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Co-design studio with different design environments: Analogue design, designing within the design and parametric design

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Abstract
This paper explores a graduate course offered by the Architectural Design Computing program at Istanbul Technical University, which is structured as a collaborative studio experience aimed at immersing students in diverse design environments. Going beyond conventional approaches, the course provides students with hands-on experiences across three distinct design settings: utilizing analogue tools, navigating a 3D virtual world, and engaging with computational tools for parametric modeling. This article presents an ethnographic assessment of this co-design studio, detailing its course structure, highlighting innovative pedagogical approaches, and showcasing the outcomes of the collaborative design endeavors.
What distinguishes this exploration is its multifaceted examination, shedding light on the intricacies of collaborative design practices across varied contexts. The paper introduces a rigorous ethnographic evaluation to assess the affordances of each design environment, offering a novel perspective to scholarly discourse. The unique focus on students' perceptions of collaborative design within these settings adds significant value, providing insights into the constraints and opportunities inherent in collaborative conceptual design processes.
By undertaking this study, the research not only addresses ongoing concerns post-COVID pandemic but also establishes itself as a distinctive and valuable contribution to advancing the understanding of collaborative learning within architectural education.

Keywords
Collaborative design, Design course, Designing in virtual worlds, Parametric design, Sketching.

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1. Introduction

In the last few decades, there has been an increase in the use of information and communication technologies within the architectural design industry. Construction projects have become more and more complex and cooperation practices have evolved to accommodate collaborative work using information technologies (Kubicki et al., 2008). Studies have shown the importance of remote collaboration in the construction industry and the need for all parties of construction to master the digital environments used for design, business management and process awareness (Astaneh Asl & Dossick, 2022).

The recent COVID-19 pandemic has also necessitated that all of us work remotely, irrespective of infrastructure and preparation, to maintain various tasks. Consequently, many schools that traditionally employed the architectural studio format had to swiftly develop alternative educational approaches due to pandemic restrictions. Faced with this abrupt situation, conventional design pedagogy has shifted towards a new paradigm by adapting online theory and studio classes. Remote teaching and learning now utilize different combinations such as blended or hybrid approaches, which incorporate a mix of face-to-face and online modes of delivery. Such combinations have been employed during this recent crisis and have been discussed in several studies (Mervyn Hsin et al., 2023; Khan & Thilagam, 2022; Peimani & Kamalipour, 2022).

This has brought challenges to design pedagogy; students need to become familiar with all modes of communication, including synchronous and asynchronous methods. They must be able to work collaboratively in both virtual and co-located environments, and they have to use a variety of digital media for which they have not received prior training. Although design studio learning embraces numerous forms of representation—visual, verbal, tactile, written—and therefore is rich in communication potential, it is still not common for students to gain experience in tailoring their presentations to different groups and playing a role in a team collaboratively developing a design (Nicol & Pilling, 2000).

Collaborative design, abbreviated as co-design, is a process where individuals work together to achieve a shared design goal. Co-designers collaborate on a design artifact or on parts of a design artifact. Collaboration as a skill has been neglected intentionally in education for a long time (Yang, 2023). Even today, architectural design studio is dedicated on the individual designer, and such action can even be seen as cheating (Lotz et al., 2015, p.3). Nicol and Pilling (2000: 8) state that the 'familiar model of architectural education seems unlikely to foster in students a positive attitude towards collaboration... while it remains primarily geared [towards] developing individual stars rather than preparing team players' (as cited in Delport-Voulgarelis & Perold, 2016). Cuff (1991, p.44) agrees, saying that students 'are rarely encouraged to work in groups on design problems explicitly intended to help them learn about the social construction of architecture, about collaboration skills, mutual satisfaction, and the like'.

From the perspective of cognitive psychology, researchers have delved into the study of collaborative design activities (e.g., see Falzon, 2004 and Darses et al., 2001), focusing particularly on the actors involved in such collaboration (as highlighted by Baudoux & Leclercq, 2022). Vygotsky's sociocultural theory of cognitive development has significantly influenced contemporary social-learning practices. He posited that cognitive development is a cultural activity embedded a social context, dependent on interactions with others (Vygotsky, 1978). Likewise, engaging with others in learning process fosters creative thinking, acceptance of others, commitment, caring, a sense of inclusion, enhanced self-esteem, and increased learning achievement (Johnson et al., 1984).

In the contemporary landscape, advancements in information and communication technologies, coupled with the widespread use of digital tools in design, have the potentials to transform co-design practices. These practices are now conducted in both co-located and remote settings through computer-mediated design environments, as witnessed during the outbreak of the COVID pandemic. Given these shifts, there is a growing demand for graduates who are not only digitally literate but also well-prepared for collaborative teamwork.

With all these considerations, the question of how and what to teach to the new generation of (architectural) design students in the digital era has become more challenging, 'requiring the consideration of new pedagogical approaches employing emerging design media' (Gül, 2011, p.203). Architecture curriculum often respond to these requirements by introducing new courses for students or updating existing ones with the aim of supporting students in: 1) acquiring a good command of different media for the field of design, and 2) gaining the skills necessary to work collaboratively in teams. The integration of design collaboration into design studios remains one of the challenges that architecture schools around the world are expected to address. Therefore, in this paper, we emphasize the importance of the affordances of the environments studied, considering the design and collaboration possibilities of the medium in a design learning context.

With these ideas in mind, we conducted graduate-level digital architectural design studio course at Istanbul Technical University in 2016 based on the theme of co-design in various design environments. In this course, we asked the students to work in teams and develop initial conceptual design solutions for three different yet similar scope-wise design problems by:

- Utilizing solely analogue tools and working in a shared setting.
- Operating in a virtual world through object-based modeling and scripting, working in both a shared co-located setting and remotely.
- Using cutting-edge parametric modelling techniques.

Here, we detail the course structure, present the design outcomes of three groups who has the consent, evaluate the constraints and affordances of design environments in supporting collaborative design practices based on our observations during the studio, and discuss the potential benefits of co-design studios in architectural design pedagogy.

Building upon the dynamic landscape of collaborative design and the evolving demands of contemporary education, this article presents an ethnographic study of a co-design studio. Participant observation serves as the primary data collection method, complemented by other methods including informal discussions, semi-structured interviews (to explore emerging issues in depth), and reflective reports. The application of ethnographic methods in architecture holds significant potential for exploring new research and design inquiries (Yaneva, 2018). In this study, akin to Donald Schön's (1987) exploration of educational practice, we aim to ethnographically unveil thinking in action by challenging the systematic, scientific, and linear modes of knowledge prevalent in professional schools. Dana Cuff, in her efforts to decipher the world of professional architects, underscores the importance of ethnographic studies, asserting, "If we are to offer a sound advice about how architectural practice ought to function, we must know more about how it functions now" (Cuff, 1991, p. 6).

Furthermore, this paper introduces an analysis of co-design across various media, examining their affordances and constraints. This analysis systematically evaluates three design settings (analogue tools, designing in the Virtual World, and Parametric design), offering a novel perspective by comparing the design capabilities of these environments and their impact on students' perceptions of the co-design process and final outcomes. The research data includes individual student reports, survey responses, and our records of discussion with students and observations during the design sessions. The unique emphasis on students' viewpoints regarding collaborative design enhances its significance, providing valuable insights into the limitations and benefits of these environments in collaborative conceptual design processes. Consequently, this study not only addresses persistent issues but also positions itself as a unique and valuable addition, enriching the understanding of collaborative design within the framework of architectural education.

2. Pedagogies of design studio in digital era

Pedagogical teaching approaches adapted to various disciplines within the design field, each with a long history, are generally categorized into three groups: those stemming from fine arts school, often following the studio-based Beaux Artes education model; those evolving in tandem with technological developments and typically following an applied science formal education model (e.g., the Bauhaus model); and those seeking alternative approaches, often combining elements of Beaux Arts and Bauhaus models. The majority of schools incorporate analytical, procedural approaches, studio-based training, and master into their programs. They utilize various combinations of scientific and studio-based approaches (see Goldschmidt, 2005 for a different approach), and a broader narrative of the development of alternative approaches can be seen in Iftikhar (2020).

The cornerstone of architectural education lies in design studio pedagogy, which is considered a 'signature pedagogy' and the traditional method of teaching architecture (Shulman, 2005, p.52). Professional education in architecture primarily revolves around this form of teaching and learning within design studio. Laurillard elaborates on the concept of signature pedagogy, referencing to it as: '… the best teaching ideas are most likely to be developed in very specific subject matter contexts. They have been referred to as the signature pedagogies of a discipline' (2012, p.220). We believe this concept is related to what Schön refers to as the 'practicum' (1987).

In his novel book 'Educating the Reflective Practitioner', Donald Schön (1987) describes design studio teaching in architecture as a 'practicum', referring to a setting of action that imitates real practise. In architectural design studio, the provided context offers experiential learning or learning by doing, where students work in a simulated practice environment. Schön refers to such a practicum as a 'virtual world', arguably free from the constraints of the real world such as such risks and budget concerns. 'It could therefore be seen to stand in an intermediate space between the practice world, the lay world of ordinary life, and the esoteric world of the academy' (Schön, 1987).

Today, the 'virtual world' as an educational environment, as proposed by Schön, has the potential to transform and provide a context enriched with the possibilities of new technologies, allowing students to engage with different media and play an active role in their learning. For example, with the recent developments in virtual reality technology and other 3D design technologies, digital design environments offer numerous simulation opportunities without the constraints of the real world, such as time, place, structural limitations. This approach to learning enables the construction of a student-centred context where real-world practice is simulated.

Another a common attitude in architectural education is that the design studio 'still remains primarily geared towards developing individual star architect as unique and gifted designers, rather than preparing team players' (Nicol & Pilling, 2000, p.7). Cuff (1991) used the term 'the primacy of the individual' to describe the inevitable consequence of the relationship between tutors and students in a design studio. After thirty years, this statement stills holds true. However, we argue that the role of an architect should be that of a facilitator and integrator, bringing together all related parties, places, and processes to create a coherent working environment. It is evident that the typical training of an architect does not provide students with the necessary skills to be effective team players. Therefore, our aim is to establish a design studio where a dual two-way relationship/interaction occurs between peers and teachers, providing a context where students also become acquainted with digital design technology in the 'practicum'.

In short, our exploration delves into the multifaceted landscape of design pedagogies, with a primary focus on the pivotal role of the collaborative design studio in architectural education. By dissecting the historical foundations and diverse approaches within the design field, we underscore the studio as a 'signature pedagogy,' offering a distinctive form of teaching and learning. Drawing inspiration from Donald Schön's concept of the 'practicum' in architecture, our paper advocates for a transformation of this virtual world within design education. Through the integration of emerging technologies, such as virtual reality and parametric design tools, we envision an enriched educational context that empowers students to engage actively in the co-design process. Moreover, our proposal for a co-design studio aims to shift the paradigm from the primacy of the individual to a collaborative ethos, fostering a two-way interaction between peers and educators. In doing so, we aspire to bridge the gap between individual-centric education and the demands of contemporary architectural practice, which necessitates collaborative and team-oriented skills.

This contribution strives to pave the way for a student-centred, technologically-enhanced, and collaborative design studio environment that aligns with the evolving needs of architectural education and professional practice. We believe that productive, active and constructive engagement of students with the content and collaboration with their peers and teachers in design studios enables them to develop an understanding of the architectural design process (Powers, 2016; Wallis et al., 2017; Iftikhar, 2020). To create a learning environment that rehearses such situations and allows students to explore what different design environments offer for design and collaboration, we offer a co-design studio where they can practice various mediums as a team.

3. Collaborative digital design studio

The Digital Architectural Design Studio (DADS) course is a compulsory component of the Architectural Design Computing graduate program at Istanbul Technical University, delivered by a different lecturer each semester. The primary objective of the course is to provide students with an environment to explore solutions to architectural design problems using computational design methods and technologies, while also examining the impact of these approaches and technologies on architectural design practice. In the spring semester of 2016 we decided to structure the course around the theme of co-design in various settings. This approach aimed to expose students not only to designing with digital technologies and methods but also to collaborative design experiences facilitated by different mediums. Through this framework, students could develop essential skills for carrying out and managing collaborative design processes. They gained an understanding of the design capabilities and collaborative affordances inherent in these different mediums, while also advancing their knowledge and skills in computational design.

In the course, the students were asked to generate conceptual designs for three distinct but scope-wise similar design problems by working in teams and utilizing three different media. For the first project, teams were assigned to design additional workshop and exhibition spaces for the Faculty of Architecture at the area located behind the faculty building, using analogue tools (this is called AT in this paper). This initial project served as the team's first collaborative design effort. By using a medium they were already very familiar with, students were able to focus their attention on working as a cohesive team and on organizing and conducting teamwork effectively. This approach allowed them to avoid issues related to differences in competencies with computational tools, enabling a smoother collaboration experience and to help building trust among members.

For the second design problem, students were tasked with creating an initial design for a high-rise tower on a virtual island within a 3D virtual world called Second Life (referred to as VW). Second Life supports object-based modelling and scripting, providing students with the opportunity to develop and model their design solutions within a shared environment in real-time. Virtual environments offer numerous benefits such as prospects of experimentation without real-world consequences, opportunities to "learning by doing", and facility to personalize an environment (Dede, 1995). Since mid 1990s, Virtual design studios (Gül et al., 2012; Kahneman & Tversky, 1996; Kvan et al., 2000; Maher, 1999; Schnabel et al., 2001) have been set up by architecture and design schools around the globe aiming to provide a shared "place" where distant design collaboration especially synchronized communications and design activities can take place. The concept of virtual design studios has evolved over time, from early approaches focused on digital design data sharing to more recent approaches involving immersive 3D virtual worlds. In these environments, designs, designers, and learners are all simulated and represented, enabling "design and learning within the design" (Maher, 1999).

In the third design problem, students were tasked with designing a pavilion at the University's main campus by utilizing a computational tool that supports parametric modelling, specifically Rhinoceros with Grasshopper plug-in (referred to as PM). Parametric modelling techniques enable the expression of design intent based on parameters and rules that control relationships between elements and parameters (Woodbury, 2010). This approach allows for the exploration of a range of design solutions by varying parameter values within defined rules. Architects often employ parametric modelling for form finding and optimization purposes. Ostwald (2012, p.9) suggests that a parametric model must have four of the following guiding principles: the first one is that parametric objects should be the combination of 'dimensional, innate and rule-based parameters'. The second one is that the models should keep 'connotative rules; this means that any change in parameter will have an impact on any others within the project'. The third one is that the model should not encumber 'established rules or they will signal to the designer if they are forced to breach the rules or requirements of the system'. The final one is that models should be able to 'output various forms of data'. With the increasing availability of parametric modelling technologies in architecture schools, students have the opportunity to develop parametric models and explore the possibilities and benefits of parametric modelling in generating and exploring alternative design solutions. This allows for a more dynamic and iterative approach to design exploration and problem-solving.

Nineteen graduate students with eighteen holding a bachelor degree in architecture and one holding a bachelor degree in interior architecture attended the course. They formed into five groups. The first requirement of the course was to establish a group blog and asked to keep logs about the experiences they had, the schemes they worked in, and the activities they carried out on a weekly basis. During the term, the AT co-design session took 2 weeks, the VW co-design session took 4 weeks and the PM co-design session took 4 weeks, following a submission and presentation week respectively. The students were introduced to the design environments of Second Life, and Rhinoceros with Grasshopper plug-in at the first week of their design processes within the respective environments. At the end of the term, students were asked to individually write reflective reports detailing their design processes, with a specific emphasis on how they collaborated throughout the process.

During the term, students worked in two different classroom settings: a classic studio setting for the first design exercise and a computer lab for the second and third design exercises. The study was conducted with the first author participating in all classes throughout the term as an observer, informing students of the motivation behind her participation. Four out of the five teams consented to participate in the study. Various forms of data were collected from these four teams, in addition to data gathered through direct observation.

Data collection methods included:

- Video recordings of team processes
- Images of drawings or sketches generated by team members
- Written materials such as notes taken during and outside of class hours

- Personal accounts gathered through unstructured interviews and informal conversations with team members about issues that arose during the study

Due to incomplete data collection from one group, the outcomes and observations discussed in this paper are based on the data collected from three out of the four groups participating in the study.

3.1. Analogue co-design session

Group A- The proposal for the first project, 'welt-beat' (Figure 1), involves a series of prismatic demountable units that gently touch the ground. Figure 1 involves a sketch expressing a section view that marked the 'idea of gently touching the ground'; proposed by one of the group members developed in their initial gathering and the sketches that they developed based on this idea for the overall arrangement of the units. As they reflected in their report a linear design process is followed started from sketches in plan followed by section drawing and finally the façade is discussed. The Units are connected around an accessible walkway starting from the back door of the main building, continuing straight to the service road at the back yard of the main building. The walkway is composed of set of stairs with different widths and a ramp composed of parts (sloped and un-sloped) running in oblique direction in between the stairs. The pavement of the stairs composing the walkway are also used at the courtyard of the main building in the same proportion with that used in stairs, as if the stairs are continuing inside the building.

Group B- The design proposal for the first project, 'the axis' (Figure 2) contains a building with two intersecting rectangular prisms with one slightly higher than the other. One of these prisms lies on the entrance-exit axis of the main building and companies the main entrance and the workshop areas. The other prism lies on an imaginary axis that is parallel to the contours of the terrain and contain the exhibition area, kitchenette, offices, and the service entrance. The slope of the landscape plays an important role in their design as they sketched several sections to examine the buildings' relation with it as shown in Figure2a. The physical model of the project also involves an undulated a canopy over the entrance, which the group included into their proposal

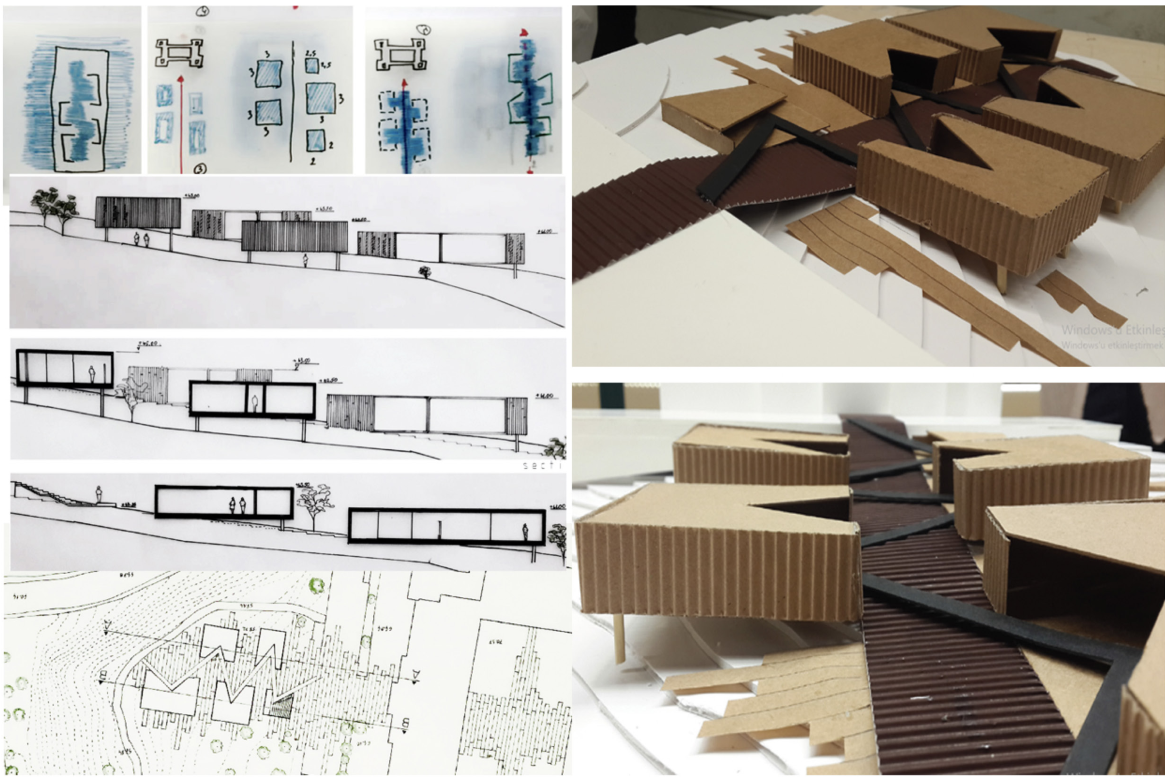

Figure 1. Representations of Group A's design proposal for the first project.

symbolically at the time, with the vision that they could further develop its design when working with PM.

Group C. The design proposal for the first project, (Figure 3) contains a mobile building that resembles an accordion, the scheme would serve as flexible as possible arrangement of the parts of the units that would move based on the need of the user. They investigated a

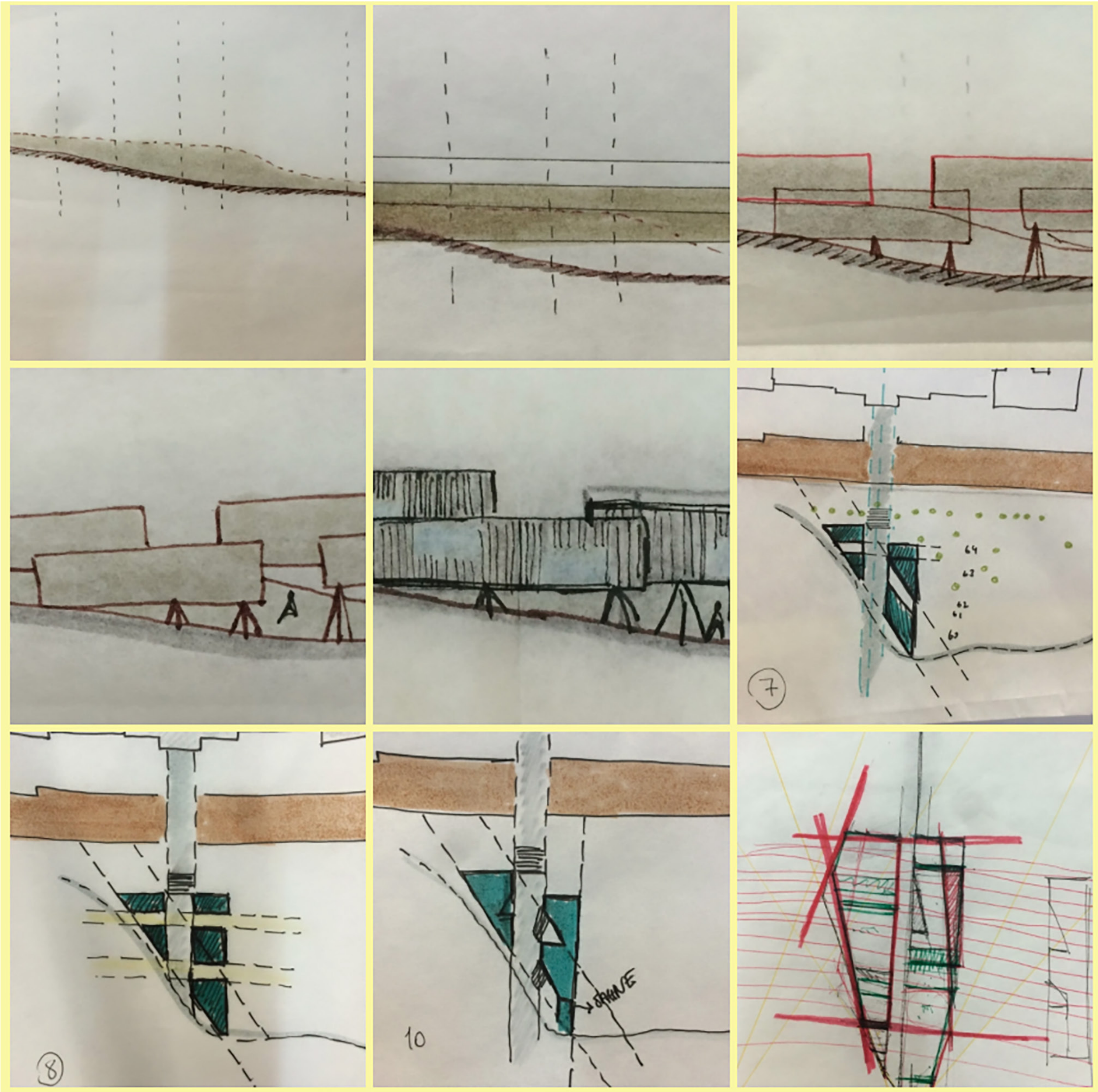

__Figure 1a.__ The idea of touching the earth gently is examined through plans and sketches.

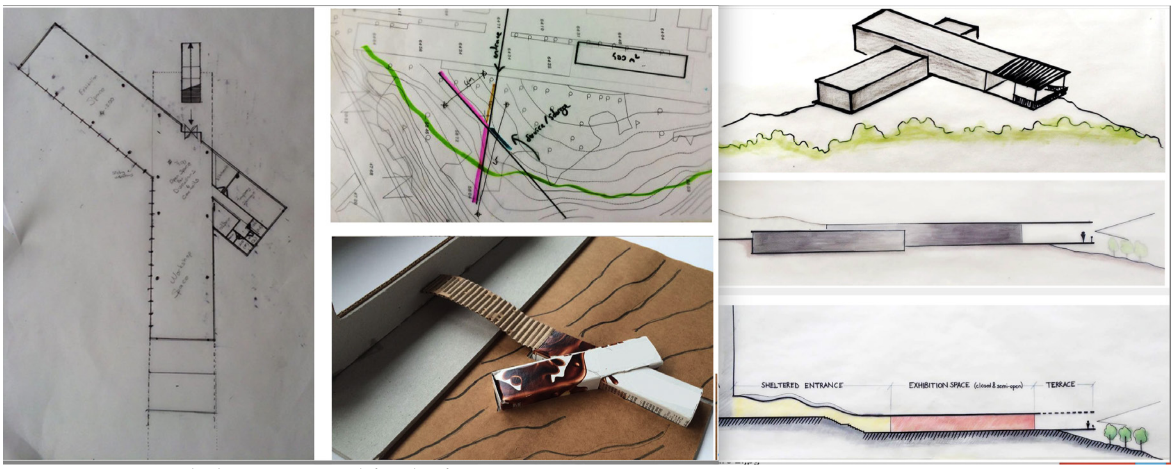

__Figure 2.__ Group B's design proposal for the first project.

modular unit that would fit in both the slope of the landscape and the existing trees, as shown in their early sketches (Figure 3a). By suggesting light materials and keeping the existing trees, students tend to address sustainability by providing open, semi-open spaces for the exhibition, arranging the building as it is going along with the slope and landscape.

3.2. Co-design in 3D virtual world

Group A's design proposal for the second project was a 'bubble tower' (Figure 4) that they developed based on the idea of taking advantage of the possibilities of being in a Virtual World. The avatar, which is the synthetic character of the representation of the user in the virtual world, can navigate within the virtual world by flying or being

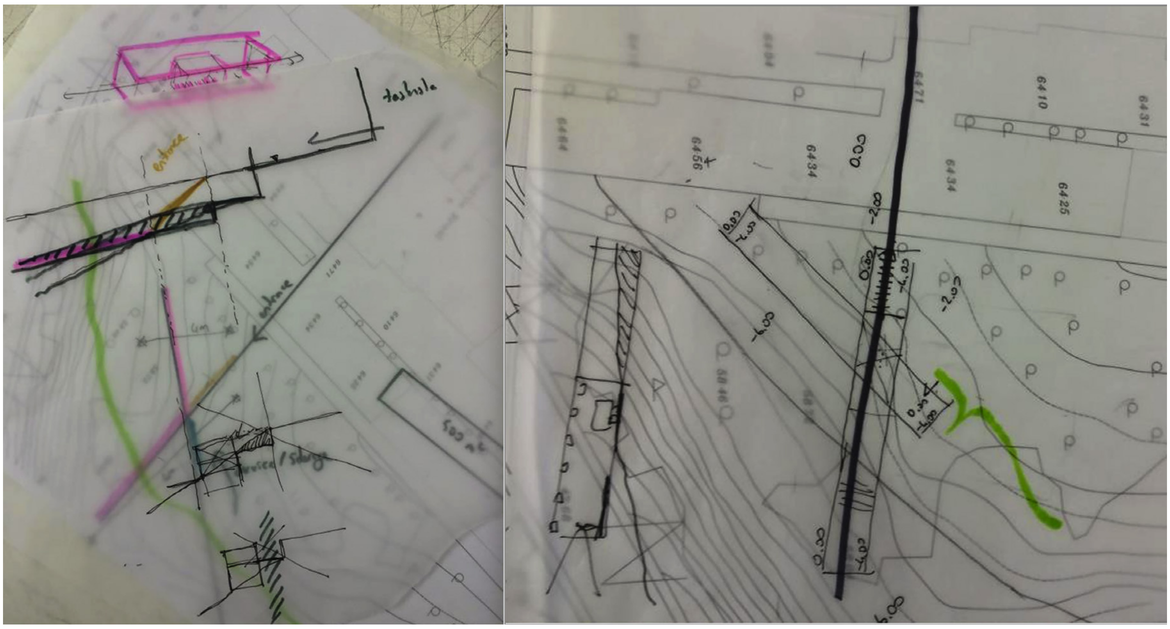

Figure 2a. *Landscape is examined on several section sketches.*

Figure 3. *Group C's design proposal for the first project.*

teleported. As they reflected in their report 'having a design of utopic blob modules that can set a life under water', they also design some components below sea level, as shown in early sketches (Figure 4a). Thus, the tower could be designed on the basis of these navigation opportunities. The tower is composed of mobile bubbles that can accommodate several programs of the tower as well as providing the avatar a portal to navigate around.

Group B's design proposal for the second project, (Figure 5) was developed based on the theme of designing a high-rise tower that would touch the ground on a symbolic core. The core indicates only where to step on. When the avatar steps on it, the avatar is teleported up to the grand place of the tower maximizing the view which is the focus of the design. Based on the position of the avatar, the panels of the tower response and open up to provide the best vista possible. This team refined their concept through the creation of a limited number of sketches. Following the production of a basic sketch, they endeavoured to formulate a script capable of rotating the panels based on the avatar's proximity within the Second Life environment (Figure 5a).

Group C's design proposal for the second project, (Figure 6) was developed based on the ideation of a tower with light vertical structural elements and mobile modules in between. They reported 'flying specific cubes,' each with its own distinct behaviour designed to generate particle effects capable of float-

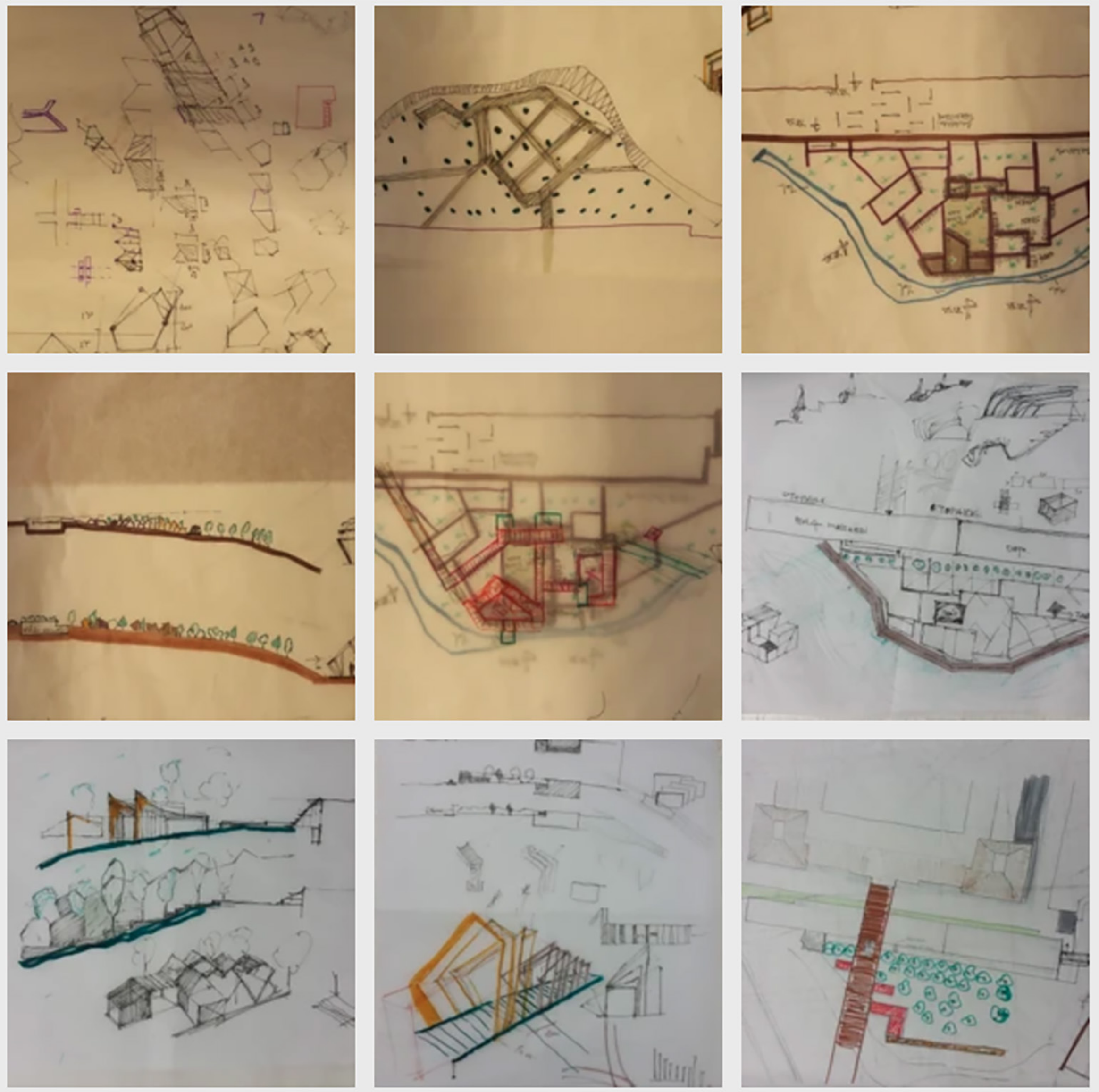

Figure 3a. *The given context that is the slope of the landscape, the university building and existing vegetation is examined.*

ing in the air, as shown in Figure 6a. The cube modules would move on the vertical and horizontal axis according to the need of the user, as explored several different forms in Figure 6a. The form finding started with a deduction from a mass block, and then, a series of manipulations applied to it such as move, scale, rotate etc.. Lighting particles and moving block scripts are also used to design the responsive tower.

3.3. Co-design with parametric modelling

Group A's third project, the 'ex-quilt' (Figure 7) is located at greenery in front of classroom building in the campus area, a space which is commonly used by the students for leisure purpose during the class breaks at the dry and warm weathers. The proposal involves a shelter designed to cover semi open and enclosed spaces defined for the

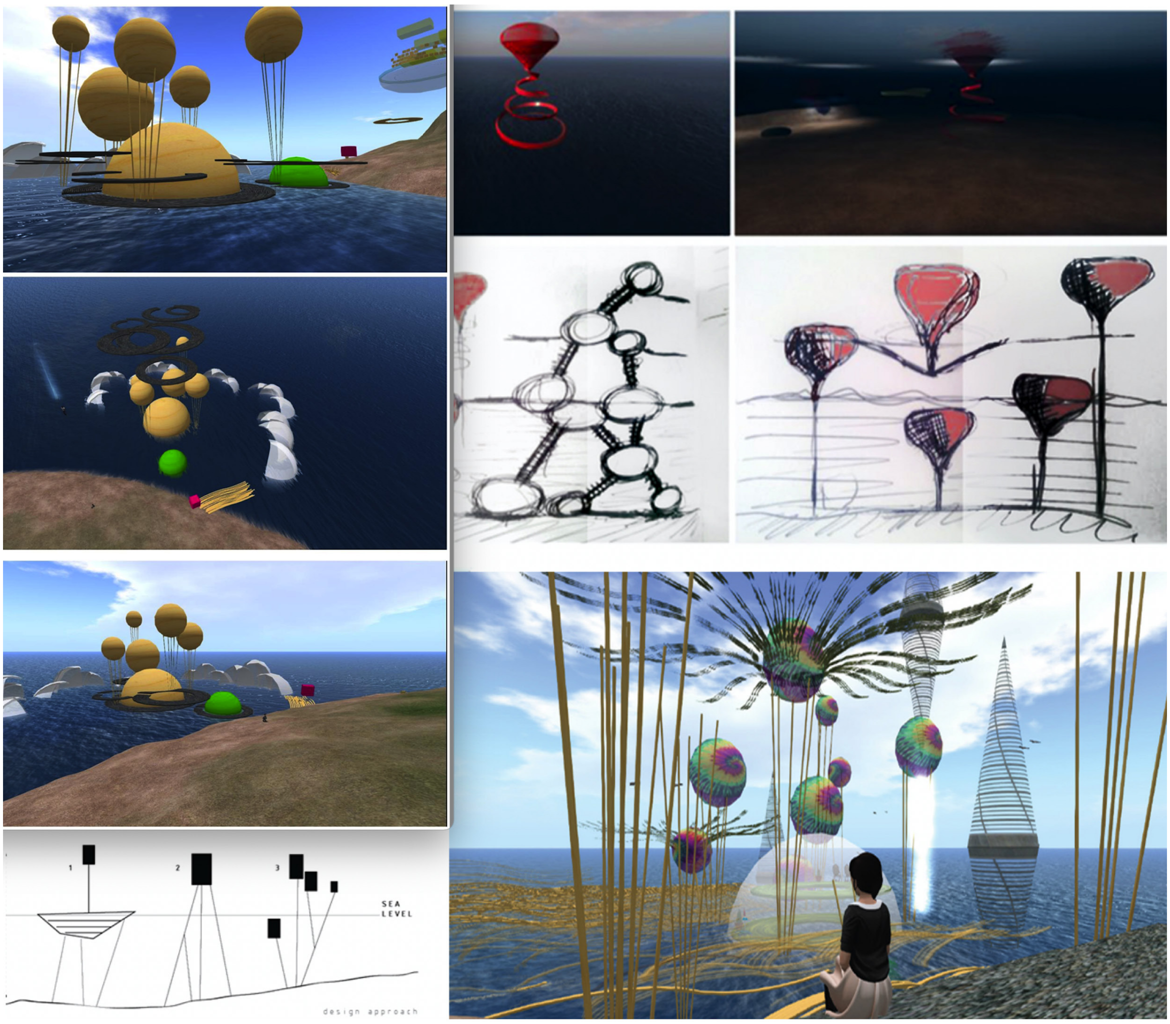

Figure 4. *Group A's design proposal in Second Life.*

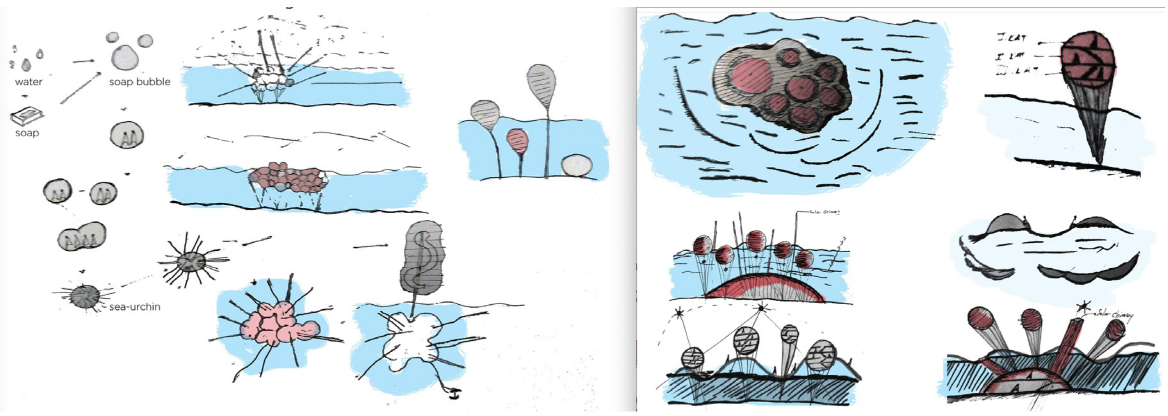

Figure 4a. *'Utopic blob modules' sketched on paper before modelling in SL.*

required facilities. As depicted in Figure 7a, the design's process of shape discovery initiates by dividing the area using a square grid. Subsequently, a swarm intelligence algorithm, inspired by pedestrian movement, is employed, and the resultant shape is then refined and developed further.

The shelter involves a free form surface that curves multiple times in both directions, is supported by tree-like columns, a surface which is located at the minimally used area on the greenery, and whose form is defined based on the paths that pedestrians were likely to take while roaming at the greenery, the relative densities of movement on these paths, and the spacing between grid underlying the organization of the classroom building's façade.

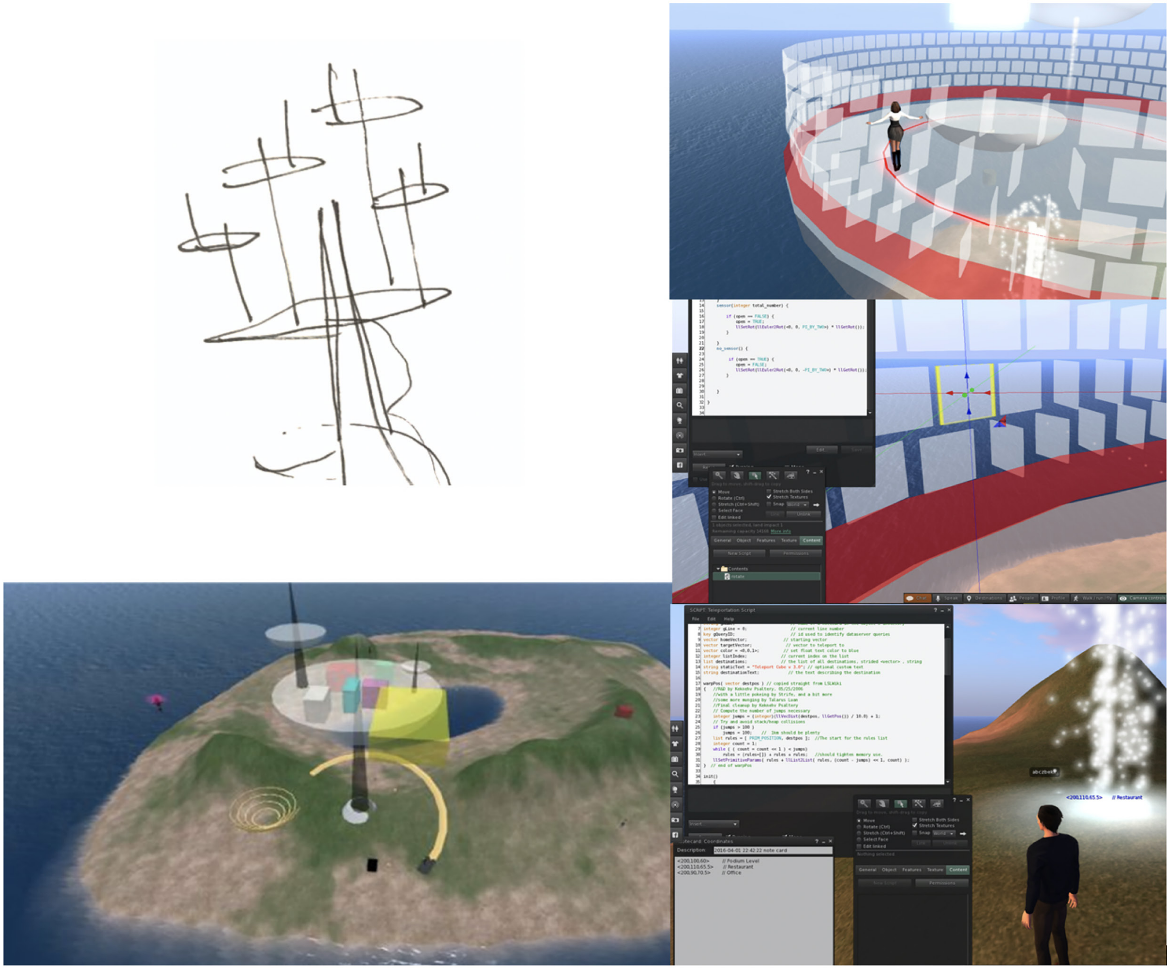

Figure 5. *Group B's design proposal in Second Life.*

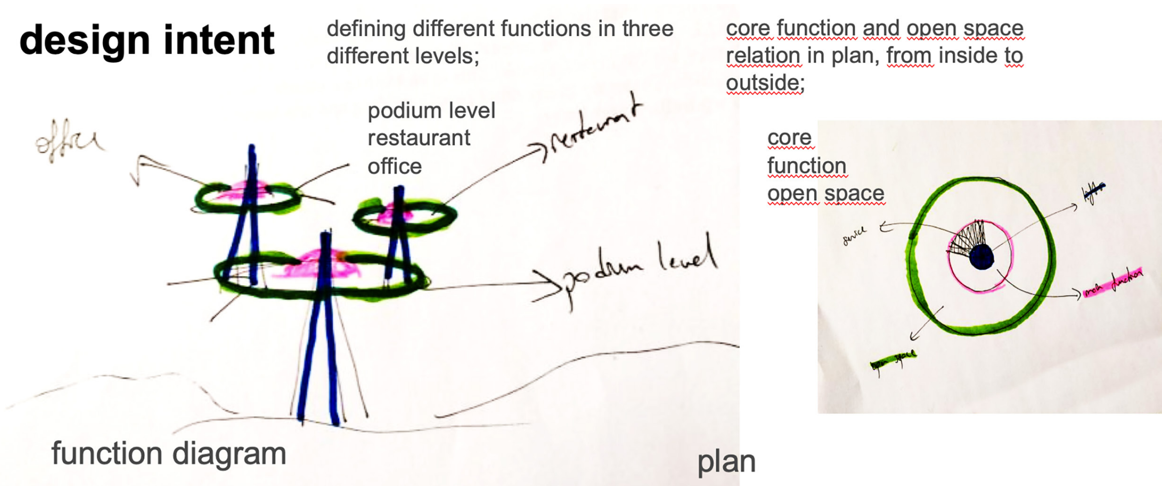

Figure 5a. *The only sketch of the group, indicating function of levels which they modelled only one platform level in SL.*

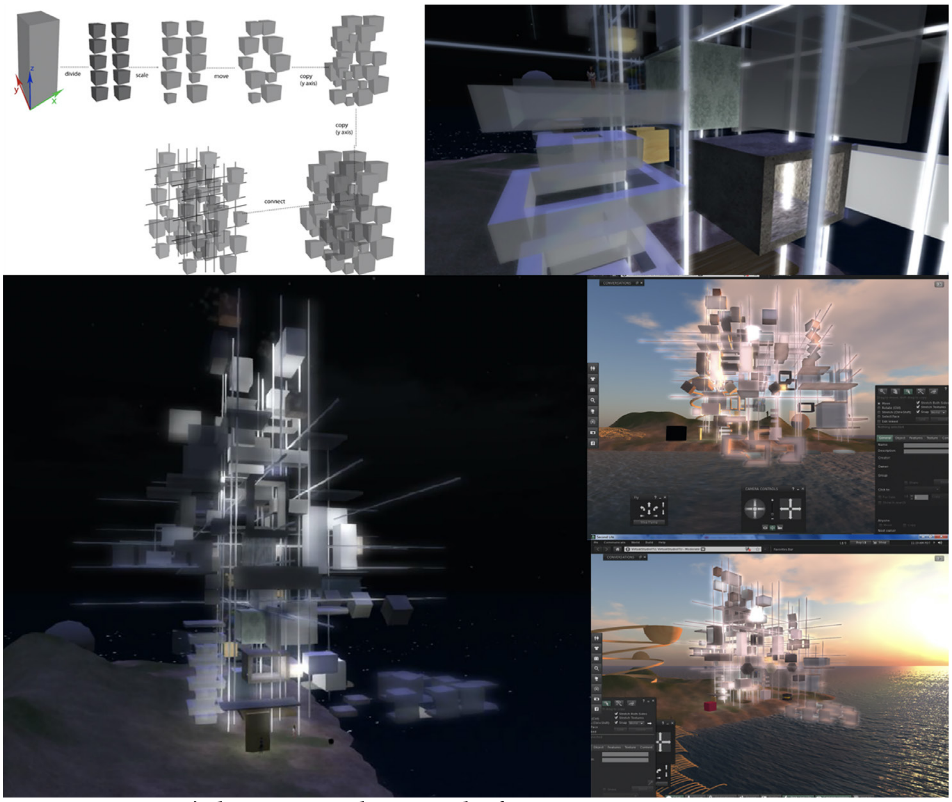

Figure 6. *Group C's design proposal in Second Life.*

This week we made so much conversation about our tower design. We research and analyzed some examples, especially beseemed for digital design. We centred upon the particular design. We have discussed how we could practice it and made some sketches about our thoughts, you can find them below. During conversations an another idea rised; moveble and flying objects.

In the rest of the course, we focused on this idea "flying particular cubes". We found different scripts like the script which make the object swivel or follow the user or move up and down. At the end of the course, we decided all of us try these scripts or other different scripts and make little models.

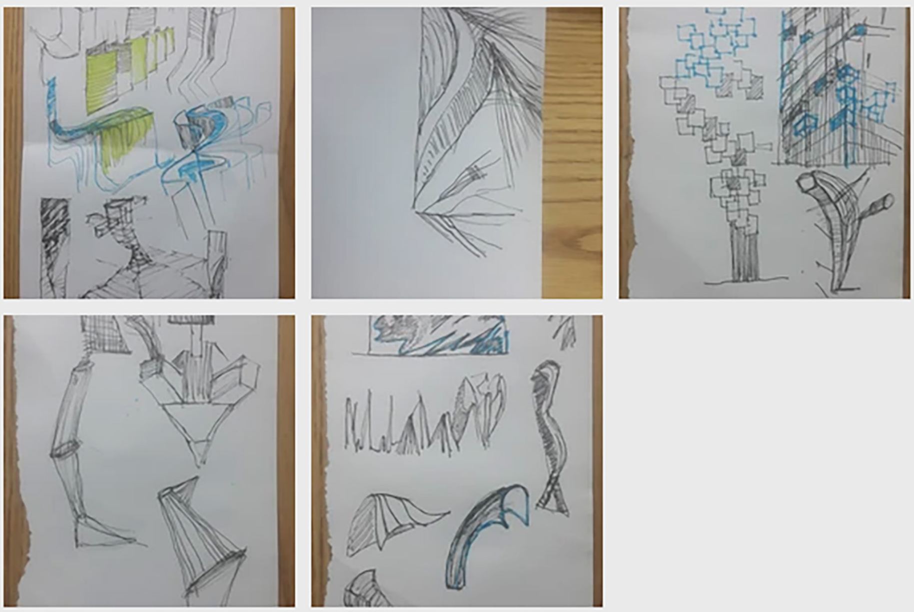

Figure 6a. *Sketches of form finding study resulted with 'flying particular cubes'.*

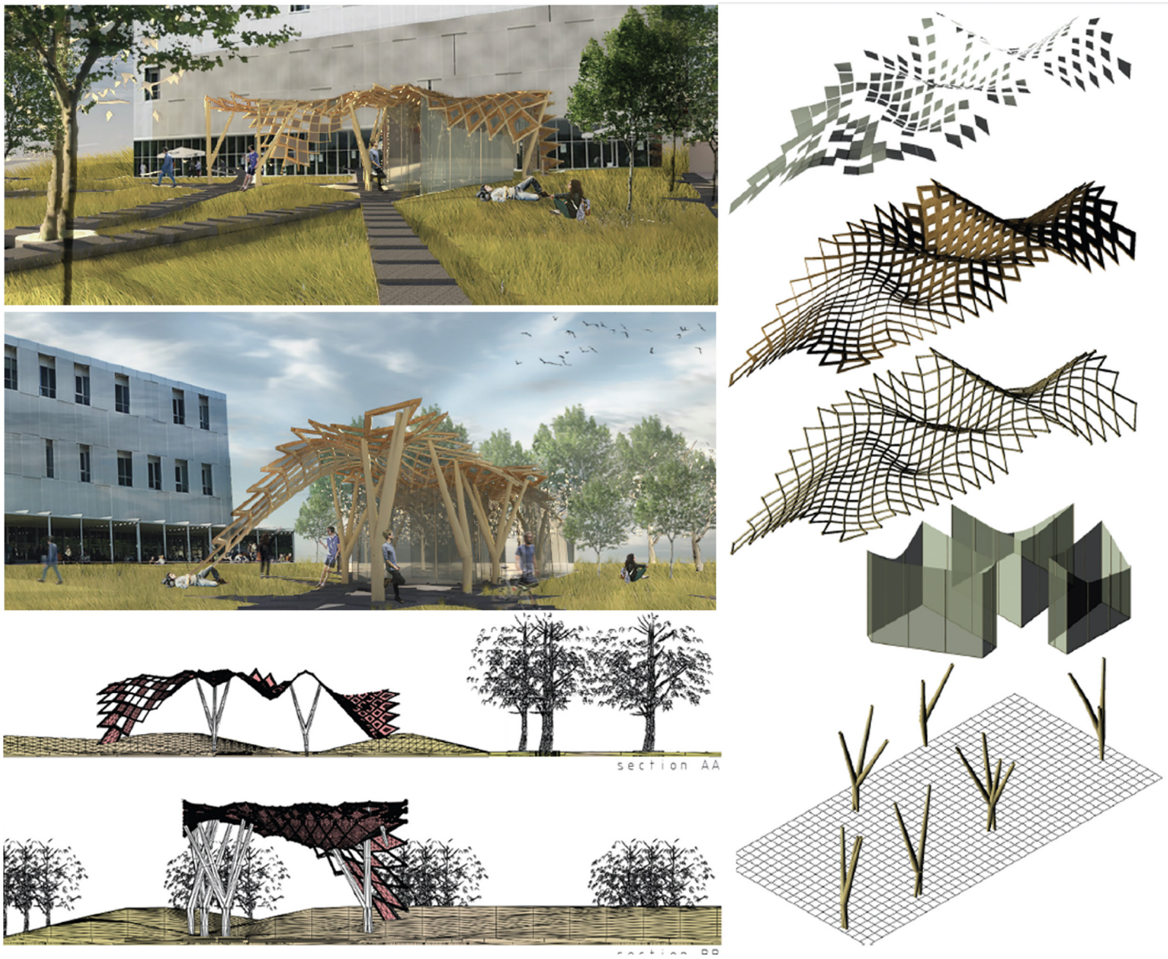

Figure 7. *Group A's proposal for parametric modelling.*

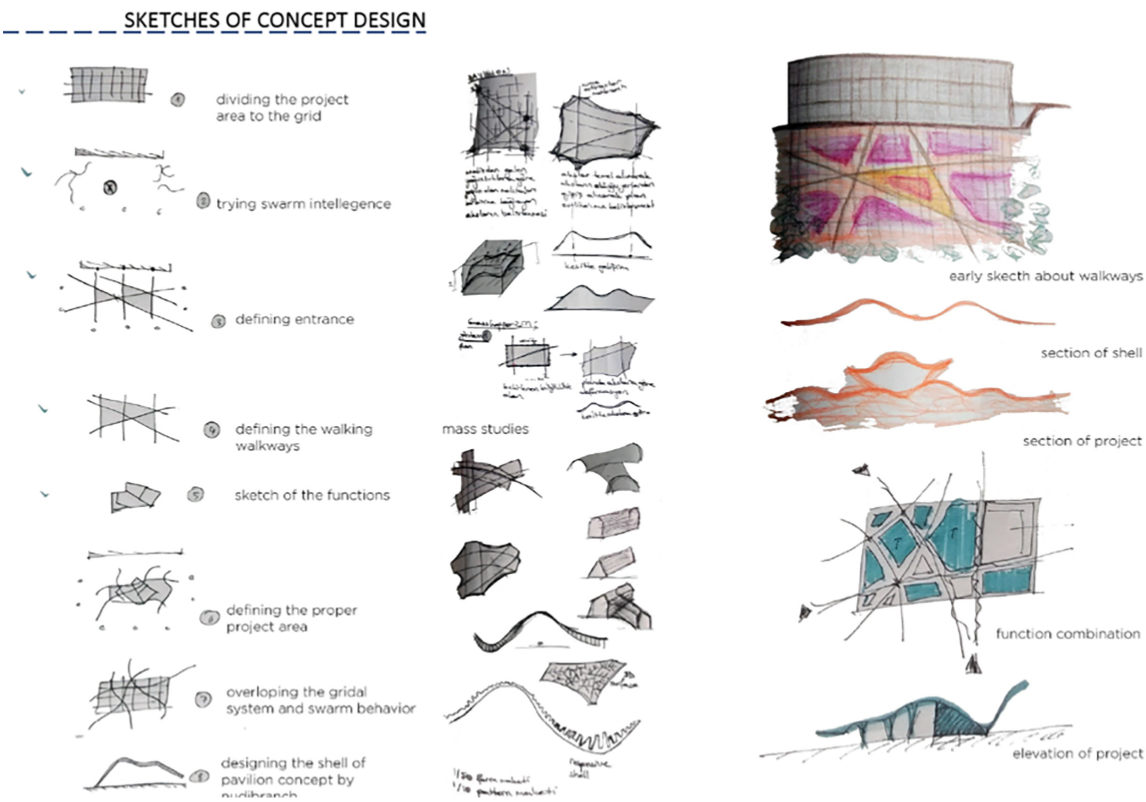

Figure 7a. *Sketches of form finding study of the shelter design.*

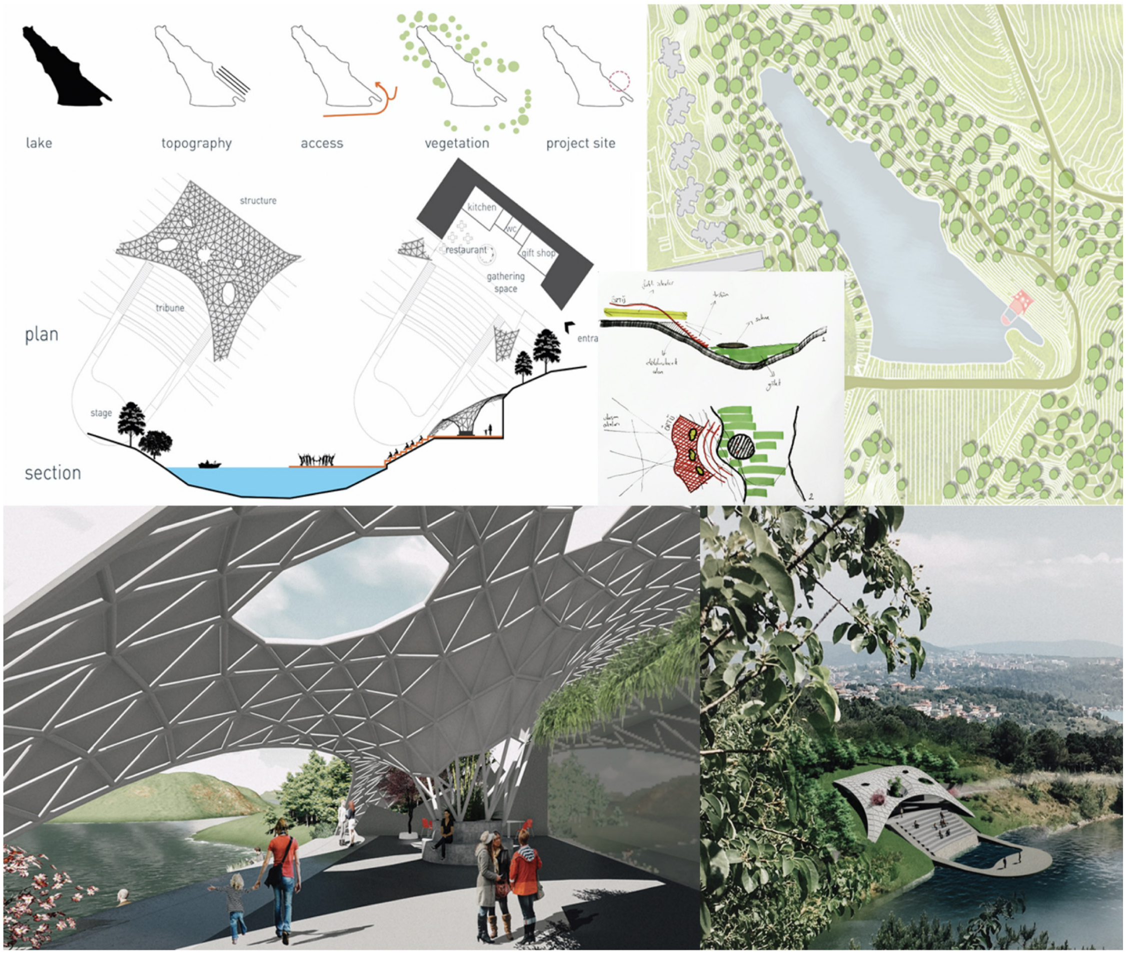

Figure 8. *Group B's proposal for parametric modelling.*

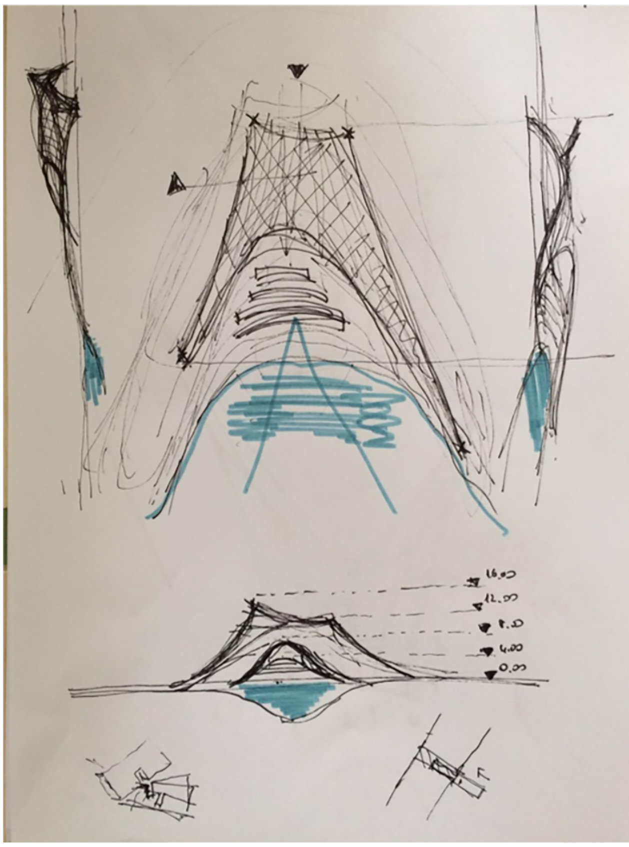

Figure 8a. *Framing the best view was a design decision.*

Group B's third project 'The amphitheatre' (Figure 8) is located at the lake in Ayazağa Campus of Istanbul Technical University which can be accessed from the road, and where the terrain slopes down towards the lake. The design mainly involved a shelter covering service areas, an area for seating and a stage for performance. As shown in the Groups' design sketch providing the best view from the theatre was evaluated through several sections (Figure 8a). The shelter is composed of a free-form shell surface that descends down in the direction of the slope towards the lake 'as if welcoming people and leading down to the stage area' as the team says. The shell sits on the ground at 5 points, 4 at the corners and 1 in the middle. The seating area rests directly on the terrain, with the terrain being carved and prepared to generate the seating area and the stage is a floating stage above the lake and is connected to the land via walkways.

Group C. The design proposal for the final project, (Figure 9) is located at the lawn of the main classroom building in the campus, which is also the location of the yearly music festival. The students extracted the soundwaves of Beethoven's 9th Symphony to feed into Grasshopper as the data source for the form generation process. But still they explored the form through sketches during the collaborative design sessions, elaborating the patterns of the neighbouring building façade as well as plant leaves (Figure

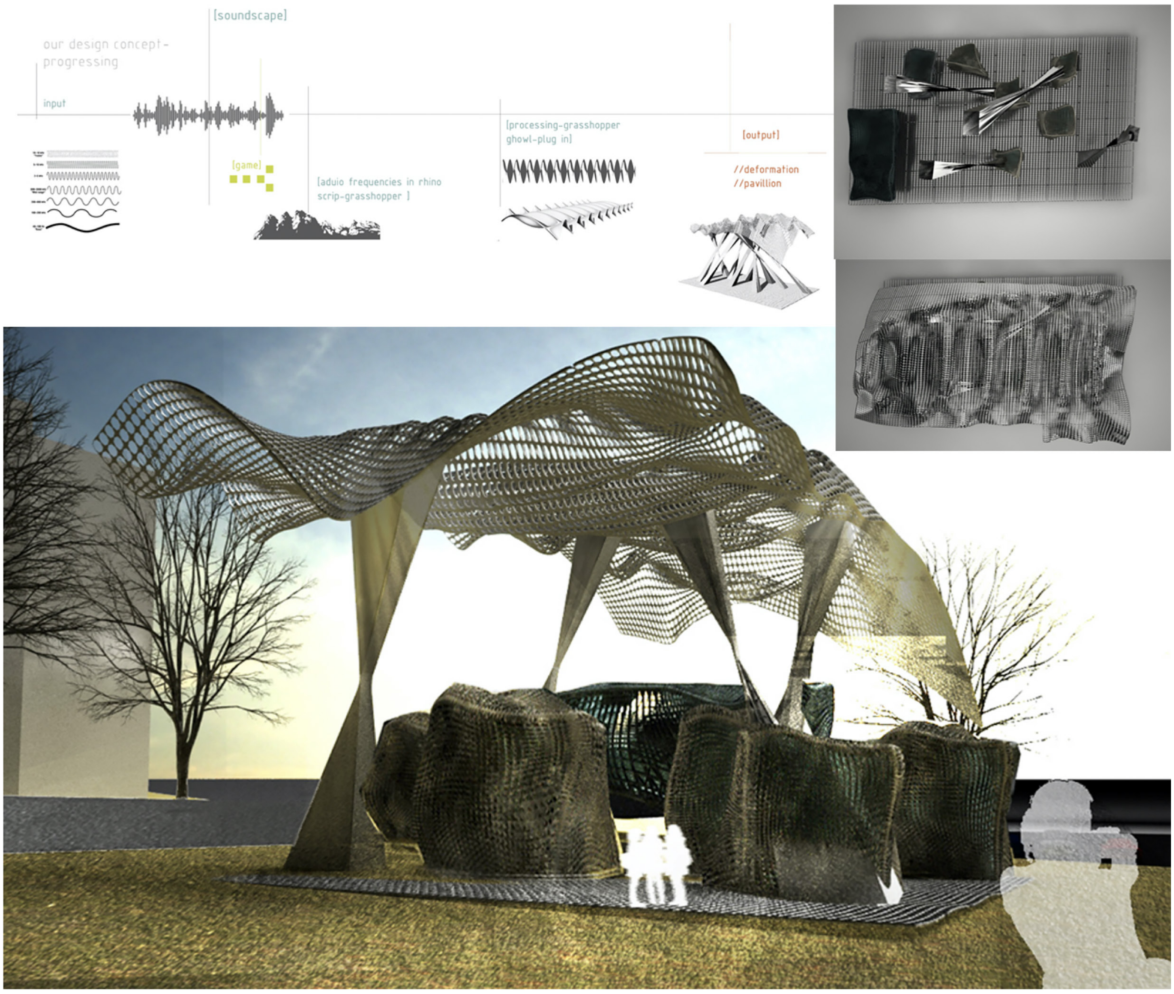

Figure 9. *Group C's proposal for parametric modelling.*

Figure 9a. *Exploring patterns that can inform the form of the pavilion.*

9a). The soundwave used as an input in the Frequency_Amplitude_Quantifier, that captures the sound waves and, then provide an output as a Max script file. Later, the sound file in Max Script fed into Grasshopper as an input of the x-y-z coordinates of curves that would be employed to generate the roof of the pavilion.

4. Evaluation of co-design in three design environments

As previously described, the data collected for this study included observation notes, video recordings, and interviews conducted during the design process. Additionally, we asked the groups to self-evaluate their collaboration processes, and these self-evaluations were aligned with the collaboration process notes that we had recorded. This comprehensive approach allowed us to gather insights into the teams' experiences and perceptions of their collaborative efforts throughout the course of the study. Figure 10 shows one of the Group's report on co-design process and outcomes.

In our evaluation, here we focus on the co-design features of the three design settings based on the approached borrowed from previous studies (Dickey, 2007; Gül et al., 2007). In those studies, researchers pointed out that affordance theory has relevance when examining learning environments (Dickey, 2007) and collaborative design environments (Gül et al., 2007). Affordances theory is developed 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". He claimed that we perceive affordance properties of the environment in a direct and immediate way, i.e. surfaces for walking, handles for pulling, space for navigation, tools for manipulating, etc. (Norman, 1988). Pols (2011) suggests four kinds of descriptions of affordances based on the perceived opportunities in relevance with the corresponding concepts. For example, opportunities for manipulation corresponds with basic action (pulling a trigger), opportunities for effect corresponds with those actions described in terms of its effect (firing a gun), opportunities for use corresponds with plan (obtaining an emergency hammer) and opportunities for activity corresponds with social activity. A more comprehensive description of affordances concept can be seen in (Still, 2013). Within this framework and based on our observations (in-class and over the video recordings) and discussions with students during the design studios, and their reports and their responses on the collabora-

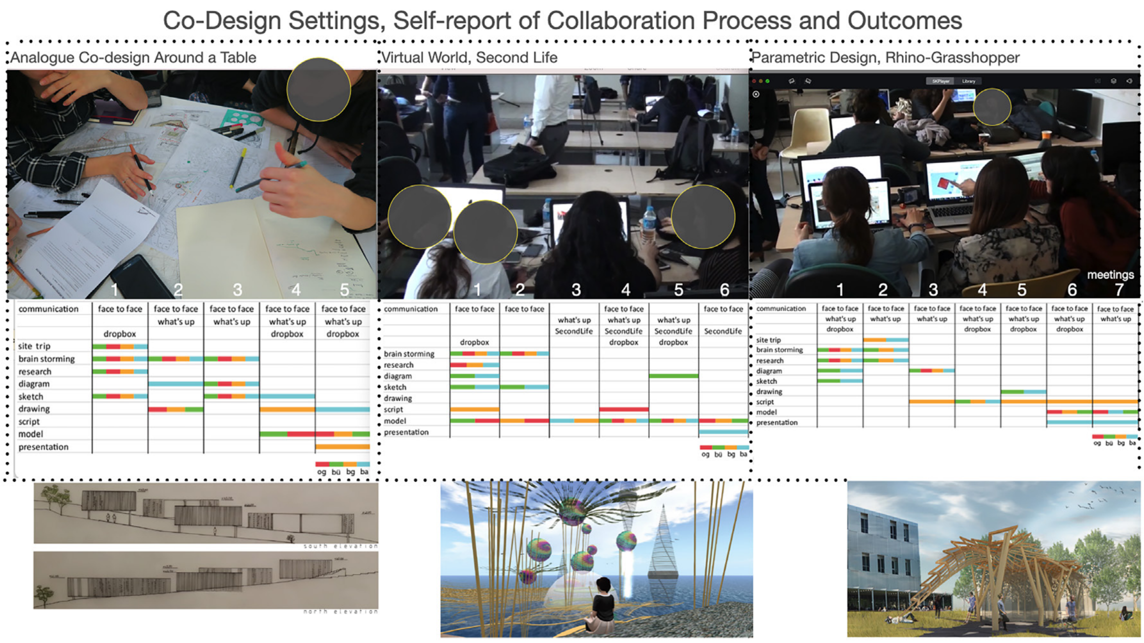

Figure 10. Group A's report of self-evaluation of co-design sessions and design outcomes.

tion evaluation reports. We highlight the perceived affordances and constraints of the three design settings as follows:

4.1. Affordance of the co-design environments

When working in AT, the groups mostly utilized sketching as the main medium for exploring their design ideas. Indeed, expect for one group's making a physical model of the terrain, none of the groups worked with physical models during their design processes. The students all reported to be quite accustomed to the practice of developing a concept design via sketching; indeed, for some this was the most preferable medium to work with at the early phases of his/her design process. Yet for most of them, this was the first time that they worked with others in developing a design proposal. Throughout their design processes, the teams worked in at least two modes of collaboration. The nature of these modes was very much like what Kvan (1996) defines as close-coupled and loose-coupled modes, where "the participants work intensely with one another, observing and understanding each other's moves, the reasoning behind them and the intentions" and where "the participants work separately on the agreed-upon parts and then they put them together" respectively. Here we use the term 'at least' because there were various instances where some members of a group worked in a close coupled mode while other(s) work independently in a loose-coupled mode. The teams often worked synchronously in close-coupled mode when working on defining the problem, exploring alternative solutions and making decisions. In preparation of the submissions, all the groups worked in a loose-coupled mode, by sharing responsibilities, such as production of the physical model, development of multi-view drawings, perspective views and the presentation poster.

Regarding their design processes with analogue tools, the students commented on the efficiency of the discussions and brainstorming sessions during the idea generation process, and how quick they have come up with an idea while they were sketching together on the paper. During co-design, the immediacy and efficiency of the face-to-face communication are expected, since previous researches show similar results noting more idea generation and design proposals developed as well as quick and short attention shifts occurred during sketching (Gül et al., 2007; Gül, 2011). In other words, since the designers' cognition is not preoccupied with the use and interface of the tools, the chunks of developing design ideas and suggesting immediate alternatives occur at short and frequent intervals. Thus we could argue that sketching around a table provide a productive co-working space where the design issues are the object of the process, but the management of the collaboration requires an extra attention, e.g. taking meeting notes, monitoring task allocations.

The 3D Virtual World, Second Life (SL), supports in-world communication as well as basic 3D modelling with parameters and computation capabilities. SL supports synchronous collaboration. Users can talk by type on the chat dialogue box or the texts appear on the avatars head, and voice chat. SL affords the presence of designers/learners (awareness of self and others), architectural metaphor/place (awareness of the place); navigation and orientation (wayfinding aids). The interface of SL comprises a set of objects / prisms whose forms are determined inside the world by selecting geometric types and manipulating their parameters. The parameters of the objects can also be modified within the world at a later stage. The user who first creates an object can control the editing permission of the object allowing a shared modelling process. Then they need to assign tasks to each other in order to co-design in SL. The affordance of SL encourages students to generate models that look unique (see more on the appearance of the design outcomes, Gül, 2011). The landscape and its features, topography, the lighting may have an impact on the general appearance of any design in SL.

Three basic awareness are mentioned in computer-mediated working environments, namely collaboration, workspace and contextual awareness. (Mantau et al., 2022) Awareness of workspace and context in a collaborative environment is provided in the SL environment in several ways. For example, while the user is typing, the avatar in the SL environment also types, or while the user is working on modelling of geometries, a yellow beam emerges from the avatars' body in SL and shows a connection with the geometry. With such visual cue, the others can see what their teammate is busy with. Thus, we can say that designing in SL affords all three types of awareness.

When designing in SL, the groups have spent their first few hours for exploring modelling and communication capabilities of the design environment. At this point, it has been observed that the opportunities for action (see Still, 2013) afforded in the environment are learned through practice and recalling / comparing the prior knowledge of how to operate in a typical 3D modelling program. They then, all started to work on defining goals and developing alternative design proposals by sketching/modelling their ideas on paper and within SL in an intermittent fashion, and working more often in a close-coupled mode as Kvan (1996) defined while sketching their ideas. All of the groups commented that they had to sketch their design ideas into a piece of paper in terms of understanding the overall design layout at the very early stage of their design process. Being in unfamiliar environment may be a challenge for some students, as some of them reported that once they agreed upon the materialization of the ideas while sketching on a paper, they switched to SL for further development of the design idea.

Parametric modelling with Rhinoceros which has NURB based 3D modelling features allows users to create free-form, complex curves, surfaces and geometries with computation capabilities via scripting and plug-in. This environment supports using any form of data such as a sound wave, people's or vehicle movement in an environment, climate data etc. as a feed for form finding parameters. Although parametric modelling in Rhinoceros and Grasshopper plug-in was not a new tool for most of the students, one of the groups used only the geometric modelling component for the purposes of generation and optimization of form, while others used the parametric modelling component along with a suite of different applications such as those supporting swarm intelligence (Group C).Unlike the SL or the AT, topics such as task sharing, group dynamics, leadership, process management, etc. were observed more prominently within the groups. This was most likely due to collaborative work in this environment requiring a clearer task definition. The groups preferred working in synchronous manner in a co-located space, and share files in order to work on the agreed tasks.

4.2. Constraints of the co-design environments

In AT the most of the student's complaints concentrated on the time management for the preparation of the submission documents. They did not feel comfortable on final documentation with analogue tools as most of them did not employ these tools for this purpose in their undergraduate design studio projects. Another general comment is that although the necessity of being in the same place for collaborative work may be positive in producing fast work in terms of design decision, working in a co-located environment does not provide much flexibility in terms of working hours and individual scheduling, etc.

In VW, the approaches of building up models can be cumbersome as users are not familiar and feel uncomfortable to model in Second Life (SL) collaboratively. As suggested in (Still, 2013), we also observed an effect of students' background experience with design tools on their perceived affordances of SL. While the initial use of the SL environment might be perceived as a challenge, it's important to note that this holds true for all groups, establishing a sense of equality in this regard. When modelling within SL environment, students often referenced to the modelling functions of the tools they have used in the past and compared the modelling possibilities of the SL environment with them, and this caused them to show a resistance to learning the new virtual world. They also found it difficult to carry out a collaborative work in a short time in this newly learned working environment. The students needed to consider who is doing what part of the model in advance, and give others the permission of model editing in order to collaboratively develop any features of the model in later stage. This kind of modelling requires in advanced planning, skills/knowledge of using the tools and task allocations as well as monitoring the progress of shared-modelling in SL.

In PM, due to Rhinoceros's not supporting shared model making and in-file communication, students had to work either in turns on the same model and/or on develop different versions of a base model for conveying, evaluating, discussing and refining their design ideas as well as when developing the final model for fabrication. Within the groups, a dynamic emerged where certain members were navigating the Rhino environment for the first time, while others demonstrated proficiency in the modelling aspect. This discrepancy influenced the distribution of tasks and the sharing of roles among group members. In the former cases, students often worked with sketches for developing their design ideas with one of them generating a model of the reconciled parts in Rhinoceros in an intermittent fashion. Here, students heavily relied on the task allocation in terms of delivering the model in time. These features of the 3D modelling environments encouraged the designers to work individually on separate parts of the design model in a collaborative task, in a loosely coupled mode as Kvan (1996) suggested.

5. Concluding remarks

In unveiling the design outcomes crafted by students, this paper discursively explores the potentials inherent in a collaborative design studio across three distinct settings. A fundamental revelation from our investigation is the imperative need to seamlessly integrate the teaching of both technique and content, methodically considering the affordances and constraints intrinsic to each design setting. Each setting, as dissected in this study, reveals its unique potentials, significantly influencing student design processes and collaborative endeavours, ultimately shaping the resultant design outcomes.

In a co-design situation, effective communication imposes several challenges. Trust, a critical element often elusive in both co-located and remote work, emerged as a formidable challenge—its establishment notably facilitated by commencing from a familiar setting, such as sketching. Starting from a familiar setting (sketching) helped building trust among group members by facilitating social bonds between people who were sitting around a table and working towards a shared goal. We observed that, working on the same assignment fostered trust and it reached its highest point at the end of the final task in PM.

Other challenges could be establishing shared understanding of the problem in a digital setting, and receiving and giving timely feedbacks. Thus, we encouraged students to allocate time for synchronous collaboration monitoring each other's tasks through a cycle of working on closed coupled for overall planning and task allocations, and then, working on loose coupled for developing agreed individual parts. Furthermore, our observations underscore the profound benefits of group learning, primarily manifest in students' enhanced abilities to articulate and critically think through design problems. The dynamic exchange of perspectives within a collaborative environment accelerated learner activity, exposing them to diverse viewpoints and contributing to the development of robust and elaborative thinking—a process akin to scaffolding.

Navigating the introduction of new design tools, an endeavour full with challenges, was a key focus of our study. These challenges often become a barrier in any effort of equipping students with digital and collaborative design skills through hands on practice with such tools, as in the case of design studio pedagogy.

Recognizing the importance of adequate preparation, we ensured students devoted ample time to familiarize themselves with the tools, with modelling and scripting examples serving as effective instructional aids. In particular, the modelling and scripting examples shown in the exercise have been used quite effectively, and the Wiki of the SL environment was explored. Another key point is that students feel the need to change some preliminary design decisions that they think they cannot model well enough during the development process when working with both digital environments, which was not observed during the sketch study. This challenge is intricately tied to the current modelling capabilities of the digital tools and the students' proficiency levels. The resolution of this matter hinges on the evolution of digital design environments, approaching the cognitive and physical effort required for externalizing and modelling design ideas more closely to that achieved through traditional sketching.

In essence, our study not only sheds light on the complexities and potentials within collaborative design settings but also provides valuable insights into overcoming challenges, fostering effective communication, and enhancing student learning experiences. As we navigate the evolving landscape of design education, the implications drawn from this research contribute substantively to the ongoing discourse, offering guidance for future pedagogical endeavours and advancements in digital design environments.

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