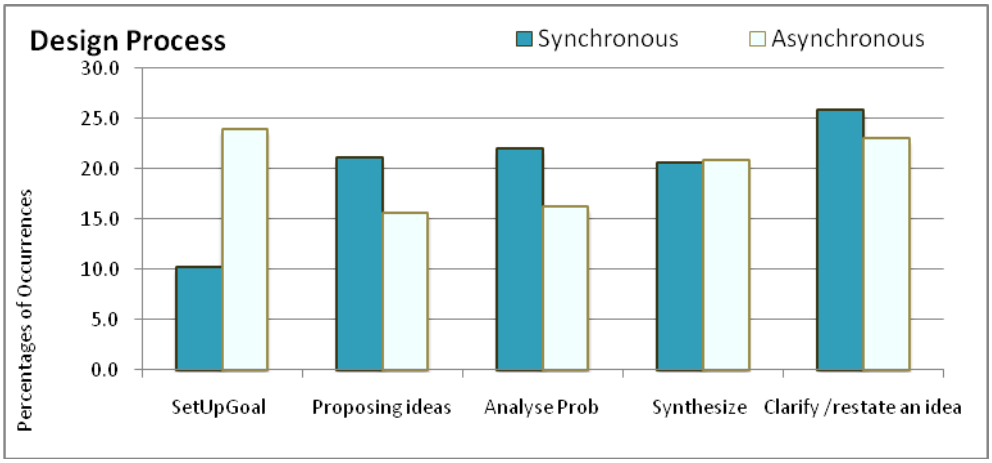


FIG 7 Occurrences of Design process actions

Design Exchanges: Fig. 8 shows the percentages of occurrences of the design scope (exchanges) actions. The percentage of the low-level design scope action is higher (55%) and the percentage of high-level design scope action is lower (42%) in the synchronous communication mode. When the students worked in the asynchronous communication mode the percentages of the low-level design scope action dropped, and the percentages of high-level design scope action increased, as shown in Fig. 8.

This result suggests that the synchronous communication mode encourages the students to elaborate the design ideas in more detail for example talking about individual design elements and their forms and colour. The asynchronous communication, on the other hand, supports more the discussions that are related to the high-level design idea exchanges, for example talking about design concepts and structure of the buildings. This result seems consistent with the findings of the collaborative design studies (Vera, Kvan et al. 1998; Gabriel 2000) when looking at the ratio of low to high-level design ideas discussed in computer mediated environments.

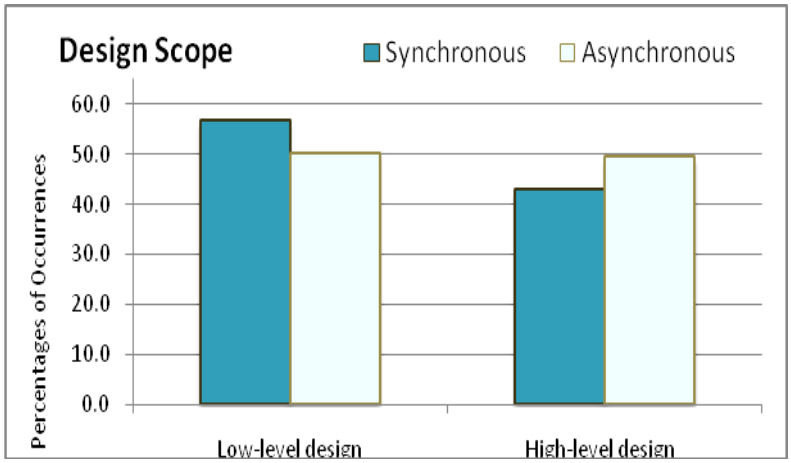


FIG 8 Occurrences of Design Scope actions

Design Task Management: Fig. 9 shows the percentages of occurrences of design task actions. The percentages of the design task actions are higher in the asynchronous communication mode, except the percentage of the design brief actions is lower, as shown in Fig. 9. Students started with reading the design brief and continued gathering information about the requirements which occurred in the synchronous communication mode. In the online design environment, during the design process most of the co-ordination and structuring of the collaborative activities for example setting up a meeting, following up a given task, monitoring the process etc. took place in the asynchronous communication mode. It seems that it is easier to track back the agreements and discussions in the asynchronous communication mode. This seems consistent with the results as in Fig 6.

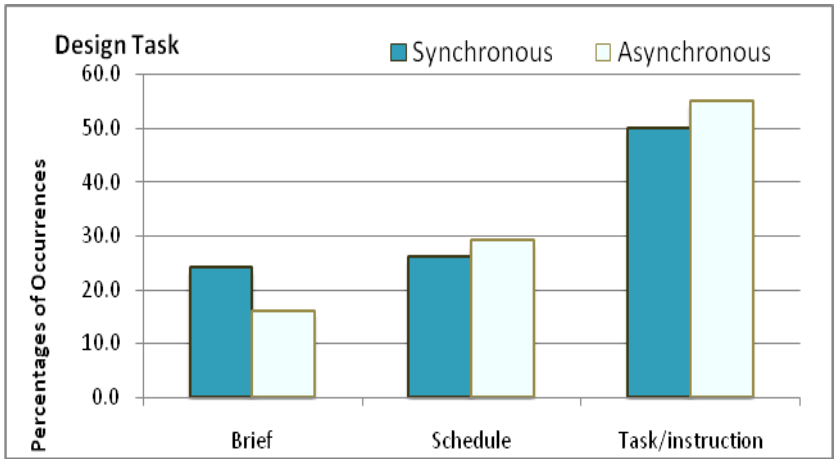


FIG 9 Occurrences of Design Task Actions

6.2 Evaluation of Students and Observations

Following the completion of the project 3, the students in USYD submitted reports that typically include two parts: the analysis of the communication protocols and the reflective report. The reflective report consists of three parts of 45 questions in total and they are highlighted below:

Technical features (answered on a five-point Likert scale): Part one of the report aims to evaluate the performance of various technical features in Active Worlds and other communications tools for supporting collaborative design and activities.

Open questions: Part two of the report includes open questions in order to develop more in-depth understanding of student perception of the used tools and virtual world in supporting collaboration. The students discussed a variety of issues such as the evaluation of the process, preferences and expectation of various key issues ranging from communication and design presentation, management of activities, conflict resolution and experienced difficulties.

Teamwork skill development (answered on a five-point Likert scale): Part three of the report focuses on surveying student's awareness and perception of teamwork skill development.

The sample size of the study is quite ideal with 30 from a class of 33 students responding. 54% of the participated students are female. 56% of the students have two to three years design experience. 18% of them have only one year design experience. 18% of them have only five year design experience. All of the students have a personal computer with internet connections at home. 80% of the students uses internet more than 6 hours per week. All students have at least one year experience in using general CAD tools which implies that the students are quite well computer literate. On the other hand majority of the students experienced Active Worlds for the very first time during the collaboration. The students therefore considered as both novice designers and virtual world users. We summarises the students' responses indicating student's perception of communication modes and tools for collaborative design in the following sections:

Collaboration and Design Processes Evaluations: Students evaluated the collaboration and design process of their team in the reflected reports. 83% of the students consider the synchronous communication mode as effective/ very effective. 47% of the students consider the asynchronous communication mode as effective/ very effective, 29% of the students stay as neutral when comparing the tools. Student's perception indicates the preference of immediate response and feedback from the peers.

Similarly the tools for synchronous communication mode are founded as effective: 86% of the students thought the chat channel in Net Meeting/ Messenger effective/very effective, as a tool to communicate and share ideas.

Students were divided in their opinions of how effective Active World was for communication. 41% of the students rated the chat channel in the Active Worlds effective/very effective as a tool to communicate and share ideas while 46% of the students rated it as not effective/not very effective.

Once again, students were divided in their opinions of how effective the asynchronous communication tools were for communication. 58% of the students consider that email correspondence as a communication tool is effective/ very effective (24% is neutral). 36% of the students consider that blog correspondence is effective/ very effective and 41% of the students consider it as neutral.

Selected comments from the student include:

"I believe [synchronous and asynchronous collaboration] they both have an important part to play in collaboration [...] it would be increasingly difficult to do any project without a mix. Synchronous collaboration allows fast and clear communication […]. Asynchronous allows flexibility above boundaries and solidification of ideas […] It was a good way to communicate and organise events and dates in advance […] sometimes took too long for people to respond".

"Synchronous was by far more effective, simply because it is faster. It takes too long to send an email, wait for a response, and send another back. 3 emails might take an entire day to be sent back and forth when synchronous communication can get the same thing done in 15 minutes".

"Really the chat feature was the most effective. When collaborating, you really just want to get to the point of what you're saying and any features like audio/video/whiteboard, while nice, are merely overkill. Whiteboard

especially... The fact is that you're not talking in person, you're talking via text over the internet so these features just get in the way".

"...asynchronous collaboration is not limited to time for both sender and receiver. It allows sender to think deeply so that the contents would be more structured and detailed...enables flexibility to act when it is most convenient".

"I disliked the long delay of receiving feedback in emails. I did like the way that the blog allowed us to write our ideas formally and in great detail...The chat windows were the most effective for understanding across cultures and easiest to use".

"I liked being able to send messages and having a record of what has been said when using message boards to collaborate, however I didn't like the time it took to get responses. It is much quicker to just talk to people in a synchronous environment to get the job done, but this is sometimes unavoidable".

Summary: The immediacy of the design communication tends to be an important factor for the students. Net Meeting/ Messenger and Active Worlds provide the students with the same kinds of text based communication mode; the chat box. The result shows that the students preferred web 2.0 type communication for the design activity. We can speculate that there may be a delay in the correspondence between the students in the 3D Virtual World. The user of the 3D Virtual World may be busy with other activities (walking, flying, observing the 3D environment, modelling etc.) and a delay can occur in order to respond to the other designer. In Net Meeting/ Messenger, on the other hand, the discussion was the only activity for the designers, thus an immediate response can be provided.

Design Exchanges Evaluations: The students have been consistent regarding their satisfaction of the final design outcome. 72% of the students were satisfied/very satisfied with their design decision and solution in homepage design task, and 68% of the students were satisfied/very satisfied with their design decision and solution in 3D place design task.

40% of the students thought Active Worlds as effective/ very effective, as a tool to design with the other group members (32% neutral), 71% of the students thought the whiteboard not effective/not very effective, as a tool to draw collaboratively with the group members.

As shown in the following direct quotes from the students, their opinions are reflecting communication and presence aspect of virtual worlds:

"I liked making buildings and objects and talking to people in digital environment. I disliked the building inspector which blocked our construction and the fact that you could not manipulate other objects made by people […] in Active World, The virtual world gave a feeling like you were communicating with people in person".

"Dislike- the system for building, very awkward... The chat is too confusing when everyone is online" (the student is referring the chat box of Active Worlds).

Summary: The students commented about some of the limitations of the 3D Virtual World, i.e. the building inspector. The construction limit of Active Worlds caused some dissatisfaction among the students. But overall they are satisfied with their design outcome.

Communication Skill Development Evaluation: Communication and teamwork skill development remains as the most challenging aspect in applying online tools for design collaboration. Students indicate that it has been difficult to work together as a group due to the inability of having group members meeting face-to-face. 47% of the participants "agreed/strongly agreed" with this statement as they considered "... face-to-face meeting was the most productive", and 32% "disagreed/strongly disagreed". Further:

46% of the students consider managing team activities difficult in remote design collaboration. 47% of the students consider that it was difficult to develop a shared understanding of the goal. 22% of the students stay as neutral.

The students have adapted diverse strategies to manage the design process. 44% of the students do agree / strongly agree that they did not develop a procedure to manage the collaborative work. 25% of the students did not have a fixed procedure and 33% of them stay as neutral. Nevertheless, 61% of the students do "agreed/strongly agreed" that teamwork tasks encouraged collaborative learning.

Commenting on the use of 3D virtual worlds for coordinating team activities in relation to other means, some students considered:

"... Email was good because we did not need to coordinate meeting times. Second Life, face-to-face (meeting) and phone call were good to get fast responses ..."

Some students indicated the reason that their group did not prefer email for design communication is because: "... people did not regularly check their emails and therefore it slowed down (the) progress", and the reason they preferred 3D virtual worlds was because they: "... could communicate instantly whilst exploring options and activities".

Summary: Developing the collaboration skills is one of the challenging tasks in a remote design teaching context. In most cases the students are not aware of the process and cannot monitor their group's activities. Thus teaching how to manage the remote collaboration requires a hands-on experience. The students tend to prefer face-to-face communication in order to develop a shared understanding and trust between them.

Student comments in ITU: Similarly, in order to get feedback from the students and understand how they perceived the collaborative virtual design process, two evaluations were collected from the students at the ITU. The first evaluation was gathered as a report right after the students completed the collaborative experiment on MS Whiteboard. In this report, the students' compared the collaborative design activity with the individual design process practiced in the previous web site design task. The students responded to this experiment as an interesting experience. However the limited capabilities of Whiteboard as a design tool prevented them to express their ideas properly. The students enjoyed from collaboration and used the Whiteboard for brain storming of the conceptual development in the early phases of design.

The second evaluation of the ITU was gathered from the students as a questionnaire at the end of the class. In the questionnaire, the students were given 37 multiple-choice questions for assessing how much the course objectives were reached. In general students had a positive attitude for collaborative virtual design and found it productive. The resulting designs were creative and matured in a relatively short time. On the other hand, the students found Active Worlds environment is very limited for architectural design and time consuming for finding the right building element or material. Half of the students said that they had a frustrating experience with Active Worlds. Technical problems such as, Internet connections, system errors and licence problems, as well as usability problems such as, ineffectiveness of mouse and keyboard, inability to develop conceptual schemas and diagrams, were the reasons of the frustration.

6.3 Summary of student's evaluations

Based on our observations and the discussion with the students during the design studio, we summarise some of the benefits and limitations of the Global Teamwork. The students pointed out that the collaboration with the ITU students gave them the opportunity to learn about a different culture, and hands-on experience of using communication and design tools. They had to develop skills to manage the collaborative design process and develop a shared understanding of design. However, the students also commented that living in different parts of the world and language became problematic in some situations where the USYD students used the slang and the abbreviation to express their feelings during the social conversations. Establishing a team sharing the same goals and establishing the trust took more time. The big time difference was another limitation of the Global Teamwork which caused the delay in the response most of the time.

7. CONCLUSIONS

This paper presents an application of virtual environments in design teaching, Global Teamwork, conducted by the University of Sydney, Australia and Istanbul Technical University, Turkey. Global Teamwork is evaluated based on a protocol study and students' perception through a reflective report. Our experiences show that Global Teamwork has offered students unique opportunities for design collaboration and communication in remote locations and new experiences of design with a peer in a geographically distant location.

As the most common pedagogical approach, problem-based learning and design-studio teaching are combined to provide a platform where students were exposed to and explored a variety of Collaborative Virtual Environments design issue, which included developing digital communication skills and learning about the cutting-edge design

and communication tools such as 3D virtual worlds, tangible design systems, augmented reality and mix-reality. The students are also given chance to design collaboratively with a group of students in Istanbul. Besides the above findings regarding collaborative design learning, the paper concludes with the following remarks.

The result of the protocol study and the reflective reports show that the communication modes have an impact on the students' communication and design activities. The students adapted themselves according to the available tools and design facilities and completed the design task satisfactorily.

Collaboration and design process: Regarding the support of the level of the communication modes, most (73%) of the students considered synchronous communication mode were 'effective/ very effective' as compared with asynchronous communication mode. However, from the collected comments and feedback, it is shown that the students' perceptions have been largely divided, indicating significant differences in the affordance of communication and design technologies among students, even when they have similar background and experience.

The results of the protocol analysis show that in the synchronous communication mode, the students were working together with their peers for the development of the design ideas staying in joint decision-making mode of negotiation and evaluation. In the asynchronous mode, the same students spent most of their time for coordinating their collaborative activities for effective time management and task monitoring. The results also suggest that working in synchronous communication mode encourage students to work collaboratively on the development of the design ideas, on the other hand, asynchronous communication mode encourages students to plan their collaborative activities, monitoring the processes and work individually.

The results also show that the students proposed more design ideas and stayed more on the analysing the design problem and clarifying the design concepts in the synchronous communication mode. The same students stayed more on the discussions that are related to the 'setting-up' goals to each other in the asynchronous communication mode.

Design Exchanges: In terms of the perceptions on communication tools in supporting decision–making and design solutions, the students have been largely divided again. 41% of the students considered the synchronous communication modes did not interfere with their ability to develop design solutions. 41% of the students rated their experiences as neutral. On the other hand, 60% of the students considered the asynchronous communication mode did not interfere with their ability to develop design solutions. Only 28% of the students rated their experiences as neutral. Regarding the satisfaction of their design outcome, 72% of the students rated their design decision and solution in homepage design task as satisfied /very satisfied'. 68% of the students rated their design decision and solution in 3D place design task as 'satisfied /very satisfied'

The results of the protocol study show that the low-level design exchanges occurred in the synchronous communication mode where the brainstorming activity mostly occurred. When there is the continuing and uninterrupted communication, there would be more low-level design exchanges. This result is also consistent with the result of the design process actions in which the percentages of the analysis and the proposing ideas actions are higher in the synchronous communication modes.

Teamwork skills: Regarding the level of support to teamwork, the main difficulty comes from working with a new partner in distance, which is lack of physical contact. 75% of the students found it difficult in developing trust among team members.

The results of the protocol study show that asynchronous mode is mostly used for monitoring the collaboration process, scheduling the meetings and performing the task allocations. This mode also provides the information to set-up the database of the teamwork. For example, the groups were able to keep the meeting log-books, the task schedule and the calendar in their group's web site to monitor the collaborative activity. In contrast, they have kept less number of records of the synchronous communication sessions.

There are also some identified shortcomings and technical problems of using Active Worlds as the CVEs for collaborative design learning. It can be considered that Active Worlds environment is very limited for architectural design and is time consuming for finding the right building element or material. Technical problems such as, Internet connections, system errors and licence problems, as well as usability problems such as, ineffectiveness of mouse and keyboard, inability to develop conceptual schemas and diagrams, were the reasons of the frustration.

Finally, the collaboration with the ITU gave the students the opportunity to learn about a different culture, and hand-on experience of using communication and design tools. On the other hand, the students also concerned that living in different parts of the world and language became problematic in some situations where the USYD students used the slang and the abbreviation to express their feelings during the social conversations. Establishing a team sharing the same goals and establishing trust took more time.

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8. REFERENCES

Baird F., Moore C. J. et al. (2000). An ethnographic study of engineering design teams at Rolls-Royce Aerospace, *Design Studies*, 21(4): 333.

Bellamy T. R., Williams A. P. et al. (2005). Design Communication: Issues Confronting both Co-located and Virtual Teams. *Proceedings of the Association of Researchers in Construction Management 21st Annual Conference*, London.

Bolter J. D. and Gromala D. (2003). Windows and Mirrors: Interaction design, digital art, and the myth of transparency, The MIT Press.

Çağdaş G., Kavakli T.,et al. (2000) . Virtual Design Studio VDS2000 as a Virtual Construction Site, *International Journal of Design Computing*, vol.3.

Clark S. and Maher M. L. (2005). Learning and Designing in a Virtual Place: Investigating the Role of Place in a Virtual Design Studio, *Proceedings of eCAADe 2005*, Technical University of Lisbon.

Cleland D. and Ireland L. (2002). *Project Management: Strategic Design and Implementation*, 4th Edition. New York, McGraw-Hill.

Cowdroy R. M. and Williams A. P. (2002). Assessing Design Activity: Issues and Actions. *Proceedings of the 7th International Design Conference*, DESIGN 2002, Croatia.

Craig D. L. and Zimring C. (2000). Supporting collaborative design groups as design communities, *Design Studies* 21(2): 187-204.

Cross N. (1999). Natural Intelligence in Design, *Design Studies*, 20(1): 25-39.

Cross N., Ed. (2001). Design cognition: results from protocol and other empirical studies of design activity. *Design knowing and learning: cognition in design education*. Amsterdam, Elsevier.

Dickey M. D. (2005). Three-dimensional Virtual Worlds and Distance Learning: Two Case Studies of Active Worlds as a Medium for Distance Education, *British Journal of Educational Technology*, 36(3): 439-451.

Gabriel G. and Maher M. L. (1999). Coding and modelling communication in architectural collaborative design. *ACADIA' 99*.

Gabriel G. C. (2000). Computer mediated collaborative design in architecture: the effects of communication channels on collaborative design communication, PhD. University of Sydney.

Gabriel G. C. and Maher M. L. (1999). Does Computer Mediation Affect Design Representation? *Proceedings of Design Thinking Symposium*.

Gero J. S. and McNeill T. (1998). An approach to the analysis of design protocols, *Design Studies*, 19(1): 21-61.

Goodyear P. (2005). Educational design and networked learning: Patterns, pattern languages and design practice, *Australasian Journal of Educational Technology*, 21(1): 82-101.

Goodyear P. (2006). Blended learning: Talking about design, *Blended Teaching and Learning Forum*, University of Western Sydney.

Gu N., Gül L. F et al. (2007). Designing and learning within the design: A case study of principles for designing and teaching 3D virtual worlds. *CAADRIA 2007:Proceedings of the 12th International Conference on Computer-Aided Architectural Design Research in Asia*, Nanjing, China.

Gül L. (2007). Understanding collaborative design in different environments: comparing face-to-face sketching to remote sketching and 3d virtual worlds. PhD, University of Sydney.

Gül L., Wang, X.et al. (2008). Global Teamwork: A Study of Design Learning in Collaborative Virtual Environments. *Undisciplined! Proceeding of the Design Research Society Conference 2008*, D. Durling, C. Chen, L. Ashton and K. Friedman. Sheffield, UK, Sheffield Hallam University

Gül L. F., Gu, N. et al. (2007). Designing Virtual Worlds: A case study of design education in and of 3D virtual worlds. *CONNECTED 07, International Conference on Design Education*, Sydney.

Gül LF, Gu N, Williams A, (2008). Virtual worlds as a constructivist learning platform: evaluations of 3D virtual worlds on design teaching and learning, *ITCon* Vol.13, Special Issue Virtual and Augmented Reality in Design and Construction, p. 578-593.

Hara N., Bonk, C. J. et al. (2000). Content analysis of online discussion in an applied educational psychology course, *Instructional Science*, 28(2): 115-152.

Hoyt B. (2000). Techniques to Manage Participation and Contribution of Team Members in Virtual Teams, *WebNet Journal*, 2(4): 16-20.

Jarvenpaa S. and Liedner D. (1998). Communication and Trust in Global Virtual Teams, *Journal of Computer Mediated Communication*, 3(4): 1-32.

Kirner T. G., Kirner, C. et al. (2001). Development of a collaborative virtual environment for educational applications. *Proceedings of the sixth international conference on 3D Web Technology*.

Kvan T., Schmitt, G. N. et al. (2000). Teaching architectural design in virtual studios. *Computing in civil and building engineering*, R. Fruchter, F. Pena-Mona and W. M. K. Roddis. Stanford: 162-169.

Kvan T., R. West, et al. (1997). Tools and channels of communication: Dealing with the effects of computer mediation on design communication. *1st International Conference on Creative Collaboration in Virtual Communities*, University of Sydney.

Lahti H., Seitamaa-Hakkarainen, P. et al. (2004). Collaboration patterns in computer supported collaborative designing, *Design Studies*, 25(4): 351.

Loeffler C. E. (1993). Distributed Virtual Reality: Applications for education, entertainment and industry, *Telektronik*, 89(4): 83-88.

Maher M. L. (1999). Variations on a Virtual Design Studio, *the 4th international Workshop on CSCW in Design*, Universite de Technologie de Compiegne.

Maher M. L., Bilda, Z. et al. (2005). Collaborative processes: research report on use of virtual environment. Sydney, the University of Sydney.

Maher M. L., Bilda, Z.et al. (2006). Impact of collaborative virtual environments on design behaviour. *Design Computing and Cognition'06*, the Netherlands, Springer.

Maher M. L. and Simoff S. (2000). Collaboratively Designing within the Design. *Proceedings of Co-Designing*, 2000.

Martin J. R., Ed. (2001). Language, register and genre. *Analysing English in a global context.* London, Routledge.

Okada M., Yamada, A. et al. (2003). DigitalEE II: RV-Augmented Interface Design for Networked Collaborative Environmental Learning. *Proceedings of the International Conference on Computer Support for Collaborative Learning.*

Oxman R. (1995). Viewpoint Observing the observers: research issues in analysing design activity, *Design Studies* 16(2): 275-283.

Purcell A. T., Gero, J. S. et al. (1996). The data in design protocols: the issues of data coding, data analysis in the development of models of the design process. *Analysing design activity.* N. Cross and H. Christiaans. Chichester, UK, John Wiley & Sons Ltd: 225-252.

Rittel H. and. Webber M. M (1984). Planning problems are wicked problems. *Developments in design methodology* ,New York, John Wiley And Sons, Inc.: 135-144.

Salter D. (2006). E -Scholars: Staff development through designing for learning, 23rd Annual Conference of the Australasian Society for Computers in Learning in Tertiary Education: Who's Learning? Whose Technology?, Sydney, Sydney University Press.

Scherer J. R. (2004). Information logistics for supporting the collaborative design process. *Collaborative design and learning; competence building for innovation.* J. Bento, J. P. Duarte, M. V. Heitor and W. J. Micthell. Westport, CT, Instituto Superior Technico, Greenwood Publishing Group.

Schnabel M. A., Kvan, T. et al. (2001). The First Virtual Environment Design Studio, Architectural Information Management. 1*9th eCAADe Conference Proceedings*, Helsinki, Finland.

Steeples C., Jones, C. et al. (2002). *Beyond e-learning: A future for networked learning*. London, Springer.

Vera, A. H., Kvan, T. et al. (1998). Expertise, collaboration and bandwidth, *CHI'98*, Los Angeles, CA: ACM SIGCHI.

Wyeld T. G., Prasolova-Forland, E. et al. (2006). Virtually Collaborating Across Cultures: A Case Study of an Online Theatrical Performance in a 3DCVE Spanning Three Continents. *Sixth International Conference on Advanced Learning Technologies.*

Yang D. F. (2007). Improving Networked Learning in Higher Education: Language Functions and Design Patterns. PhD.