p-issn: 2581-1347 | e-issn: 2580-2607 | Pg. 19 - 30

Fostering Critical Collaborative Thinking through Digital Platform: An Empirical Study on Interdisciplinary Design Project

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ABSTRACT

This study addressed an increasing need for collaborative skills for architecture graduates in the AEC (Architecture, Engineering, and Construction) industries and fill in the gap of studies in collaborative engagements in architecture schools where most of the studies had focused on the creative collaboration in the design process to increase collaborative teamwork within architecture students. The study was conducted as a project-based interdisciplinary course for 4th-year undergraduate programs which involves engineering departments: Civil and Environmental Engineering, Mechanical Engineering, Electrical Engineering, Engineering Physics, and Interior Design. The aim of the study is to critically evaluate the experience gained in the collaborative and interdisciplinary courses, as well as a valuable lesson learned based on students' perspectives. The results showed that an innovative pedagogy must be provided to foster collaborative works, through a concurrent-integrative approach. Another finding is the digital platform potentially increases students' engagement in interactive discussion and teamwork when appropriately implemented. This was confronted with several challenges, specifically the legacy of a conventional mono-discipline pedagogy and the liberation of critical collaborative thinking among the students.

Keywords: collaborative class, interdisciplinary project-based course, concurrent-integrative approach

1. Introduction

An increase in the need for collaborative skill development and teamwork participation as a competitive advantage is reportedly observed in the Architecture, Engineering, and Construction (AEC) industry. This is due to the competitive and increasingly complex work environment within the field [1-3]. Architecture as a historically applied discipline, collaborative mindset, adequate workability with others, and consensus decision-making production are inevitably crucial for student success during professional practices. Moreover, the internal forces of this discipline are found to be shifting practices to more collaborative models.

According to Brause [4], architects/designers were advised to adopt and maintain disciplinary and extra-disciplinary knowledge, since project requirements had become increasingly complicated. These requirements included regulatory standards, emerging materials, and processes, a large set of digital tools, and project delivery methods having the potential to dynamically change both practice and industry. Collaboration is highly necessary to solve issues intrinsic to the design practice (Brause, 2016). However, change and integration are two keywords in solving the future trends of architectural design and practice. Based on Kanaani [5], the trend towards the integration of various disciplines and professional fields was addressed. This concurrently affected the expansion of the design territory, where designers and engineers in different fields collaborated within their domains, as well as created several architectural territories.

Despite the importance of fostering collaborative architectural knowledge and performances, it is still found to be very challenging. According to a Reflection in-Action/Reflective Practicum approach in core architectural education, Schön [6] argued about the methods of integrating new theories and techniques within the architectural studio system (Schön, 1985). This indicated that students facilitated by studio mentors actively engaged in a reflective conversation with the design problems encountered, which involved multi-disciplinary perspectives. Therefore, the school should provide the space for explorative and experimental actions within the department, as well as include professionals and experts from other disciplines. Collaborative mindsets are also needed to enable such activities and environments, indicating that cooperation should be built on the relationships among individuals with mutual respect and acceptance. In a diverse social, economic, and cultural background, a collaboration focused more on the efforts to avoid Social Loafing or Free Rider, as indicated by Deutch [7]. This was the tendency to follow orders or abdicate responsibilities when others are observed to perform the hard work (Deutsch, 2020). A significant challenge to a successful collaborative group was compromised solutions, which led to a watered-down design. This group had difficulty connecting the development of collaboration abilities with the desired design results, with each member scared that the output was mediocre and had less quality. These phenomena indicated that architects and designers often expressed their creative abilities through work performances, as collaboration is known to be equated with joint authorship.

However, the increasing trend toward a more highly efficient building design and low carbon footprints seems inevitable for an architect to switch their design approach with collaborative mindset in the design process. The benefit of collaboration in practice are encouraged by professional associations, practices [8-10] and academia as well [11-12]

Based on these conditions, a project-based interdisciplinary course for 4th-year undergraduate students was initiated by the architecture program in collaboration with the engineering and design departments: civil and environmental engineering, mechanical engineering, electrical engineering. engineering physics, and interior design. The aim of this course was to examine and investigate the factors to encourage collaborative learning in the design process among diverse discipline backgrounds, moreover, to foster and develop soft skills, such as leadership, responsibility, risk, initiative, and teamwork, which had highly declined among the students, as reported by various studies [13-16].

2. Related Studies

Architectural collaborative pedagogy was investigated and implemented following the increased requirements of soft skills in the AEC industries [17-19]. As architecture required the involvement of many people, potential practical graduates were likely to collaborate with a wide range of professionals. This indicated that their abilities to collaborate effectively were more important over time. According to Deutch [7], other reasons required to have collaborative knowledge included: (1) avoiding cultural blindness and gender/age bias, as well as (2) problem observations from different perspectives. These were due to the diversity of opinions, insights, and inputs, as architects often strive to understand their building perspectives (Deutsch, 2020).

According to Menzel, et al. [20], an international, project-centered, collaborative teaching effort was analyzed and conducted for architecture and civil engineering students. This indicated that IT-supported teaching methods contributed to an improvement of interaction and course content, where a change from individual performance participants to collaborative working students was considered in the interdisciplinary contexts. Based on this condition, lecturers inductively developed a course pedagogy with three principles, namely hierarchy, patterns, and modularity. Hierarchy is known to decompose complex problems into smaller ones, due to assisting lecturers in establishing a straightforward arrangement and teaching content. In addition, the pattern principle helps to describe issues with unknown deterministic solution strategies, while modularity is a combination of resources and a detailed interface description to external disciplines.

In a study conducted by Soibelman, O'Brien, and Elvin [21], a collaborative design process was created, where students from the University of Illinois and the University of Florida participated in learning the enhanced methods of cooperation through information technology. This indicated that students from remote locations collaborated and worked on a facility design in various multidisciplinary teams, through the Internet. An innovation of this course showed that students also developed process designs, to integrate technology into multidisciplinary teams (Soibelman, et al., 2004). Based on the most common feedback, the results showed that students utilized sufficient and insufficient durations in the design production and process planning, respectively. Although there was an attempt to improve the cooperative environment through short communication and collaboration training, students still worked alone or at least in a small and mono-discipline group. This was not enough to overcome the mindset and habits of the independent students. In addition, three significant barriers to the adoption of more integrative and collaborative design methods were observed as follows:

1. Lack of knowledge of the information requirement of others.
2. Lack of integrative knowledge and abilities within/across disciplines.
3. Cultural expectations vary with individuals and disciplines.

Another finding from Emam, Taha, and El Sayad [22] noted that a collaborative methodology was very effective in teaching students concerning the techniques of designing in a cooperative environment. This indicated that the collaborative learning method effectively increased students' motivation. Also, it helped students share knowledge and increased their learning capacity through collaborative tools. Based on this study, the student-centered approach directly affected student learning efficiency. This indicated that several issues were tackled by focusing on the strategy to improve students' coordination skills, using the Time and Task Schedule tool (Emam, et al., 2019), which helped develop work sequences and periodic activity orders. In this study, the tool effectively ensured work organization among students.

3. Course Structure & Pedagogy

The four-credit unit course with 200 mins of weekly activities in 14 weeks was implemented with the block method where all lectures were delivered in the first two weeks. For the rest of the weeks, groups of students were engaged in a series of group work, discussion with mentors, and crit sessions in the seminar. Since the program was project-based, each group must deliver output requirements.

The project theme was determined as Planning and Design an Integrated Building System, and it is delivered through the topics of lectures that related to the issues of the building systems which were provided by the multi-disciplinary lecturers. In addition, several practitioners from the AEC industries were invited to provide the present development and insights. This was based on their experiences in digital and collaborative works within the industrial sectors.

The ice-breaking period was crucial at the beginning of the program, where students from various departments met either physically or digitally through a video conference platform.

To facilitate and promote a blended interaction among students, the course coordinator designated four (4) multidisciplinary groups, where each group contained 18 students from 7 departments. Furthermore, each team was required to meet during the following week, to discuss the project's goal and strategies, as well as investigate the selected existing building issues. Since seven departments were involved in this program, 7 departmental lecturers were assigned as studio mentors, to coach their students in a collaborative group.

3.1. Project and Case Study

The course was carried out using a project-based and case-study approach, where each collaborative group analyzed and redesigned an existing building. As case studies, the course coordinator provided four existing General Lecture Buildings where the brief description is as follows (see Table 1).

Table 1. Case Studies

	Bld #1	Bld #2	Bld #3	Bld #4
Total Area	4,222 m2	4,400 m2	4,320 m2	4,250 m2
Total Floors	4	4	4	4
Total Height	21 m	19 m	20 m	21 m
Main Function	Lecture Halls & Classrooms	Lecture Halls & Classrooms	Lecture Halls & Classrooms	Lecture Halls & Classrooms

The criteria for redesigning are defined as follows:
1. The component or part of the building excluded from the redesign includes the main structure and circulation, respectively,
2. The component or part of the building that is the object for redesign includes facades, roof, classroom layout, utility, and auxiliary rooms.

The workshop on the introduction of BIM (Building Information Modeling) was mandatory for architecture students and an elective for other students. Within the digital design workflow, BIM was positioned as a platform and information exchange, specifically when a group member needs to model and analyze the structural components added as part of the redesign proposal or evaluate the architectural double-skin façade related to daylight and energy performance.

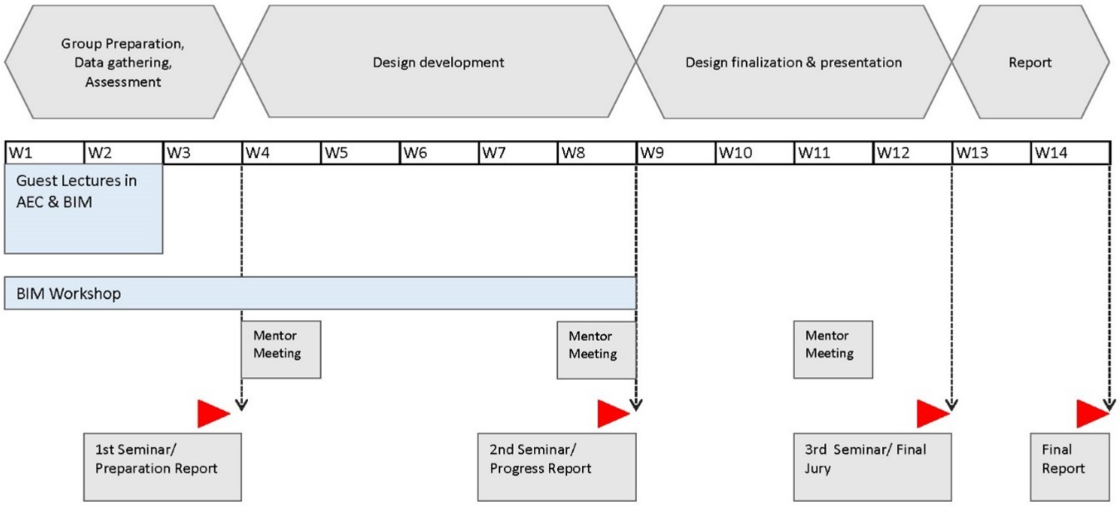
3.2. Seminar & Critique

Three seminars were mandatory for the participants throughout the program and attended by all lecturers. The first and second seminars provided input and evaluated the group's performance, while the third was the final jury. Moreover, each group was encouraged to meet once in two weeks, to maintain engagement and evaluate progress. In this session, the lecturer provided input on the group's specific issues and assessed their performance.

4. Methodology

A total of 72 students from 4th-year undergraduate programs participated in this course, coming from 7 departments including Architecture, Civil Engineering, Environmental Engineering, Mechanical Engineering, Electrical Engineering, Engineering Physics, and Interior Design. At the beginning of the program, students were divided randomly into groups of an average of 12 students that consists of several departments. Each group was handed a project brief and a random case study, output requirements, and final evaluation criteria.

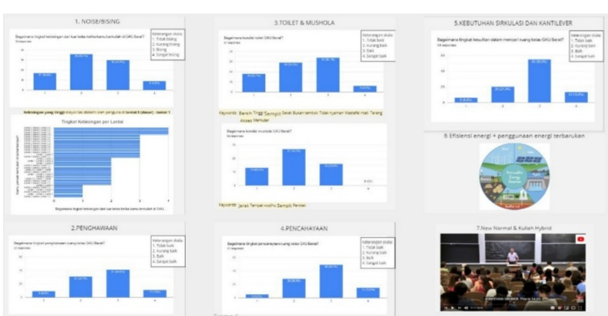
The researcher discussed the platform, and tool for collaborative work as well as the approach each group will undertake to begin working on the project. The overall schedule of the program is shown in Figure 1.



Source: (Author, 2023)
Figure 1. Overall Course Schedule

4.1. Collaborative Problem Formulation

Before the development of the design, each group worked together in formulating significant existing building issues of their case study, based on their experiences. With a case study of the Common Lecture Building, each group member had past experiences leading to the formulation of major issues. At this stage, the group used an online collaborative platform to develop problem formulation while discussing the priority of the solution related to the course objective. This online and collaborative platform served as a pin-up board, which effectively promoted each member to participate, formulate, and set goals (Figure 2).



Source: Author (2023)
Figure 2. Preliminary Result on Facility Requirements

Furthermore, the online canvas/whiteboard seamlessly imitated the ideation process, as each group member from different departments quickly posted new problems based on their perspectives. This was carried out without much concern about document formatting, interoperability, and credentials (see Figure 3). Based on the conformation of problem formulation, each group subsequently surveyed the initial questionnaires to the university students, as the primary users of the existing lecturer buildings. The data obtained from this survey were used to help to formulate and validate each team's innovation topic in redesigning the building. These questionnaires were collaboratively developed and digitally distributed through social media (e.g., Instagram and Google Forms). Based on the results, these groups developed the case study's problem formulations and the proposed solution priorities. The priority of the problem formulations is shown in Table 2.

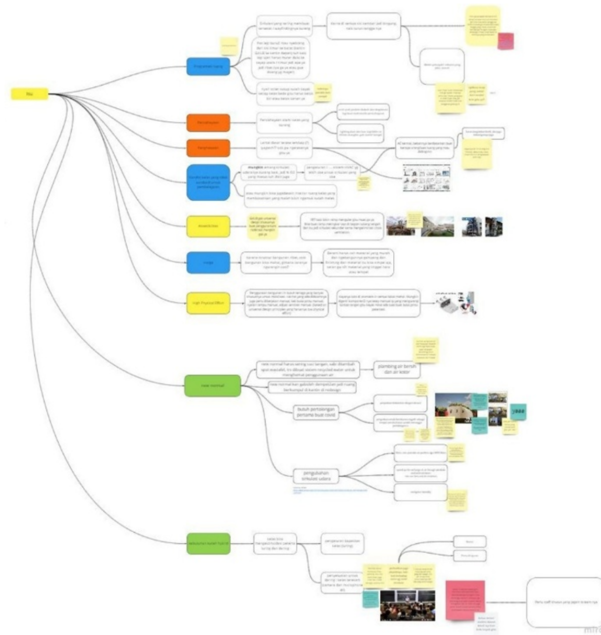
Table2: Problem Definition & Priority

Problem	Proposed Solution	Field of Discipline
Noise	- Noise reduction using indoor vegetation and building perimeter,	Engineering Physics, Architecture, and Interior Design

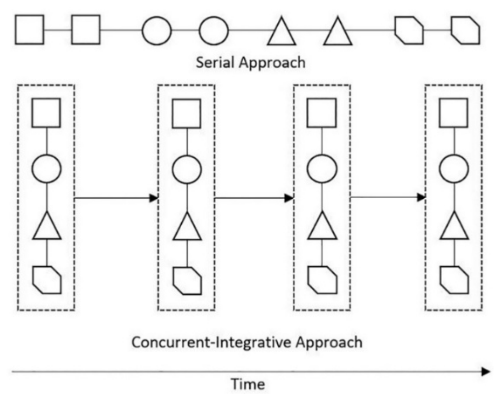
	- Redesign the ceiling (geometry, material) for better acoustic performance.	
Thermal Comfort	- Maximizing cross-ventilation principle, - Utilizing the buoyancy principle to propagate the stack effect, - Set up dynamic HVAC set points.	Engineering Physics, Architecture, Interior Design, as well as Mechanical and Electrical Engineering
Lighting	- Optimize side lighting for daylight, - Dynamic shade control for side lighting.	Engineering Physics, Architecture, and Interior Design
Circulation	- Additional space (cantilever) for personal learning room, - Re-layout one-way route for emergency egress, - Additional ramp for universal design accessibility.	Architecture and Civil Engineering
Efficiency & Renewable Energy	- Building Integrated Photovoltaic (BIPV), - Energy-efficient HVAC system.	Electrical Engineering, Engineering Physics, and Architecture
New Normal	- Additional control room for multimedia & hybrid classrooms, - Occupancy and thermal sensors in every classroom.	Architecture, Engineering Physics, and Interior Design

4.1. Working Together

Students' learning was greatly influenced by the methods of training, with many of them studying best through active, collaborative, and small group work, within and outside the classroom (Soibelman, et al., 2004). Based on the questionnaire result from the previous stage, the groups subsequently set up small groups to work on each proposed solution. These groups contained multi-disciplinary students (see Table 2) that virtually worked to focus on the task. To improve the collaboration environment, all teams established an online platform. This was simple and effective in supporting the group work. In addition to the collaborative tool, each team adopted the study of O'Brien [23], which was identified as the concurrent-integrative work strategies. This indicated that each group contained multi-disciplinary students simultaneously working on separate tasks from the others, with frequent exchange of information (O'Brien, et al., 2003) (see Figure 4).



Source: Author (2023)
Figure 3: Brainstorming through Digital Canvas



Source: (Author, 2023)
Figure 4: Concurrent-integrative Work (modified from O'Brien, 2003)

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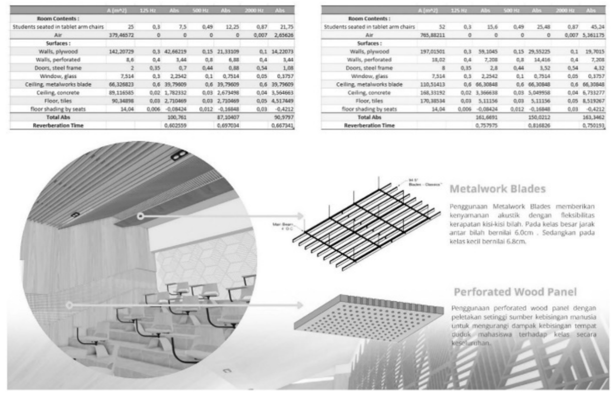
The design interations and two-way information exchange in this study depended on the involved issues and disciplines. For example, the design and interactive processes frequently occurred in the noise reduction issues, among the Architecture, Interior Design, and Engineering Physics students, respectively. However, the dialogue during the design process was less frequent in the structural integrity of the building, since the Civil Engineering. students focused on the modeling and analysis provided by the Architecture, Interior Design, and Mechanical Engineering departments. Based on the workflow, structural analysis was performed after the final design, including floor addition or new equipment installation (e.g., elevator), as proposed by the Architecture, Interior Design, and Mechanical Engineering students. The following reports are some of the collaborative performances of the multidisciplinary students that conducted several issues in achieving the team's goal.

5. Collaborative Result Strategy

5.1. On Noise Reduction

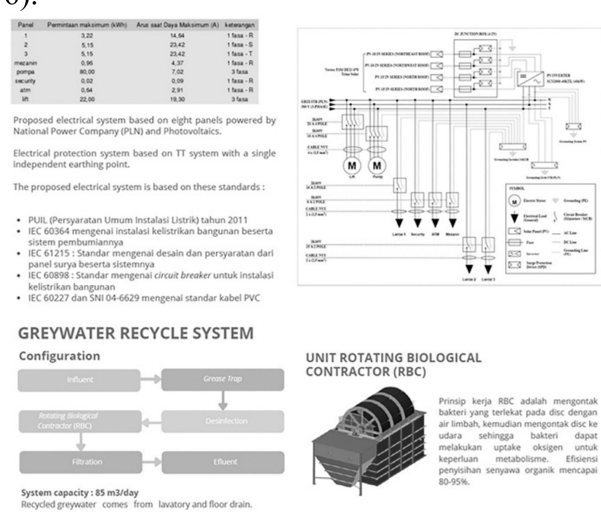
One of the main issues of the existing lecture building was the classrooms' noise and poor acoustic performance. A small group from the Architecture, Interior Design, and Engineering Physics departments worked on noise reduction and improved acoustic performance in the classroom of the case study, where the internal materials and pieces of furniture were initially identified. This was subsequently accompanied by model creations and simulated reverberation time, based on the geometry and interior materials (see Figure 5).



Source: (Author, 2023)
Figure 5: Noise and Interior Improvement Strategy

5.2. On Renewable Energy & Waste Management

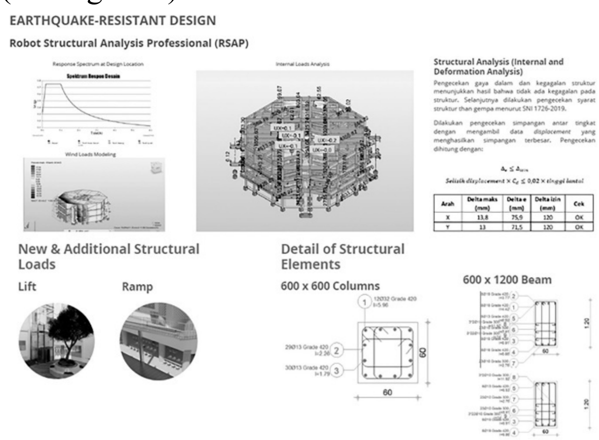
Another group containing five (5) multidisciplinary students from the Architecture, Electrical, Mechanical, and Environmental Engineering departments, focused on investigating the optimization of electricity loads and usages. The potential of utilizing various approaches was also investigated to save energy, such as green facades for the East and West sides of the building, calculating catchment area and water tank for rain harvesting, as well as configuring greywater recycling system through Rotating Biological Contractor (RBC) and other WC (water conservation) mechanisms (see Figure 6).



Source: (Author, 2023)
Figure 6: Renewable Energy & Waste Management Strategy

5.3. On Additional Workspace & Structural Analysis

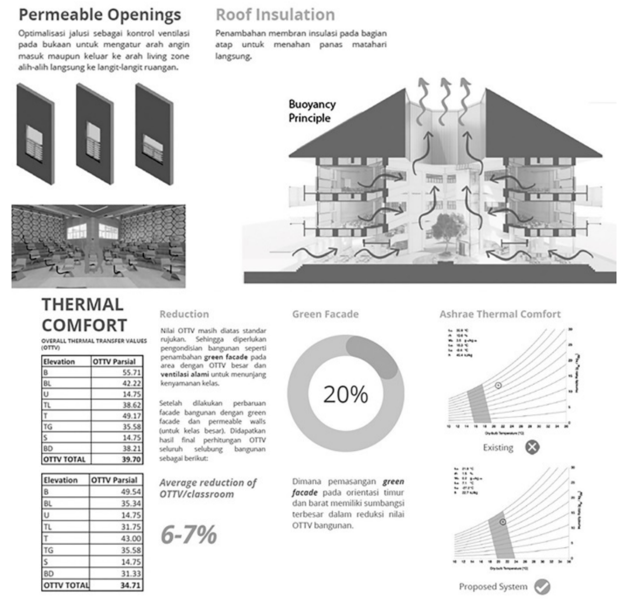
Based on the requirement for additional work and study spaces, three students from the Architecture and Civil Engineering departments focused on analyzing and modeling earthquake-resistant buildings, as well as adding structural reinforcement elements to the existing structure. Moreover, the proposed 3D model with additional building features such as an elevator, ramp, toilet, and the floorplan was then analyzed to check the integrity of the existing structural components (see Figure 7).



Source: (Author, 2023)
Figure 7: Additional Workspace & Structural Analysis Strategy

5.4. On Natural Lighting & Thermal Comfort

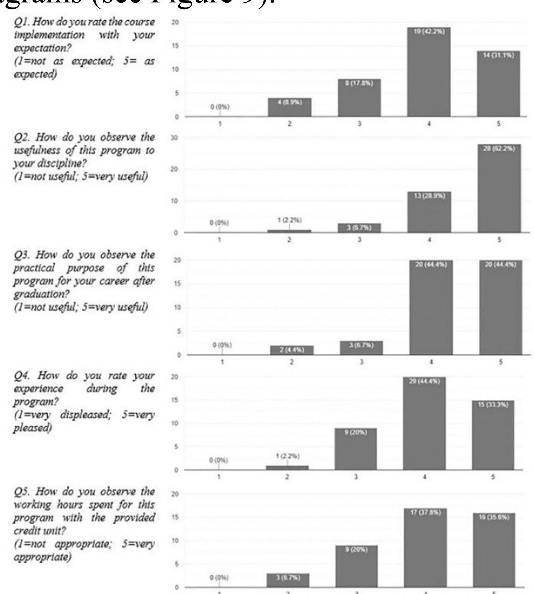
The strategy to maximize the penetration of daylight into the classroom includes the façade redesigning (specifically the East and West sides of the building), as well as a light shelf and high-performance glass utilizations. This was conducted to ensure deep and distributed daylight penetration. Meanwhile, daylighting sufficiency should decrease indoor temperature and the risk of thermal discomfort. The optimization of these two tasks was carried out by a group of Architecture and Engineering Physics students (see Figure 8).



Source: (Author, 2023)
Figure 8: Natural Lighting & Thermal Comfort Strategy

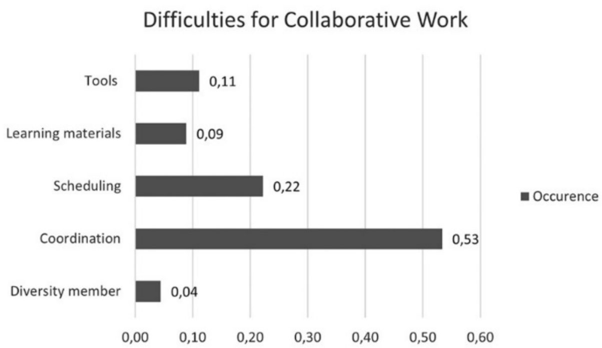
6. Results and Discussions

After three months of completing the design projects, students were provided with a post-evaluation questionnaire, concerning their opinions on the program implementation, as well as the quality and interaction of their team's work. Approximately 60% of students participated in this evaluation practice, and the results are summarized in the following diagrams (see Figure 9).



Source: (Author, 2023)
Figure 9: Course Evaluation

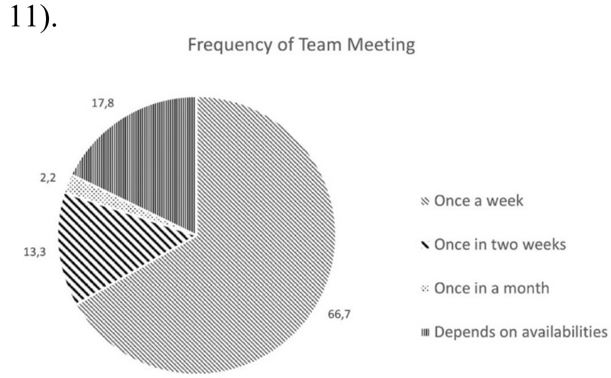
Based on this study, most of students believed the program was essential and had a practical purpose on the potential industries to work in after graduation. The result showed a positive opinion towards the importance of the collaborative course based on the students' discipline. A good experience was also observed during the collaborative work. On open-ended questions, students were asked to provide their opinions on the difficulties experienced during this program. After the collection of answers through keywords, five issues from 45 respondents were summarized as follows (see Figure 10):



Source: (Author, 2023)
Figure 10: Identified Difficulties for Collaborative Work

1. *Coordination and communication*: Based on the online environment, students experienced difficulties in conversation engagements, conveying ideas, and persuading others to understand the concept. This showed that the lack of coordination and teamwork was due to their real-life anonymity.
2. *Scheduling*: Based on each member originating from/with different departments and academic schedules, these teams experienced difficulties in determining the available program for everyone. This was more challenging because of the online environment.
3. *Tools*: The compatibility between software was the issue to streamline the modeling and analysis workflow.
4. *Learning materials*: Some students were shy with their knowledge when collaborating with issues from other disciplines. This indicated a need for them to deepen their understanding of principles and concepts.
5. *Diversity*: Students argued that discipline diversity in a team played a crucial role in the completion of work. This indicated that a team with proportionally diverse members and good leadership benefited from collaborative work. A team majorly containing members from similar disciplines subsequently leaves little room for critical discussion and group cohesion. In addition, a multi-disciplinary team should not be a large group. This was because a small group of three members from each discipline was suitable for collaborative work.

Based on the questionnaires, one of the critical factors to overcome the lack of coordination and miscommunication was the frequency of online meetings. This was because 66.7% of the students confirmed that their team averagely held an online meeting once a week during the project work. Approximately 17.8 and 13.3% of the students indicated that they had meetings based on the availability of team members and once in two weeks, respectively. Despite its limitation and constraints, the online meeting was the only choice to accommodate coordination and communication (see Figure 11).



Source: (Author, 2023)
Figure 11: Frequency of Team Meetings

7. Conclusion

7.1. The Role of the Lecturer

Besides its essential outcome, a course to promote collaborative thinking and performance was an exhaustive and rewarding effort, specifically in the lecturer's sector. This was because detailed preparation, planning, and coordination were the most significant component in ensuring a smooth and meaningful program. According to Deutch [25], collaboration was challenging, due to the delay in building relationships, eradicating misunderstandings, listening, and completing tasks. On large teams, underperformance is easy, specifically when roles are blurred or ill-defined (Deutch, 2019). This was widely observed in this program, specifically in the team where there was a lack of leadership, as well as poorly defined tasks and roles to be performed by each member, regardless of the mentor's availability.

Through the questionnaires, some students indicated that the program's Terms of Reference should include a detailed collaborative workflow, stating that each team should perform. Another feedback was the importance of each mentor's engagement with the team. This indicated that students should learn something new from other departmental lecturers and subsequently engage in distinct critical discussions over specific issues. Active engagement also required more commitment from the lecturers and other administrative processes on the existing curricula, to accommodate a seamless teaching flow across disciplines.

Another result was the continuous effort to maintain the concurrent-integrative approach in collaborating as a multi-disciplinary team, to avoid the predictably serial measures in each team. This was a challenging process, due to slowly changing the mindset of the monodisciplinary students. However, the study of O'Brien [23] indicated that the combination of instruction, interaction, action, and reflection was an appropriate model to foster a concurrent-integrative type of collaborative work, with the lecturers as one of the critical factors.

The instruction and interaction through normal and guest lectures, lively discussion, hands-on workshop action, and collaborative teamwork, as well as the serial reflection of seminars and critiques, were all necessary factors in fostering critical cooperative thinking. The promotion of critical collaborative thinking was also very essential in this study. This was because the use of a project-based course was achieved through the intensive engagement of the lecturers, specifically in the undergraduate program.

7.2. The Role of the Tools

Although the information technology helped to enable brainstorming, ideation, documentation, and problem formulation at the beginning of the program, these tools did not provide sufficient capabilities to support realistic collaborations during the development processes. In a specific issue such as BIM (Building Information Modeling), the process of model authoring and analysis between Architecture, as well as Civil and Mechanical Engineering was still in line with the conventional workflow, where each discipline worked based on a conceptual design provided by the architect. Based on the design development stage, the process of modeling and analysis by each team member was still encountering conventional problems, such as file format and software interoperability.

These examples are the real issue in the AEC industry, with the technological challenge that should be addressed in simulating a collaborative work environment.

Based on the possession of specific software for modeling and analysis in this study, these tools were suited mostly for serial approach work, as they rarely supported collaboration in real time. In this study, the course used BIM (Building Information Modeling) as a platform to support data exchange between software. However, students' capability in operating this tool varied, where the Architecture and Civil Engineering departments had more experience than others. To enrich the collaborative experience, some students suggested a crash-course workshop on software and workflow, accompanied by a framework for digital-assisted collaboration (i.e., Common Data Environment or CDE-like platform). According to Marble (2012), the performance between multiple software platforms emphasized interoperability, which encouraged students to expand their design problems, as well as search for a specific and relevant link to the model workflow as suggested by Marble [25]. This new role of digital tools avoided the pitfalls of academic trends and obtained a more inclusive approach to digital technology. This was conducted to merge qualitative and quantitative goals into a continuous workflow.

Architectural education needs to embrace collaborative and interdisciplinary work through its project-based course. Based on Schön's proposal more than 30 years ago, architecture education should reflect more as the normative curriculum of other university-based professional schools (Schön, 1985). This should be carried out by incorporating new fields of specialized knowledge into the studio experience. To achieve this goal, the first action is to embed a collaborative course into the curriculum, with multi-disciplinary and project-based approaches. According to this present study, good insight and recommendation for enriching the architectural education curriculum was found, although it still lacked integrative and comprehensive preparations, constructed a knowledge-based system, and operated through a rigid school administrative system. This indicated that a collaborative course with a concurrent-integrative approach enhanced experiential learning and nurtured critical cooperative knowledge when the curriculum and lecturer mindset was ready to engage in multi-disciplinary performances. Therefore, this program should focus on building complex and integrated knowledge bases as part of the problem-solving process, as well as include various exercises to foster critical collaborative thinking (Willingham [26]). Based on the suggestions of experts, critical collaborative thinking should serve as a crucial trait for architects as the integrator [5] or Superuser[24]. It should also serve as a trait for the design professionals as specialists and generalists, due to leveraging tools and technology with skillsets and mindset.

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