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Abstract: This study explores the relationship between interactive imagery and shared mental models in a design learning environment. The study focuses on design, design learning, and the cognitive components of design. In this research, conceptual project development processes of third year architecture students, in a design studio where four instructors gave desk critiques on a rotational basis, are examined. Within the scope of the study, interviews were conducted with four students and four studio instructors. The process was analysed and interpreted based on the collected data and interviews. It is argued that interactive imagery and shared mental models, which are shaped in the studio's desk critiques, juries and panel reviews, affect students' conceptual project development. It is possible to conclude that if there is more than one studio instructor giving desk critiques on a rotational basis, students may have both advantages and disadvantages.

Keywords*: design learning; design cognition; reasoning; representation; imagery*

1 Introduction

It is a challenge to learn and teach the design process because design has a complex structure often escaping any exhaustive definition. Some have argued that learning in design is primarily based on *learning-by-doing* (Schön & Wiggins, 1992). Finke and his colleagues (1992) have claimed that one of the most important aims of design education is the acquisition to realize cognitive behaviours. Design learning consists of getting acquainted with these behaviours (Oxman, 2001). In studies of design learning, Schön (1983) and Goldschmidt (2005) explain design learning through three main components. Especially in the studies on design studios, these components are defined as instructor, student, and representation (tool). According to these studies, the interaction of the three components shapes the design learning process together with cognitive abilities.

Schön (1985) and Goldschmidt (2007) have separately touched upon the interactions between these three components, cognitive abilities, and the design learning process. These and other similar studies have focused mainly on short moments of interactions between an instructor and a student and a momentary exposure to instructor's mental models. However, in design studios, the conceptual project development process is elongated. The aim of this study is to examine this interaction along an elongated process.

Schön (1985) describes how students learn through communication facilitated through verbal and graphical language used by students and instructors. According to Uluoğlu (1990), these verbal and graphical expressions complement each other in communication through expressions and grammar. Goldschmidt (2005) argues that people have acquired a body of knowledge in their previous education and life experiences and any field-specific knowledge and skills are based on this body of knowledge. Moreover, each person has his or her own cognitive and personal characteristics (Goldschmidt, 2005). When faced with a design task, the designer solves the design problem by using this knowledge and characteristics. Therefore, each person creates a unique conceptual space in the design process. If this process is experienced in the context of an instructor-student desk critique in the studio, this process is shaped through students' and instructors' knowledge and personal-cognitive characteristics (Goldschmidt, 2005). These two components, i.e., instructor and student, are important factors affecting the design learning process. The third component of design learning process is representation.

According to Akin (1986), representation is an important part of design synthesis and there are two types of representation. One of them is external representation as stimulus. The other is internal representation that occurs in mind as the result of external and internal representations. Therefore, representation is a tool for shaping thought (Akin, 1986). According to Goldschmidt (1997), internal representations are the basis of cognition. Internal representation is the visual state of the image of an idea or object in memory. Internal representations can be seen with the *mind's eye* (Goldschmidt, 2017). When mental representations are organized in such a structured way that identify and predict objects, conditions, phenomenon, and people, they are called mental models (Goldshmidt & Surasky, 2011). Mental models are systems that interact and develop with the environment or the mental models of others. These mental models are shaped by experiences and knowledge (Goldshmidt & Surasky, 2011).

In many disciplines, language is the dominant medium in the transmission of mental models and construction of shared mental models among different individuals. In the design studio environment, the interactive communication between a student and an instructor facilitated through verbal and visual representations targets at achieving a shared mental model. In design learning, different from learning in other fields, visual images are irreplaceable to create a shared mental model (Goldschmidt, 2017). In the design process, the interaction of representations and shared mental models brings new knowledge and creative results (Rouse & Morris, 1986). Therefore, it is possible to say that in design learning environment, representation has an important role and it is one of the main components in the design learning process. The interaction of the three components shapes the design learning process together with cognitive abilities such as thinking, reasoning, mental and interactive imagery. In this study, the role of these abilities in the process is investigated. Our main argument is that studio learning environment is a loosely structured collaborative learning environment supported through external representations facilitating the construction and sustainment of shared mental models. This learning environment is a cognitive system including students, multiple instructors, external representations and internal representations.

The study examines four case studies in a design studio with more than one instructor to understand the construction of shared mental models through visual and verbal communication throughout the whole semester. It especially focuses on how a student's mental model of a design situation keeps changing or remains unchanged in a design studio where students take critiques from different instructors. The students selected for this study are third-year students in the architecture department at İzmir Institute of Technology. They were selected based on their accessibility, availability of data, and volunteering.

The study focuses on the conceptual development process of students' projects and is based on students' and instructors' retrospective accounts of desk critiques, panel reviews and midterm juries. The research carried out in this study is of qualitative nature, using qualitative data collection strategies to examine an elongated design learning process. In this study, data gathering began at the end of the project development. The cases were investigated after the phenomenon. During the research process, semi-structured interviews were used to collect students' and instructors' accounts of the design process for each studied student. In these interviews, open ended questions were used to ensure that the accounts would provide rich and detailed data. In the interviews, visual and verbal documents related to students' projects produced by students and instructors during panel and desk critiques were collected. The collected data and documents were analysed and interpreted in the light of literature studies.

2 Design and Design Learning

Designing and learning are closely related styles of interrogation. At the beginning of the design learning process, design students start to learn how to design as a *novice*. However, they do not have any conceptual or procedural knowledge about design (Schön, 1983). They do not know the specific meanings of the esoteric conditions of both the operational movements and the related design word knowledge (Schön & Wiggins, 1992). This body of knowledge is used during the practice of the profession. This knowledge is referred to as *procedural knowledge* (Crowder, 1993). According to Eastman (2001), studio instructors present this *tacit knowledge* generally in design studios.

Goldschmidt (2005) argues that two types of learning take place in the design studio. These learning types are *conceptual learning* and *professional learning*. According to Goldschmidt (2005), the design process, after determining the problem, is shaped by designers through interpreting the problem based on the *background knowledge* that people have had in their previous education and life experiences. Moreover, each person has his or her *own notes* with their own cognitive and personal characteristics. These notes and knowledge shape the design process. Conceptual learning is concerned with concept identification and shaping. Professional learning is concerned with using field-specific knowledge to solve a design proposal or concept (Goldschmidt, 2005). *Professional learning* as described by Goldschmidt (2005) is about the ability to use *procedural knowledge* (Crowder, 1993). Therefore, design is not just about *doing* an action. Design activity is based on cognitive abilities. In the design process, cognitive abilities guide the process. These abilities, which include competences such as reasoning, thinking and learning, can be different in each person.

3 Cognitive Components of Design

Design involves different mental stages (Akin, 1986). Designers learn these mental stages by experimenting, thinking, intuiting, and doing. Designers work in a process that proceeds from abstract and ill-defined problems (Dunbar, 1998). The human cognitive system has extraordinary abilities to deal with ill-defined problems such as design (Goldschmidt, 2017). Representation is the basic component of this process both as a mental activity and as an externalization of this activity (Goldschmidt, 2007). According to Goldschmidt (2017), the design process contains certain stages. These stages are acquisition of knowledge, selection of appropriate knowledge, association or transformation, production of alternative synthesis and formation of new design ideas (Goldschmidt, 2017). As in the actual design environment, the design studio has similar stages in the design process (Suwa & Tversky, 1997). While seeking solutions to design problems at hand, students are transforming their knowledge and experiences they have learned in combination with other interactions in the process (Goldschmidt, 2017). A synthesis of existing knowledge and new learned knowledge emerges in instructor-student critiques in the design studio. The resulting product is an example of interactions within the process. The design feedback that is carried out to transfer the mental models of the instructor and the student to each other usually takes place with visual representations.

3.1 Representation

Designers re-represent their mental representations through externalizations, and images that are externalized become internalized again in the mind of the designer. The designer needs representations to describe the image of the design in his/her mind and to communicate with himself/herself and others. They use representations to both solve these problems and create a language (Oxman, 2001). According to Akin (1986), representation is an important part of a physical intuition and design synthesis. Representational activity has an important role in design problem solving and it is used externally in graphic domain or internally in imagery domain (Akin, 1986). Representation is the tool of shaping thought (Akin, 1986). In other words, representation is not only a passive mechanism that externally displays what the mind contains, but it is actively guiding design (Akın & Moustapha, 2004). The relationship between external and internal representations should be examined to understand the importance of representations in the design process (Johnson, 1998). Internal representations and external representations are coupled and enable a complementary cognitive system. External representations are either externalized versions of internal representations or modifications of already existing representations. Everything we perceive with our sense organs, such as visual images, speeches and writings, is an external representation. In general, external representations in the field of design are plan, section, elevation, 3D or 2D images, models, diagrams, graphics, digital representations, or sketches. Unlike internal representations that occur in the mind during design, external representations also allow interaction with other persons and teams involved in the design process (Brereton, 1999).

In design, the most common type of representation is sketch. The reason for this is that the nature of the sketch overlaps with the image as they are both blurred and vague. In the design process, the image is uncertain, blurred and undefined. For this reason, it takes time for the image to become visible. The vague nature of sketch is very suitable for this situation. Sketching is fast enough that it does not interrupt the flow of thinking. Goldschmidt (2017) argues that sketch is a *laboratory* where the designer can test solutions. According to Goel (1995), the sources, which are used in the serial sketch process, are obtained from either long-term memory or previous solutions. Each drawing in the sketch process includes both a syntactic source and a semantic source. Sketching enables changes in design along lateral and vertical transformations. The lateral transformation implies a differentiation of thought. Vertical transformation suggests a change of an idea by way of detailing. In these transformations, the freehand sketches facilitate creativity and exploration through their dense and ambiguous structures (Goel, 1995). Thus, lateral transformation reduces the risk of fixations that may occur at the beginning of the design (Goel, 1995). In the design process, serial sketch activity aims to provide new options. This repetition comes with continuous feedback. This process is basically the stage that Goel (1995) refers to as a vertical transformation. In the design process, internal representations and external representations influence each other. At the same time, it is possible to say that they are part of a system where they are constantly changing into one another. Following this line of argument, this study questions how external representations support and/or enable the process of design thinking and learning in the studio environment during interactions among a student and multiple instructors.

3.2 Reasoning

Reasoning is one of the cognitive components that determine the response of people to conditions or events (Rittel, 1987). According to Rittel (1987), reasoning is in the essence of design process and design thinking. In design, reasoning is theorized as abductive, deductive and inductive reasoning (Dorst, 2011). When looking for a solution to a design problem, designers transform their knowledge and experience they have learned and continue to learn by combining it with other interactions in the process. In the design process, visual images or representations are a very effective component for some reasoning types such as analogical reasoning (Gentner & Stevens, 1983), case-based reasoning (Kolodner, 1993), pictorial reasoning (Gero, Tham & Lee, 1991) and visual reasoning, which includes mental imagery and visual representations, (Oxman, 2001). According to Oxman (2001), representation which is used in visual reasoning, can be an external representation that can be matched to an internal representation. Studies on visual reasoning show that visual reasoning interacts with external representation in the perceptual process (Schön & Wiggins, 1992). According to Goldschmidt (1991), it is possible to directly access the knowledge contained in the images through pictorial reasoning. However, it is also possible to access knowledge that they do not expressly disclose (Goldschmidt, 1991). Goldschmidt (1991) argues that in the design process, pictorial reasoning takes place in two different ways. The first is *seeing that* and the other is *seeing as*. *Seeing that* is reasoning by perceiving the image as is. In other words, it is a reasoning that does not invoke different associations than its initial and immediate signifier. *Seeing as*, in contrast, is the result of interaction with association of ideas (Goldschmidt, 1991). Sketching is a process that involves both *seeing as* and *seeing that*. Goldschmidt (1991) argues that sketch is a systematic dialectic between seeing as and seeing that.

In the design process, any stimulus recalls knowledge from memory. The recalled knowledge and existing knowledge come together by way of reasoning and a new idea/product is created. This transformation allows the designer to produce an alternative solution. So, reasoning and knowledge transformation is important in the design process. Especially, in design teams like instructor-student, sharing knowledge between team members is important to create alternative solutions. So, sharing knowledge allows knowledge transformation in this process. In design, sharing knowledge is sharing mental models. Shared mental models are created by way of interactive imagery. Images in interactive imagery are not taken directly from memory. A person can take an image of a previously perceived image in this process. According to Goldschmidt (1991), imagery is the essence of seeing something as something else. If this happens in the sketch process or with any external representation, it is "interactive imagery" in words of Goldschmidt (1991, p. 131). The interactive imagery allows the designer to communicate with the materials (Goldschmidt, 2001).

4 Case Studies

Four students' project developments were investigated in this study. These were analysed specifically with a focus on their conceptual phase. The project development continued for fourteen weeks and in some cases the conceptual phase continued till after the tenth week when the third midterm of the semester was scheduled. The students were asked to design a work place that will foster creativity and collaboration among the workers as an alternative to office plaza work environments. In each case study, the relationship between design learning and interactive imagery facilitated through shared mental models are examined. Lateral and vertical transformations in students' representations are examined based on Goel's study (1995). In addition to this, episodes of *seeing as* and *seeing that*, as defined in the work of Goldschmidt (1991), are identified in each design process. Each student's process is broken into steps according to the nature of transformations in their schemes accompanied with the determination of the kind of pictorial reasoning, i.e., seeing that or seeing as, used by the student.

4.1 Student 1

The student began the project with the idea of "creating connections between high buildings" but quickly after changed his concept as "work-game". During the conceptual development process of his project, he tried to reflect the concept requirements on his design scheme. His project was transformed mostly through *lateral transformations* instigated by instructors' contributions and his willingness to pursue them at every step. After each communication with instructors, the student managed to conceptually shift his proposal throughout the conceptual phase. It is possible to interpret that the student took into consideration the instructors' proposals and he tried to use them and expand on them. Therefore, his attitude is determined to be closer to that of an *explorer*. The process of the student is summarized graphically in consecutive steps: Step 1 (Figure 1), Step 2 (Figure 2), Step 3 (Figure 3), Step 4 (Figure 4), and Step 5 (Figure 5); and the types of reasoning and transformations are tabulated (Table 1, Table 2, Table 3, Table 4, and Table 5) as follows:

Step 1: Panel Review

Table 1. Step 1 of Student 1

Step1	**Type of Reasoning**	**Type of Transformation**
Student	seeing as	lateral transformation
Instructor 1	seeing as	lateral transformation
Instructor 3	seeing as	x

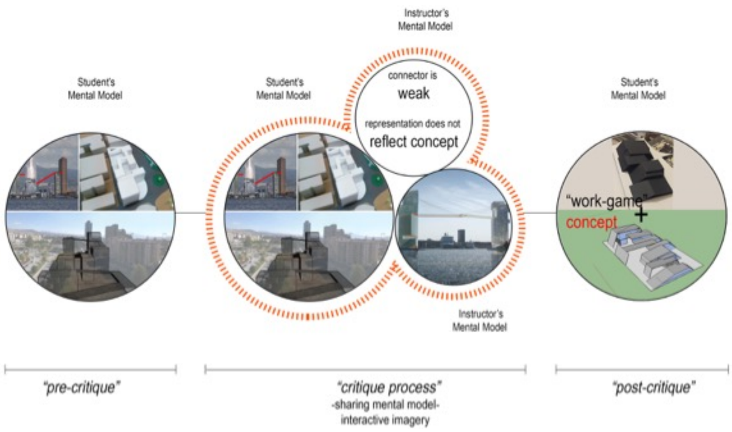

Figure 1. Step 1 of Student 1

Step 2: Desk Critique with Instructor 1

Table 2. Step 2 of Student 1

Step 2	**Type of Reasoning**	**Type of Transformation**
Student	seeing as	lateral transformation
Instructor 1	seeing as	lateral transformation

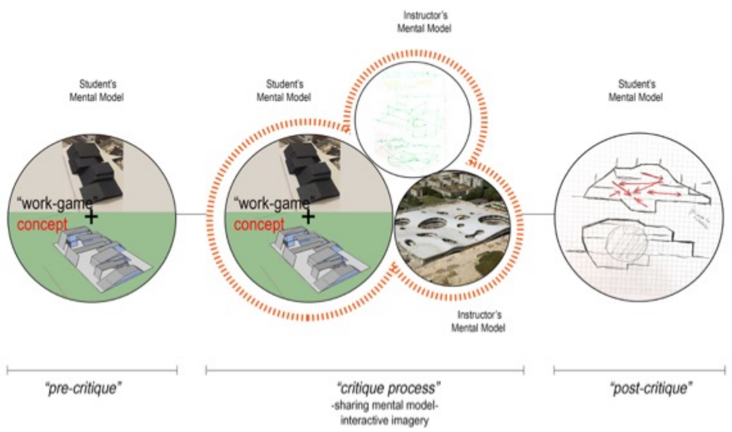

Figure 2. Step 2 of Student 1

Step 3: First Midterm Jury

Table 3. Step 3 of Student 1

Step 3	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 2	seeing as	lateral transformation
Instructor 3	seeing as	x

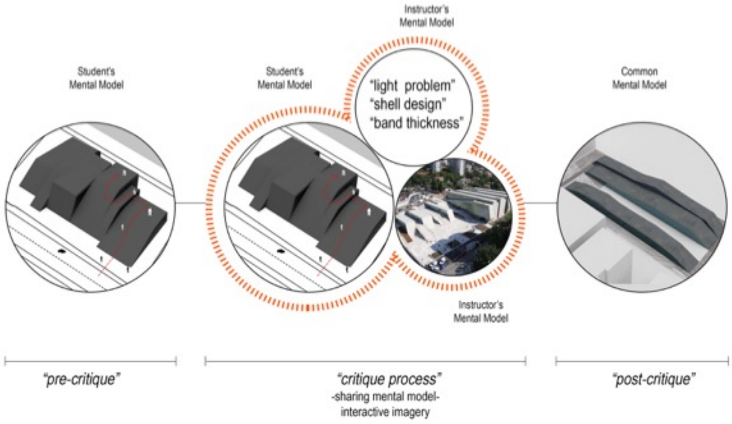

Figure 3. Step 3 of Student 1

Step 4: Desk Critique with Instructor 4

Table 4. Step 4 of Student 1

Step 4	**Type of Reasoning**	**Type of Transformation**
Student	seeing as	lateral transformation
Instructor 4	seeing as	lateral transformation

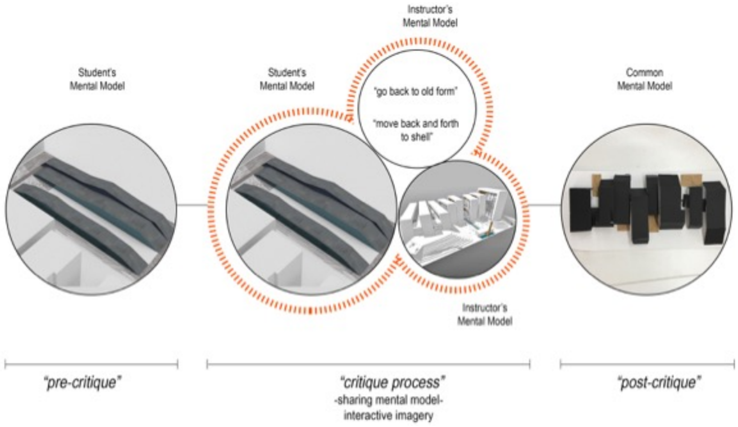

Figure 4. Step 4 of Student 1

Step 5: Desk Critique with Instructor 1

Table 5. Step 5 of Student 1

Step 5	**Type of Reasoning**	**Type of Transformation**
Student	seeing as	lateral transformation
Instructor 1	seeing as	lateral transformation

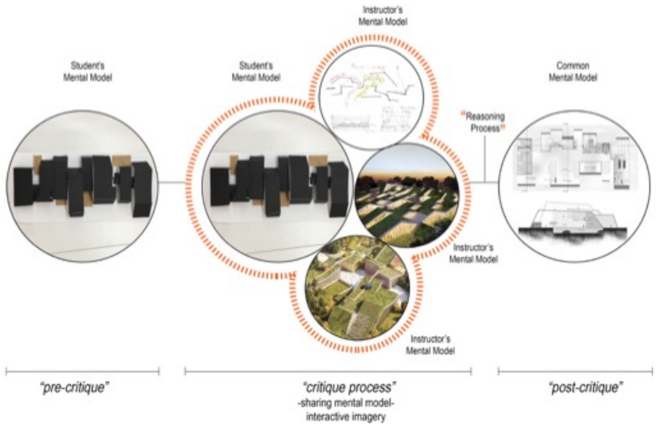

Figure 5. Step 5 of Student 1

Discussion

In this case, the student achieved a final scheme mostly with lateral transformations (in Step 1, Step 2, Step 4, and Step 5) in the conceptual development process (Figure 6). And also, in the conceptual phase of this student, pictorial reasoning is mostly "seeing as" (in Step 1, Step 2, Step 4, and Step 5) (Figure 7). It is possible to say that the student used the conceptual and procedural knowledge which is given by the instructors (Figure 8).

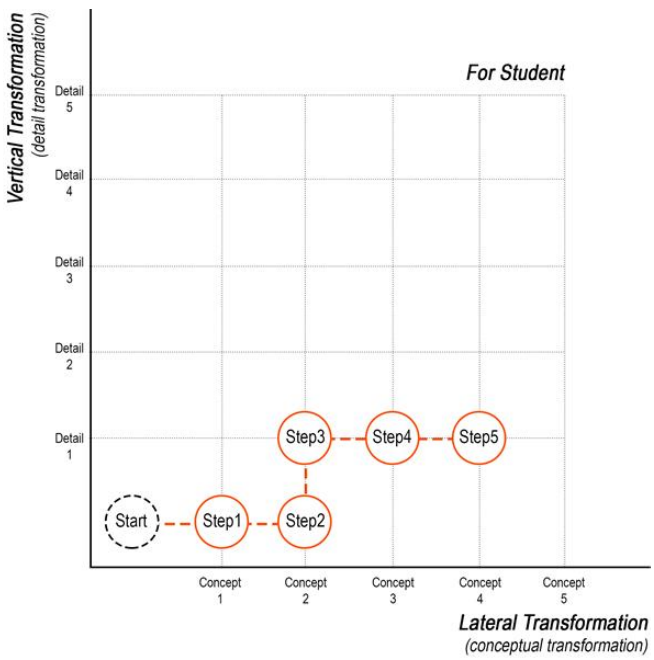

Figure 6. Transformation process of Student 1

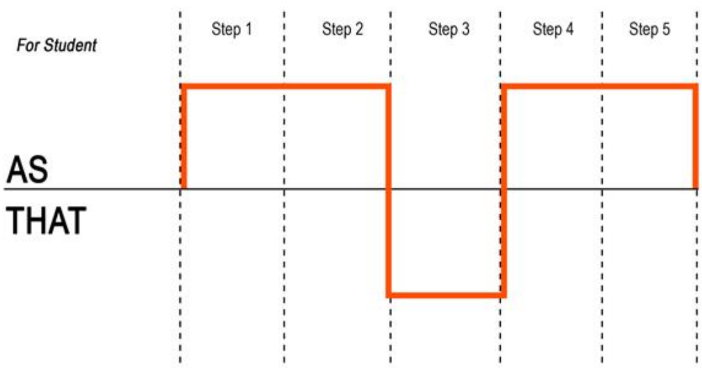

Figure 7. Pictorial reasoning process of Student 1

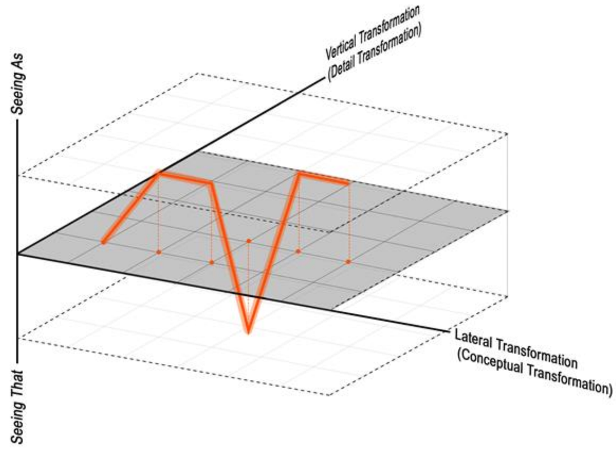

Figure 8. Design path of Student 1

4.2 Student 2

The student's concept was "ant colony". During the conceptual development process of his project, he did not make many changes to the form and the concept of the project. He did not want to change his project radically. Therefore, his attitude is labelled as *scrutinizer*. At this point, it is possible to interpret that the student did not take into consideration the instructors' proposals closely at the jury, panel review and desk critiques. In this case, interactive imagery remained limited with the initial image proposed by the student. During the project process, he made little changes in both conceptual and technical aspects of his project. The process of the student is summarized graphically in Step 1 (Figure 9), Step 2 (Figure 10), Step 3 (Figure 11), Step 4 (Figure 12), and Step 5 (Figure 13) and the types of reasoning and transformations are tabulated (Table 6, Table 7, Table 8, Table 9, and Table 10).

Step 1: Panel Review

Table 6. Step 1 of Student 2

Step1	**Type of Reasoning**	**Type of Transformation**
Student	x	x
Instructor 1	seeing as	x

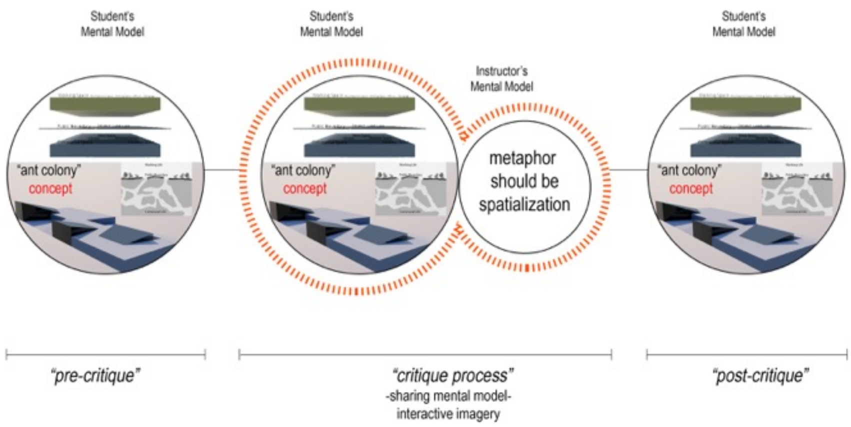

Figure 9. Step 1 of Student 2

Step 2: Desk Critique with Instructor 1

Table 7. Step 2 of Student 2

Step 2	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	lateral transformation
Instructor 1	seeing as	lateral transformation

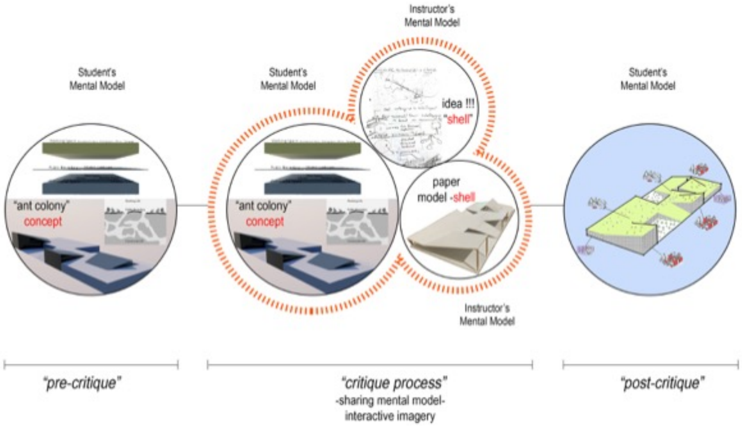

Figure 10. Step 2 of Student 2

Step 3: Desk Critique with Instructor 2

Table 8. Step 3 of Student 2

Step 3	**Type of Reasoning**	**Type of Transformation**
Student	seeing as	lateral transformation
Instructor 2	seeing that	vertical transformation

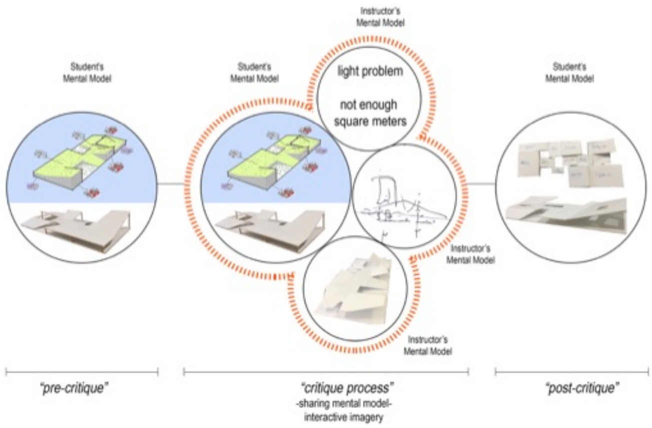

Figure 11. Step 3 of Student 2

Step 4: First Midterm Jury

Table 9. Step 4 of Student 2

Step 4	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 1	seeing as	x
Instructor 2	seeing as	vertical transformation

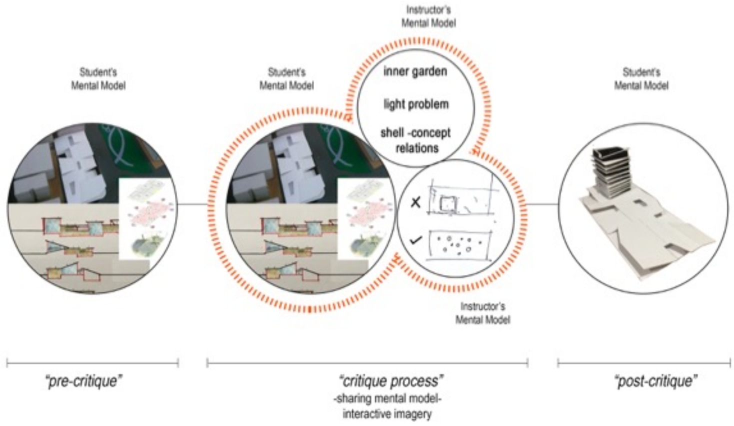

Figure 12. Step 4 of Student 2

Step 5: Desk Critique with Instructor 1

Table 10. Step 5 of Student 2

Step 5	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 1	seeing that	vertical transformation

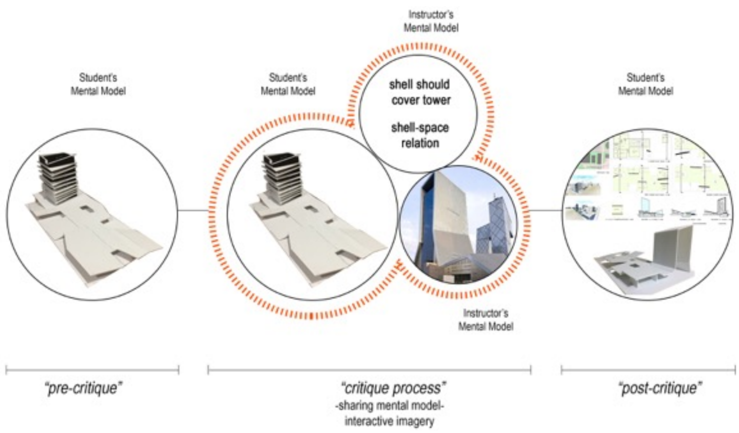

Figure 13. Step 5 of Student 2

Discussion

The student achieved a final product through both lateral transformation (in Step 2, and Step 3) and vertical transformation (in Step 4, and Step 5) in the project development process (Figure 14). It is possible to say that in the middle of the process, the student had a conceptual shift triggered by critiques. Student's pictorial reasoning is mostly *seeing that* (in Step 2, Step 4, and Step 5) (Figure 15). It is possible to say that the student did not make conceptual changes during the majority of the process (Figure 16).

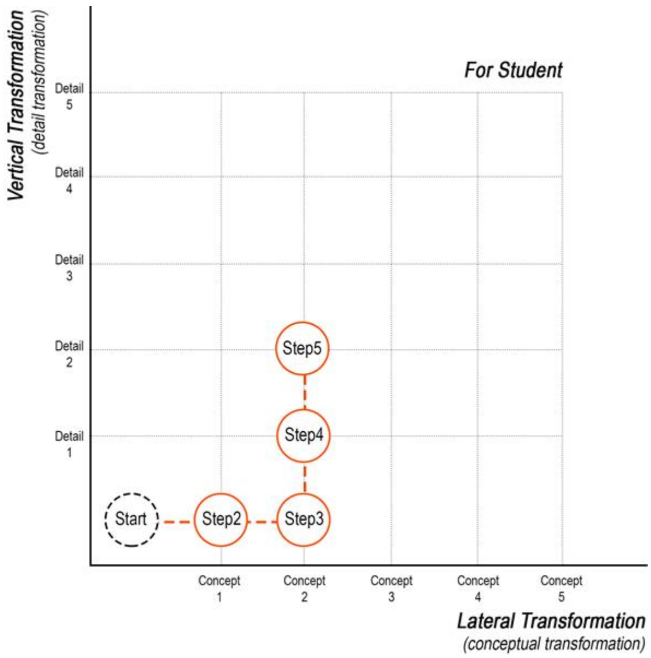

Figure 14. Transformation process of Student 2

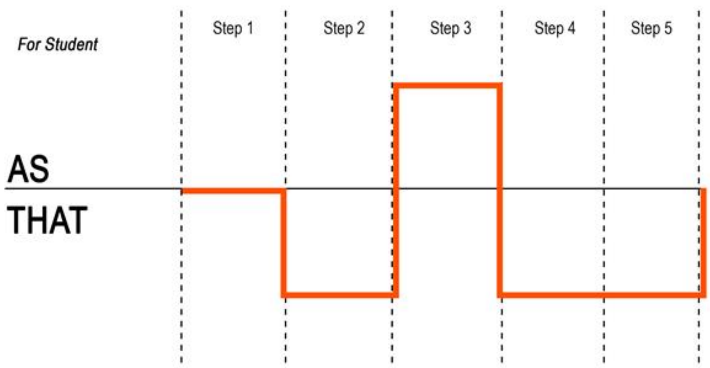

Figure 15. Pictorial reasoning process of Student 2

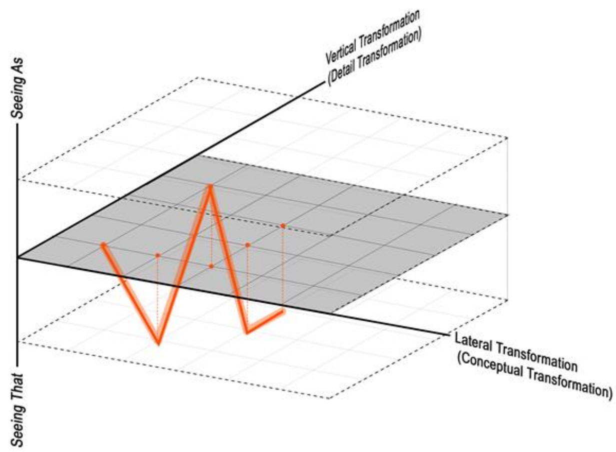

Figure 16. Design path of Student 2

4.3 Student 3

This student began the project with "creating a pedestrian axis" but he continued with a different concept. This concept emerged from the valley metaphor which was proposed by Instructor 1. During the conceptual development process of his project, he could not reflect properly on the metaphor. At some points the student directly copied some proposals which were offered by the instructors. Therefore, his attitude is described as a *follower*. He did not make an extra effort in adapting the suggestions to the project. In other words, he did not mix the instructors' suggestions with his own ideas. Perhaps, at the beginning of the project process, he did not have the knowledge or ability to represent these changes. However, during desk critiques, jury, and panel review, he conceptually developed his project through applying the instructors' proposals. The process of the student is summarized graphically in consecutive steps: Step 1 (Figure 17), Step 2 (Figure 18), Step 3 (Figure 19), Step 4 (Figure 20), and Step 5 (Figure 21); and the types of reasoning and transformations are tabulated (Table 11, Table 12, Table 13, Table 14, and Table 15).

Step 1: Desk Critique with Instructor 4

Table 11. Step 1 of Student 3

Step1	**Type of Reasoning**	**Type of Transformation**
Student	x	x
Instructor 4	seeing as	x

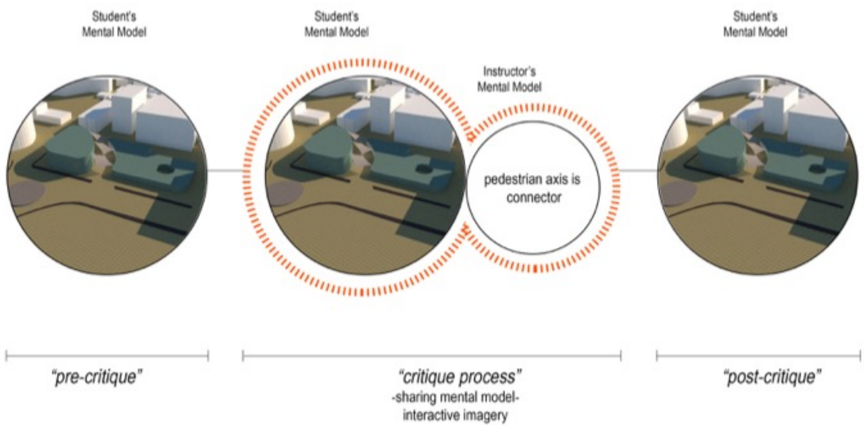

Figure 17. Step 1 of Student 3

Step 2: Desk Critique with Instructor 1

Table 12. Step 2 of Student 3

Step 2	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	lateral transformation
Instructor 1	seeing as	lateral transformation

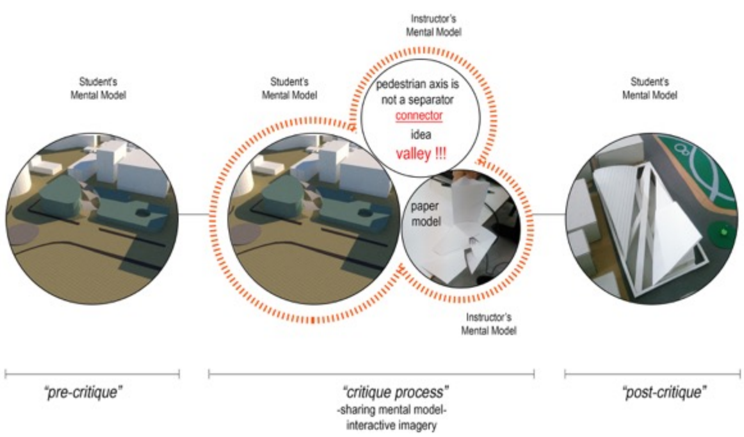

Figure 18. Step 2 of Student 3

Step 3: First Midterm Jury

Table 13. Step 3 of Student 3

Step 3	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 2	seeing as	lateral transformation
Instructor 4	seeing that	x

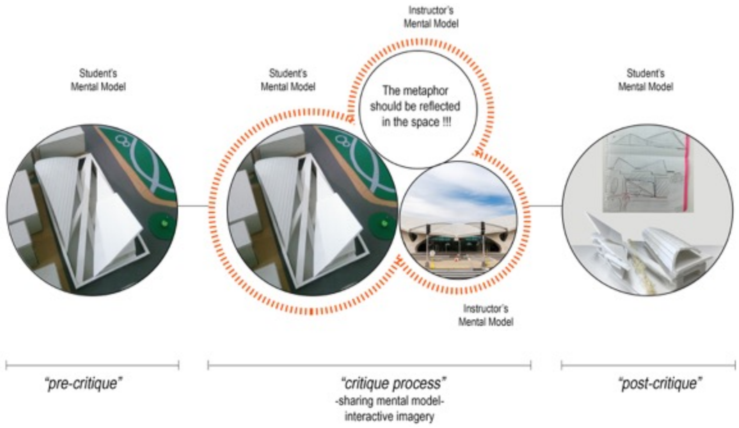

Figure 19. Step 3 of Student 3

Step 4: Desk Critique with Instructor 3

Table 14. Step 4 of Student 3

Step 4	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	lateral transformation
Instructor 3	seeing as	lateral transformation

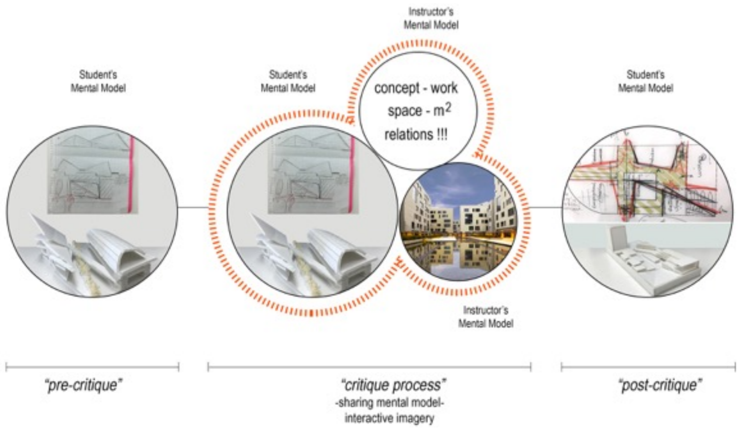

Figure 20. Step 4 of Student 3

Step 5: Desk Critique with Instructor 1

Table 15. Step 5 of Student 3

Step 5	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	lateral transformation
Instructor 1	seeing as	lateral transformation

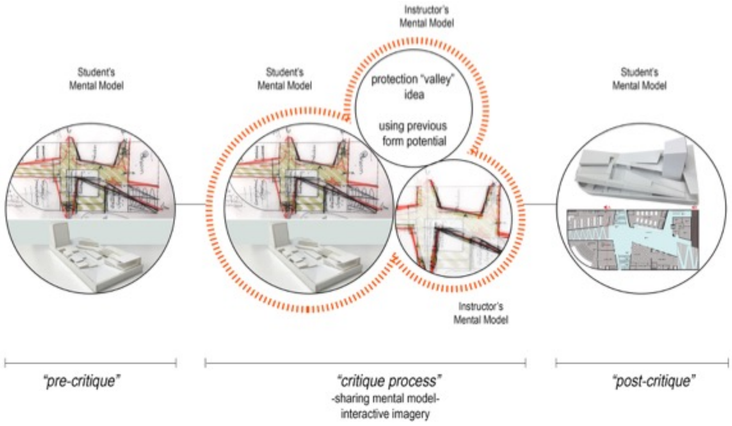

Figure 21. Step 5 of Student 3

Discussion

The student achieved a final product mostly with lateral transformations (in Step 2, Step 4, and Step 5) in the project development process (Figure 22). It is possible to say that the student produced a new scheme mostly with conceptual shifts from the knowledge which was obtained from critiques and juries. But his pictorial reasoning is *seeing that* at all steps (Figure 23). It is possible to say that the student did not add any interpretations on instructors' proposals which were given at the critiques (Figure 24).

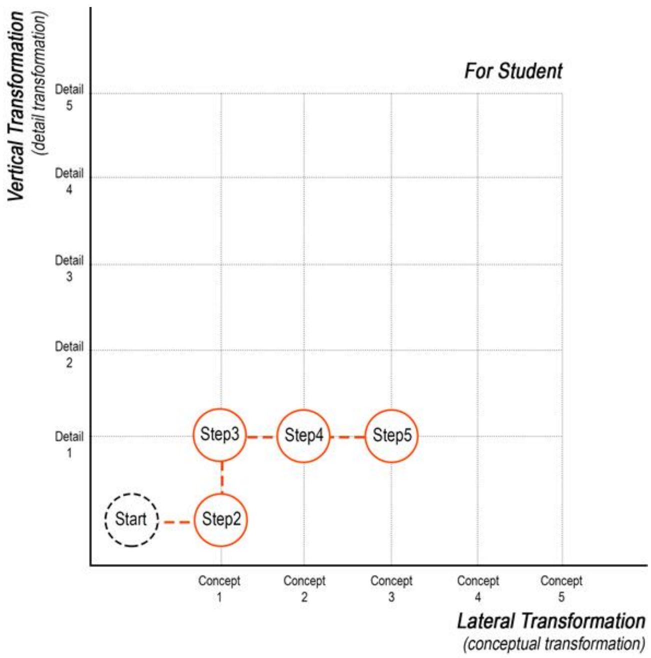

Figure 22. Transformation process of Student 3

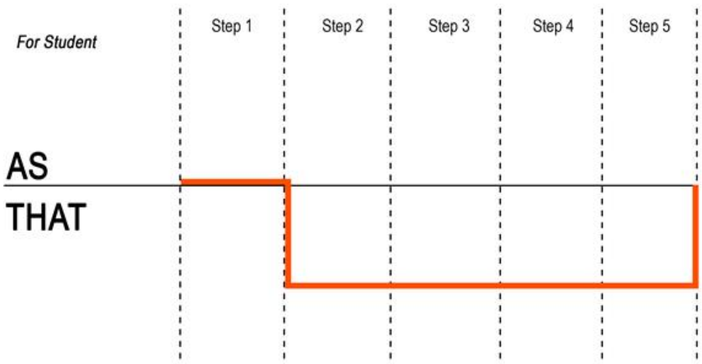

Figure 23. Pictorial reasoning process of Student 3

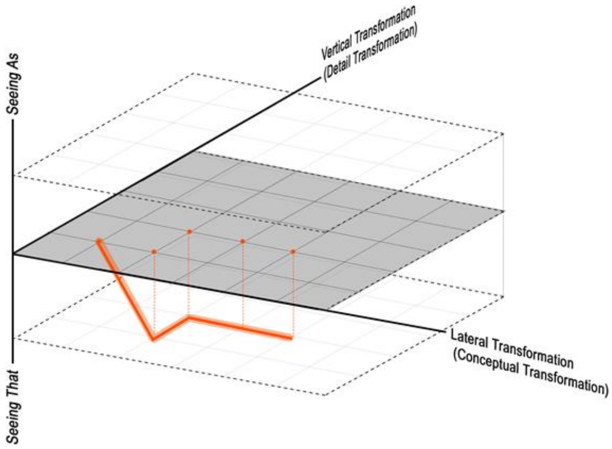

Figure 24. Design path of Student 3

4.4 Student 4

The student's concept was "cross pollination". During the conceptual development process of her project, she could not adequately reflect her concept and metaphor. Instructors proposed different perspectives to develop her project at the jury, panel review and desk critiques. However, the student could not grasp the different perspectives. Thus, she developed her project with only minor changes, but she managed to keep her initial concept until the end of her project. She made efforts to reflect the concept to the project. She took into consideration the instructors' suggestions during the project development process. Although she was not very successful while adapting the instructors' suggestions to the project, she was eager to develop it. Therefore, her attitude is characterized as a *struggler*. The process of the student is summarized graphically in consecutive steps: Step 1 (Figure 25), Step 2 (Figure 26), Step 3 (Figure 27), Step 4 (Figure 28), and Step 5 (Figure 29); and the types of reasoning and transformations are tabulated (Table 16, Table 17, Table 18, Table 19, and Table 20).

Step 1: Panel Review

Table 16. Step 1 of Student 4

Step1	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 1	seeing as	x
Instructor 2	seeing as	lateral transformation
Instructor 4	seeing as	x

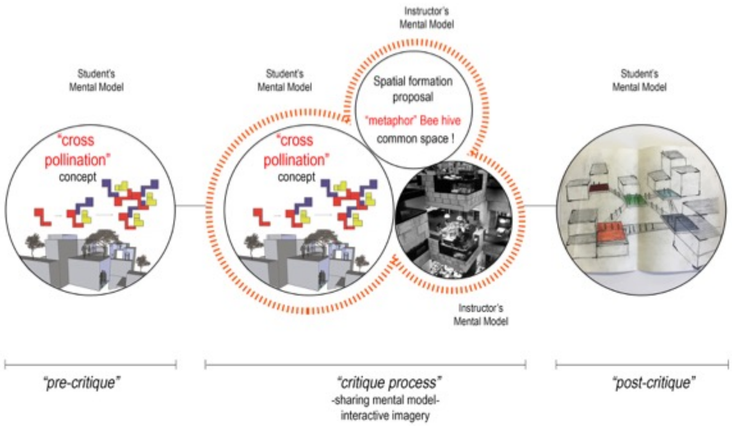

Figure 25. Step 1 of Student 4

Step 2: Desk Critique with Instructor 1

Table 17. Step 2 of Student 4

Step 2	**Type of Reasoning**	**Type of Transformation**
Student	seeing as	lateral transformation
Instructor 1	seeing as	lateral transformation

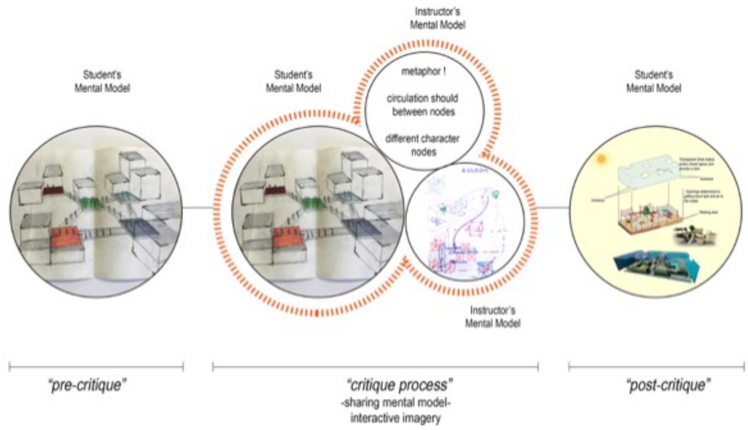

Figure 26. Step 2 of Student 4

Step 3: First Midterm Jury

Table 18. Step 3 of Student 4

Step 3	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 1	seeing as	x
Instructor 2	seeing as	lateral transformation

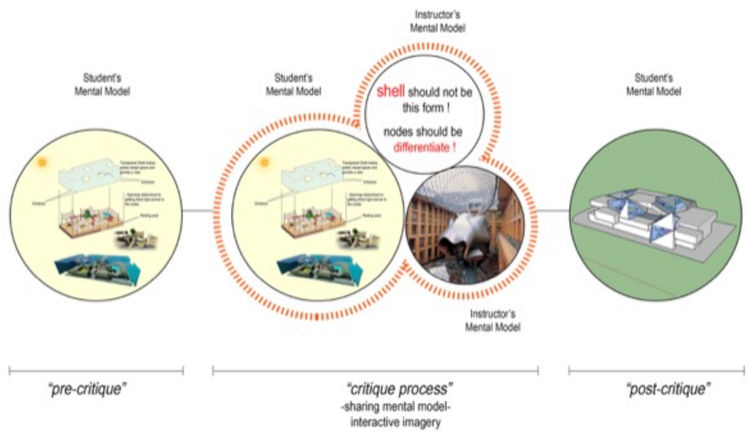

Figure 27. Step 3 of Student 4

Step 4: Desk Critique with Instructor 2

Table 19. Step 4 of Student 4

Step 4	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 2	seeing as	lateral transformation

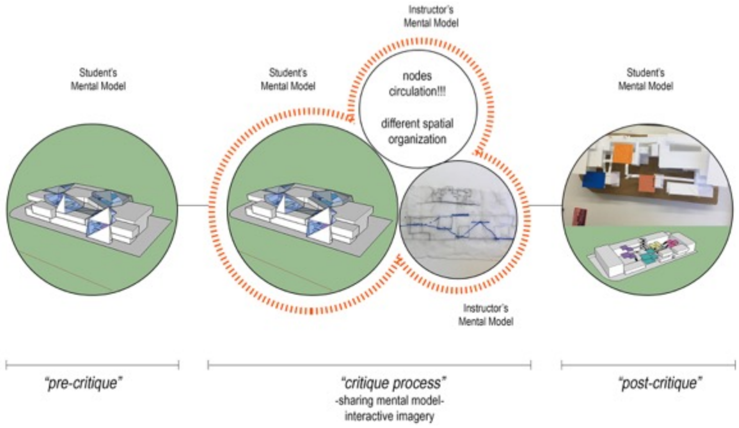

Figure 28. Step 4 of Student 4

Step 5: Desk Critique with Instructor 1

Table 20. Step 5 of Student 4

Step 5	**Type of Reasoning**	**Type of Transformation**
Student	seeing that	vertical transformation
Instructor 1	seeing as	lateral transformation

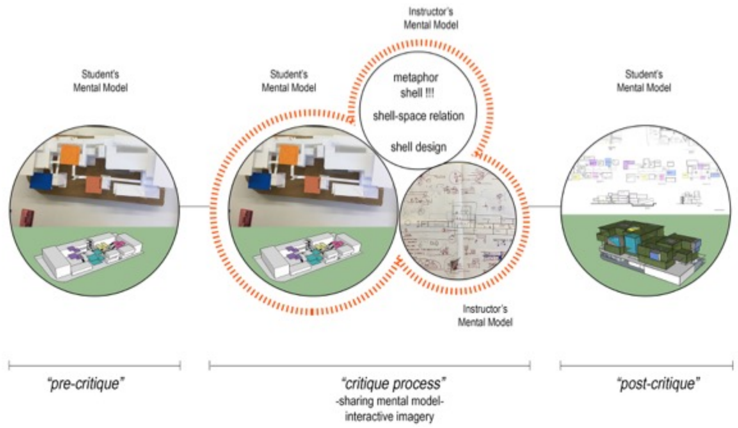

Figure 29. Step 5 of Student 4

Discussion

The student achieved a final scheme mostly with "vertical transformations" (in Step 1, Step 3, Step 4, and Step 5). At this point, it is possible to say that the student produced a new scheme mostly with changes concerning detailing (Figure 30). The student created a new scheme with conceptual knowledge during the reasoning process. In the project process of this student, pictorial reasoning is mostly *seeing that* (in Step 1, Step 3, Step 4, and Step 5) (Figure 31). At this point, it is possible to state that the student could not add new conceptual approaches to her scheme after desk critique or juries (Figure 32).

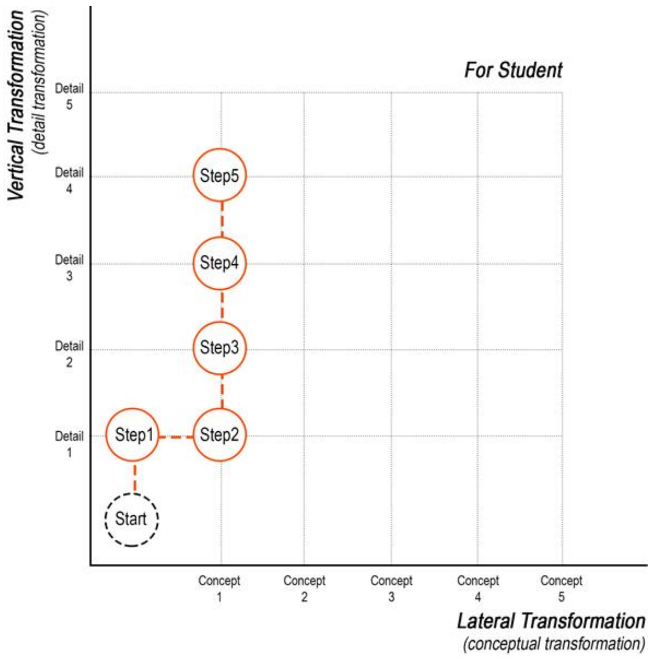

Figure 30. Transformation process of Student 4

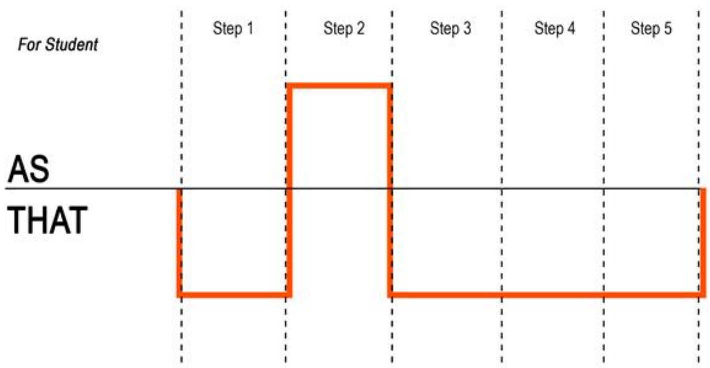

Figure 31. Pictorial reasoning process of Student 4

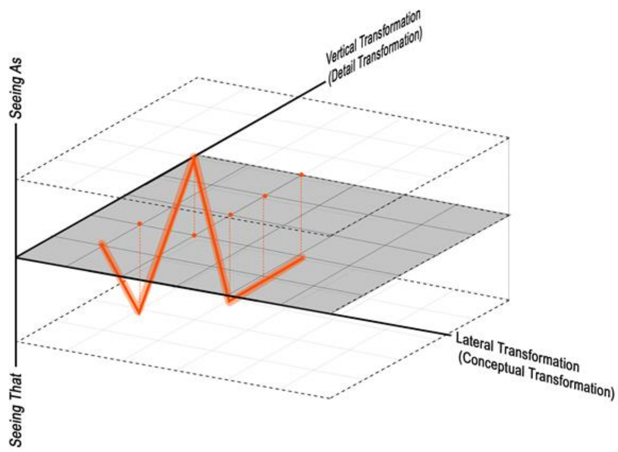

Figure 32. Design path of Student 4

4.5 Results

In this study, four cases were discussed and analysed. In each case, conceptual development processes of students' projects were analysed in terms of visual reasoning strategies, i.e., *seeing as* and *seeing that*, used by instructors and students and of shifts in design ideas, i.e., lateral and vertical transformations. When four cases are compared, it is possible to say that each case illustrates a different process. Both students and instructors during the interactive imagery sessions of design critiques created new images with externalized mental models through external representations facilitated by interactions between different media, the instructors, and the students.

In these cases, the initial schemes are conceptually and/or formally transformed. These transformations took place differently in each case (Figure 33). At panel reviews, midterm juries, and desk critiques, instructors provided conceptual and procedural knowledge to the students. Students, in turn, designed new schemes with conceptual and procedural knowledge during the pictorial reasoning process. However, each student developed a product with different pictorial reasoning. When the pictorial reasoning processes of the students are examined, it is possible to say that each student follows a different process (Figure 34). Transformations (lateral-conceptual, vertical-detail) and pictorial reasoning styles (seeing as, seeing that) occurred with different frequencies and followed different paths in the process of each student. The reasons for these differences could vary from case to case (Figure 35).

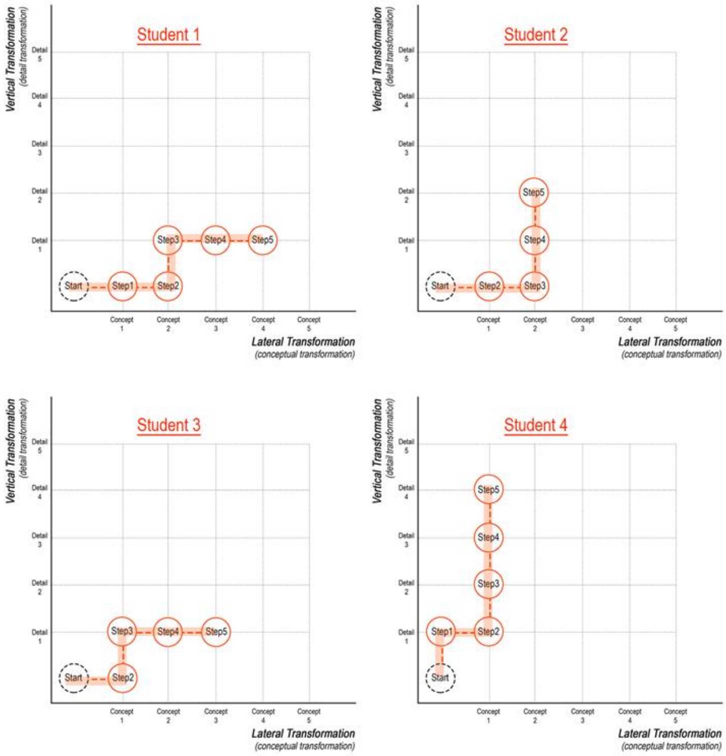

Figure 33. Transformation process of students

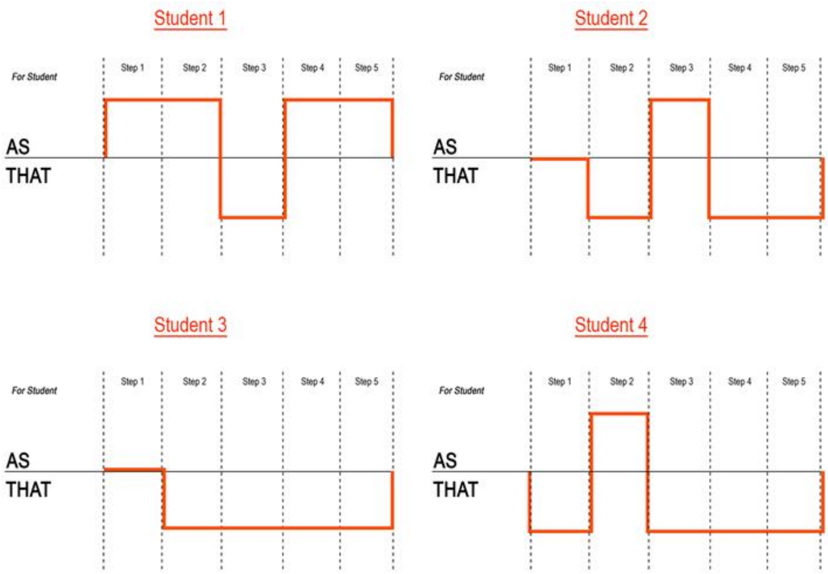

Figure 34. Pictorial reasoning process of students

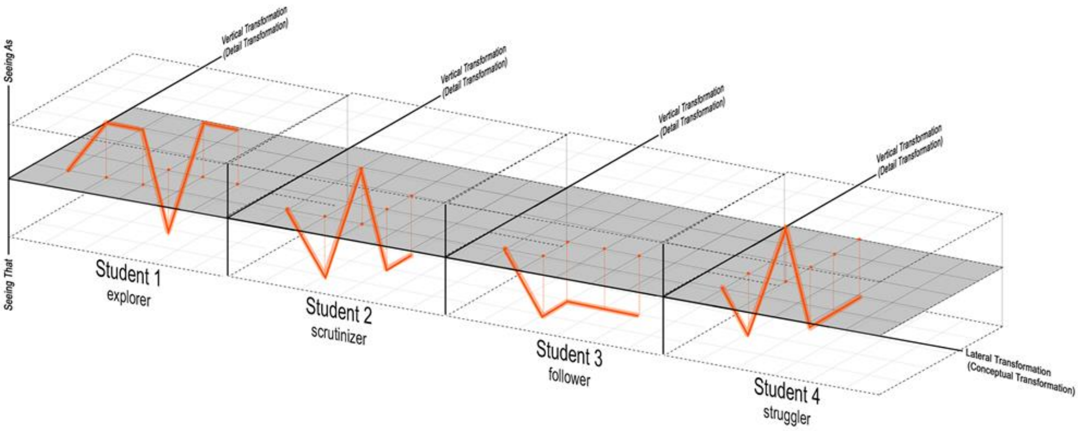

Figure 35. Design path of students

According to Goldschmidt (2005) and Schön (1985), one of the reasons is the personal interpretation of the design situation in hand by each designer. The design process is shaped by designers through interpretations of the problem. However, the designer is not objective in this interpretation process. The reason for this could be related to *background knowledge* that people have had in their previous education, their life experiences and their *own notes* with their own cognitive and personal characteristics. These notes and knowledge shape the design process. Furthermore, in the design studio environment, instructor-student as a design team work together. A synthesis of existing knowledge and new learned knowledge emerges during instructor-student interactions. In other words, a new mental model emerges with shared mental models and this can be different in each team. Especially, in these cases, the final schemes emerge through synthesizing four different instructors' personal and cognitive characteristics in addition to the students' own personal and cognitive characteristics.

Briefly, in this study, different processes were observed due to the nature of the design process and the cognitive characteristics of the individuals. Although the processes of students were different from each other, it is possible to state that interactive imagery and shared mental models contributed to the students' design learning process through the learning of conceptual development.

5 Conclusion

The aim of this study was to investigate two questions: how interactive imagery facilitates construction of shared mental models in a design learning environment and how interactive imagery that occurs in the desk critique process performed by more than one instructor through the rotation method affects the student's conceptual space (solution space). Within the scope of the study, two cognitive components of design were explained to answer the research questions. These cognitive components are representation and reasoning. The effects of these components on design learning and design were examined. According to Uluoğlu (2000), design can be taught and learned through interaction between designers. Design activity is based on cognitive abilities that foster reflection on action and on other reflections. This approach explains why design cannot be taught with existing knowledge and skills (Uluoğlu 2000). When faced with a design task, the designer solves the design problem by using his/her knowledge and characteristics. Therefore, each person can create a different conceptual space in the design process.

In this study, the interactive imagery that takes place during the design process allows many different mental models. In a teamwork of instructor-student, mental models shape the process giving way to a synthesis of mental models. Therefore, each design process is unique and also is not linear. Being aware of cognitive activities, sharing mental models, and understanding the role of representations in guiding the process can contribute to design learning and teaching processes. In the design studio environment, the realization of the interactive imagery and shared mental models can affect the conceptual space of the students. It is possible that being exposed to different instructors would enhance interactive imagery.

When the rotational critique method applied in these cases is examined, it can be said that there are positive and negative aspects. As a positive aspect, students' designs benefit from four different instructors' personal and cognitive characteristics in addition to their own personal and cognitive characteristics. This method has the potential to expand the conceptual space (solution space) of students and to avoid early fixations or strict and utmost control of a single instructor over students' projects. However, sometimes this situation may be different. In the process, the student or instructor may be the dominant one. When the student is dominant, he or she can be fixated, stubborn, or a scrutinizer. When the instructor is dominant, students can become explorers, followers or submissive. These possibilities may cause or block divergence in the process. However, in the learning process, lack of convergence is not a failure because this possibility provides more opportunities for the students to try out new ideas. If it is considered that studio learning is a process rather than a product, this could be beneficial. On the other hand, this method can create confusion in the mind of the students and prevent them from arriving at a solution at all. However, when everything is taken into consideration, instructors' awareness of the relationship between the cognitive activity and the design process can lead to more successful results in design learning.

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