



A Knowledge Conversion Model Based on the Cognitive Load Theory for Architectural Design Education

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ABSTRACT

The education of architectural design requires balanced curricular arrangements of respectively theoretical knowledge and practical skills to really help students build their knowledge structures, particularly helping them in solving the problems of cognitive load. The purpose of this study is to establish an architectural design knowledge conversion model, helping students to obtain architectural design knowledge through a learning process of knowledge sharing/socialization, extraction, externalization, integration, creation and internalization. This model can help students to effectively solve the problems of cognitive load in the learning process, achieve knowledge construction and storage through meaningful learning, apply their knowledge in their future designs and, ultimately, improve their design capability.

This study starts with a literature review on theories of knowledge conversion and cognitive load to establish an architectural design knowledge conversion model complemented with especially designed curricular contents and activities. The model is applied in actual teaching to find out if the application of this model has a positive influence on the students in their learning of architectural design, solving the ill-defined problems in their learning and easing their cognitive load.

Keywords: knowledge conversion, cognitive load, ill-defined

INTRODUCTION

The education of architectural design requires suitable curricular arrangements and teaching activities that cover both the theoretical and practical aspects of architectural design, structure, construction and the others to help students build comprehensive cognitive structures of

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State of the literature

- The purpose of this study is to establish an architectural design knowledge conversion model, helping students to obtain architectural design knowledge through a learning process of knowledge sharing/socialization, extraction, externalization, integration, creation and internalization.
- Previous research on the design-studio model of architectural education, the knowledge acquisition, organization and application of students mostly depend on the instruction and teaching from their teachers. Therefore, their learning of architectural design is subject to the influence of the teachers' own cognitive structures and experiences.
- The existing studies on knowledge management in the construction industry focus on practical application rather than education. Recent research is mostly about software architecture knowledge management, application of knowledge management to guide the process of architectural design, or application of knowledge management to improve organizational performance and operation management. There has been little discussion about the possible benefits of knowledge management for students in their learning of architectural design

Contribution of this paper to the literature

- Based on the literature review of knowledge conversion and cognitive load theories as well as the results of in-depth interviews in this study, a knowledge conversion model for architectural design education was developed together with corresponding curricular arrangements and teaching activities/units.
- The propose model in this study is applied in actual teaching to find out if the application of this model has a positive influence on the students in their learning of architectural design, solving the ill-defined problems in their learning and easing their cognitive load.
- Both the teachers and the students had high recognition of the knowledge conversion model for architecture design education developed in this study.

architectural design. Since architectural design is a knowledge-intensive activity (Rogers, 2001), students have to depend heavily on regular design revisions and suggestions from their teachers in the design-studio-like class (Schön, 1983). In addition, students have to collect a massive amount of external information to solve their problems in the process of architectural design. However, the problems students encounter in their learning of architectural design are often ill-defined and, therefore, students are prone to not knowing how to collect knowledge and formulate their problems (Rittel & Webber, 1984). Since architectural design is a "knowledge-intensive" activity that covers knowledge of different disciplines, students have to acquire a diverse variety of knowledge about issues such as design, structure, construction and materials before they can apply the knowledge in their designs. While facing the deadline of each assignment, students also have to keep on looking for required knowledge to solve the ill-defined problems (Rittel & Webber, 1984). Curricular arrangements of this "design studio" nature can easily cause excessive extraneous cognitive load and students often have little idea of how to extract useful information out of a massive amount of different data in order to solve

ill-defined problems of architectural design. In addition, students lack in deep and sufficient understanding about architectural design; therefore the knowledge they acquire is often fragmented. Students cannot effectively organize, retain or accumulate their experiences and knowledge, which causes problems of cognitive load for them (Leahy & Sweller, 2004, Cierniak, Scheiter, & Gerjets, 2009).

The existing studies on knowledge management in the construction industry focus on practical application other than education (Dave & Koskela, 2009; Forcada, Fuertes, & Macarulla, 2013). Recent research is mostly about software architecture knowledge management (Wu et al, 2016; Capilla et al, 2016; Wu, Young, & Wen, 2016), application of knowledge management to guide the process of architectural design (Zapata-Lancaster & Tweed, 2016), or application of knowledge management to improve organizational performance and operation management (Othman, Halim, 2015; Öztürk et al., 2016). There has been little discussion about the possible benefits of knowledge management for students in their learning of architectural design.

This study is an attempt to incorporate the knowledge conversion theory into the curricular design to develop an architectural design learning model in order to encourage students to (1) accumulate experiences through the process of knowledge collection, storage, sharing and application; (2) construct their knowledge structures of architectural design to solve problems of “cognitive overload” and “ill-defined” problems in their learning of architectural design; and (3) achieve the effects of germane cognitive load through suitable curricular arrangements and teaching activities.

Based on the literature review of knowledge conversion and cognitive load theories as well as the results of in-depth interviews in this study, a knowledge conversion model for architectural design education was developed together with corresponding curricular arrangements and teaching activities/units. The model and teaching activities/units were applied in real-life teaching in order to find out if they can have a positive influence on the teaching/learning of architecture design and promote the development of germane cognitive load among students and if they can have a positive influence on reducing students’ intrinsic cognitive load by helping them solve the ill-defined problems they encounter in the learning process of architectural design.

LITERATURE REVIEW

Learning Process of Architectural Design

The core courses of architectural education are mostly courses of architectural design. The learning of architectural design is composed of different stages starting with easy and small-size design tasks to more difficult and larger ones with more complicated functionality requirements. In more advanced stages of architectural design courses, students have to consider more factors in their designs. In the architectural design education, the “design studio” model of training is a teaching method that almost every student has experienced or

will experience. It is also one of the major sources of knowledge for students in architectural design departments. A typical model of “design studio” teaching is to give students with an architectural design assignment and teachers give individual instruction to each student, helping them complete their designs by repetitively revising their drafts and giving them suggestions. This is also the traditional method of architectural design education (Schön, 1983).

According to previous research on the design-studio model of architectural education, the knowledge acquisition, organization and application of students mostly depend on the instruction and teaching from their teachers. Therefore, their learning of architectural design is subject to the influence of the teachers’ own cognitive structures and experiences (Akin, 2002). Under such circumstances, students obtain knowledge mostly from one single source only. The lack of diverse sources of architectural design knowledge is likely to demotivate students in proactive learning. Therefore, it is better to divide knowledge for students to acquire into different units and activities to reduce the complexity and size of knowledge students need to process, making it easier for them to combine the contents in each unit with their existing knowledge to form new cognitive structures. In addition, architectural design is a knowledge-intensive activity and knowledge is usually created and shared through complex social interactions and experience exchanges (Gütl & Pivec, 2003). For learners of architectural design, having discussions and sharing information with peers in the design process is helpful for their knowledge conversion and design capability improvement (Banbury & Wellington, 1989). As indicated above, revisions of the draft and discussions with peers are the two major and significant sources of knowledge for students in their “design studio” type of architectural design learning. These two methods require both teacher-student and student-student discussions and exchanges face to face to transmit and share knowledge. Therefore, group discussions are frequently conducted in classes of architectural design in addition to comments and suggestions given by teachers on the individual draft of each student. However, due to the limitation of time and space, the teacher-student interactions in the classroom cannot cover all the questions or problems that students encounter, causing limitation in students’ learning. In addition, some students may feel intimidated by having one-on-one and face-to-face discussions with their teachers or peers, which will lead to ineffective communication and learning impediment instead. Therefore, digital platforms or systems such as the blog can be used for students to present their works and experiences, interact with one another and learn from the designs by their peer on the internet to achieve the purpose of knowledge sharing (Jarvenpaa & Staples, 2000). They can also record their own thoughts and receive feedbacks from others on these platforms or systems (Alavi & Leidner, 2001). It is a research-worthy topic to find out how to reduce the cognitive load for students to acquire knowledge more effectively in their learning of architectural design through suitable arrangements of teaching units/activities designed to promote knowledge conversion.

Knowledge Conversion

Since the publication of the book, *The Knowledge-creating Company*, authored by Nonaka and Takeuchi, knowledge management has been regarded as an effective tool to improve a

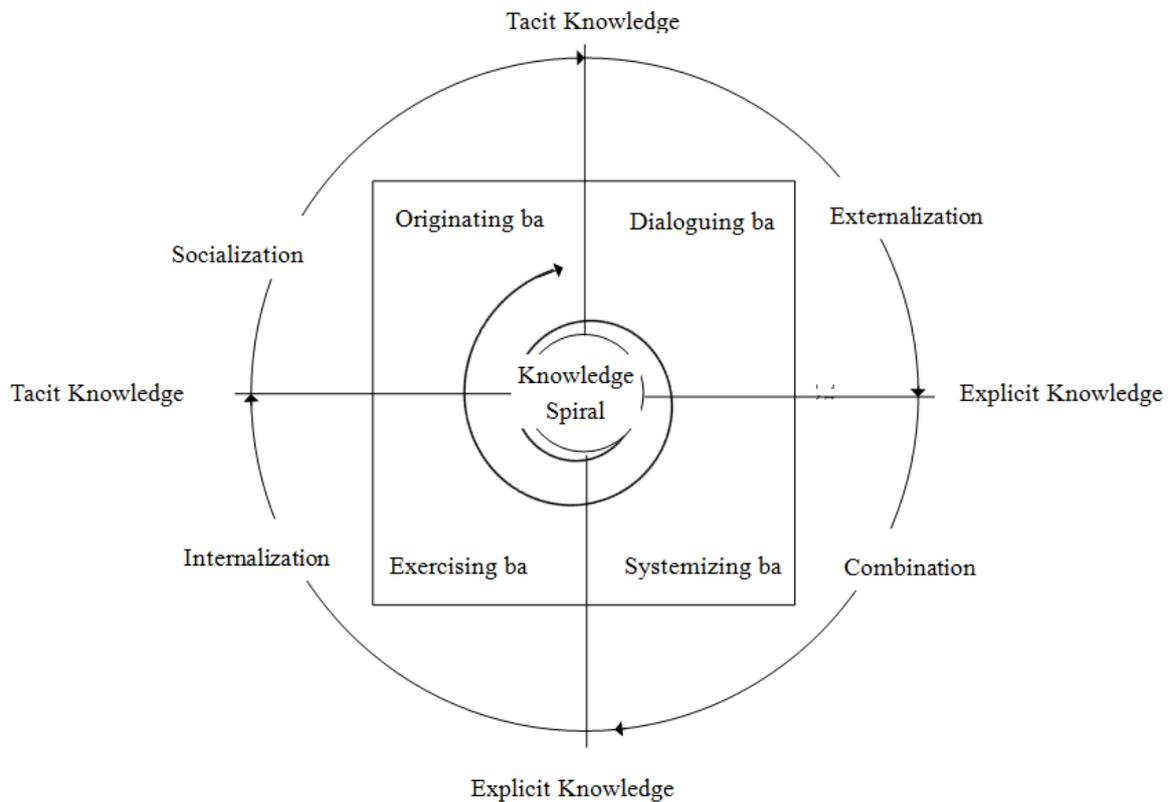


Figure 1. Knowledge Spiral (SECI Model)

company's indicators of business performance such as "creating revenue growth", "shortening design and production time", "improving customer and employee satisfaction" and others (Mertins, Heisig, & Vorbeck, 2001; O'Dell, Elliott, & Hubert, 2000). The early research on knowledge management mostly discusses the differences among data, information and knowledge (Carrillo & Chinowsky, 2006). From the perspectives of process and inventory, there is a hierarchy of four data levels: data, information, knowledge and wisdom (Davenport & Prusak, 1998). Data can be converted into useful information after they are analyzed for particular purposes or requirements. Information can be converted into knowledge after it is academically organized or constructed (Nonaka, 1994). Knowledge can be effectively used to help with decision making and create wisdom. Therefore, data is the basic component of knowledge. Data are neutral while information extracted data is targeted for a specific purpose. Knowledge is the value-added result of organizing, analyzing and integrating data. Knowledge is of practical values and can be used in the process of architecture design. In terms of the process of knowledge creation, knowledge and information are significantly different. Knowledge is not knowledge about certain objects only but also the process of how the objects are created. Therefore, knowledge covers both content and process. According to Prof. Ikujiro Nonaka of UC Berkeley, knowledge is created, shared and used in a process. He also proposed the concept of "Ba", categorization of knowledge, and SECI model of knowledge conversion (Nonaka, Konno, & Toyama, 2001).

In terms of the operation of knowledge, Professor Nonaka believed that knowledge conversion and self-improvement is a continuous spiral composed of four steps: socialization, externalization, combination and internalization. It is called the SECI model (Nonaka, 1991) as illustrated in **Figure 1**. When the model is integrated with knowledge management strategies, tacit knowledge is first externalized to create new knowledge, which is then combined with the explicit knowledge to enhance the knowledge depth of the organization. Furthermore, the explicit knowledge is internalized and shared among members of the organization. Finally, the tacit knowledge is socialized to improve the productivity and competitiveness of individual members of the organization.

Cognitive Load

In the field of education, the discussions of “cognitive load” focus on the influences of “learning contents” and “teaching methods” on what learners acquire and how they function cognitively. Cognitive load is the total amount of mental efforts being used in the working memory to process the information perceived by human senses (Sweller 1988, 1989). The size of cognitive load is determined by one’s existing cognitive structure and the learning environment (Gerjets & Scheiter, 2003). Cognitive load can be divided into three types: intrinsic cognitive load, extraneous cognitive load and germane cognitive load (Sweller, Merriënboer, & Paas, 1998). Intrinsic cognitive load is determined by the connections between the inherent difficulty levels of learning materials and the existing knowledge of the learner. Learning materials are composed of different elements and each element is a knowledge unit learners have to learn in the learning activities. When an element in the learning materials can be learned separately and has no connection with any other element, it has low element interactivity and will require less processing in the working memory. Therefore, such an element will cause lower intrinsic cognitive load. To achieve better learning results in terms of both memorization and comprehension, it is suggested to minimize cognitive load by giving information segment by segment for processing in the working memory instead of giving all the information at one time. In other words, it is suggested to teach students unit by unit so as to reduce their cognitive load and achieve better learning results (Mayer, et al, 1999). Extraneous cognitive load refers to the extra cognitive load imposed upon learners when the same teaching materials are presented to them in different ways (Paas, Renkl, & Sweller, 2003). Helpful for the improvement of overall learning results, germane cognitive load is achieved by using suitable teaching materials to attract the attention of students to their learning materials and consequently improve their learning results (Paas, Renkl, & Sweller, 2003). Therefore, a knowledge conversion model for architectural design education is developed in this study with a view to helping students in their learning of architectural design by effectively promoting germane cognitive load.

KNOWLEDGE CONVERSION PROCESS FOR LEARNING OF ARCHITECTURAL DESIGN

Cognitive development is based on thinking and learning with the focus on knowledge acquisition, extraction, application and storage (Daugherty & Mentzer, 2008). Knowledge about architectural design is mainly tacit knowledge, which is acquired through social learning activities such as teacher-student and peer interactions to achieve cognitive assimilation and adaptation (Stahl, 2000). When the cognitive structure reaches a balanced and steady state, it will become a knowledge asset. Therefore, this study is an attempt to incorporate the theories of knowledge management and knowledge conversion in the learning process of architectural design to promote the creation of germane cognitive load and achieve meaningful learning results. The model, curricular design and teaching units/activities developed in this study were applied in real-life teaching to verify their benefits.

Exploration of Learners' Requirements

The subjects in this study were totally 170 freshmen in the Department of Architectural Design, China University of Technology in Taiwan. In-depth interviews were conducted with the subjects to find out their learning requirements in architectural design courses. The interview results together with the results of the literature review and interviews with eight teachers of architectural design courses were used to construct the framework of the knowledge management and conversion model for architectural design education in this study. The in-depth interviews covered seven topics: (1) arrangements and difficult levels of the units in the teaching materials; (2) connections between the teaching units and students' existing knowledge/experiences; (3) influence of the teaching unit/activity arrangements on the improvement of students' design capability; and (4) influence of the teaching unit/activity arrangements on students' motivation of proactive learning.

Knowledge Conversion Learning Model

The learning model and corresponding teaching activities in this study were developed based on the four cyclical steps in the SECI model (Nonaka, Konno, & Toyama, 2001): socialization, externalization, combination and internalization. In addition, the teaching/learning in this model was conducted unit by unit in order to reduce the cognitive load for students. The following is an introduction to each step in the model:

Knowledge Sharing and Socialization

The traditional architectural design education is mostly based on the "design studio" method, in which students are like apprentices of their teachers. With such a method, students acquire their experiences and intrinsic knowledge through activities such as observation, imitation, demonstration and hand-on practice. In other words, they obtain knowledge through social learning. Therefore, online community forums, virtual classrooms and blogs

were used in this step to not only enable teacher-student and student-student interactions but also achieve social learning and knowledge sharing.

Knowledge Extraction and Externalization

The process of architectural design is a process in which a designer expresses his or her concept and knowledge through the actual work. Therefore, it is also a process of knowledge extraction and externalization. Explicit knowledge can be extracted from design cases for students to have analogical learning. In the learning process of architectural design, knowledge externalization can help to achieve knowledge extraction and creation. In this step, the teaching materials, cases, work demonstration and knowledge management (information search and categorization) are used to help students extract helpful knowledge for their design concept development and design creation.

Knowledge Application and Combination

In the process of architectural design learning, students present their explicit knowledge of architectural design in their design works (Davenport & Prusak, 1998). Through knowledge sharing, students can extract, absorb and then apply useful knowledge in their designs. Through the functions of work demonstration, self-reflection and peer assessment on a digital learning system used in this study, students can share knowledge, extract and categorize useful knowledge, combine new knowledge with existing knowledge to build their own knowledge structures.

Knowledge Creation and Internalization

The process of knowledge creation is a process of continuous interactions between tacit knowledge and explicit knowledge (Nonaka & Takeuchi, 1995). In the model of this study, the measures of self-reflection, learning logs and learning statistics are used to encourage students to apply their newly acquired knowledge, internalize it into their tacit knowledge and ultimately improve their design capability.

Teaching Activities in the Model

The teaching activities in the architectural design education model of this study start with the selection of a topic for students' architectural design assignments. The purpose of the teaching activities is to teach students the concept of environmental awareness and the basic knowledge of architectural design. Excluding the introduction to environmental awareness before the teaching, there are totally nine weekly teaching units over nine weeks: Unit 1: Base; Unit 2: Case Study; Unit 3: Building Volume; Unit 4: Layout; Unit 5: Appearance; Unit 6; Unit 7: Structural System; Unit 8: Details; and Unit 9: Self-reflection Conclusion, Joint Assessment and Final Design.

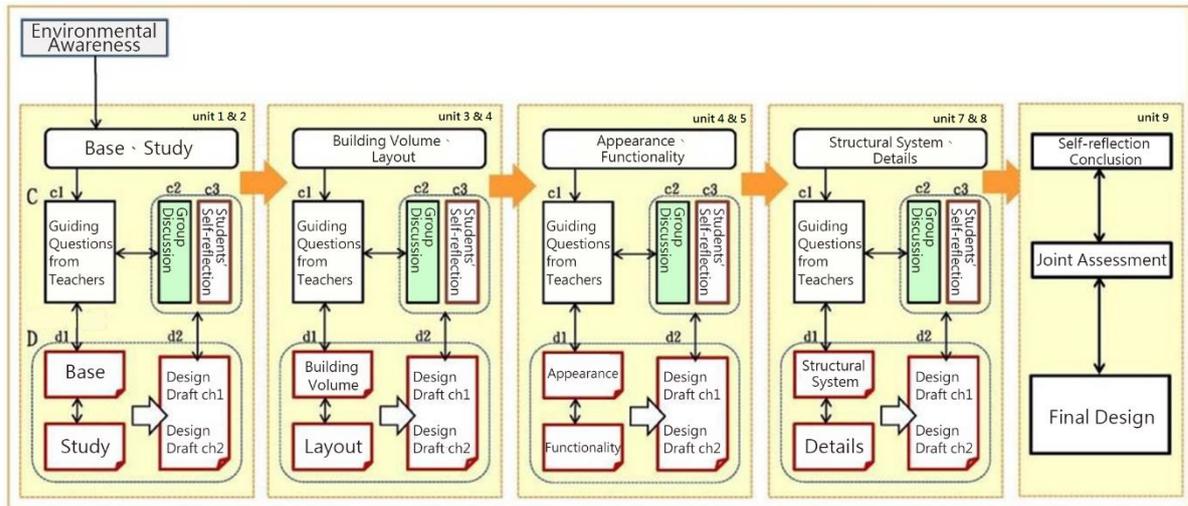


Figure 2. Knowledge Conversion Model for Architectural Design Education

Based on the knowledge conversion model for architectural design education developed in this study, the four steps in the SECI model of knowledge sharing (socialization), extraction (externalization), application (combination) and creation (internalization) are applied in each of the nine teaching units to guide students in their architectural design knowledge acquisition/accumulation and their completion of design works through a learning process of social interactions and knowledge conversion. Each teaching unit is based on the four steps in the SECI model—c1: knowledge sharing and socialization; d1: knowledge extraction and externalization; d2: knowledge application and combination' and c2 & c3: knowledge creation and internalization. The knowledge conversion model with its teaching units and activities developed in this study is illustrated in **Figure 2** and the major points in each of the nine units are introduced in the following section.

MAJOR POINTS OF THE TEACHING UNITS

The knowledge conversion model and teaching activities for architectural design education of this study were applied in the courses of basic architectural design attended by the 170 subjects. In addition to the teaching in the classroom, the subjects were requested to use online systems and platforms for design work sharing, peer interaction and self-reflection. Environment awareness is a topic that all architectural design learners must learn in the beginning stage. Different environments will cause different design problems and requirements. The first eight teaching units in the model of this study respectively cover eight basic dimensions an architectural designer must consider in his or her design: base, case study, building volume, layout, appearance, functionality, structural system and details. The final unit is a conclusion of the teaching. The following is an introduction to the major points in each of the nine teaching units:

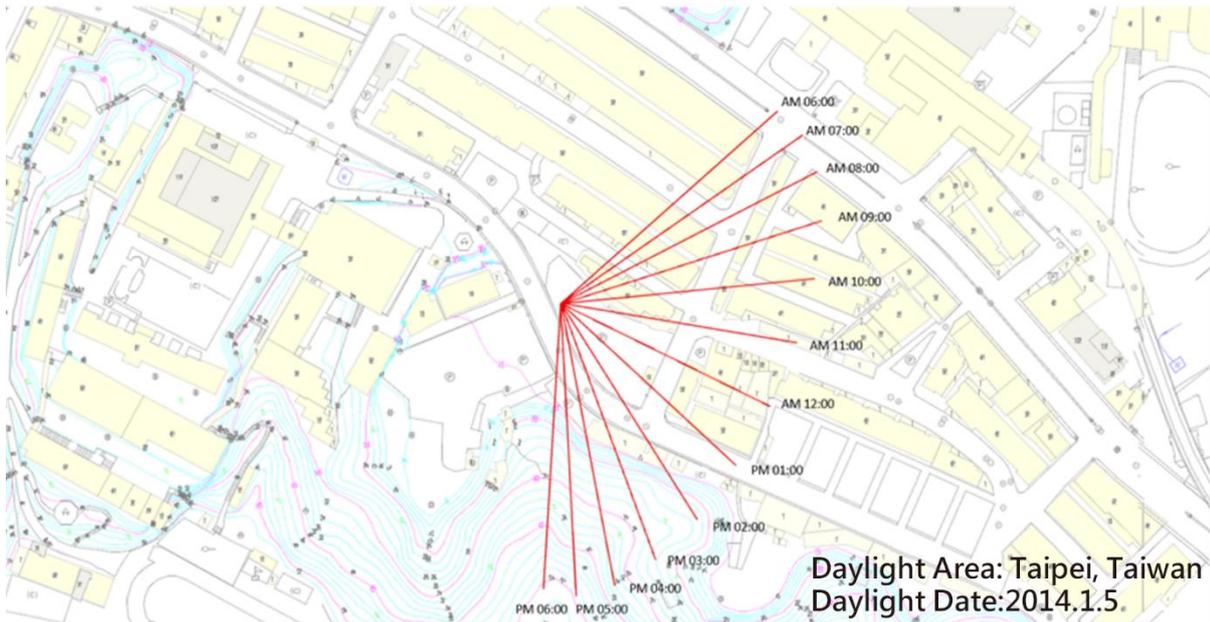


Figure 3. Daylight path and base observation

Unit1- Base

In the course of architectural design, the base refers to the environment and location of the building and it is often designated by the teachers. Before students start their design, they have to analyze the characteristics of the base, such as the surrounding environment, climate, traffic and others, in order to create design works that are closely connected with the base.

Unit 2- Case Study

The purpose of case collection and case study is to provide students references for their designs from relevant cases. The references can guide students to apply their existing knowledge. The cases are often not completely identical with the topic in the architectural design assignment and learners only extract information that is relevant and useful for their designs from the cases.

Case Name : GP House in Hidalgo, Mexico.

Designer : Héctor Bitar de la Pena of Bitar Arquitectos

Building area : 516.18 m²

Completion time : 2011



Figure 4. Case study

Unit 3- Building Volume

The size and form of building volume is determined by the connections between the building and its surrounding environment. In this unit, students not only select the form of building volume suitable for their design concepts but also have to consider the influences of the building volume in their designs on its surroundings. In other words, they have to apply their knowledge to make sure the building volume in their design will fit the environment.

Unit 4 - Layout

The layout of a building decides the location of the building in the base and its correlations with the surrounding spaces. Therefore, the layout must incorporate considerations of the connections between the building and the environment such as natural ventilation, sunlight and landscape. In addition, how people enter, exit and move around in the building must also be considered.

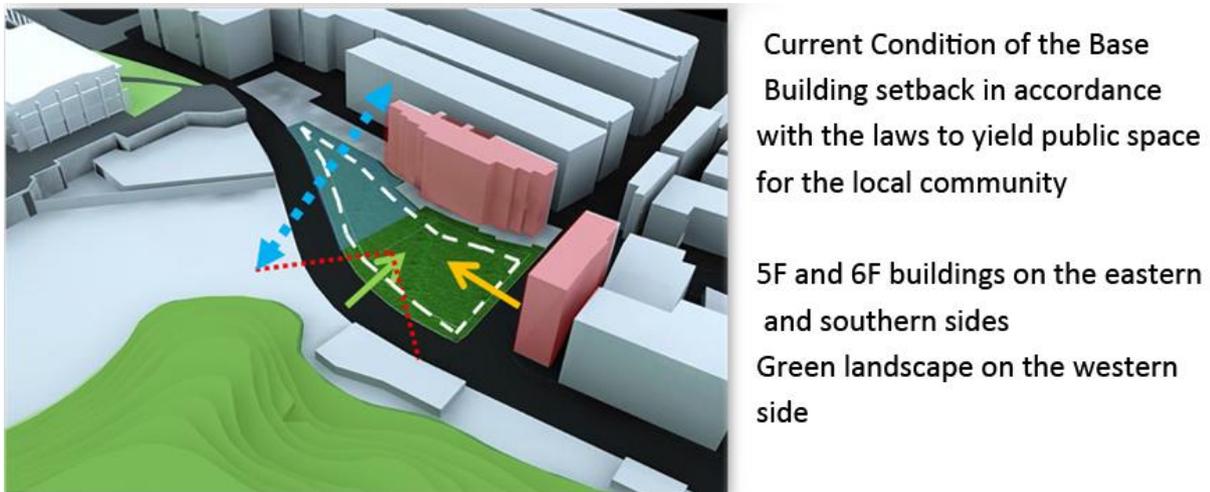


Figure 5. Building environment analysis



Figure 6. General layout and design description

Unit 5- Appearance

The appearance of a building is how it looks on the exterior, through which the designer can express his or her design concepts. The appearance of a building also indirectly reflects how its internal space is used. Designers can use different materials in different combinations for the appearance of their designs to express their unique ideas.



Figure 7. 3D presentation of building appearance and design concept generation

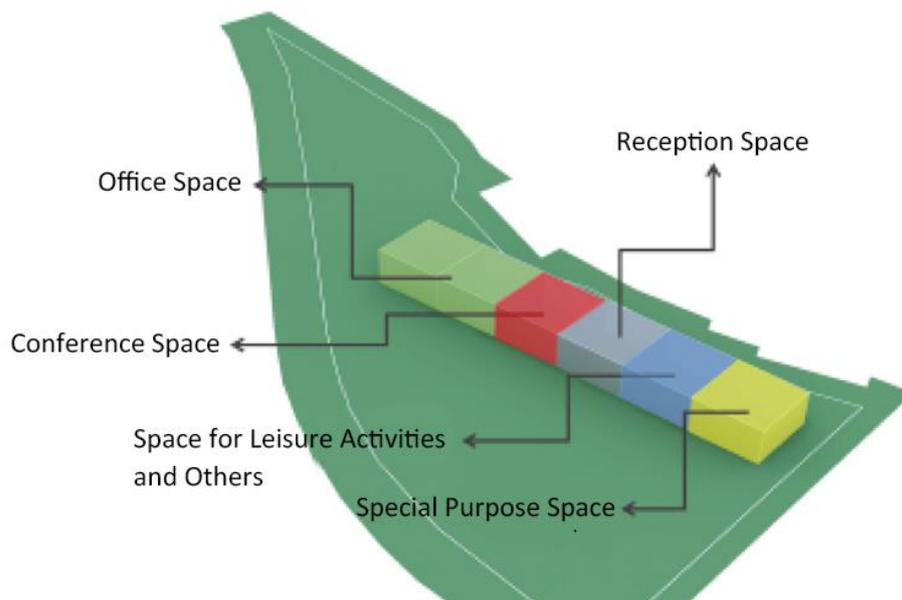


Figure 8. Functionality Design

Unit 6- Functionality

The functionality of a building is how the building functions as a whole to satisfy the requirements of activities in both its internal and external spaces. Students must categorize the activities of the building users inside and outside the building and then plan different spaces, such as public space, service space and personal space, in their designs to satisfy the requirements of different categories of activities. Students must also consider how people can move smoothly among different spaces and how these spaces are deployed in their designs.



Figure 9. Structure system desi

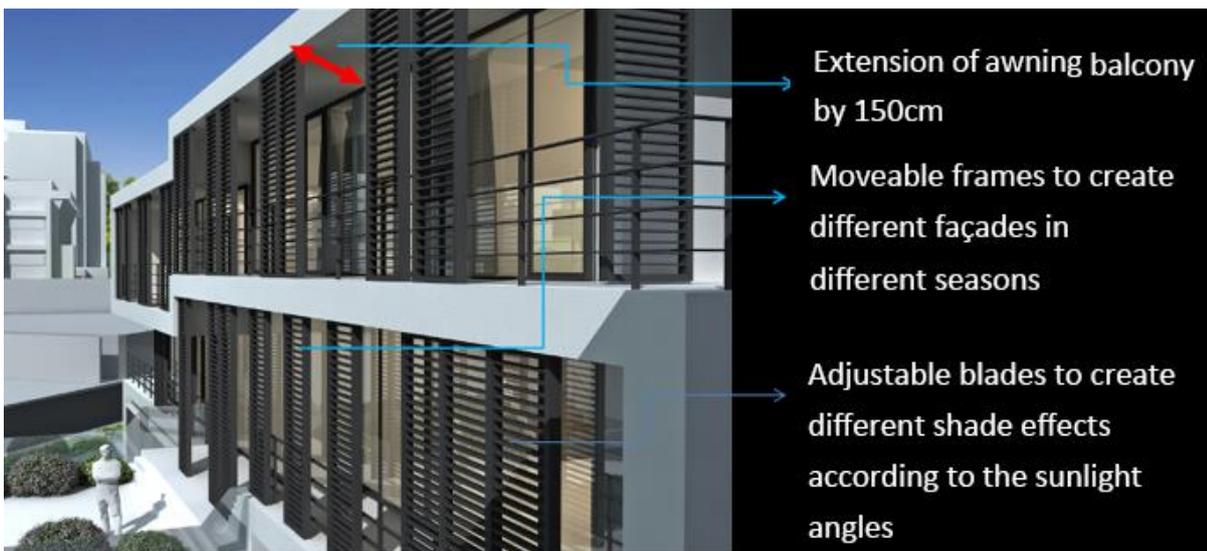


Figure 10. The design of a building's details

Unit 7 - Structural System

After considering all the above-mentioned design aspects, students have to consider the rationality and feasibility of their designed buildings with respect to safety factors such as resilience against the force of gravity. To ensure safe use of a building in the future, the consideration of the building's structural system is very important in the design stage. The decision of the building's structural system will also decide the appearance of the building.

Unit 8 - Details

The details of a building are like its facial expressions. The design of a building's details can fully reflect the designer's design concept, thoughtfulness and ingenuity.

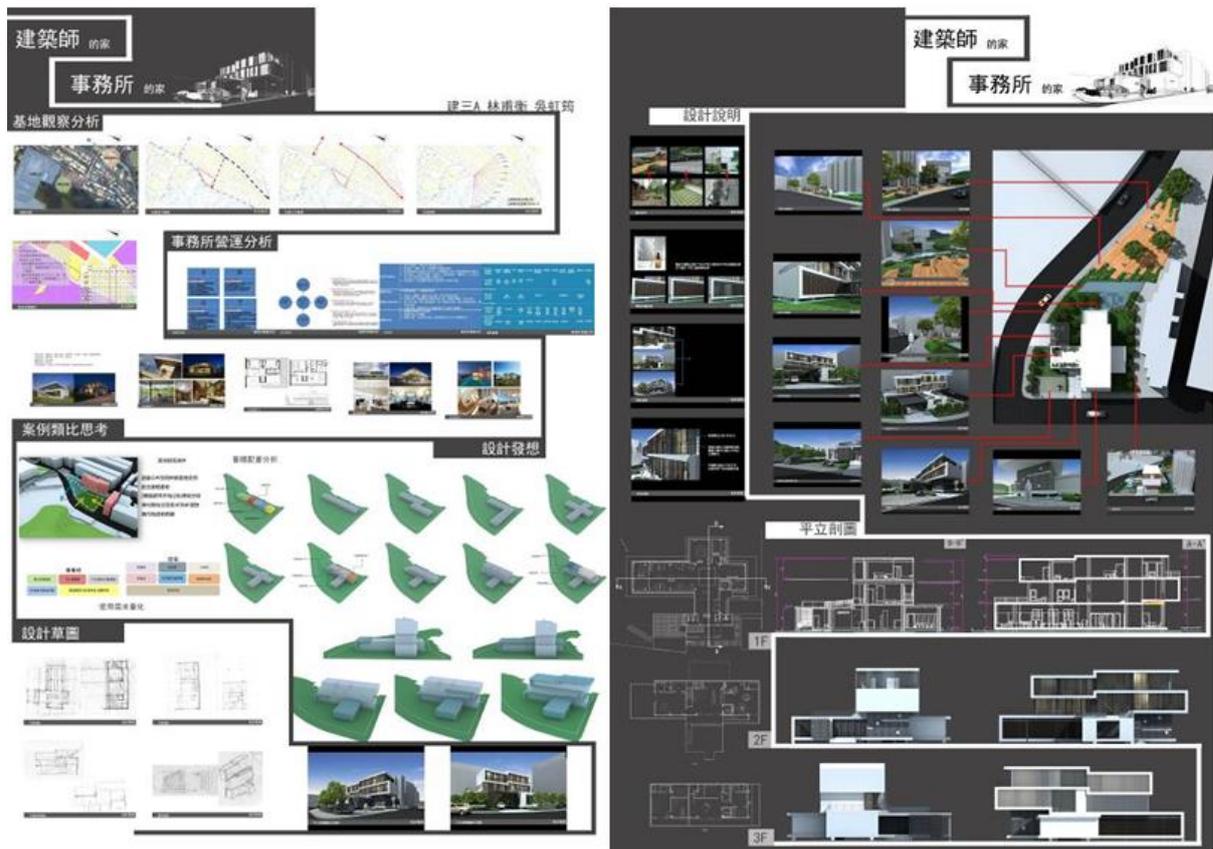


Figure 11. final design work from a group of student

Unit 9 - Final Design

Students submit their final design works as their assignments. In addition, students are requested to assess the works of their classmates, give critiques and reflect upon their works as well. Students are requested to submit their self-reflection conclusion reports afterwards to promote more knowledge creation.

Evaluation

Lastly, an interview questionnaire survey with five-point Likert scale was conducted on the students and the teachers were interviewed after the courses using the model and teaching activities were completed. In the interviews, the teachers of the courses indicated that, compared with traditional methods, using the model indeed helped to improve the quality of the students' design works. In addition, after the exclusion of invalid questionnaire results, totally 102 of the subjects indicated "the course helped me to fully understand what I need to learn" ($M = 4.28$, $SD = 0.80$), "the course benefited me greatly" ($M = 4.32$, $SD = 0.76$), and "I am overall satisfied with the course" ($M = 4.22$, $SD = 0.78$). Therefore, both the teachers and the students had high recognition of the knowledge conversion model for architecture design education developed in this study (**Table 1**).

Table 1. Mean and standard deviation of students' (sample size = 102) feedback after they finish the course

Questions	Mean	Standard Deviation
Q1:the course helped me to fully understand what I need to learn	4.284	0.801
Q2:the course benefited me greatly	4.324	0.760
Q3:I am overall satisfied with the course	4.216	0.779

CONCLUSION

Based on the theories of cognitive load and knowledge conversion, a knowledge conversion model for architectural design education with corresponding teaching activities was developed in this study. Through the teaching activities, the students in this study learned about architectural design unit by unit. The teaching activities provided a learning process of social interactions and knowledge conversion for the students to accumulate knowledge, complete their designs and improve their design capability. The model and the teaching activities developed in this study were implemented in real-life teaching and, based on the results of the empirical implementation, the following conclusions are reached:

Firstly, compared with the other curricular designs and teaching activities of architectural design education without any unit-based arrangement, the arrangement of nine teaching units in the model of this study can reduce the complexity of teaching materials for students to learn and effectively reduce the students' intrinsic cognitive load in the learning process. In other words, the unit-by-unit arrangement is helpful for reducing cognitive load. This teaching method is also consistent with the propositions of "worked example effect" and "problem completion effect" (Sweller, 1988; 2006 & 2010) regarding cognitive load in education. The introduction about environmental awareness, the base and case study in this method provide good worked examples for the students to learn and find out their own solutions. Moreover, in each teaching unit, there are guiding questions from the teachers, to which the teachers provide some solution examples and leave the other questions for students to solve by themselves and/or through group discussion. This can inspire students to have independent thinking in solving problems while the guidance from teachers can help to reduce the extraneous cognitive load for students.

Secondly, in all the units of the model, there are always guidance from teachers, teacher-student and student-student interactions, mutual learning among students from one another's works, and peer assessment for students to share and extract useful knowledge, combine and categorize knowledge, establish their own cognitive structures, and use the accumulated knowledge in their future designs. Mutual learning and peer assessment are two very important and positive teaching methods in design education (Carnell, 2015; Tucker & Abbasi, 2015). The use of these two methods in architectural design education is expected to also help students achieve better learning results. In the nine units of the model in this study, there are

teaching activities of mutual learning and peer assessment to promote more knowledge conversion and creation among students.

However, the model developed in this study has its own restrictions for the model is used only in basic courses of architectural design. For more advanced courses, the contents and arrangements of the units must be adjusted differently. It is suggested that future research is conducted to find out different applications of the model and its teaching units for different levels of architecture design education to further verify the benefits of the model. In addition, although the proposed model is developed for helping the educational goal of general design topics (e.g., multimedia design, visual and communication design and interior design), however, the model is only applied in architectural design education in this study. It is worthy of future research to find out if the model is suitable for education in other design topics.

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