# THE INFLUENCE OF EMERGENT MIXED-REALITY TECHNOLOGIES ON DESIGN THINKING

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# ABSTRACT

## THE INFLUENCE OF EMERGENT MIXED-REALITY TECHNOLOGIES ON DESIGN THINKING



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Design Thinking is still an unexplored field in terms of usage of emergent technologies such as Virtual Reality (VR). This thesis focuses on the potentials of the Mixed-Reality (MR) environment, as the most recent evolution of VR-based technologies, in the context of architectural basic design education. The research analyzes the influence of emergent MR technologies on design thinking abilities of the first-year architectural students in the context of three-dimensional basic design tasks by comparing the two different design environments, which are the physical environment and the MR environment. The study consists of two sets of protocol studies based on a series of design processes by using regular design tools in the physical environment and using a new design tool in the MR design environment via Microsoft HoloLens. The protocol studies were conducted with four participants, who were the first-year architectural design students at METU, Department of Architecture. A mixed-methodology, which is a combination of think-aloud protocols, interviews, observation, and Linkography, was used to reach a reliable understanding of the potentials of the MR environment. Analysis of the protocol studies showed that there was a positive correlation between MR technology usage and the design thinking processes of the first-year architectural students. The results indicated that the participants experienced more creative and productive design processes in the MR design environment rather than the physical environment.

Keywords: Architectural Basic Design Education, Design Research, Linkography, Mixed-Reality Environments

# ÖZ

## GELİŞEN KARMA GERÇEKLİK TEKNOLOJİLERİNİN TASARIM ODAKLI DÜŞÜNME ÜZERİNDEKİ ETKİSİ



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Tasarım odaklı düşünme, sanal gerçeklik gibi gelişmekte olan teknolojilerin kullanımı açısından hala keşfedilmemiş bir alandır. Bu tez, sanal gerçeklik temelli teknolojilerin en yeni evrimi olan karma gerçeklik ortamının mimari temel tasarım eğitimi bağlamındaki potansiyellerine odaklanmaktadır. Araştırma, ortaya çıkan karma gerçeklik teknolojilerinin, birinci sınıf öğrencilerinin üç boyutlu temel tasarım görevleri bağlamında, iki farklı tasarım ortamını karşılaştırarak (fiziksel ve karma-gerçeklik ortamları) tasarım odaklı düşünme yetenekleri üzerindeki etkisini analiz ediyor. Bu çalışma, fiziksel ortamda alışılagelen tasarım araçlarını ve karma gerçeklik tasarım ortamında Microsoft HoloLens aracılığıyla yeni bir tasarım aracını kullanarak bir dizi tasarım sürecine dayanan iki aşamalı protokol çalışmalarından oluşmaktadır. Protokol çalışmaları ODTÜ Mimarlık Bölümü birinci sınıf öğrencisi olan dört katılımcı ile yürütülmüştür. Karma-gerçeklik ortamının potansiyellerinin güvenilir bir şekilde anlaşılmasını sağlamak için, sesli düşünme protokolleri, röportajlar, gözlem ve Linkografinin birleşimi olan karma bir metodoloji kullanıldı. Protokol çalışmalarının analizi, karma gerçeklik teknolojisi kullanımı ile birinci sınıf mimarlık öğrencilerinin tasarım düşünme süreçleri arasında pozitif bir ilişki olduğuna işaret etmektedir. Sonuçlar, katılımcıların fiziksel tasarımdan ziyade karma-gerçeklik tasarım ortamında daha yaratıcı ve üretken tasarım süreçleri yaşadıklarını göstermiştir.

Anahtar Kelimeler: Mimari Temel Tasarım Eğitimi, Linkography, Tasarım Araştırmaları, Karma Gerçeklik Ortamı

To My Brothers, İ.İlham Cindioğlu and Önder Cindioğlu

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# CHAPTER 1

# INTRODUCTION

## 1.1. The Motivation of the Research

The basic design studio has significant importance for the first-year students and their educators in architectural design education. According to Findeli, Basic Design is the most accurate tool pedagogically for advancing students' 'visual intelligence, ethical sensibility, and aesthetic intuition'.[1] As an introductory course, the basic design studio can be considered as the composition of an organizational procedure to make students ready for the architectural design and to use the visual media in a logical framework. During Basic Design course, the designer (student) is expected to be able to make rational, supported, and 'defendable' design decisions.[2] As such, she will become competent in perceiving and construing the medium she operates on in relation to that she will reach resources to manage it to serve society's needs and desires.[3] To this extent, students need an exploration process to acquire visual thinking abilities and learn how to make logical and creative design decisions during the design process. However, novice designers usually start architecture education with weak abilities necessary for designing, because their earlier education may not support their design thinking procedures. Due to the dominance of instructional teaching methods in pre-university education, the students typically have rather limited experience in divergent thinking, which is necessary for different perspectives that encourage authentic and creative ideas. On the other hand, the basic design studio supplies an environment that opens to exploration and experimentation of novel ideas and solutions. It expects from

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[1] Alain Findeli, "Rethinking Design Education for the 21st Century: Theoretical, Methodological, and Ethical Discussion", *Design Issues* 17, no. 1 (2001): 16.
[2] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979).
[3] Ibid., 7.

designers to achieve their own exclusive perception[4], and that may become a challenge for a novice designer, which comes without divergent thinking experience. Despite the expectations and the nurturing environment of the basic design studio for idea generation, there could be still several challenges that limit students' divergent thinking abilities, such as their poor visual thinking, unawareness of the environment, lack of motivation caused by the unfamiliar learning environment and the deficiency of tinkering process, which covers generating a solution to a design problem and endeavoring to create better and more satisficing answers for it. Inherently, this situation affects the students' development process.

Basic design education not only requires the expectations above but also anticipates self-confidence and creative personality skills. Türel Saranlı emphasizes that basic design courses include an education of personality for the first-year students in a real term and he states that the designer's personality may allow to define the given problem, describe it clearly, comprehend the borders, all variables and examine the real problematic.[5] Saranlı also adds that all these objectives have not always been an opportunity for actualization and reflection into the design work of the first-year students in the basic design studios. Consequently, many design studio educators may prefer to evaluate their students' success based on not only the final products but also their development process during the basic design course. Still, students may end the course with lack of the generating creative thinking ability and the learning outcomes of tinkering, even if they succeed to detach from their familiar thinking and problem-solving mechanisms, or at least understand the design fundamentals in some degree. Instead of generating creative solutions, searching for new relations between spatial orders and develop their design-thinking processes, students may face the challenges

[4] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017).
[5] Türel Saranlı, "Başlangıçtan Bugüne Temel Tasarım", in *Temel Tasarım / Temel Eğitim* (Ankara: METU Faculty of Architecture Press, 1998).

of consuming their limited time to struggle with the physical limitations of the craft materials and craftsmanship details.

This research supports that the lack of development process for a design problem is a result of not being capable of fully exploring the design space by the first-year students. Exploring design space refers to searching for alternative design solutions and evaluating the alternatives during the design process. This study estimates that students could not have enough time for generating a sufficient number of alternative design solutions in a specific given time during the first year of their architectural education. Lawson states that continuing architectural design education with a few traditional craft materials is not the right attitude anymore, so new technologies must be involved in the learning process of the students.[6] In consideration of these abovementioned challenges, the use of emergent technology in design education has been investigated, and it has been observed that the idea of the agency of emergent design tools is not new. Nevertheless, the past studies, which have been focused on the usage of digital media or immersive environment technology in design education, have some specific limitations. Although computational design tools (mostly modeling tools such as AutoCAD, 3DsMax and algorithmic tools such as Grasshopper 3D) have been utilized for first-year design problems, they do not address the problem specific to the first-year design studio defined above. On the other hand, immersive environments such as Virtual Reality Aided Design (VRAD) obligate to add more data to the virtual model than CAD tools.[7] Consequently, this research study investigates the potentials of immersive environments in design education and covers the implementation of a new design tool. A Mixed-Reality (MR) environment has been proposed as a supportive design tool for basic design education in terms of its

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[6] Bryan Lawson, *How Designers Think: The Design Process Demystified* (Elsevier, 2006): 6.
[7] Philippe Fuchs, Pacal Guitton and Guillaume Moreau, *Virtual Reality: Concepts and Technologies* (Boca Raton, FL: CRC Press, 2011).

possibilities to maintain a more encouraging design environment and alleviating the disadvantages of the physical world.

## 1.2. Research Questions

The usage of VR-based technology in design education has been evaluated in many studies through questionnaires It is now well established that VR-Based technologies have a motivational impact on the designer despite their limitations such as restricted interaction abilities to manipulate the design elements. However, the influence of VR-based design tools on design thinking has remained unclear.

The aim of the study is to contribute understanding of how these emergent technologies influence design thinking activities of the designers. In this regard, the current study addressed the following research questions:

- How could MR effect the tinkering process of the user and what influenced most the users for reframing the problems to improve the solutions? (Tinkering)
- What are the advantages and disadvantages of MR design environment on productive thinking? (Productive Thinking)
- How is MR affecting the users' creative thinking abilities? (Creative Thinking)
- How could MR be supportive to understand 3D relationships and manipulating design elements through 3D perception? (Thinking in 3D)
- What could be the benefits of MR on finding ideas and searching for alternatives? (Idea Generation)
- What could be the possible effects of MR for designation necessary design components of solution ideas? (Providing Needs)
- How did the novice designers adapt the MR tool and learn to use basic abilities to design in the MR environment? (Adaptation and Usability)
- What is the most effective gesture-based manipulation for interaction with the design in MR? (Gesture-Based Manipulation)

To addressed abovementioned research questions, a comprehensive methodological approach has been needed for this study. The methodological approach taken in this research is a mixed methodology based on a set of protocol studies, which include Linkography, observation and semi-structured interviews with the participants. The mixed methodology is a combination of quantitative and qualitative approaches. The pilot studies were conducted to develop a new design tool and the mixed methodology to evaluate the design tool in regard to the research questions. The methodology of this research will be expanded in Chapter 3.

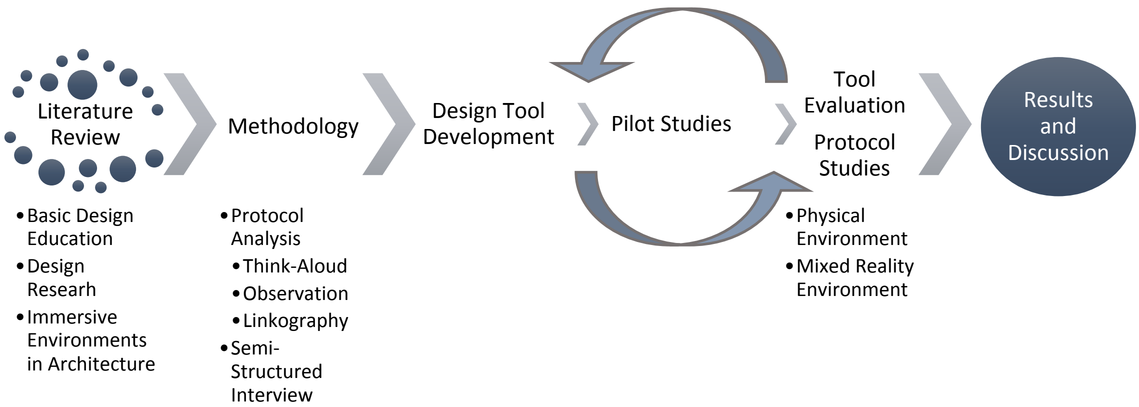


*Figure 1-1.* Research Process Illustration

### 1.3. Structure of the Thesis

The thesis consists of six chapters and they will be expressed in this present introduction chapter for a finer comprehension of the research study. The current chapter also includes the research statement and motivations.

Chapter two presents a refined literature review to specify and explain the essential concepts in three major parts. The first part emphasizes the aim of the Basic Design education and its origin, objectives, learning outcomes and nature. This part also states the key role of creativity in design education and the importance of creative learning strategies and tools through the past years. The second part of the literature review focuses on the design cognition and the major methodologies to examine design cognition and creativity. The first part of this section mentions of the design research and the empirical studies that utilized through the history by design-thinking researches, which aim to reveal design processes of the designers and discover the source of design creativity. Then, Linkography and related methodologies have been analyzed as an analytical method to be used in this study. This part has a crucial impact on the study in terms of evaluation of MR's potential in design-thinking procedures of the subjects. At the end of this sub-section, a brief design tool history has been presented. As a final part of the literature review, the third part explains the basic definitions of immersive environments including MR and gives information about the similar projects on utilization of immersive environments in design throughout the last few years. The scope of this chapter is providing the necessary knowledge to clarify the problems and obtain an awareness of recent studies in these fields. In relation to the literature review and researches, the thesis aims to figure out potentials of utilizing MR application in a basic design studio setting as a design tool.

Chapter three explains the methodology that has been used in this research and presents the protocol study used in the research. The most reliable methodologies have been discussed and a combined methodology, which is consists of protocol analysis, semi-structured interviews, and observation, has been selected. In addition to the combined methodology, Linkography, which is a technique to visualize design processes proposed by Gabriela Goldschmidt, has been stated as a representative implementation of a design process. Linkography has been utilized to visualize the design processes to provide a finer comparison between the two phases of the protocol studies in two different mediums in terms of explorations mainly for creativity, and design productivity. Linkography has been illustrated with its major components such as link index, link types and critical moves in this section. This chapter also covers both procedures of the protocol studies in the physical environment and in the MR environment. The new design tool has been tested and experienced by the first-year architecture students through a three dimensional (3-D) basic design task.

Chapter four presents the new design tool to use in the MR environment that has been developed with Burak Güneş Özgüney (METU, Graduate School of Informatics). This new design medium has been sustained by using an MR-based device, Microsoft HoloLens, and the developed design tool, which have been elaborated in this chapter explicitly. The motivation of the tool development, the features of the new design tool, geometry definitions, geometry transformations, and the apparatus, HoloLens, are the sub-sections of this chapter. Chapter five evaluates the new design tool through the protocol studies, interviews, observations, and the linkographs of the design processes. The results of the protocol studies in the physical environment through usage of the regular design tools have been compared with the protocol studies in the MR environment by using the new design tool. The results have been presented through the quantitative and qualitative data to observe the cognitive impacts of the MR on four first-year architectural students. The results and the comparisons have been discussed to define the potentials and limitations of the new design tool and the MR environment in terms of the outcomes of basic design education in architecture.

Finally, the last chapter summarizes the research questions and the scope of the study. Then, it presents a conclusion through the findings.

# CHAPTER 2

# LITERATURE REVIEW

The second chapter of the thesis presents a literature review on several related topics, including three main aspects that are focused on (1) basic design education; its origin, objectives, and nature, (2) design thinking and creativity research in design processes, and (3) Mixed-Reality and its application studies in various design processes.

## 2.1. Basic Design Education and Its Origin

Basic Design has originated in Bauhaus as a 'course' that aims to equip the designers for the future's design requirements and Basic Design course emerged from "the idea of formulating theories concerning vision and human behavior toward visual phenomena in conjunction with a desire to relate materials, patterns, and industrialized technologies."[8] Basic Design education has been one of the significant courses in the curricula of architectural schools since the foundation of Bauhaus in 1919. Lang emphasizes the relationship between Gestalt psychology, art, and the basic design course, and states that Itten, one of the prominent figures of the Bauhaus Foundation Course, grounds the principles of Basic Design on Gestalt theory to distance itself from the dominant pedagogical approach of the time, Ecole des Beaux-Arts[9]. Design education and visual arts have been influenced by the Gestalt theory since the late 1920s. Moholy-Nagy was a significant figure of Bauhaus that has pioneered the use

[8] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 9.
[9] Jon Lang, "Öğrenciler için Mimarlığa Giriş: Temel Tasarım Dersini Yeniden Düşünmek", trans. Aytaç-Dural Tuğyan in *Temel Tasarım / Temel Eğitim* (Ankara: METU Faculty of Architecture Press, 1998): 6.

of Gestalt principles in design education.[10] Gestalt Theory is based on the idea that the whole is more than the total of the parts and emphasizes that the relationships between objects in a composition change the perception.[11] Denel notes:

> In all visual phenomena, we will assume that the Gestalt Theory is true and good. Without going into the arguments and counter-arguments whether this is so or not, one can say that the wholism of Gestalt Theory, its rational approach that attempts to explain visual organization and perception will be accepted as the valid way we participate in our visual world.[12]

As also noted by Zuhal Ulusoy, the basic design ideas of Bauhaus continued to influence other advancing institutions that were developing a new approach in educational strategies in design, even after Bauhaus lost its activity in 1933.[13] To illustrate, Moholy-Nagy maintained the ideas of Bauhaus with some improvements for the New Bauhaus in Chicago.[14] Findeli mentions that the two significant improvements in the Basic Design course were developed by Moholy-Nagy. The first idea was the expansion of the curricula as addition of 'more technological arts like photography, film, kinetic and light sculpture, and nonvisual arts like music and poetry'.[15] The second important improvement was that Moholy-Nagy added a third dimension, 'science,' built on Gropius's famous motto: 'Art and Technology: A New Unity'.[16]

Özkar also emphasizes the relationship between Bauhaus and the technological developments in the past. To illustrate, Özkar mentions the administration of Hannes

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[10] Aktan Acar, "The Construction and Execution of Beginning Design Education" (M. Arch, Middle East Technical University, 2003): 18.
[11] Christian Norberg-Schulz, *Intentions in Architecture* (Cambridge, Mass.: The M.I.T. Press, 1966): 34.
[12] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 7.
[13] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 12.
[14] Alain Findeli, "Moholy-Nagy's Design Pedagogy in Chicago (1937-46)", *Design Issues* 7, no. 1 (1990): 4
[15] Ibid., 7.
[16] Ibid.

Meyer at Bauhaus, who transformed the institution into almost a research laboratory to practice an integrated approach between architecture and technologies.[17]

Özkar also states that the basic design education is accepted today still as the heritage of Bauhaus and as a starting point of the architecture education based on the exploratory design processes, which involves experimentation and design exploration with different materials, abstract forms, and problems in unfamiliar ways.[18]

Lang, on the other hand, states that Gestalt has a limited effect on the 3D world, and it is based on the two-dimensional (2D) design exercises mostly.[19] Lang revised the earlier Bauhaus objectives to present while also considering the ecological perspective, and states that there are three main objectives of the Basic Design course. The first one is making students conscious of the environment and how it works. The second one is improving students' communication skills, and as a third, developing the creative problem-solving mechanisms of the student.[20] He also points out the powerful effect of Bauhaus and its Basic Design course, on the many other architecture schools through the limitations of the Gestalt Theory.[21]

Consequently, the Basic Design education currently still appears as a preliminary course of the architectural curricula in many institutions in various forms. The foundation of the basic design courses in Turkey has been originating from METU and this research has been designed to conduct at METU, Department of Architecture, which is one of the institutions influenced by Bauhaus and Gestalt Theory during its presence. The following section of the literature review focuses on the common ground into defining the objective of the basic design studios.

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[17] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017): 100.
[18] Ibid., 88.
[19] Jon Lang, "Öğrenciler için Mimarlığa Giriş: Temel Tasarım Dersini Yeniden Düşünmek", trans. Aytaç-Dural Tuğyan in *Temel Tasarım / Temel Eğitim* (Ankara: METU Faculty of Architecture Press, 1998): 7.
[20] Ibid., 13.
[21] Ibid., 3.

### 2.1.1. The Course Objectives of Basic Design

Basic Design course has been greatly valued, due to its essential influence on the first-year students in architectural education. Basic Design is an introductory course for students of architecture, who need to develop necessary design skills for design problems in general. Thusly, Basic Design aims to provide these fundamental design skills in the first place, although its objectives have been changed and reevaluated since Johannes Itten and Bauhaus. Itten had stated his three major goals in the Basic Design Course, which were (1) revealing the students' creative thinking abilities and encourage them to have their own experiences and perception with their practices, (2) ensuring appropriate career decisions for the students through the experiments with various material types and (3) teaching the principles of design, the essentials of form and color.[22] On the other hand, Molohy-Nagy evaluated the original Bauhaus objectives in New Bauhaus, Chicago. Findeli summarizes the objectives defined by Moholy-Nagy, as comprehending 'plastic elements such as line, shape, volume, motion, etc.' and learning to use certain tools such as 'brush, pen, camera, wood, paper, etc.' in design.[23] In this way, he aims to reveal students' creativity through sensorial experimentations at basic workshops.[24]

Another critical view was proposed by Bilgi Denel. He criticizes the basic design approaches that blindly follows and implements Itten's personal thoughts through only the final products. According to him, realizing the design process itself is the sole reason that one has to be appraised for.[25]

To reconceptualize the Basic Design education to his time, Denel also questioned the secondary educations of the students before beginning an architectural institution.[26]

[22] Johannes Itten, *Design and Form: The Basic Course at the Bauhaus* (Reinhold Pub. Corp., 1964): 9.
[23] Ibid.
[24] László Moholy-Nagy and Daphne M. Hoffmann, *The New Vision 1928 and, Abstract of an Artist* (New York: Wittenborn, 1947): 22.
[25] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 12.
[26] Ibid., 4.

He observes that the students begin the architectural design education with lack of skills regarding independent thinking, critical thinking, visual awareness, and discipline.[27] Hereby, Denel adopts the main ideas of the Bauhaus and clarifies the fundamentals of Basic Design education at METU as follows. According to Denel, 'logic' is the first tool that must be developed as a foundation.[28] According to him, the main objectives of Basic Design are preparing students to utilize the visual media properly in a rational thinking process, to compose reasonable design decisions and to be able to represent their design ideas with a valid vocabulary.[29]

According to course catalog of METU, Department of Architecture, the major objectives of the Basic Design are imposing the studio culture upon students to ensure them being ready for architectural design, and studio culture has become familiar to them through the settlement of the necessary skills of design thinking and design exploration.[30] The design thinking, and design exploration processes cover exploration of organization, form, and space as the usage of various design elements and materials. The students are encouraged for experimental design thinking and making techniques.[31]

These abovementioned objectives are defined to prepare students for future architectural design problems, familiarize them with the studio environment and developing necessary abilities to design. In this regard, the course content could be summarized as an introduction to establish a brief vocabulary for their future design education and provide them fundamental design skills. Therefore, the Basic Design course includes several exercises to improve students' cognitive and sensorial skills to deal with design problems. These exercises commonly consist of the structuring

[27] Ibid., 12.
[28] Ibid., 6.
[29] Ibid., 7.
[30] "ARCH 101 Basic Design", METU Academic Catalog, accessed 26 August 2019, https://catalog.metu.edu.tr/course.php?prog=120&course_code=1200101.
[31] Ibid.

and production of 2-D and 3-D ‘spatial creation’[32] with the improvement of visual senses.[33] As the main concern, architecture has a great interest in creating spaces for human activities. Naturally, architectural design education prepares students for this concern. Moholy-Nagy defines that

> Space creation is an interweaving of the parts of space, which are anchored, for the most part, in clearly traceable relations extending in all directions as a fluctuating play of forces.[34]

Denel also emphasizes the significance of 3-D thinking for architects in terms of learning to manipulate spaces for human activities in the 3-D world.[35] ‘Manipulating spaces’ simply refers to design knowledge of the students that they have to develop for their future life as architecture students and architects. Therefore, in the Basic Design studio, students have been obligated to deal with different learning methodologies and their perceptual outcomes. Students learn the design process through a combination of two or three-dimensional practices and theoretical knowledge. These combined methodologies encourage the students to develop critical thinking, synthesis, and creative problem-solving skills.[36] Hereby, students continue architectural design education at the end of the course with the related learning outcomes. These outcomes have been defined based on the Basic Design studio at METU and the summary of the abovementioned approaches.

### 2.1.2. Learning Outcomes

The primary scope of the first-year design studio is building the fundamental design abilities with supporting the students for ‘exploration of visual organization, form ad

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[32] László Moholy-Nagy and Daphne M. Hoffmann, *The New Vision 1928 and, Abstract of an Artist* (New York: Wittenborn, 1947): 57.
[33] "ARCH 101 Basic Design", METU Academic Catalog, accessed 26 August 2019, https://catalog.metu.edu.tr/course.php?prog=120&course_code=1200101.
[34] László Moholy-Nagy and Daphne M. Hoffmann, The New Vision 1928 and, Abstract of an Artist (New York: Wittenborn, 1947): 62.
[35] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 18.
[36] Zeynep Onur, "Mimarlık Eğitiminde İlk Yıl", in *Temel Tasarım / Temel Eğitim* (Ankara: METU Faculty of Architecture Press, 1998).

space'.[37] Consequently, at the end of the course, the student should have been left the studio with some certain learning outcomes. Dino summarizes these outcomes not only as of the comprehension of the principles of design, which are referring design elements, organization, and tectonic articulation. But also, being able to apply them in a logical design thinking process, which covers defendable design decisions and rules.[38]

To better understand and by the reason of the predefined limitations of the research that have been mentioned in the first chapter, the thesis study highlights the learning outcomes of Arch101 Basic Design at METU. The course syllabus considers the learning outcomes of Basic Design course in three categories; 'knowledge', 'skills', and 'attitudes' that the students will have by the end of the semester, at METU.

**Knowledge:** As mentioned before, one of the significant outcomes of the course in a knowledge level is that the students will internalize the design skills to understand and interpret the basic concepts and principles of design. Students also perceive the relations between these principles and concepts.[39]

**Skills:** Thinking through making is another essential part of studio-based design education. Students will be able to design through making, i.e. hands-on learning. They learn by using their manual tools such as drawing, modeling as a thinking tool, therefore as a design tool. Therefore, Basic Design studios lead the students to have other related skills. Forasmuch as the thinking and design processes are the processes that include management of several design elements and various relations orderly to analyze and define a set of relationships in a composition. To handle these relationships between design elements at an organizational level, students will have the perception of solids and voids. This perception enables students to relate and

[37] İpek Gürsel Dino, "An Experimental Pedagogy of Concept Development in the Introductory Architectural Design Studio", *Online Journal of Art and Design* 5, no. 1 (2017): 7.
[38] Ibid.
[39] "ARCH 101 Basic Design", METU Academic Catalog, accessed 26 August 2019, https://catalog.metu.edu.tr/course.php?prog=120&course_code=1200101.

interpret the spatial and tectonic relations in space[40]. Since architects' design space is a three-dimensional, thinking three-dimensionally has become an inevitable skill to learn by students in the Basic Design studio and students will be able to discuss 3-D relationships and express their ideas in a various way such as graphically, written and verbally.[41] However, starter exercises have been defined in two-dimensions in terms of the deficient visual awareness of the student[42] and 2-D design exercises support students to develop the basic organizational skills while learning the valid vocabulary to express their design ideas clearly. On the other hand, Denel also emphasizes that the process with 2-D exercises should be kept at the minimum. Moreover, students comprehend the basic principles of organization, which is learned better in the 2-D realm and should be led for 3-D design problems, which are more problematic for students.

In conjunction with these 2-D and 3-D exercises, students improve their decision-making abilities and adjust the design processes with a set of design criteria. They evaluate their own design criteria while experiencing some certain cognitive phases such as analysis and synthesis. Students are required to make decisions such as selecting a proper scale, materials, and techniques.[43] Herewith, they become responsible for their decisions, so they realize that a designer must attribute her decisions to rational reasons. To support rational decisions, students should learn conducting research and analysis on related interdisciplinary subjects. This kind of skill nurtures the above-mentioned cognitive skills, analysis, and synthesis. The studio culture also encourages the students to work collaboratively in harmony and handle the design process as teamwork.

The Basic Design studio encourages the students to cope with various design tools in different mediums. Usually, craft and model making with various materials are the

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[40] Ibid.
[41] Ibid.
[42] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979).
[43] "ARCH 101 Basic Design", METU Academic Catalog, accessed 26 August 2019, https://catalog.metu.edu.tr/course.php?prog=120&course_code=1200101.

prominent design tools of the Basic Design education. Model making also has a key role in improving three-dimensional thinking ability. According to Denel, learning how to manipulate spaces to sustain proper designs for human-life is one of the abilities that students must improve, since the designer's environment is a three-dimensional one.[44] To express these manipulations, students will learn working with design tools and materials in the studio, and they have been expected to work in harmony with different kind of design methods and modes of learning. The interaction between the body and the physical world has a key role in learning and connection with materials, tools and related methods are vital for the design process.[45] The correlation between various design tools, methods or modes of thinking supports the students to follow logical thinking paths regardless of the limitation of any specific design medium and aims to prepare them for future architectural design problems. At last, students will be able to transmit their critical thinking approaches and intellectual curiosities into architectural problems.

**Attitudes:** Students are also expected to express qualified attitudes by the end of the course at METU. First, cultivating self-confidence in the design process is significant. The students should take responsibility for their own design decisions in a limited time. Then, they must become open to criticism and react to it positively.[46]

Presenting a contributor attitude in teamwork is also important for their future architectural education and careers.[47] Therefore, students are expected to enhance their personalities to be able to work collaboratively.

Another learning outcome of the Basic Design course is encouraging students to become critical thinkers and intellectuals who are interested in architectural issues.[48] Finally, students will be expected to show self-discipline to managing design

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[44] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979).
[45] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017).
[46] "ARCH 101 Basic Design", METU Academic Catalog, accessed 26 August 2019, https://catalog.metu.edu.tr/course.php?prog=120&course_code=1200101.
[47] Ibid.
[48] Ibid.

processes in a limited time.[49] Relying on strong work ethics is also one of the major expectations as an attitude in design studios.[50]

### 2.1.3. Nature of Basic Design

The main objectives of the Basic Design education have been explained in the previous section. Thus, the aim of the current section is introducing the principles of Basic Design education based on the objectives that have been stated previously. This section focuses on the nature of the basic design.

> 'Basic' refers to isolating the design problem in the relations between material and other external qualities. Abstract forms that one the signature of basic design education one tools to isolate and focus relations. The form is not the objective of a basic design problem. Rather, the aim is to consciously produce it.[51]

As noted by Özkar, Basic Design education has been based on experimentation with materials, abstract forms, and constrained abstract problems.[52] Utilization of abstract forms has a significance on separating learners from their routine thinking process and encouraging them to explore new methodologies and relations.[53] Therefore, understanding the design problems, parameters and analyzing the problems in an analytic manner could be stated as the leading scope of basic design courses. Basic Design aims to develop students' design skills regardless of the material type, tool usage in case of any design problem, which could be emerged in the future, in an unfamiliar medium, or context. Hence, students use abstract forms and materials for

[49] Ibid.
[50] Ibid.
[51] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017): 143.
[52] Ibid.
[53] Ibid.

abstract design problems during basic design education in terms of exploring the problem space.[54]

It is an undeniable fact that technological and scientific improvements have been influenced by design education, especially since the industrial revolution. Another influencer of design education has been psychology. As the legacy of Bauhaus, the wholism of Gestalt Theory still has been recognized as a valuable approach to clarify these visual organizations. As regards, the Basic Design studio follows the methods that will be led the students to order. Order refers to the systematical composition of the design elements or groups in terms of controlling the design.[55] Order is the major standpoint of the Basic Design. Therefore, the basic design studio has consisted of the various exercises that explore and require the utilization of basic principles of organizing and ordering in 2 and 3-dimensional mediums with abstract components.

Unfamiliar materials or design mediums support the students to comprehend and explore the changing definitions.[56] Therefore, the students are forced to leave behind their familiar thinking processes and search for new relations. Abstract forms create advantageous to focus on alternative relations and separate the designer's mind from habits.[57] According to Denel, the basic forms of the Euclidian geometry are the most suitable to perceive and the students as a beginner designer should learn how to organize this kind of geometry as a first step.[58] He also refers to visual psychologists to state that the perception of a human being, as a part of the physical development process, begins with comprehending the structural characteristics.[59] The structural characteristics of basic geometries are the easiest ones for visual recognition. Therefore, they become the most proper structures to deal with abstract design

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[54] Ibid., 2.
[55] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 41.
[56] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017): 146.
[57] Ibid.
[58] Bilgi Denel, *A Method for Basic Design* (Ankara: Middle East Technical University, Faculty of Architecture, 1973): 34.
[59] Ibid.

problems. Basic Design problems try to eliminate the intangible components of architectural design problems such as socio-cultural or economic interrelationships and simplify the novice designer's problem space, by reason of prioritizing ordering skills first. Denel states that order is fundamental in design. Because, order refers to conscious decisions and control, thus, it prevents any design moves that are made by chance. According to Ross, harmony, balance, and rhythm are the modes of order[60] and order requires setting rules.

Setting rules is emphasized to evaluate the students' reasoning mechanism. The rules could be defined by the student or the instructor. The key point in setting rules is that not only defining relationships between line, plane, volume with conscious control to organize a space, but also, maintaining accurate relations among the design medium, related materials, and visual structure in the required environment.[61] Consistency of the rules, completeness within the specified framework, number of orders, and type of the ordering principles are the definite features that design educators desire to find in designs that visually requires grouping.[62] Ulusoy defines 'grouping' as "placing together of elements by their common properties like size, color, shape, etc. to be perceived as a whole, a 'group'".[63]

In the Basic Design studio, students start to deal with 2-d design exercises firstly to explore the ordering principles. As mentioned in the previous section of the literature review, 2-d design problems aim to introduce basic ordering principles as well as the foundation of a valid vocabulary to communicate. By drawing on the concept of ordering principles, the research presents some of the adopted definitions.

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[60] Denman Waldo Ross, "Design as a Science", *Proceedings of the American Academy of Arts and Sciences* 36, no. 21 (1901): 358.
[61] Bilgi Denel, *A Method for Basic Design* (Ankara: Middle East Technical University, Faculty of Architecture, 1973).
[62] Ibid., 36.
[63] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 39.

The very first definition needs to be stated is 'geometric relations', which arise from relating design elements through their geometric characters and visual potentials for arrangement.[64] After dealing with the characteristics of geometry, students have been encouraged to order through grouping a) by the similarity of forms (Figure 2.1.), b) by size (Figure 2.2.) and c) by proximity (Figure 2.3.), which is the nearness of the design elements or groups.[65] As grouping originates from the design decisions by the designer, it should be seen and realized visually.[66]

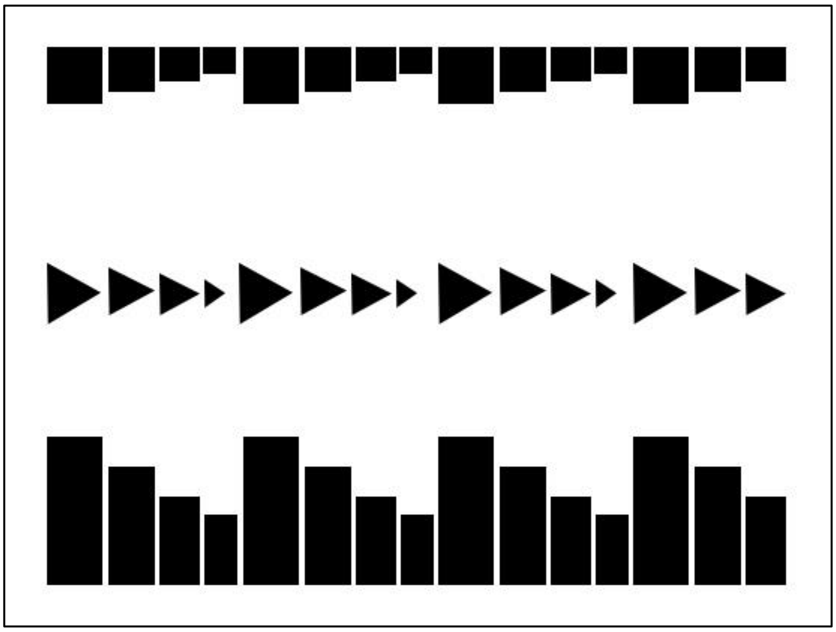

*Figure 2-1.* Grouping by Similarity

Source: Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979), 26.

[64] Ibid., 40.
[65] Ibid., 39.
[66] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 27.

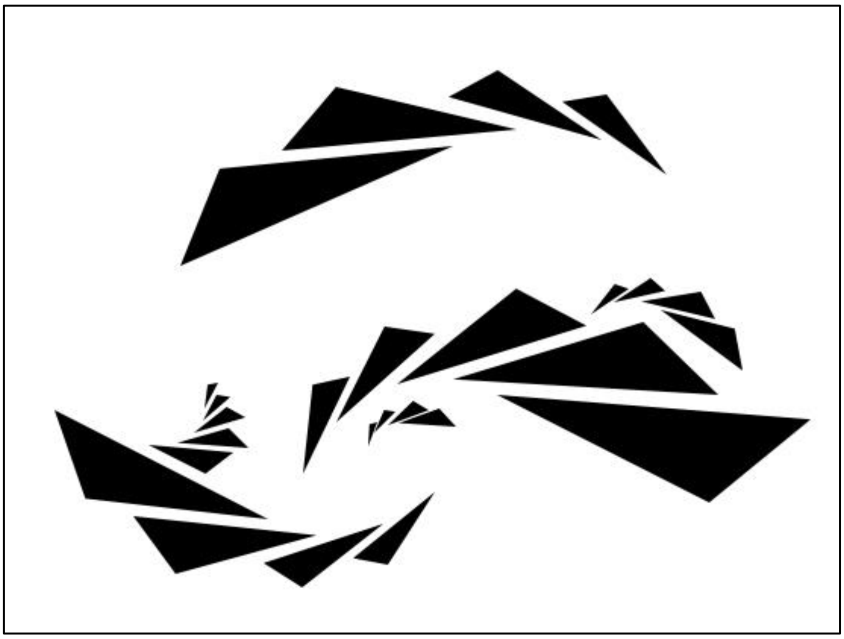

*Figure 2-2.* Groping by Size

Source: Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979), 27.

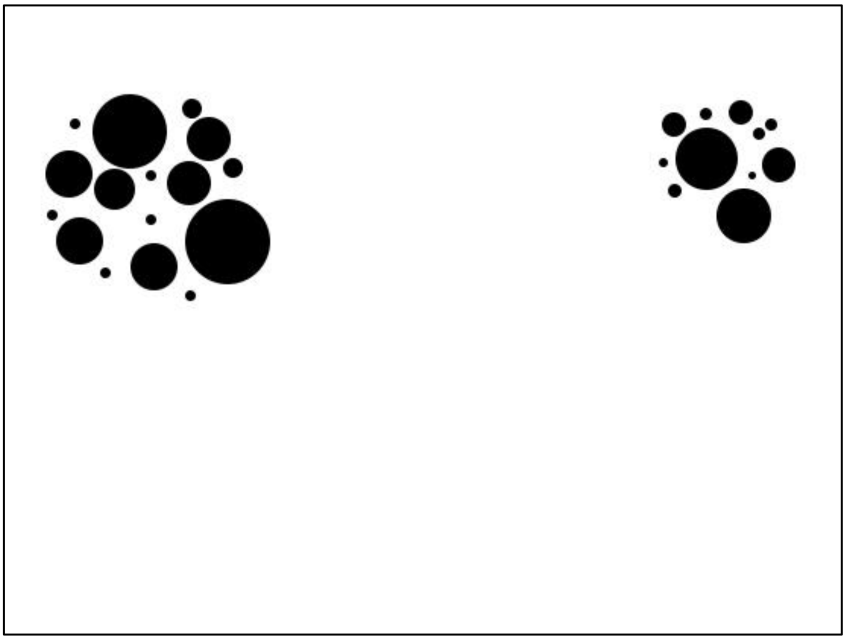

*Figure 2-3.* Groping by Proximity

Source: Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979), 28.

Hierarchy is accepted as one of the most significant ordering principles by Ulusoy. She states that hierarchy is possible when more than one order, which have a different level of importance, come together.[67] Ching defines hierarchy as another ordering principle is usually about emphasizing a form or a shape regarding its distinctive size (a), its individual shape (b), or its strategic position (c) in the composition.[68] Therefore, hierarchy requires creating a distinction between the design elements. In the case of hierarchy by size (a), one component of the design has a dominance over the other elements and is distinguished in the whole composition visually.[69]Another way for achieving hierarchy is dominating other elements that differentiate by shape (b). In this situation, one specific design element becomes selective to eyes by its unique form.[70] The designer highlights the visual field of the specific design elements through edges, corner, or diagonals.[71] As a third method, positioning (c) an element at the strategic location in the composition exclusively than others, draws attention and brings hierarchy to the organization (Figure 2.4.).

[67] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 42.
[68] Francis D. K. Ching, *Architecture: Form, Space, & Order*, 3rd ed. (Hoboken: John Wiley & Sons, 2007): 358
[69] Ibid., 358.
[70] Ibid., 359.
[71] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 41

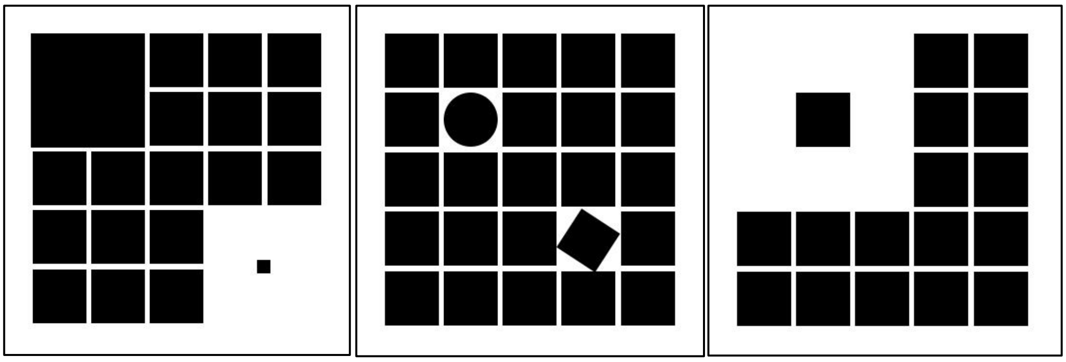

*Figure 2-4.* Hierarchy by a) Size, b) Shape, and c) Position

Source: Francis D. K. Ching, *Architecture: Form, Space, & Order*, 3rd ed. (Hoboken: John Wiley & Sons, 2007), 359.

Rhythm is repeating a design element, a group, or a relationship between the design components in a specific order.[72] Rhythm as an ordering principle defines the features of the movements, which are settled through the iteration of the design elements regularly or irregularly. As can be understood, rhythm requires repetition in the composition (Figure 2.5.). [73] Rhythm correlates with repetition to specify meaningful sequences of the design elements.[74]

[72] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 40.
[73] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 30.
[74] Francis D. K. Ching, *Architecture: Form, Space, & Order*, 3rd ed. (Hoboken: John Wiley & Sons, 2007): 382

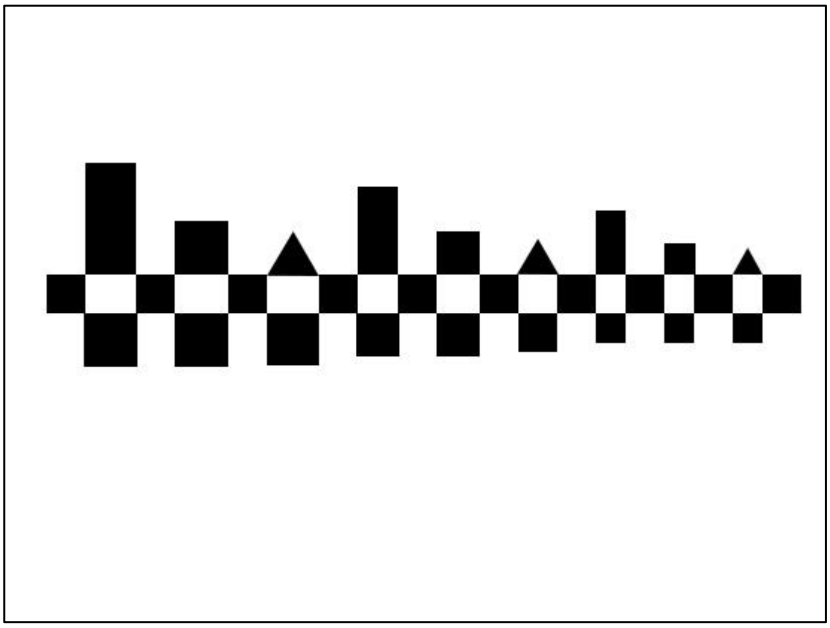

*Figure 2-5.* Rhythm

Source: *Bilgi Denel,* A Method for Basic Design *(Kalite Matbaası, 1979), 30.*

Transformation is another significant principle in design. According to Ulusoy, a transformation could be achieved through "changing of an element into another with some order".[75] Hence, transformation needs manipulation of design elements to adopt a certain context in the problem space. Naturally, the search on the responsive manipulations forces the designer to seek for possibilities through analysis and synthesis. The students apply more trial and error to set valid transformation rules.

As noted by Denel, students seek for rules by trial and error in any medium. They try to maintain ordering rules that are asserted by themselves and focus on proving and applying their rules without contradiction in each design step. Hence, they explain the reasons for design decisions and reach an acceptable answer to the design problem.[76] Despite the significance of the trial and error experience on the design thinking process, students may not have enough time for this experience. The trial-error

[75] Zuhal Ulusoy, "A Study of Perceptual Organization Principles as Related to Basic Design" (Master of Architecture, Middle East Technical University, 1983): 40.
[76] Bilgi Denel, *A Method for Basic Design* (Ankara: Middle East Technical University, Faculty of Architecture, 1973): 47.

experience is not a linear thought process and it depends on the tinkering, which refers to thinking with hands and learning through doing. Instead of following a step-by-step instruction to reach a final and certain solution, the students are questioning and interpreting the well-known recognitions and try to explore alternatives in their own aspects.[77] In the same vein, Denel, in his book A Method for Basic Design, notes that Basic Design education force the students to think and generate alternatives rather than focusing on the first idea. Hereby, Basic Design aims to sustain a form of creativity for the students.[78] As understood, experience discovering alternatives and tinkering are accepted as a method to lead creativity in the Basic Design studio. This view is supported by Özkar who writes that there are two characteristics of basic design studios to encourage creativity in many institutions today and these are based on the explorations likewise the methods of Ross and Dow.[79] The first one is abstract forms and abstract design problems of the Basic Design. As mentioned before, basic forms of the design objects and the simplified design problems try to canalize the students to concentrate on relations between the design elements. Besides, handling with unknown materials and forms leads the students to search for miscellaneous perspectives. In this way, students are forced to explain their own perspectives and defend the rules, which have been defined by them. Therefore, the students have become responsible for their design decisions and they learn how to define form relations consciously. The second characteristic of Basic Design to trigger creativity is that the course is based on ideas of 'repetition, comparison, and variance'.[80] As related to the abstract forms and problems, the students are expected to seek individual ways to handle the materials and problems. Visual and tactile representations are required in preference to verbal communication to overcome the routine way of thinking. And, the repetition supports realizing similarities and variance. Özkar

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[77] Mitchel Resnick and Ken Robinson, *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play* (Cambridge: The MIT Press, 2017).
[78] Bilgi Denel, *A Method for Basic Design* (Ankara: Middle East Technical University, Faculty of Architecture, 1973): 185.
[79] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017): 142.
[80] Ibid.

emphasizes the non-static and continuous form of the creative process and states that it does not have a certain vocabulary.[81] However, the concept of creativity has been one of the major aims in the design process.

Moholy-Nagy believes that anyone could produce creative works and basic design course helps to reveal the emotional and intellectual potentials of the students.[82] Therefore, he structured the course methodologies on this idea and valued the basic workshops to encourage students' 'sensorial experiments' with various tools, machines with various type of materials.[83]

Basic Design is still one of the fundamental courses in architectural education in terms of not only preparing students to be ready for the architectural design studios but also its close association with creative thinking ability. The major concern of a basic design course should be to maintain the knowledge of the elasticity of visual rules and diagrams.[84] In other words, the basic design should aim that the students gain the ability to set relations with different perspectives and to generate alternative solutions for design problems. There is no doubt that this situation refers to creativity that is acknowledged as a fundamental component of the design thinking process.[85] Supportively, many architecture schools embrace the Basic Design education with different approaches in terms of their pedagogy and circumstances depend upon the relationship between the background of the students and technical competence currently.

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[81] Ibid.
[82] László Moholy-Nagy and Daphne M. Hoffmann, *The New Vision 1928 and, Abstract of an Artist* (New York: Wittenborn, 1947): 22.
[83] Ibid., 21.
[84] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017): 14.
[85] Nigel Cross, "Design Cognition: Results from Protocol and Other Empirical Studies of Design Activity", in *Design Knowing and Learning: Cognition in Design Education* (Oxford: Elsevier Science Ltd., 2019), 79-103.

### 2.1.4. Creative Thinking as a Learning Outcome of the Basic Design Studio

As understood, creativity has been associated with Basic Design education in the literature. Since achieving a creative attitude is one of the essential outcomes of the Basic Design education and the significance of exploration depends on cultivating a creative approach to encourage the students for alternative solutions. The main points of the abovementioned educational approaches in Basic Design are usually focusing on stimulating creativity in the studio. Therefore, students have been forced to experiment with unfamiliar materials or using well-known materials with unfamiliar techniques in the Basic Design studio. Mine Özkar exemplifies the folding exercises in Basic Design programs. She states that the major purpose of this exercise is perceiving the unknown functions of a familiar material such as paper and showing even a slight component could become an enduring one with a new usage approach.[86] Creativity has a key role in the application of a new usage approach in this kind of exercises. According to Gropius, developing a new approach to maintaining essential connections between the objects and the past in a creative design process is only possible with the consisted interaction with emerging technology, utilization of a wide range of new materials and unknown construction techniques.[87] The reason for the emphasis on unfamiliarity is about stimulating creativity. An explanation for this might be that creativity has been nourishing from mode-shifting, which are known as divergent and convergent thinking, in the individual’s thinking process. This is because, creative design is not concerning as a sudden inspirational moment, which only belongs to some gifted people, today. On the contrary, according to Taura and Nagai, creative design is about the ability of the individuals to enlarge their design space.[88] Sensorial experimentation in the design process, which is supported by Dow

[86] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017).

[87] Walter Gropius, "Teaching the Arts of Design", *College Art Journal* 7, no. 3 (1948): 160.
[88] Toshiharu Taura and Yukari Nagai, *Concept Generation for Design Creativity: A Systematized Theory and Methodology* (London: Springer, 2019).

and Ross, or the idea of connection with advanced technology, both are based on the provoking the mode shifts and expanding the students' design spaces.

## 2.2. Design Research

*"... design thinking is something inherent within human cognition; it is a key part of what makes us human."* [89]*-Nigel Cross*

The major motivation of this study is exploring the potentials of mixed reality environments for Basic Design and understanding its potentials on the architectural design educations of the novice designers in their first year. Understanding and evaluating the potentials of the new design environment are important in understanding the design processes of the designers while using the developed design tool in the Mixed-Reality Environment. Therefore, this section of the literature review focusses on 'design research' and its methods.

The beginning of design research dates after World War II.[90] According to Nigan Bayazit's statement, after the war, new technologies and inventions for war equipment had attracted the designers. Also, the American government began to promote research on creativity and the usage of the current technologies for the welfare of human needs in daily life.[91]

The first serious discussions and analyses of design research emerged during the 1960s with the movement called 'design methods'.[92] The movement was based on the idea that design could be a science and it could be possible to make it systematic. Thus, it would be possible to teach anyone and to be learned by anyone.[93] However, the first

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[89] Nigel Cross, *Design Thinking: Understanding How Designers Think and Work* (Oxford: Berg Publishers, 2011): 3.
[90] Nigan Bayazıt, "Investigating Design: A Review of Forty Years of Design Research", *Design Issues* 20, no. 1 (2004): 17.
[91] Ibid., 17.
[92] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 10.
[93] Ibid., 11.

attempts of this movement only produced some prescriptive models that consist of consecutive design phases. Thus, the design method perception had referred to the design process itself.[94] Design was accepted as an operational problem-solving process.[95] To illustrate, 'The Analysis- Synthesis- Evaluation' (ASE) model of Morris Asimov, had reached a recognition. Gabriela Goldschmidt writes that the definitions of these three stages rely on John Luckman's statements.[96] According to these statements, the first phase of the design, Analysis, refers to relevant data collection on the design problem. Synthesis is about generating potential solutions considering the data on the first phase. Finally, Evaluation concerns selecting the most satisficing and accurate solution through the other potentials.

Design process was seemed too complicated to apply with a systematic method. Fortunately, in the early 1960s, computational drafting techniques began to attract the designers as well as the researchers on design methods. Computer became a new hope for the design method movement, and it has been expected to facilitate the loan of the traditional design tools such as freehand-drawing and craftsmanship. Under this scientific improvement, the researchers hoped that computation could create *machine-generated drawings* and the design process could become an automatic procedure as well. Therefore, one of the major aims of 'computer-aided design' (CAD) is to develop the machine-generated drawings to be supplanted freehand drawing.[97]

Meanwhile, Christopher Alexander became a prominent name on design methods with the first Ph.D. thesis in this research field.[98] His research, 'Notes on the Synthesis of Form', was the most impressive approach to generate a system for not only analyzing design problems but also synthesizing of solutions.[99] He proposed a methodology to

[94] Ibid.
[95] Ibid.
[96] Ibid., 13.
[97] Ibid., 14.
[98] Nigan Bayazıt, "Investigating Design: A Review of Forty Years of Design Research", *Design Issues* 20, no. 1 (2004): 18.
[99] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 15.

parse the design problems into smaller parts, so designers could be able to visualize the structure of the complex design problems with the usage of computational tools.[100] His methodology was based on the elimination of faulty relationships between the requirements and form to find the most suitable solutions with error reduction and correction of the structure of the design problem.[101] According to his method, the designer should not aim to create form but answer the requirements by removing the misfits.[102] Alexander explains this idea and states that:

> It is based on the idea that every design problem begins with an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem; the context defines the problem.[103]

Alexander's method has affected the design method movement and design thinking for a long time. Goldschmidt comments on 'Notes on the Synthesis of Form' and defines that "it is probably the most original and significant contribution to the literature on design methods."[104]

Eventually, Alexander had to admit that his method failed by reason of its heavily work loan and unpractical system. Besides, there was no evidence to prove any difference between the design solutions, which was produced by using Alexander's method and the usual design approach, in terms of quality.[105] In 1977, Alexander rejected the design method and detached himself from this research field.[106]

In the 1960s, there was another pioneering name, Herbert Simon, with his research, 'The Sciences of the Artificial'. What he meant by 'artificial' is that all the things

[100] Bryan Lawson, *How Designers Think* (Architectural Press, 1980): 27.
[101] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 17.
[102] Christopher Alexander, *Notes on the Synthesis of Form* (Cambridge, Massachusetts: Harvard University Press, 1964): 24.
[103] Ibid., 15.
[104] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 15.
[105] Ibid., 18.
[106] Nigan Bayazıt, "Investigating Design: A Review of Forty Years of Design Research", *Design Issues* 20, no. 1 (2004): 21.

‘man-made as opposed to natural’.[107] Therefore, while every natural component of life could become a science such as biology, chemistry, why not the artificial? The idea behind his work is implementing the scientific approach to all kind of things, which were produced and organized by men, such as engineering and design.[108] As a result, Simon introduced the Artificial Intelligence (AI) to the world. The earlier design methods were based on Operational Research (OR) and there were not suitable for design problems. On the other hand, Simon states that the design problems have never-ending solutions, so AI methods do not focus on finding the best solution.[109] With his own words, “the alternative methods provided by AI, most often in the form of heuristic search (selective search using rules of thumb), find decisions that are ‘good enough,’ that satisfice.”[110] According to Schön, Simon’s method had depended on the extension of the optimization methods and it could have only been applicable to solve well-formed problems.[111] Schön emphasizes that Simon’s method is not suitable for messy real-life problems as based on theoretical rationality. He states that the practitioners handle with the real-life problems, which have uncertain and unlimited constraints, ‘thinking by doing’[112]. According to Schön, designers ‘reflect-in-action’ to reframe the problem into something more manageable when they got stuck.[113] Collectively, these studies outline a critical role in the discovery of designers’ reasoning process and developing methodologies to accomplishing this goal.

### 2.2.1. Revealing Designer’s Mind

As mentioned before, the data from several studies suggest that prescriptive design methods were not fulfilling the expectations to reveal real-life design thinking. Thus,

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[107] Herbert A Simon, *The Sciences of the Artificial* (Cambridge: The MIT Press, 1969): 4.
[108] Nigan Bayazıt, "Investigating Design: A Review of Forty Years of Design Research", *Design Issues* 20, no. 1 (2004): 19.
[109] Herbert A Simon, *The Sciences of the Artificial* (Cambridge: The MIT Press, 1969): 27.
[110] Herbert A Simon, 1969, op.cit., 27.
[111] Howard S. Schwartz and Donald A. Schon, "The Reflective Practitioner: How Professionals Think in Action.", *Administrative Science Quarterly* 32, no. 4 (1987): 47.
[112] Ibid., 69.
[113] Ibid., 63.

‘descriptive design methods’ began to gain researchers’ attention. The essence of the ‘descriptive design method’ idea was that design thinking during real design practice could be understood through convenient descriptions of real design behavior.[114] This attempt led the researchers into changing their approach to computational tools. The idea of using computation instead of a human designer has shifted to the idea of a collaboration between the human designer and the computer.[115] Yet, the lack of knowledge about how designers think and create was making hard to adopt any computational design tool into the design process of a human designer.[116] In the light of cognitive science, which had just begun to be addressed in problem-solving and revealing ‘mind,’ understanding design thinking became a prior stage of the design tool development.[117] Consequently, a need for empirical studies, which are based on real-life condition, has been emerged by design thinking researchers.

Nigel Cross categorizes the methods that have been used to understand how designers think as “interviews with designers, observations and case studies, experimental studies, reflection and theorizing, and simulation.”[118] The brief history of theorizing design research has been presented already and simulation is a technique for AI researchers to simulate the thinking process of man through AI techniques. Among these abovementioned design research methodologies, interviewing, observations on case studies, and experimental studies will be examined as follows to stay in the context of real-life evidence of design thinking.

Interviewing with designers is one of the preferred methods to investigate designers’ reasoning processes and it has been used by Jane Darke to see reasoning schema of the architects during the design of housing[119]. Darke carried out interviews with the architects and revealed that designers begin to design with some selected ideas by

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[114] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 19.
[115] Ibid.
[116] Ibid., 20.
[117] Ibid.
[118] Nigel Cross, *Designerly Ways of Knowing* (London: Springer, 2006): 3.
[119] Jane Darke, "The Primary Generator and the Design Process", *Design Studies* 1, no. 1 (1979): 36.

themselves in the context of the design problem. Darke called this kind of ideas as "primary generator" and proposed a map to show that the design process consists of 'generator-conjecture-analysis' activities instead of the 'analysis-synthesis-evaluation' idea.[120]

Bryan Lawson studied with a different formal study, which consisted of a set of interviews and observational case studies with designers. He carried out significant research with some final-year students and first-year students in architecture and science. His empirical study with colored blocks shows that the architecture students were using a problem-solving strategy of analysis through synthesis. [121] They try to generate solutions to explore the problem instead of analyzing the problem itself towards the end of their architectural education.[122] These studies could be useful in terms of providing a valuable perspective to understand the 'intuitive' behaviors of designers during the design processes. On the other hand, the reliability of this kind of methods, based on interviews or surveying, depends on the participants' honesty of course.[123] These retrospective studies, based on expressions after the design process, could be tricky considering that the designers' memories could misguide to remember what actually happened and try to make the design processes more rational than the real-case.[124]

Another method that has been used by design researchers is experimental studies based on protocol studies. The protocol studies parse the micro-scale design processes onto small units of thoughts, which are presented by the designer, in a kind of laboratory environment. The designer is asked to 'think-aloud' during the pre-defined design process[125]. Protocol studies have allowed the researchers revealing the design

[120] Ibid., 43.
[121] Bryan Lawson, *How Designers Think: The Design Process Demystified* (Elsevier, 2006): 44.
[122] Ibid.
[123] Ibid., 45.
[124] Ibid., 45.
[125] Nigel Cross, *Design Thinking: Understanding How Designers Think and Work* (Oxford: Berg Publishers, 2011): 26.

process and understand the most significant eligibility of human designers versus computational tools, which is creativity. The structure and functions of protocol studies and its relationship with creativity research will be explained in the following section.

### 2.2.2. Protocol Analysis and Creativity

Creativity has been a major component of the design-thinking process throughout the years. Cross states that according to the empirical studies that have been carried out, creative design is not merely associated with an intuitive, heroic “creative leap” from problem to solution.[126] Creativity has been investigated not only through its definitions but also potential initiators to assist the creative design.

Brewster Ghiselin states that creativity is a process of change, of advancement in the system of life that is ordered subjectively[127]. Louis A. Fliegler, another scientist who studied on creativity in the 1950s, emphasizes that the manipulation ability of external elements of life to form an unordinary incident unfamiliar for the current set of surroundings is how a person acts during the creative process[128]. Kneller remarks the correlation between creativity and intelligence and then, he states that creativity is nourished from reorganizing what is known already to seek for unknown. [129] Kneller also states the five stages of creative thinking (Figure 2.6.) as ‘first insight’, ‘preparation’, ‘incubation’, ‘illumination’, and ‘verification’.[130]

[126] Nigel Cross, "Creativity In Design: Analyzing And Modeling The Creative Leap", *Leonardo*30, no. 4 (1997): 311

[127] Brewster Ghiselin, *The Creative Process* (Los Angeles: University of California Press, 1952): 2.

[128] Louis A. Fliegler, "Levels of Creativty ", *Educational Theory* 9, no. 2 (1959): 105-115.

[129] George F. Kneller, *The Art and Science of Creativity* (New York: Holt, Rinehart and Winston, 1965): 59.

[130] George F. Kneller, *The Art and Science of Creativity* (New York: Holt, Rinehart and Winston, 1965): 48.

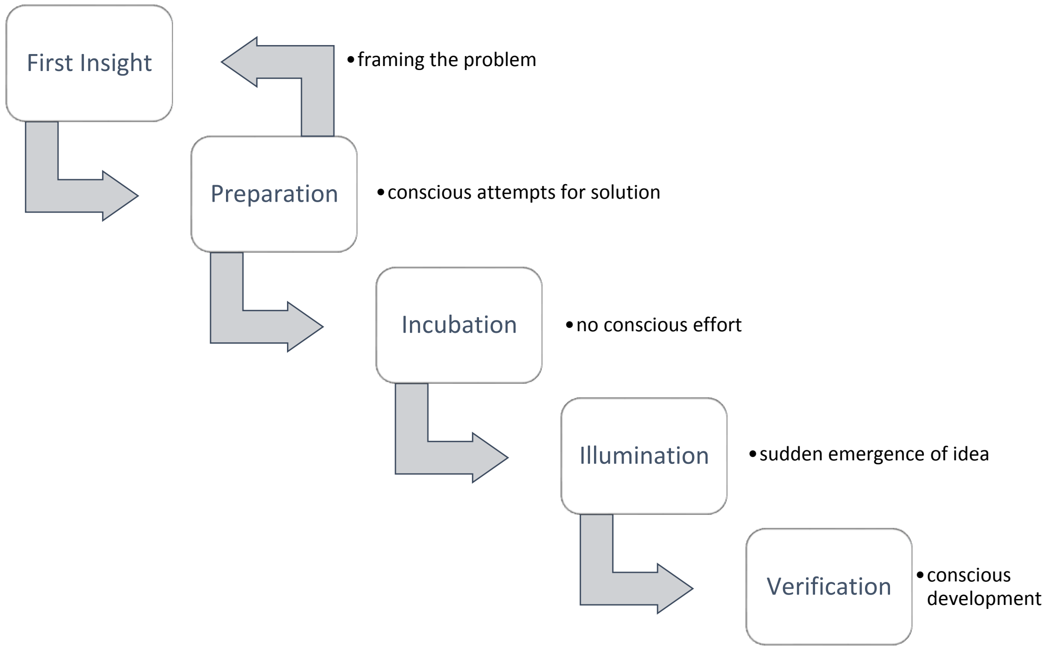


*Figure 2-6.* Creativity Process Model

Source: Adapted from *Bryan Lawson, How Designers Think: The Design Process Demystified* (Elsevier, 2006).

John Fletcher makes a distinction between creative thinking and reflective thinking. He defines creative thinking as fluent, unformalized and rule-breaker on the contrary of reflective thinking, which is defined by him as methodological and regular.[131] The categorization of thinking abilities has proceeded under different headings. Guilford named them as ‘divergent’ and ‘convergent’ thinking. According to Guilford, divergent thinking occurs when there is no determined pattern to reach a solution and the problem is open to discovery. On the other side, convergent thinking is more applicable when the problem is solid, predetermined and there is a specific solution for it with the usage of limited methodologies. Rogers called the same thinking modes as openness and defensiveness.[132] Getzels and Jackson explain the two modes and

[131] Jack M. Fletcher, "Differentiating Characteristics of Creative Thinking", in *Psychology in Education, with Emphasis on Creative Thinking* (Garden City, NY: Doran & Company, 1934), 321-380.
[132] Carl R. Rogers, "Toward a Theory of Creativity", *A Review of General Semantics* 11, no. 4 (1954): 249-260.

state that while the one mode is more inclined to learning the pre-agreed knowledge and defense it, the second mode tries to expand what is already known and it is more available to explore the uncertainties. They also declare the actions of the person who has the first mode as 'usual and expected' and the actions of the person who has the second mode as 'novel and speculative'.[133]

Since the beginning of cognitive psychology researches in the 1960s, there has been also combined efforts for the development of methods that could facilitate the analysis of the design thinking process, designers' cognitive mechanisms in problem-solving, and the understanding of 'the creative leap'[134], which is an idea that has been centralized in design process.[135] Herewith, the process of analyzing design-thinking requires some specific methods to understand the thinking periods. Protocol studies have been preferred as an efficient method for design-thinking research by various theorists and architects for over 30 years.[136]

Protocol Analysis is a method used by Allen Newell first time to study on information-processing systems.[137] Newell defines 'protocol' as a list of recorded verbal behaviors of the problem-solver, who asked for think-aloud during the thinking process.[138] The logic of thinking-aloud depends on the assumption that the verbal expressions of the subjects do not infer the direct connection with their mental processes.[139]

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133 Jacob W. Getzels and Philip W. Jackson, *Creativity and Intelligence: Explorations with Gifted Students* (London: John Wiley, 1963).
134 Nigel Cross, "Creativity In Design: Analyzing And Modeling The Creative Leap", *Leonardo*30, no. 4 (1997): 311
135 Leonard Bruce Archer, *Systematic Method for Designers* (London: Council of Industrial Design, 1966).
136 Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 63.
137 Ömer Akın, *Psychology of Architectural Design* (London: Pion, 1986): 181.
138 Allen Newell, *On the Analysis of Human Problem Solving Protocols* (Arlington: Computer Microfilm International, 1966): 1.
139 Karl Anders Ericsson and Herbert Alexander Simon, *Protocol Analysis: Verbal Report as Data* (Cambridge, Mass.: MIT Press, 1992).

Think-aloud is an introspective study and helps to understand and follow the designer’s reasoning process better.[140] Think-aloud, as a verbal protocol study provides quantitative and qualitative data to analyze the design process. According to Cynthia Atman and Jennifer Turns, the execution of verbal protocol studies could be challenging to interpret the results and take a lot of time.[141] Atman and Turns, also list the main steps of a verbal protocol study as follows:

1. “Develop a coding scheme,
2. Choose a problem,
3. Collect protocols from students as they solve the problem,
4. Code the protocols according to the coding scheme, and
5. Analyze and interpret results.”[142]

Atman and Turns states that the first step of the verbal protocol analysis is developing a coding schema defining the coding schema as the link to analyze the relations between the protocols and research questions which has been asked in the context of the research.[143] The researcher develops the coding schema to identify the design behaviors which have been explored, then categorize the data according to the coding schema. One of the well-known coding schemas belongs to John Gero. He developed a schema (Figure 2.7.) to categorizing the design reasoning acts, which includes three main categories: ‘The Function-The Behavior- The Structure’[144]

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[140] Charles M. Eastman, W. Michael McCracken and Wendy C. Newstetter, *Design Knowing and Learning* (Amsterdam: Elsevier Science B.V., 2001): 15.
[141] Cynthia J. Atman and Jennifer Turns, "Studying Engineering Design Learning: Four Verbal Protocol Studies", in *Design Knowing and Learning: Cognition in Design Education* (Elsevier Science, 2001): 39.
[142] Ibid.
[143] Ibid., 40.
[144] John S. Gero, "Design Prototypes: A Knowledge Representation Schema for Design", *AI Magazine* 11, no. 4 (1990): 26-36.

| | Dwelling | Editing software | Manufacturing process | Team |
|---|---|---|---|---|
| Function (F) | Provide safety, provide comfort, provide affordability | Be time efficient, provide affordability | Be safe, be time efficient, provide sustainability, provide affordability | Be time efficient, provide affordability |
| Behaviour (B) | Strength, weight, heat absorption, cost | Response times, cost | Throughput, accuracy, speed, waste rate, cost | Working speed, success rate, cost |
| Structure (S) | Geometrically interconnected walls, floors, roof, windows, doors, pipes, electrical systems | Computationally interconnected program components | Logically and physically interconnected operations and flows of material and information | Socially interconnected individuals |

*Figure 2-7.* Examples of function, behavior, and structure of different artifacts

Source: John S. Gero and Udo Kannengiesser, "The Function-Behaviour-Structure Ontology of Design", in *An Anthology Of Theories And Models Of Design* (London: Springer, 2014), 266.

Choosing a problem is another step of the protocol study due to collecting necessary data through the implementation of the chosen problem. Naturally, the problem should be chosen to support the required data collection in the given time. Then, having subject to execute the protocol analysis is another significant step of these studies. Atman and Turns state that "the heart of a verbal protocol analysis study is the point where the subjects solve the chosen problem while concurrently providing verbal protocols associated with their actions."[145] Data could be collected using video-recording, any kind of representation such as drawings, models, or etc. After collecting the protocols from subjects, the researcher codes the protocols according to the coding schema. According to the coding approach of Atman and Turns, the coding process consists of transcribing all protocols, parsing it into idea units, and categorizing these idea units dispose of the coding schema.[146] Finally, coding the protocols makes the analysis and interpreting of the results.

[145] Cynthia J. Atman and Jennifer Turns, "Studying Engineering Design Learning: Four Verbal Protocol Studies", in *Design Knowing and Learning: Cognition in Design Education* (Elsevier Science, 2001): 42.
[146] Ibid., 44.

Despite its potential in capturing designer motivations during the design process, the think-aloud protocol has several weaknesses. Disharmony between thinking and talking periods are regarded as the most challenging weaknesses of think-aloud protocols. Designing and verbalizing simultaneously during design activity can be a challenging task for designers and can impose a cognitive load that can complicate the design process. Ericson and Simon offer a retrospective study that includes asking questions about the problem-solvers' undefined reasonings right after the think-aloud process to examine the protocols more accurately.[147] On the other hand, retrospective studies could also be tricky in ill-defined problems. In this case of the design problems, problem-solvers' memory could fail to remember the actual reason of the design behavior and could try to make it more meaningful.

Another issue on think-aloud protocol studies is its aim to code the protocols to reach a problem-solving model or a pattern on design thinking. Sometimes subjects could not be able to make clear statements during the task or the design process could not be well-structured.[148] The verbal expressions during the tasks could not be the direct representations of the thoughts but there is no possible way to reach the direct thoughts. Thus, verbal protocol analysis promises the potential to provide "second best" empirical evidence regarding the cognitive process of the subjects. Therefore, protocol studies have been conducted and interpreted in various ways over the design research history by many researchers. Some of the significant protocol studies have been mentioned below to indicate the value of this design research method in the context of the thesis study, which aims to understand the potentials of a new design environment on the design processes of the first-year architectural students.

Protocol studies have been widely used in design studies to understand design cognition and design activity. Charles Eastman used protocol studies on intuitive

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[147] Karl Anders Ericsson and Herbert Alexander Simon, *Protocol Analysis: Verbal Report as Data* (Cambridge, Mass.: MIT Press, 1992).

[148] David Latch Craig, "Stalking Homo Faber: A Comparison of Research Strategies for Studying Design Behavior", in *Design Knowing and Learning: Cognition in Design Education* (Oxford: Elsevier Science Ltd., 2001): 21.

design process through a task, which requires designing a bathroom. The main finding of the study is that showing the correspondence between the constraints of the design problem and the representations used by the designer.[149] Exploring the problem space through alternative solutions has been recorded by Eastman as a meaningful finding in these protocol studies. On the other hand, the results of the studies have not included any considerable distinction between analysis and synthesis during the design process.[150]

Ömer Akın has tried to reveal the position of the designer's self-conscious approaches in architectural design and understand the application of problem-solving mechanism in architecture through 'design information-processing system (DIPS)' based on 'information -processing theory.' [151] Information-processing theory (IPT) offers a symbolic language (Figure 2.8.) to represent and understand the thinking processes of problem-solvers.[152] He carried out a set of protocol analysis on more complex design problem than Eastman's bathroom problem.

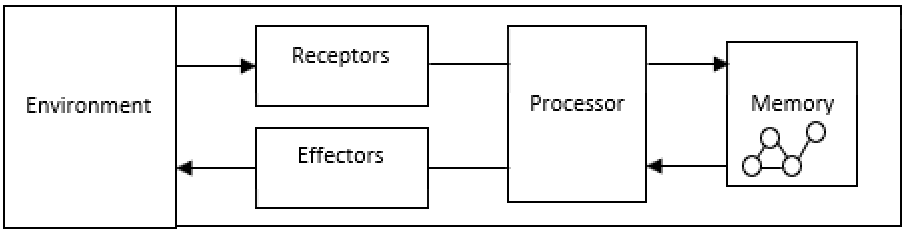


*Figure 2-8.* Information-processing system representation

Source: Adapted from Allen Newell and Herbert A. Simon, *Human Problem Solving* (Prentice-Hall, 1972), 20.

As a result, Akın states that creativity is not a mystical behavior and it could be understood as using proper tools, IPT, to analyze the mechanisms behind the

[149] Charles M. Eastman, *On the Analysis of Intuitive Design Processes* (Pittsburgh, Pa.: Carnegie-Mellon University, 1968): 30.
[150] Bryan Lawson, *How Designers Think: The Design Process Demystified* (Elsevier, 2006): 44.
[151] Ömer Akın, *Psychology of Architectural Design* (London: Pion, 1986): 3.
[152] Allen Newell and Herbert A. Simon, *Human Problem Solving* (Prentice-Hall, 1972): 12.

creativity.[153] In his later research, Akin observed that the designers tend to change the problem definitions through reorganizing the constraints and restructure the design problem to advance their current solutions or when they felt stuck.[154] He also emphasizes that this restructuring tendency refers the Schön's idea of reframing the problem is about creative behavior.[155]

Chiu-Shui Chan is also another name which studied with protocols and architects. He utilized the protocol analysis to investigate the ability to select rules in constraint schemata and the ability to develop new constraints for the test of a newly generated design unit.[156]

Vinod Goel conducted his protocol studies with architects and found that the designers have the tendency to work on the problem partially and transform their solutions until the finalize instead of starting all over for another solution. According to his study, the designers prefer to continue for their partial solutions rather than change them and generate again.[157]

Gabriela Goldschmidt also studied on the design process as using protocol analysis. She conducted a set of protocol studies with the architects to understand the potentials of sketching during the design process. After the protocol studies, she claimed that "process of sketching is a systematic dialectics between the 'seeing as' and 'seeing that' reasoning modalities."[158] Furthermore, Goldschmidt states that the design reasoning process is not absolutely linear or hierarchical to follow and there could be no reasonable sequence between the design decisions.[159]

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[153] Ibid., 179.
[154] Ömer Akın, *A Cartesian Approach to Design Rationality* (Ankara, Turkey: Middle East Technical University, Faculty of Architecture, 2006): 71.
[155] Ibid.
[156] Chiu-Shui Chan, "Cognitive Processes in Architectural Design Problem Solving", *Design Studies* 11, no. 2 (1990): 60-80.
[157] Vinod Goel, *Sketches of Thought* (The MIT Press, 1995).
[158] Gabriela Goldschmidt, "The Dialectics of Sketching", *Creativity Research Journal* 4, no. 2 (1991): 131.
[159] Ibid., 126.

A seminal study in this area is another work of Goldschmidt. She offers a new approach to examine protocol studies: Linkography. Her new methodology is not based on the idea that the creative design process should be linear, sequential, or hierarchical.[160] According to Goldschmidt, focusing on the design phases, which certainly exist, as coding does not meet the expectations of understanding design thinking process effectively.[161] On the other hand, Linkography tries to segment the design process into 'design moves' and define links between each move instead of defining the design phases.[162] As a result, Linkography generates a visual map of the network of links (Figure 2.9.) for the design process and it presents a valuable method to evaluate creativity during the design process through the visual evidence of divergent and convergent thoughts. [163] Therefore, its potentials on the design research will be expanded in the following section in more detail.

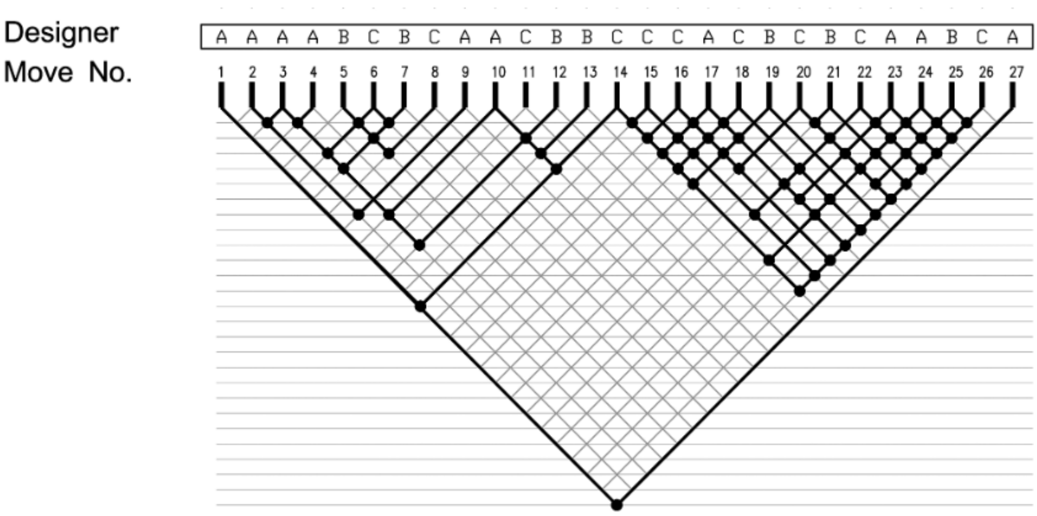


*Figure 2-9.* As an example of the visual map of the network of links

Source: Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014), 56.

[160] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 41.
[161] Ibid.
[162] Ibid.
[163] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014).

### 2.2.3. Reading Creativity Through Linkography

Goldschmidt emphasizes that design includes creative behavior, so design thinking and reasoning naturally indicates for creative thinking.[164] According to her, reading design creativity could be possible with linkographs, which are the representations of the networks of links between the design moves.[165] To better understand Linkography, its components have been explained as follow.

As mentioned before, after the necessary video-recording during the design process, Linkography begins with the parsing operation of the design process into design moves. Design moves have been detected over time-sequences or coded idea units in the other protocol analysis methods before Linkography. On the other hand, Goldschmidt defines ‘design move’ as “a step, an act, an operation, that transforms the design situation somewhat relative to the state it was in before that move.”[166] Deciding design moves and links should be made by someone who has ‘good acquaintance’ with the discipline and the design process.[167] To understand the contents of the moves and to decide if there is a link between each move, the researcher’s acquaintance has a key role to minimize the difficulties of the think-aloud method, such as incomplete sentences or unclear and repeated words. After detecting design moves, the links between design moves must be determined and coding links is a subjective process. Goldschmidt states that the process of coding links is depended on the ‘common sense’. According to her method “a link between two moves is established when the two moves pertain to the same, or closely related, subject matters, such as a concept or a design strategy”[168] To support the decision process, the researcher could benefit from the video-recordings, sketches and models that have been made during the design process to perceive moves and links more accurately.

[164] Ibid., 46.
[165] Ibid., 118.
[166] Gabriela Goldschmidt, "The Designer as a Team of One", *Design Studies* 16, no. 2 (1995): 195.
[167] Ibid., 47.
[168] Gabriela Goldschmidt, & Maya Weil. (1998). Contents and Structure in Design Reasoning. Design Issues, 14(3): 85.

Goldschmidt recommends having three people to judge the existence of links in an ideal procedure.[169] Mc Neill, Gero, and Warren suggest ‘inter-coder arbitration’ to reduce the subjectivity to link coding with ten days intervals by more than one judges.[170] Inter-coder arbitration has been used by the researchers as ‘self-arbitration’ in case there is only one researcher to judge.[171] In this method, the researcher makes the first parsing session to define design moves and coding links, then she gives a ten days break to begin the second session to detect design moves and coding links. Independently of the first parsing session. After one more interval (ten days), the researcher compares the first two protocol results and makes the final decision to end the coding process with ‘self-arbitration’. Links are represented by nodes in Linkography. To illustrate, as can be seen in Figure 2.10., which is an excerpt protocol texts of D4, the node between ‘move 15’ (M15) and ‘move 17’ (M17) indicates a link among these design moves. D4 makes a design decision in M15 about changing the size of the elements to reach a hierarchical order and then applies this idea in M17. There can be seen also a link between M16 and M17. For M16, D4 acts independently from the idea in M15 but he/she uses the same design element after changes its position to apply the design decision in M17. It can be seen that each design move could have a different number of links in terms of its content and relation with other moves.

> **M15** now I want to be hierarchical not only in size but also in the differentiation of geometric objects, so I will add something sharp to this group
> **M16** [changes the relation between cube and pyramid] – hah
> **M17** let's increase the size of it -scales the pyramid x2

169 Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 48.

170 Thomas McNeill, John S. Gero and James Warren, "Understanding Conceptual Electronic Design Using Protocol Analysis", *Research in Engineering Design* 10, no. 3 (1998): 129-140.

171 Benay Gürsoy, "The Cognitive Aspects of Model-Making in Architectural Design" (Master of Architecture, Middle East Technical University, 2010).

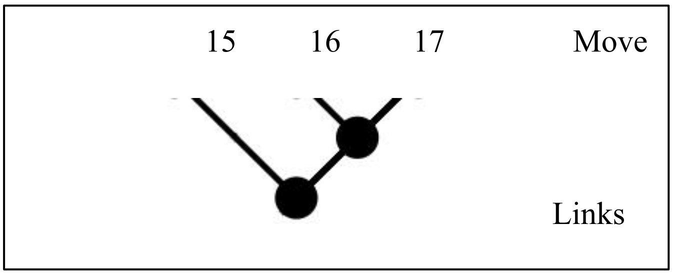


*Figure 2-10.* Excerpted Linkograph part belongs to D4's protocol

The density of these nodes presents a visual idea to understand the inter-connection between the ideas during the design thinking process.[172] If the nodes are distributed separately and in an unstructured way, this indicates that the design process is unsystematic and poorly developed. On the other hand, too dense linkograph could be mean design fixation rather than a highly productive design process.[173] Goldschmidt points out to looking for some geometric link patterns of Linkography to read productivity, which is 'chunk', 'web', and 'sawtooth' (Figure 2.11.).[174] Chunks are the groups of nodes that can be observed as a triangular structure in a linkograph and the presence of chunks indicates high efficient thinking and reasoning during the design process.[175] Webs consist of a small number of moves, which have more related links in a narrow triangular area.[176] Goldschmidt states that webs are smaller than chunks but they have denser inter-connection between links so they do not occur always in a linkograph.[177] Webs can be seen in the design process when some specific sub-problems needs to be solved. Usually, webs include no more than seven moves,

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[172] Gillian Hatcher et al., "Using Linkography to Compare Creative Methods for Group Ideation", *Design Studies* 58 (2018): 127-152

[173] El-Khouly, T., & Penn, A. (2014). On an Integrated Analytical Approach to Describe Quality Design Process in Light of Deterministic Information Theory. Design Computing & Cognition '12, 451.

[174] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 62.

[175] Ibid., 64.

[176] Ibid.

[177] Ibid., 65.

which are inter-connected densely, due to the limitation of short-term memory.[178] Chunks and webs are the components of productive and creative design processes.[179]

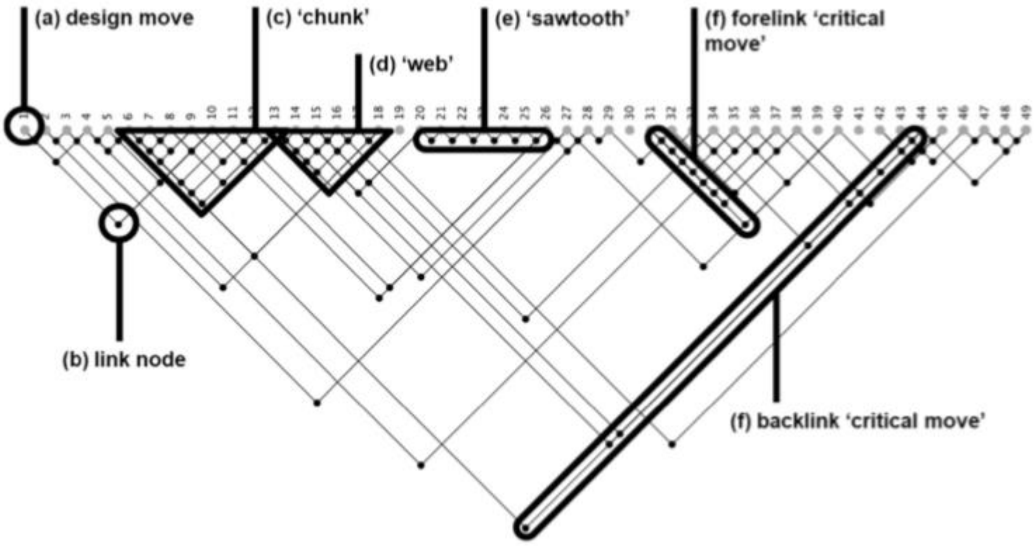


*Figure 2-11.* An example of linkography to illustrate terminology

Source: Gillian Hatcher et al., "Using Linkography to Compare Creative Methods for Group Ideation", *Design Studies* 58 (2018), 130.

Sawtooth is another move sequence in Linkography and it appears as a zigzag pattern like a sawtooth when the designer makes a series of design moves without any attempt of design exploration and follows a linear thinking process.[180] Goldschmidt states that a sawtooth track must be included at least four moves to be defined.[181]

Deciding if there is a link between two moves is critical to read linkograph on later to evaluate link types, which are 'forelinks' and 'backlinks'. Forelinks shows the moves, which relate to other subsequent moves later on. On the other hand, backlinks refer to the related design moves made in the earlier phases of the design process. Backlinks

[178] Ibid., 65.
[179] Gabriela Goldschimdt, "Serial Sketching: Visual Problem Solving in Designing", *Cybernetics and Systems* 23, no. 2 (1992): 191-219.
[180] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 65.
[181] Ibid., 65.

can be defined at the moment that the design move is made; however, the whole design process must be ended to define forelinks.[182] The meaning of a high number of backlinks is that the design move is integrated with several previous design moves, whereas the meaning of a high number of forelinks shows that the design move influenced the many other following design moves so it has a significant role for the ideation process.[183] According to Goldschmidt, forelinks refer to divergent thinking and backlinks refer to convergent thinking.[184] The balance of these two types of moves presents an insight for creative behavior and this significant idea will be understood after defining the other essential components of Linkography, which are the types of the design moves and link index value.

Goldschmid defines four types of design moves, which are ‘orphan moves’, ‘unidirectional moves’, ‘bidirectional moves’, and ‘critical moves’. Orphan moves are the ones that have no links to relate any other design moves. This could be possible when the designer made an irrelevant design move. According to Goldschmidt, the linkographs of the novice designers have more orphan moves than the experience designers.[185] Unidirectional moves occur in the first and the last moves, or when the designer was focusing on the current event only or on the new ideas, which has no connection with the moves until that move.[186] Unidirectional moves are the moves that have only backlinks or only forelinks, whilst bidirectional moves have both types of links.[187] Goldschmidt emphasizes that bidirectional moves refer to important things for the design process. She states that “bidirectional moves suggest a rapid shift between the two modes of reasoning that are associated with divergent and convergent

[182] Gabriela Goldschmidt, "The Designer as a Team of One", *Design Studies* 16, no. 2 (1995): 195.
[183] Gillian Hatcher et al., "Using Linkography to Compare Creative Methods for Group Ideation", *Design Studies* 58 (2018): 130.
[184] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 117.
[185] Ibid., 57.
[186] Ibid., 57.
[187] Ibid., 57.

thinking".[188] She also states that the ability to shifting between the two modes of thinking easily refers to creative ability based on Gruber's idea:

> Interesting creative processes almost never result from single steps, but rather form concatenations and articulation of a complex set of interrelated moves.[189]

In the context of creativity, another important type of move is 'critical move'. When a design move has a high number of forelinks or backlinks, it is called as 'critical move'.[190] A high number of critical moves with backlinks indicates for integrating ideas as convergent thinking mode and a high number of critical moves with forelinks indicates for idea generation as divergent thinking mode.[191] Linkography assumes that the ability to synthesize a solution with its good fit elements indicates for the creativity of the design process.[192] Thus, the density of links among the design moves signifies something to understand design creativity and productivity. Therefore, knowing the proportion of links in a design process becomes crucial to reading creativity through Linkography. In this context, Goldschmidt mentions on the Link Index value to see the ratio between the number of links and the number of the design moves as a proportion.[193] The link index value is an easy way to interpret data in terms of seeing a designer's effort during the design process and gathering hints for creativity. However, Goldschmidt warns that a high value of a link index may not be always referred for a creative design process, instead it could mean for a design process that includes many repetitive moves or too many attempts for an alternative solution without continuity.[194]

In recent years, there has been an increasing amount of literature on Linkography. Remko van der Lugt applied Linkography by using a matrix to analyzing creative

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[188] Ibid., 58.
[189] Hans Peter Gruber, "Afterword", in *Beyond Universals in Cognitive Development* (Praeger, 1980): 177.
[190] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 58.
[191] Ibid.
[192] Ibid., 73.
[193] Ibid., 69.
[194] Ibid., 70.

problem-solving processes of design groups through brainstorming with various tools.[195] Lugt also compared 'brain sketching' and 'brainstorming' techniques through Linkographic results comparatively.[196] Vidal et al. used Linkography to compare 'visual', 'objectual', and 'sentential' brainstorming in design groups. According to Vidal et al., the most effective method for brainstorming is the one through 'objectual variant'.[197] Kan and Gero studied on cluster analysis through examining the link density and distance between the links.[198] To reach a better interpretation of linkography results, they preferred the 'entropy' notion. Kan and Gero used forelink entropy to measure the opportunities for idea generation and backlink entropy to measure opportunities referred to responsive and enhancive design movements.[199] They also focused on coding design moves through FBS (Function-Behavior-Structure) to observe the distribution of the links in the design process.[200] After the abovementioned study on FBS, Pourmohamadi and Gero developed an analysis tool, LINKOgrapher, for Linkography based on FBS.[201]

Gero also used the entropy to understand design fixation (Figure 2.12.). According to him, entropy should be lower during the fixation comparing to the other phases of the design process.[202]

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[195] Remko van der Lugt, "Developing A Graphic Tool for Creative Problem Solving in Design Groups", *Design Studies* 21, no. 5 (2000): 505-522.
[196] Remko van der Lugt, "Brainsketching and How It Differs from Brainstorming", *Creativity and Innovation Management* 11, no. 1 (2002): 43.
[197] Rosario Vidal, Elena Mulet and Eliseo Gómez-Senent, "Effectiveness of the Means of Expression in Creative Problem-Solving in Design Groups", *Journal of Engineering Design* 15, no. 3 (2004): 285-298
[198] Jeff W.T. Kan and John S. Gero, "Acquiring Information from Linkography in Protocol Studies of Designing", *Design Studies* 29, no. 4 (2008): 315-337.
[199] Ibid.
[200] Jeff W. T. Kan and John S. Gero, "Using the FBS Ontology to Capture Semantic Design Information in Design Protocol Studies", in *About: Designing - Analysing Design Meetings* (CRC Press, 2009), 213-229.
[201] Morteza Pourmohamadi and John S. Gero, "Linkographer: An Analysis Tool to Study Design Protocols Based on FBS Coding Scheme", in *18Th International Conference on Engineering Design - Impacting Society through Engineering Design*, 2011, 294-303.
[202] John S. Gero, "Fixation and Commitment while Designing and Its Measurement", *The Journal of Creative Behavior* 45, no. 2 (2011): 108-115.

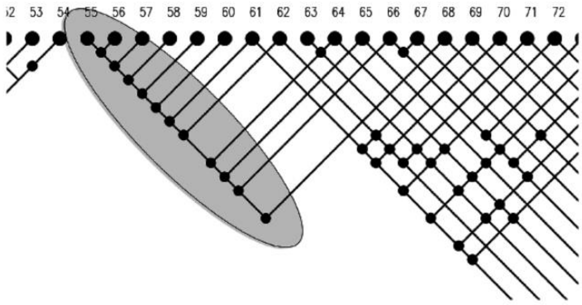


*Figure 2-12.* Move 55 indicates for fixation

Source: John S. Gero, "Fixation and Commitment while Designing and Its Measurement", *The Journal of Creative Behavior* 45, no. 2 (2011), 112.

Benay Gürsoy and Mine Özkar carried out an experimental study to observe how designers use three different design medium in their design processes, which are freehand sketching, model making by hand, and digital modeling.[203] Due to understanding the design productivity, they preferred to use Link Index value and tracked for lateral and vertical transformations during the design phases.[204] El- Khouly & Penn developed a methodology to evaluate linkographs through quantifying entropy for each design move in the design process.[205] They figured out that 'a multi-level design concept' in the design processes, which are "(1) an intermediate medium of representation for the concept initiation, (2) an execution process of the idea, and (3) a retrospective reflection on earlier thoughts."[206] Lee et al. also studied on Linkography as a methodology to analyze design cognition during the parametric architectural design with algorithmic scripting.[207] At the end of the study, Lee et al.

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203 Benay Gürsoy and Mine Özkar, "Is Model-Making Sketching in Design?", in *Design Research Society International Conference on Design and Complexity* (Montreal: Design Research Society, 2010).
204 Ibid.
205 Tamer El-Khouly and Alan Penn, "On an Integrated Analytical Approach to Describe Quality Design Process in Light of Deterministic Information Theory", in *Design Computing and Cognition* (Springer, 2012), 1-20.
206 Ibid., 18.
207 Ju Hyun Lee, Ning Gu and Michael J. Ostwald, "Architectural Design Using Algorithmic Scripting: An Application of Linkographic Analysis Techniques", in *Cutting Edge: 47Th International Conference of the Architectural Science Association* (Hong Kong: The Architectural Science Association (ANZAScA), 2013), 133-142.

stated that the designers generate solutions by applying expanded iteration and modifying parameters to reorganize in the parametric design process based on the results that indicated a higher number of backlink entropy than forelink entropy.[208] The research of Hatcher et al. is another significant study on linkography. They used the linkography to compare brainstorming and the newly developed ideation method, Design Improv.[209] Linkography is not used for the design process only. To illustrate, Blom and Bogaers applied linkography to explore the thinking processes and find out information on using habits of the students between the age of 13-14 during a STEM task.[210]

In all the studies reviewed here, linkography is recognized as a method to evaluate design creativity and productivity in many layers. Next section will be focused on the creative thinking ability as one of the essential learning outcomes of Basic Design.

### 2.2.4. Design Tools for Learning and Creative Thinking with Developing Technology

The importance of learning in design has given way to the development and application of a variety of tools aiming to trigger students' creativity. Basic design education was heavily influenced by Johann H. Pestalozzi and Friedrich Froebel, the child educators in the 19th century.[211] Friedrich Froebel made a crucial impact on educational systems with his pedagogical paradigm named 'hands-on learning'.[212] He stated that children learn best by interacting with the world around them. As a result, Froebel developed a new education model that allows young children to interact with

[208] Ibid.
[209] Gillian Hatcher et al., "Using Linkography to Compare Creative Methods for Group Ideation", *Design Studies* 58 (2018): 127-152.
[210] Nicolaas Blom and Alfred Bogaers, "Using Linkography to Investigate Students' Thinking and Information Use During a STEM Task", *International Journal of Technology and Design Education*, 2018.
[211] Gillian Naylor, *The Bauhaus Reassessed* (London: Herbert Press, 1985).
[212] Mitchel Resnick and Ken Robinson, *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play* (Cambridge: The MIT Press, 2017).

toys and craft materials. He designed new types of toys to enhance their creativity. Froebel's approach also has been related to design education. Arthur Wesley Dow took the leading point for teaching the principles of design with studio practices and adopted the experience-based material model in the design studio.[213] Piaget also emphasized the essential role of the right material usage and communication with the external world in the learning processes of children in his theory of constructivism in education[214]. Seymour Papert moved forward the criticism of instructive teaching methods in schools and pointed to the importance of constructivist teaching strategies in education[215]. Thus, the concept of 'Bricolage' was proposed by Seymour Papert to develop constructive skills again since Levi-Strauss[216]. Bricolage, or tinkering, is a process of failing, fixing, and continuing to develop the design during the process of learning.[217] The process also has an inseparable connection with the transformation of abstract knowledge to more concrete learning tools as an initial phase of tinkering.

In the age of technological developments, computational tools have not only transformed creative learning tools for education but also are used in architectural curricula's essentials as with many other disciplines. Nevertheless, the usage of computational tools is still a controversial subject as design tools in terms of their effects on the design process of a designer. Computational tools such as AutoCAD, 3DsMax, Rhino, Sketchup, Revit or even some parametric design tools such as Grasshopper have been utilized in many higher-education institutes for architectural design. Yet, the basic design is a fundamental course, which has been accepted as an introductory studio for the novice student in their first-year of architectural education. Therefore, these abovementioned programs may create weaknesses for these students without basic knowledge of design fundamentals and at least medium level skills to

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[213] Nanyoung Kim, "A History of Design Theory in Art Education", *The Journal of Aesthetic Education* 40, no. 2 (2006): 12-28.
[214] Mitchel Resnick and Ken Robinson, *Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play* (Cambridge: The MIT Press, 2017).
[215] Seymour Papert, "Instructionism versus Constructionism", in *The Children's Machine: Rethinking School in the Age of the Computer* (New York: Basic Books, 1993), 137-156.
[216] Ibid.
[217] Ibid.

use these programs. Mine Özkar states the key role of basic design education in terms of the present technological environment and defines basic design as a connector between computation and design education.[218] Nevertheless, current computational tools for design have weaknesses in providing a medium that supports the designer in exploring the design space. According to Levent Kara, premature implementations of digital tools in design studios at the first stage of the design learning process has some negative consequences in the sense of design education. The students that have been introduced with the digital tools at the very beginning of their architectural education, run the risk of lacking spatiotemporal sensation and design ability.[219] Ladovksy is another name that points to the relationship between the bodily sensation and comprehension of spaces or objects[220]. The space organization, as argued by Kara, would not be able to progress outside of the digital medium, as the digital tools force the student to content oneself with the limitations of the certain digital tools. Inherently, the students might not be able to improve the skills required by an independent designer[221]. On the other hand, according to Benay Gürsoy, digital models are unambiguous design tools that limit the designer's sketching and reasoning process.[222] Gürsoy's study agrees with Goel's idea that computational drawing tools have more passive effects on lateral transformation than free-hand drawing.[223] She also states that another reason for the unsuccessful result of the digital models could be derived from her subjects' inability to benefit from the ambiguity potentials of the computational tools yet.[224] However, ambiguity in the design processes is still valued.

[218] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017).
[219] Levent Kara, *A Critical Look at the Digital Technologies in Architectural Education: When, Where, and How?*, 2015.
[220] Ladovsky, Nikolai. 1991. "The Psycho-Technical Laboratory of Architecture." Architectural Design 61 (9/10): 26
[221] Levent Kara, *A Critical Look at the Digital Technologies in Architectural Education: When, Where, and How?*, 2015.
[222] Benay Gürsoy, "The Cognitive Aspects of Model-Making in Architectural Design" (Master of Architecture, Middle East Technical University, 2010): 15.
[223] Vinod Goel, *Sketches of Thought* (The MIT Press, 1995).
[224] Ibid.

Ozkar emphases that the creative thinking process is a thought process that explores uncertainties and redefines constraints.[225]

Due to the limitations of computational tools' use in design, such as limiting ambiguity, they are mostly used for design representation and visualization. Accordingly, computational tools' capacity to support creative design has become problematical. To this extent, Ozkar states that the main purpose of basic design materials at the first place is enabling the designer to 'create and/or manipulate'.[226] She also supports that the early integration of computational tools in design education can result in increased awareness in the students' reasoning process.[227]

## 2.3. Mixed-Reality Environments for Design Education

Reality means the environment that actually exists and has an interactive connection between visual or comprehensible elements of the existing world physically. In the context of this study, reality refers to the physical design environment of the design studios with the substantial materials and tools that allow active connectivity among each other. However, reality notion has been immersed in company with developing virtual reality technologies. Reviewing the reality spectrum and the definitions of these immersive environments could be useful in terms of clarifying the significance of MR environments in architectural design education. Therefore, this section includes these definitions and the next section presents the recent studies on architectural design education with the usage of several types of VR technology.

VR technologies are diverse in terms of the contribution levels of the real-world components into the computer-generated virtual worlds. VR and AR stand the opposite points of the reality spectrum. Virtual-Reality (VR) is an environment that the user acts in a virtual world generated by a computer in full, whereas Augmented-

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[225] Mine Özkar, *Rethinking Basic Design in Architectural Education: Foundations Past and Future* (New York: Routledge, Taylor & Francis Group, 2017): 142.
[226] Ibid., 151.
[227] Ibid.

Reality (AR) is an environment that the user still has opportunity and perception to connect with the components of real and virtual worlds in a combined 3D space.[228] AR requires the transmission of the virtual components to the real environments. According to Azuma, the user is able to be aware of the real world and interact with virtual objects embedded or combined in the real world.[229] He also assumed three characteristic features to prevent restrictions on AR definition depend on changeable technologies. Based upon his signification, AR environments overlap the virtual components with the real environment, suggests interaction in real-time, and registered in 3-D.[230] On the contrary of AR, Augmented-Virtuality (AV) refers to another type of virtual environment, where the computer-generated 3D virtual world is supported by real objects from the existing world. According to Schnabel, AV enables a multi-layered 3D experience integrated into the virtual world.[231] Currently, the game industry and commercials or various movie techniques could be mentioned as the main user areas of AV.

Mixed-Reality is a complete intersection in between real-reality and virtual reality environments. Milgram and Kishino define Mixed-Reality as an environment between the opposite points of 'virtuality continuum' which includes real-world components and virtual world components exist together in a single display.[232] Schnabel states that

> The intersection of real and virtual environments is defined as a Mixed Environment (ME), within which physical and digital elements co-exist, and interact and intermingle in a more expansive form.[233]

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[228] Gwyllim Jahn et al., "Making in Mixed Reality", in *Recalibration: On Imprecision and Infidelity* (rMexico City, 2018), 91.
[229] Ronald T. Azuma, "A Survey of Augmented Reality.", *PRESENCE: Virtual and Augmented Reality* 6, no. 4 (1997): 355-385.
[230] Ibid.
[231] Marc Aurel Schnabel, "Framing Mixed Realities", in *Mixed Reality in Architecture, Design & Construction* (Springer, 2008): 3.
[232] Paul Milgram and Fumio Kishino, "A Taxonomy of Mixed Reality Visual Displays", *IEICE Transactions on Information Systems* 77, no. 12 (1994): 1321-1329.
[233] Xiangyu Wang and Marc Aurel Schnabel, *Mixed Reality in Architecture, Design and Construction* (Dodrecht: Springer, 2009): 6.

Virtuality continuum ends with the Virtual-Reality. VR is an environment which does not contain any real-world components in itself. VR environments are completely computer-simulated environments and they have many common usage areas today including architecture. Davidson and Campbell (1996) stated that VR is a collaborative design tool that supports architectural communication and interaction. Yet, there is a fact that both VR and MR technologies have been utilized mainly for collaboration and as various kind of representation techniques in the architecture field, as mentioned in the following sections of the thesis.

### 2.3.1. Mixed-Reality in Architecture

There have been some studies recently focused on searching for new design tools and learning ways to improve the efficiency of basic design education and the learners' creative design process, under consideration of the ongoing technological developments such as interactive animation techniques, technological devices for Virtual-Reality environments. Immersive environment technologies have been applied in architecture and design learning for the aim of interdisciplinary communication, collaboration, and visualization predominantly during the past years.

GreenSpace II is one of the outstanding studies that had been carried out particularly on architectural design.[234] Three types of hotel guest rooms were designed by students and the faculty of the College of Architecture and Planning (CAUP) in a virtual environment. AutoCAD was utilized to create the essential geometries and they were exported into Lightscape and 3DStudio. Finally, GreenSpace application was used for simulation. The participants utilize Head-Mounted Display (HMD), joysticks and on-screen display for visual collaboration. As a result of this study, the authors stated that new media had a positive impact on collaborative design with usage of proper abstract

[234] James N. Davidson and Dace A. Campbell, "Collaborative Design in Virtual Space - Greenspace II: A Shared Environment for Architectural Design Review", in *Design Computation: Collaboration, Reasoning, Pedagogy* (Tucson: ACADIA, 1996), 165-179.

representation of scale models and orthographic projection drawings.[235] Only two manipulative tools had been implemented in this research, which was 'move' and 'color' commands and the participants were represented as avatars in the VR environment. BUILD-IT is another study that had been focused on the immersive environment and its impacts on interactive construction and design.[236] The research team expressed that the main success and the purpose of AR rely on the given opportunities to use human skills for interacting with real-world subjects and objects. Therefore, they designed the application (BUILD-IT) to ease the early phase of the design process by promoting assembly lines and plants[237]. They utilized a system supported by video-cameras and a table which had been used as a horizontal projection and interaction area that makes possible to recognize the designers' interactions on the table and to render them as a result in two views. The project tries to emphasize the significance of the ability to use essential human skills in AR as a difference between VR and AR environments.

W. Broll et. al. have conducted another developmental study named ARTHUR, which presents a supportive approach on architects' designing and planning processes through the simulative movements of pedestrians by using an integrated design table with the existing CAD tools.[238] It is an implementation that allows real form creation and manipulations of these form geometries, which are a box, sphere, cylinder, and cones, by gestures. The users were allowed to use a pointer to select operations in the 3D menu and manipulate the objects.[239] ARTHUR has been proposed as an architectural and urban design tool that boost collaboration. Nevertheless, it has

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[235] Ibid.
[236] Matthias Rauterberg et al., "BUILD-IT: A Video-Based Interaction Technique For A Planning Tool For Construction And Design", in *5Th International Scientific Conference - WWDU '97* (Takorozawa: NORO Ergonomics Lab, 1997), 175-176.
[237] Ibid.
[238] Francis Aish et al., "An Augmented Reality Collaborative Design System", in *Institution of Electrical Engineers Conference* (Hertsfordshire: IEE, 2004), 49-73.
[239] Ava Fatah gen Schieck et al., "Interactive Space Generation through Play Exploring the Role of Simulation on the Design Table", *International Journal of Architectural Computing* 3, no. 1 (2004): 3-25

resulted in increasingly complex problems with regard to users' input and interaction in consequence of the integration of CAD into ARTHUR.

MxR is another study that can be used with a system that consists of a webcam attached to a head-mounted display and the system also is connected to a PC running the ARToolKit software.[240] MxR has been developed to work with a video-based MR/AR configuration. Despite its advantages such as being a supportive design tool for alternative material testing and collaboration, MxR has limitations to support the generation of geometric primitives.[241]

BuildAR software provides a means to overlay the virtual model over the marker, reposition it, scale it or rotate it.[242] Students use their own laptops to test the AR models. It has been found supportive as a design education tool for students' 3-D comprehension, although it is not sufficient to utilize in early design phases and it is not allowing generating forms. Dorta et. al. utilized Hyve-3D and the 3D Cursor in their study, and they focused on sketching in the architectural design. As a result of the study, Dorta et. al. stated that the Cave Automatic Virtual Environment (CAVE) as a VR-based technology has weaknesses in terms of the idea generation process and visualizing leads for a passive way to interact with VR design environment.[243] Additionally, the 3-D models, which used in VR, still being made by using 3-D computational tools outside VR.[244]

Recent studies indicate that immersive environments have potentials in architectural design education. However, they need to be improved for more productive utilization.

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[240] Daniel Belcher and Brian R. Johnson, "MxR: A Physical Model-Based Mixed Reality Interface for Design Collaboration, Simulation, Visualization, and Form Generation", in *Silicon + Skin: Biological Processes and Computation* (Minneapolis: ACADIA, 2008), 464-471.

[241] Ibid.

[242] Tilanka Chandrasekera, "Using Augmented Reality Prototypes in Design Education", *Design and Technology Education: An International Journal* 19, no. 3 (2014): 33.

[243] Tomás Dorta, Gokce Kinayoglu and Michael Hoffmann, "Hyve-3D and the 3D Cursor: Architectural Co-Design with Freedom in Virtual Reality", *International Journal of Architectural Computing* 14, no. 2 (2016): 87-102.

[244] Ibid.

Table 2-1. *Similar Works*

| Year | Tool | Researchers | Concepts | Environment |
|---|---|---|---|---|
| 2019 | HoloArch 1.0 | Akin, S., Ergun, O., Dino, I. G., Surer, E. | Performative Architecture, BIM | VR-MR |
| 2018 | Rhino and Grasshopper | Jahn, G., Newnham, C., | Architectural and Industrial Fabrication | MR |
| 2018 | Wikitude | Chu, M. et al. | BIM- AR | AR |
| 2017 | CORAULIS | Milovanovic, M. et al. | Representational environment – design studio | VR-SAR |
| 2017 | Mobile App | Ren, J.et al. | BIM-AR | AR |
| 2016 | Hyve-3D -3D Cursor | Dorta, T. et.al. | Architectural co-design – sketch | VR |
| 2016 | Lab D3D | Neves, A. G., Duarte, E. | VE in Basic Design Education | VR |
| 2015 | AR Creative-Classroom | Wei, X., Weng, D., Liu, Y., & Wang, Y. | AR for technical creative design course | AR |
| 2014 | BuildAR | Chandrasekera, T. | Design education | AR |
| 2014 | CAP VR Environment | Angulo, A., Velasco, G. V. de. | Immersive Simulation of Architectural Spatial | HMD-VR |
| 2012 | Secondlife | Gül, L., Gu, N., Williams, A. | Collaboration – design studio | VR |
| 2008 | MxR | Belcher, D., Johnson, B. | Collaboration during the early phases of architectural design | MR |
| 2008 | ARUDesigner | Wang, X., Gu, N., Marchant, D. | Collaborative architectural design | AR |
| 2004 | Benchwork | Seichter, H. | Urban design | AR |
| 2004 | ARTHUR | Broll, W. et. al. | Collaborative architectural design and urban planning | AR |
| 2003 | Sketchhand | Seichter, H. | Collaborative sketching – architecture | AR |
| 2003 | MRCVE | Wang, X., Shin, D., Dunston, P.S. | MR-based design and | MR |
| 2002 | SpaceDesign | de Amicis, F., Stork, M. | MR Based Creation and Editing for Industrial Design | MR |
| 2002 | MIXDesign - ARToolKit | J.M.S. Dias, P. Santos, and N. Diniz | Tangible interaction for conceptual | AR |
| 2000 | dVISE | Frost, P., Warren, P. | The educational design process in architecture | VR-CAVE |
| 1997 | BUILD-IT | Rauterberg, M. et. al. | Interactive construction and design | VR |
| 1996 | GreenSpace II | Davidson, J. N., Campbell, D. A. | Architectural collaboration | VR |

# CHAPTER 3

# METHODOLOGY

The aim of the study is to explore the potentials of the MR environment as a new design medium for the first-year architectural design students and discovering the MR's advantages and disadvantages in Basic Design. Herewith, firstly, a design tool was developed to enable designing in MR for the usage of the participants with a specific apparatus, which was Microsoft HoloLens. The tool development process will be mentioned in Chapter 4 in detail. This chapter focusses on the methodology of the research.

The study followed an empirical research methodology to explore the potentials and the limitations of MR in the architectural basic design studio. A mixed methodology, which is a combination of protocol analysis with linkography, observations, and semi-structured interviews, was used to investigate the potential of MR design environment by a newly developed design tool in this research. A series of design tasks were carried out for (a) domain exploration and (b) the validation of the mixed reality environment. This experiment-based design research methodology adopted a quantitative and also a qualitative approach for examining the design-thinking processes, which include a series of problem-solving operations in two different design environments, physical and MR, to compare these two design environments objectively through observations, semi-structured interviews, protocol analysis, and linkography. Considering the scope of this study, protocol analysis and linkography constitute critical parts of the research progress. As a research strategy, the protocol analysis with linkography suggests a rigorous perspective to understand design creativity and productivity during the design processes due to the evaluation of the design process, not the end products.

### 3.1. Developing Methodology through a Pilot Study

As previously mentioned, the main scope of the study was understanding the potentials of the MR environment for Basic Design and this scope was tracked through design creativity and productivity during the design processes comparatively in two different design environments, which are a physical environment and MR environment with the newly developed design tool. Since the primary scope was not identifying the design phases but identifying potentials and limitations on the creative and productive design process, current protocol analysis methods, which include coding processes, were not found suitable for the research, solely. Therefore, linkography was preferred to compare the design processes with some adaptions in the context of the study. To analyze these necessary adaptations the pilot studies were carried out.

Linkography is a method mostly using think-aloud, but also could be supported by the sketches, models, and any other visual components occur during the design process. Nevertheless, the participants of the protocol studies were the first-year architectural students as novice designers. During the pilot studies with a few architectural graduate students, it was observed that even the graduate students were not able to talk consistently while concentrating on using the design tools in both environments. On the other hand, they were generating related design moves while saying uncompleted words such as ‘hah’, ‘OK’ or ‘yeah’ during design development. The observations of the researcher while tracking the visual operations of the participants during the design processes were also used to support the think-aloud protocols. Another reason for using a mixed methodology was understanding the effects of using MR on not only their design processes but also the students themselves. To this purpose, a semi-structural interview was prepared to ask participants’ comments and feedback on MR experiences for Basic Design in terms of educational and usability aspects. As a result, a mixed methodology and its guidelines were built in the context of the study and its procedure will be focused on the next section.

## 3.2. Protocol Studies Using Linkography and Interviews

The mixed methodology was built to include five stages: (1) a coding schema as a translator to define which data are used for addressing the research questions, (2) determination of participants and establishment of required settings for the experiments, (3) Choosing a design task and setting constraints in terms of the defined context, (4) data collection stage that the experiments were executed in both design environments, and (5) data analysis as a final stage, which consists of a set of operations (Figure 3.1.). The first operation in data analysis was the transcription of the collected data such as verbal statements and visual representations during the design processes and exit-interviews, which were sustained by video-recordings and HoloLens real-time screen recordings. Then a criterion was designed as a second operation for detecting design moves and links. Thirdly, the link coding process was conducted. To ensure 'self-arbitration' and achieve less subjective results, link coding process was repeated and checked three times. The parsing procedure applied three times through ten days intervals between each coding processes. Finally, the interviews were coded to support the evaluation process.

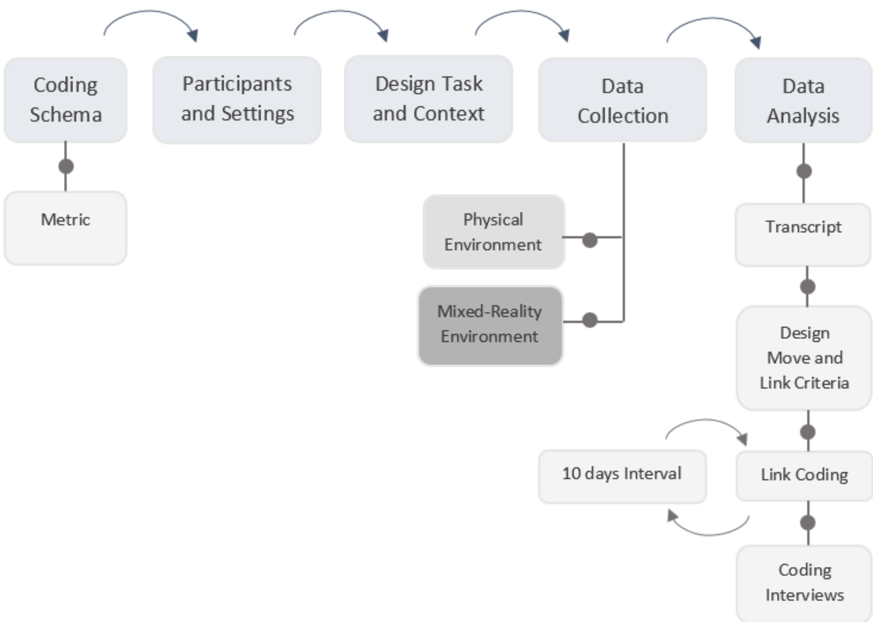


*Figure 3-1.* The developed mixed methodology

### 3.3. Coding Schema and Settings Before the Experiments

According to Atman and Turns, generating a coding schema is an essential part of the protocol studies in answering the research questions on related cognitive perspectives, or testing hypotheses on relative subjects by establishing a link with verbal protocols. [245] Coding schema is a significant stage of the protocol studies, which tries to identify design phases and activities. However, this research was not about to focus on the identification of design phases, but the identification of related design activities. Therefore, a coding schema was established to secure a guideline, a translator between the research questions and the related metrics to evaluate the design processes in both design environment (physical and MR) more structurally and objectively.

Since the main interest of this research is basic design, the coding scheme is developed as a series of eight design activities with respect to the research questions, which were stated in the introduction. These activities include adaptation and usability, thinking 3-D, gesture-based manipulation, idea generation, providing needs, tinkering, productive thinking, and creative thinking. Table 3.1. shows the descriptions of these design activities in accordance with the coding and their related metrics.

[245] Cynthia J. Atman and Jennifer Turns, "Studying Engineering Design Learning: Four Verbal Protocol Studies", in *Design Knowing and Learning: Cognition in Design Education* (Elsevier Science, 2001), 37-60.

Table 3-1. *Codes and Descriptions*

| Codes | Code Descriptions | Related Metric |
|---|---|---|
| Adaptation and Usability | Learning and using basic abilities to | Chunks, Related Verbal statements, observations |
| Thinking 3D | Understanding 3D relationships and manipulating design | Visual Representations, Verbal statements, Gestures |
| Gesture-based manipulation | The possibilities for interaction by hand | Related Verbal statements, observations |
| Idea Generation | Finding solution ideas and searching for | Chunks, forelink critical moves |
| Providing Needs | Designation necessary | Webs, observations |
| Tinkering | Improving solutions and reframing the | Chunks, backlink critical moves |
| Productive Thinking | Not wasting time on ideas that cannot be | The balance between CMs in both directions |
| Creative Thinking | Ability to shift between divergent | Link Index, Balance between CMs in both directions |

These design activities were the ones the research assumes that the new MR design environment could have potentials to support in design learning processes of the architectural students. Adaptation and usability indicate the insights for users' learning and using basic abilities to design in MR. Users' related verbal statements during the design processes and exit-interviews aimed to obtain related metrics to the evaluation of this code. The observation of the researcher and the chunks, which were generated through linkographs, were also utilized as metrics of adaptation and usability aspects. The second design ability that the new design environment aimed to encourage was thinking in 3D. It refers to understanding 3D relationships between the design elements and manipulating them through 3D perception. This ability was evaluated through participants' visual representations during the design processes, related verbal protocols, and observations. The third code was defined to observe users' gesture-based manipulations during the design processes. The reason for the examination of this code is understanding the interaction possibilities by hand /body in the MR design environment comparing physical environment. In this regard, related verbal protocols and observations were supported by gathering qualitative data. Idea generation refers to finding solutions for design problems. The solutions could be inspirational ideas at the beginning of the design process, or they also could be for the sub-problems at any phase of the design process. As mentioned in Chapter 2, chunks and critical moves with forelinks as linkographic data presents a metric for this code. Another design activity was determined to be included in research questions is that how the new design environment MR could encourage the users to provide necessary design components during the design process more efficiently. The research estimates that the new design environment could be beneficial to produce necessary design elements, objects, or the relationships between any kind of design component in less time than the physical design environment and tools. The numbers of design move within the same time for both design environments were calculated to compare as a metric. By the reason of using the ratio between the number of design moves and the elapsed time during the design process was that each design move was looked upon as an operation on purpose to provide a possible need for design. Tinkering was designed as a significant code to understand the designers' attempts to improve the solutions and reframe the problems in terms of advancing the design and the design processes. The critical moves with backlinks, which referred to combining earlier ideas with the new design moves, and chunks were chosen as the related metrics to gathering necessary data for comparing the impacts of the two different design environments over tinkering. Other important criteria to compare these environments was 'productive thinking'[246], which means not wasting time and effort on the discontinued design ideas, and the balance between the critical moves with forelinks and backlinks provided information to understand design productivity.[247] At last but not least, creativity was included in the codes in the context of the research. As mentioned in Chapter 2, the creative design process is highly related to the ability to shift between

[246] Joy Paul Guilford, "The Structure ıf Intellect.", *Psychological Bulletin* 53, no. 4 (1956): 267-293.
[247] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 94.

divergent and convergent thinking modes. Therefore, they were related to forelinks as the indicator of divergent thinking and backlinks as the indicators of convergent thinking.[248] Also, link density (L.I.) was determined to understand creative design thinking levels in two different design environments. Table 3.2. shows the related metrics and the related references to evaluate the new design tool.

Table 3-2. *Related Metrics and References*

**Chunks**

- indicates high efficient thinking and reasoning during the design process (Goldschmidt, 2014)
- are the components of productive and creative design processes. (Goldschmidt, 1992)

**Webs**

- can be seen in the design process when some specific sub-problems needs to be solved. (Goldschmidt, 2014)
- are the components of productive and creative design processes (Goldschmidt, 1992)

**Critical Moves with forelinks (CM>)**

- indicate for idea generation as divergent thinking mode (Goldschmidt, 2014)

**Critical Moves with backlinks (<CM)**

- indicate for integrating ideas as convergent thinking mode (Goldschmidt, 2014)

**Link Index Value (L.I.)**

- is significant to understand design creativity and productivity (Goldschmidt, 2014)
- may refers to many repetitive moves or too many attempts for an alternative solution without continuity. (Goldschmidt, 2014)

**Balance between CMs in both directions**

- presents an insight for creative behavior (Goldschmidt, 2014)

**Forelink Entropy**

- to measure the opportunities for idea generation (Kan&Gero, 2008)

**Backlink Entropy**

- to measure opportunities referred to responsive and enhancive design movements (Kan&Gero, 2008)

[248] Ibid., 117.

**Participants and Settings:** The four architectural students at METU were invited by the researcher based on the following criteria: (a) they should volunteer to contribute to the research, (b) they should be a first-year architectural student who already had experience at the basic design studio, (c) they should have different level of grade at the end of the Arch101, and (d) they should be able to communicate with the researcher fluently during the protocol studies.

After selecting the participants, the experiments were conducted at METU, Department of Architecture. A classroom was used as an isolated lab environment for the protocol studies without disturbing the designers during the design processes.

**Design Task and the Context:** The context of the experiment was the basic design studio and the participants were novice designers as the first-year architectural students recently experienced this studio. In this regard, the design task was chosen to analyze the impacts of MR as effectively as possible. As mentioned in Chapter 2, most basic design courses begin with the 2D assignments to establish main ordering principles such as rhythm, hierarchy, similarity, growth, proximity, and so on through grouping and then continue with 3D assignments. 3D assignments have critical roles in developing 3D thinking ability and leading students to design 'space'. Organizing 3D relations between design elements and creating conscious volumes are significant design abilities for novice designers in their first year in architectural education. Herewith, the basic design task that was given to the participants to solve was designed to meet the requirements of the 3D basic design assignments to understand the impacts of the new design environment. The task that the researcher designed for this research was adapted from a previous assignment of the basic design studio at METU.

Table 3-3. *Basic Design Task*

| | |
|---|---|
| **Basic Design Task \| 3D – Bounded Voids** | |
| | **Given:** White and craft cardboard pieces as many as needed (3mm) as planar elements (min. edge 5cm) |
| | **Asked:** 3D design with a given number (29) of design elements with basic geometries. The volumes should be created and related without using glue. |
| | **Design Themes:** Hierarchy |
| | **Discussions:** design elements and relationships<br>primary principles of construction<br>unity and balance; proportions |

### 3.4. Data Collection

This section presents the implementation of the protocol studies to evaluate the potentials and the limitations of the Mixed Reality environment. By means of a systematic comparative study, protocol studies consisted of two different design environments, which are the MR environment through a newly developed design tool and the physical environment through the physical materials and tools.

Data collection during protocols differed for the two different environments in terms of the methods and the devices to collect data. During the experiments in the physical environment, video-recording and model images, sketches were involved in the protocol analysis part. On the other hand, in the other phase of the experiment with MR, all data were recorded through real-time screen-recording by HoloLens. The protocol studies were conducted at METU, Department of Architecture between 10$^{th}$ June 2019 and 13$^{th}$ June 2019. "Human Subject Ethics Committee" approval was obtained before conducting the studies.

Table 3-4. *Procedure of the Protocol Studies*

| Protocol Analysis Procedure for Basic Design Exercise in Mixed Reality | Protocol Analysis Procedure for Basic Design Exercise in Physical Environment |
|---|---|
| Introduction and collecting information about participants (age, registered semester, school and past experiences) | Briefing on the second phase of the research study and remembering the participants about the process |
| Briefing on the research study and a presentation to inform participants about the process | Remembering the requierements of the think-aloud |
| **Presenting HoloLens and testing how it works and use by the participant** | Informing participants about the same basic design task. Giving time for asking questions and examining the basic design problem. |
| **Giving information about think-aloud protocol and pre-trials to ensure the participants are going to able to provide proper verbalizations during the real exercises with using Hololens**. | Performing the task by participants and video recordings. |
| **Introducing the New Design Tool and its properties.** | **Semi-Structured Interviews** |
| **Asking for a set of mini-task to make participants familiar with the new design tool.** | |
| Informing participants about the basic design task. Giving time for asking questions and examining the basic design problem. | |
| Performing the task by participants and recordings | |

**Basic Design Task in the Mixed Reality Environment (Mixed-Reality):** As the first stage of the protocol study, the participants were informed about the research and their background information have been collected such as age, registered semester, institution, and if they have any past experiences. Then, the MR device, Microsoft HoloLens, is introduced to the subject and she learns how to use the device through basic gestures like "bloom" and "tap". Then, the subject was trained about the user interface and its abilities through the minor pre-tasks. The information has been given about the think-aloud protocol and minor pre-tasks have been asked from the subjects to ensure the participants can provide proper verbalizations during the real tasks during design. Right after the participants have been comfortable to use the New Design Tool, the basic design task has been given to examining by the participants.

*Figure 3-2.* D4 during the MR design process

The subjects may have asked questions about the process and the design problem to the researcher. Following, the design processes began. During the design process, screen-recordings have been done via HoloLens and the researcher has observed all processes and has taken notes. Each protocol lasted approximately 60 minutes due to microscopic analysis in a limited time. This period has been implemented to each of the four voluntary subjects, who are architecture students at METU, Department of Architecture.

**Basic Design Task in the Physical Environment (Real-Reality):** The participants have already been informed about the research study at this second stage of the protocol study, and they have already been familiar with the regular design tools of the physical environment. So, they have only been told to apply necessary verbal protocol rules, in that case, it is thinking-aloud as much as possible. Then, the same design problem has been given again. Students have been allowed to ask questions about the protocol studies and the design problem. Required materials and tools have been supplied during the design processes. Then, all requirements have been met, the design processes have begun. During the design processes, video-recordings have been done by a camera across the workplace, and the researcher has observed the processes. Each protocol has proceeded for approximately 60 minutes due to microscopic analysis in a limited time. This period has been implemented to each of the 4 voluntary subjects, who are architecture students at METU, Department of Architecture, too. At the end of the protocols, the participants have been required to share their comments on the new design tool and the design process in two different environments over the interviews. Finally, each participant has filled the questionnaires, which had been sent via e-mail.

*Figure 3-3.* Video-recording during the protocol studies in the physical environment

### 3.5. Data Analysis

The data collection took four days with intervals between the design processes. Then, the video-recordings and screen-recordings had to be transcribed to generate linkographs for each design sessions. Goldschmidt points out that the utterances such as “yeah”, “hmm”, “OK” and so on may not be included in protocols as they do not refer design moves.[249] However, during the transcription, each verbal statement had been included even the utterances such as “yeah”, “hmm”, “OK” and so on to consider

[249] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014): 42.

on later, while determining the design moves. The reason behind that was the observation of the researcher that the novice designers could not continue think-aloud constantly instead, they were using impulsive verbalization sometimes while making design decisions. To illustrate, the excerpted protocol of Designer 1(D1)'s design process in MR shows that D1 made a design move through relating some design elements in Move 21 without verbalization and also, Move 22 indicates a design move through scaling another design element whereas D1 only said "hmm".

**M21** 10:16 [relates the group with the yellow cube]

**M22** 10:35 hmm… [scales the group x5 on XYZ axes]

To not miss this kind of design moves, the researcher did not remove any utterances during the transcription. On the other hand, there were verbalizations without constituting design move, and they were removed during parsing the design processes into design moves. To detect the design moves the definition, which was made by Goldschmidt, was followed. She states that "design move is a step, an act, an operation, that transforms the design situation somewhat relative to the state it was in before that move."[250] Furthermore, movements such as meaningless repetitions, irrelevant discussions to the design tasks, and the abovementioned utterances without the company of a design decision were omitted from the design protocols.[251] Then, the detected design moves were enumerated chronologically to complete the transcriptions. Therefore, the design processes became ready for the link coding phase to analyze through the mentioned metrics.

As the second phase, each design move was checked to define if there is a link between the design moves or not. Coding links is an activity by using common sense to define links based on the relations between design moves' contents.[252] However, common

[250] Gabriela Goldschmidt, "The Designer as a Team of One", *Design Studies* 16, no. 2 (1995): 195.
[251] Gillian Hatcher et al., "Using Linkography to Compare Creative Methods for Group Ideation", *Design Studies* 58 (2018): 127-152.
[252] Gabriela Goldschmidt, *Linkography: Unfolding the Design Process* (Cambridge, Massachusetts: The MIT Press, 2014), 47.

sense could not be enough to ensure a reliable approach to judge whether there is a link between each design moves or not. Goldschmidt suggests three judgers with 'educated common sense' to detecting links. On the other hand, according to the study of Hatcher et al., link coding could be possible by one single judge using intervals between coding sessions. Therefore, the link coding process was carried out by the researcher alone and it was applied three times by ten days intervals until accurate linkographs were achieved. To minimize the subjectivity of the link coding process, a guideline was needed. Therefore, a coding guideline was built to generate linkographs based on the related works of the other researchers (Lugt 2000, Goldschmidt 2014, Hatcher 2018). Links were detected when there were one or more of the following criteria between the design moves:

- There were related verbal expressions of the ideas directly[253]
- There were related actions and visual representations such as hand gestures, 3D modeling, and sketching, of the ideas[254]
- Design moves belonged to the same chain of thought sequentially in the context of a single solution[255]
- Design moves with different concepts of the same main idea[256]
- Design moves applied to the same design elements
- There was similar reasoning between concepts and associations[257]

The researcher followed these guidelines to apply a more objective and consistent approach to define links and produce linkographs. After producing the linkographs of

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[253] Remko van der Lugt, "Developing A Graphic Tool for Creative Problem Solving in Design Groups", *Design Studies* 21, no. 5 (2000): 513.
[254] Nicolaas Blom and Alfred Bogaers, "Using Linkography to Investigate Students' Thinking and Information Use During a STEM Task", *International Journal of Technology and Design Education*, 2018
[255] Remko van der Lugt, "Developing A Graphic Tool for Creative Problem Solving in Design Groups", *Design Studies* 21, no. 5 (2000): 513.
[256] Gillian Hatcher et al., "Using Linkography to Compare Creative Methods for Group Ideation", *Design Studies* 58 (2018): 127-152.
[257] Remko van der Lugt, "Developing A Graphic Tool for Creative Problem Solving in Design Groups", *Design Studies* 21, no. 5 (2000): 513.

each design process, the semi-structured exit-interviews with the novice designers were also coded to support data analysis. The questions of the semi-structured interview were determined to know the participants' backgrounds on the technology usage and Basic Design experiences before and after the protocol studies. The questions were mostly open-ended questions and the participants also had the allowance to contribute and giving feedback without the limitations of the interview questions in Table 3.5.

Table 3-5. *The questions of the semi-structured interview*

| Semi-Structured Interview Questions | |
|---|---|
| | How was your experience in the basic design studio? |
| | Have you ever used any device to experience virtual/augmented or mixed reality environments? Which devices have you used and how was your experience with them? |
| | Do you enjoy using technology in your education and your daily life? |
| | How would you describe your experience with the new design tool? Did you enjoy when you use it? |
| | Have you felt any discomfort during the design task with Hololens? |
| | How could you compare your experiences in Mixed-Reality Environment and the physical environment? |
| | Would you like to use the new design tool if you could for your previous basic design assignments? How do you think it could help? |
| | What is the best part of designing with the new design tool? |
| | What do you think about the user interface? Do you think that it was a user-friendly one? |

# CHAPTER 4

# A NEW MR-BASED DESIGN TOOL FOR BASIC DESIGN

As mentioned in the literature review, Basic Design is a discipline highly relatable with the usage of new technologies in terms of its nature and objectives. However, it still remains as an unexplored research field in the context of the new technologies such as VR, even though its coherent approach to benefit from the potentials of VR technologies.[258] According to Neves and Duarte, VR-based design tools are promising for influencing first-year design students positively by encouraging their engagements and visual intelligence during the manual tasks.[259] Also, VR-based tools were found to be effective for the students' emotional attachments with the abstract objects of the basic design.[260] As mentioned in the literature review, VR-based tools were mostly proposed for interaction virtual 3D structures and working collaboratively. However, there are still unrevealed opportunities for design education regarding usage of VR technologies. The main reason for this restriction is that the current VR technologies need improvements, particularly on the limited interaction abilities.[261] The research field of the VR-based technology usage in design education needs more flexible and easily used features to design creatively[262] such as enabling design without the help of any supportive device (e.g. keyboard, mouse) and allowance in designers' natural movements.[263]

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[258] Ana Glória Neves, Emília Duarte and Diana Dias, "Basic Design Meets Virtual Reality: A Tentative Methodology", in *Design Doctoral Conference* (Lisboa: IADE-U, 2016), 104-111.
[259] Ibid.
[260] Ibid.
[261] Ana Glória Neves et al., "The Impact of a Virtual Reality-Based Tool on a Basic Design Rooted Discipline: Early Perceptions", in *Design Doctoral Conference* (Lisboa: IADE-U, 2017), 167-174.
[262] Häkkilä, Jonna, Ashley Colley, Jani Väyrynen, and Antti-Jussi Yliharju. 2018. "Introducing Virtual Reality Technologies to Design Education". *Seminar.Net* 14 (1): 2.
[263] Ana Glória Neves et al., "The Impact of a Virtual Reality-Based Tool on a Basic Design Rooted Discipline: Early Perceptions", in *Design Doctoral Conference* (Lisboa: IADE-U, 2017), 167-174.

In the light of these suggestions for further studies and development of more advanced technologies for using VR technologies in basic design education, a new design tool was developed to integrate the technological advancements with preliminary architectural design education. The development process was conducted with Burak Güneş Özgüney (METU, Graduate School of Informatics) collaboratively to accommodate a hybrid environment, MR technology, for the usage of the students in the context of the basic design.

### 4.1. Apparatus: Microsoft HoloLens

One of the significant aims of the tool development process was proposing the user to experience both the physical and virtual environment at the same time and the same space in its new medium. Herewith, Microsoft HoloLens Development Edition has been chosen as a proper apparatus, an appropriate device for usage of the new design tool. The major distinction of Microsoft HoloLens (Figure 4.1.) from the other similar VR technologies (e.g., CAVE), is that HoloLens has an optical head-mounted display (HDM), it is the first fully self-contained, holographic computer, that allows users to interact with high-definition holograms without detachment of the present physical world.[264] According to Colley et al., HDM based visualization technologies present more realistic design experiences comparing to screen-based technologies and CAVE. [265]

[264] "Buy Microsoft Hololens Development Edition- Microsoft Store En-SG", Microsoft Store, accessed 26 August 2019, https://www.microsoft.com/en-sg/p/microsoft-hololens-development-edition/8xf18pqz17ts?activetab=pivot%3Aoverviewtab.
[265] Häkkilä, Jonna, Ashley Colley, Jani Väyrynen, and Antti-Jussi Yliharju. 2018. "Introducing Virtual Reality Technologies to Design Education". *Seminar.Net* 14 (1): 1.

*Figure 4-1.* Microsoft HoloLens source

The HoloLens is enabling the interaction with the holographic virtual content in the physical world. Its cameras are able to track the hand location of the users and detect the hand gestures, gaze and preferably voice commands.[266] The new design tool has been developed by using the 3D game engine, Unity for the necessary software application.

The interaction ability of the HoloLens is based on the hand gestures and gaze detection. The user targets by gaze and then acts by hand gestures, which are air-tapping and drag (Figure 4.2.). In this way, the user becomes able to interact without any additional accessories.[267]

Air-tapping works similar to a mouse click on the targeted holographic objects with the gaze. Dragging is used for moving the virtual elements of the Mixed-Reality environment.

[266] Gwyllim Jahn et al., "Making in Mixed Reality", in *Recalibration: On Imprecision and Infidelity* (rMexico City, 2018), 88-97.
[267] "Gestures - Mixed Reality", Microsoft, accessed 26 August 2019, https://docs.microsoft.com/en-us/windows/mixed-reality/gestures.

*Figure 4-2.* Air-tapping and Dragging

## 4.2. Geometry Definitions

As mentioned in the literature review, basic geometries are an essential part of the basic design education. Bilgi Denel states that "the basic shapes of Euclidian geometry are the most easily grasped as complete entities than other invented shapes."[268] Therefore, the basic geometries have the key role in the first-year students to gain them fundamental perception to order and, the foundation of an eligible vocabulary to communicate in the studio as a novice designer.[269] The positions of the basic geometries are defined in a 3-Dimensional Cartesian space. Therefore, it is suitable to utilize a Cartesian coordinate system in 3 dimensions (X, Y, Z).

As an initial application, the new design tool presents a simple user-interface and toolbar to facilitate the user experience. The user-interface introduces a library of basic geometries both 2-D and 3-D and related transforming operations in the new design medium of the tool. Planar elements of the library specify length, width, orientation, position and indicate surfaces. The 2-D objects of the tool are 'square', 'triangle' and 'circle'. Square is defined through a surface by four equal edges and the length of the edges are accepted as one unit. As a planar element, the square is able to be converted

[268] Bilgi Denel, *A Method for Basic Design* (Kalite Matbaası, 1979): 34.
[269] Ibid.

into a rectangle by virtue of the transformations that are allowed by the New Design Tool. Triangle and circle are the other basic geometries in the library, and they are also accepting the transformations.

### 4.3. Geometry Transformation

One of the major aims of the new design tool is allowing the user to interact and manipulate the design elements in lieu of just helping the comprehension of the 3-D models, which have been made at the end of the design process. Interaction and manipulation in real-time with design thinking provide an opportunity for hands-on learning. Thereby, the designer will be able to tinker and generate alternative solutions, rather than be dwell on merely one idea for a solution.

The abovementioned transformations could be categorized as congruence transformation, which maintains the predefined angles and distance between the points, and the scaling transformation. Congruence transformations refer to translation and rotation. The tool allows to move the selected objects and rotate them based on x, y, z-axis. There are rotation angle options for the designer, which are +30°, -30°, +45° and –45° (Figure 4.3.). However, the designer has not number limit to apply these options into objects and she is able to carry out the abovementioned rotating operations as much as she requires.

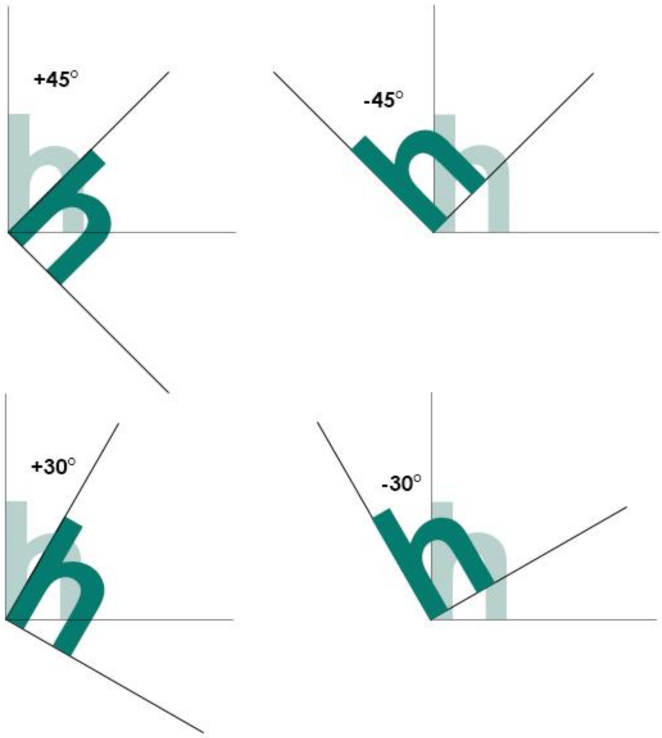


*Figure 4-3.* Rotation options

Scaling transformation could allow preserving the primary shape of the object and this type of scaling is called ‘uniform scaling’. Uniform scaling requires an origin point and a scaling factor that indicates the proportion between the related lengths. Again, scale operation is able to occur in three different axes with various pre-defined alternative ratios, which are x2, x3, x5 and ½, 1/3, 1/5 (Figure 4.4.). In a similar way with rotation, scale options could be repeated without limitation, too. These abovementioned transformations include not only planar transformations but also spatial ones. ‘Spatial congruence transformations’ cover the act of translation and rotation into 3-Dimensional objects in the new design medium. The 3-D objects in the library are cube, sphere, triangular pyramid, and square pyramid. The regulation of the transformations for the planar objects are operative for the spatial objects, too. Additionally, ‘reset scale’ and ‘reset rotation’ options secure the earliest form of both 2D and 3D objects.

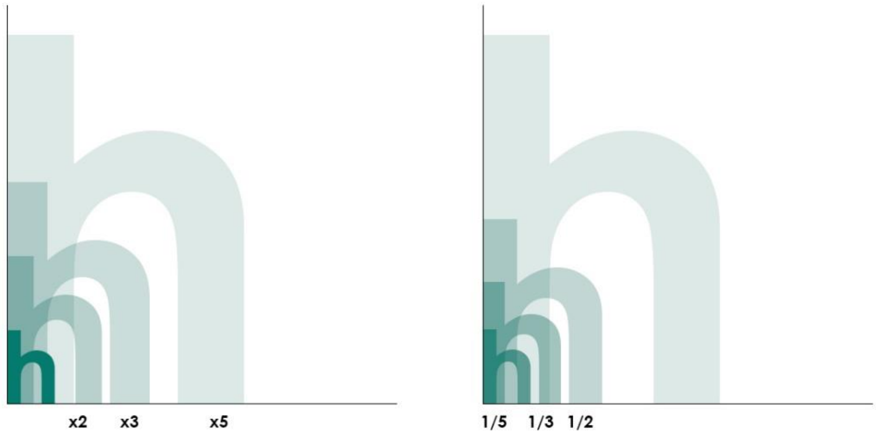


*Figure 4-4.* Uniform-scaling

**Non-uniform scaling:** Besides, the uniform scaling options, the developed design tool also allows the non-uniform scaling through the ability to enabling permutations of axis selection. To illustrate, the user can select only X and Y axes to scale a design element and eliminate the Z-axis (Figure 4.5.). Then again, applying theses non-scaling options could be more than once.

*Figure 4-5.* Non-uniform scaling examples

### 4.3.1. Other Necessary Functions for Transformation

**Precision:** The new design tool's objects appear with special points in their corner points to join an object with another one or more (Figure 4.6.). Snapping provides the ability to connect the geometric objects each other assertively and a more clear vision to comprehend the positions of the objects. Also, it secures perceiving the relations of the design components with each other. Therefore, the snapping system idea has been inspired by CAD programs to maintain an accurate composition with the geometric objects of the tool.

*Figure 4-6.* Snap points for precision

**Self-Created Library:** As mentioned in the literature review, defining groups is an essential process to order. The new tool enables bringing more than one design component together and defining them as a group. The user has the ability to solve the groups, which have been defined previously, and creates different groups with the same or new objects.

The users of the new design tool are also able to secure their compositions at any level with saving them as a block for their own personal library. Thus, they can import these blocks from their self-created libraries whenever they desire to use during the design processes. The blocks that have been saved by the designers appear at the bottom-left corner of the user interface. The user is able to tap the preferred block icon and insert it during the design process with the new tool.

**Labor-Savers:** Basic design exercises may require the usage of one design element with multiple numbers or repetition of some components to derive the designer for ordering by size, shape, and similarity. To this extent, duplication serves to multiply any desired design element unlimitedly. The user is able to operate this design act as much as she needs. Another user-friendly feature of the design tool is ‘undo’.

# CHAPTER 5

# RESULTS AND DISCUSSION

This chapter presents the results of the protocol studies conducted during three days with four first-year architecture students at METU, Department of Architecture. Each designer worked on the given basic design task in both design environment, which were MR and physical environment. Considering that it was the first experience of the students in MR as an unfamiliar design environment by using an unfamiliar design tool, the design processes were kept long enough to allow them accustomed to the developed tool. They spent approximately one hour for each different design environment. Four of them in MR and four of them in the physical environment, totally eight design processes were recorded and analyzed. Data analysis process lasted almost one month to ensure the reliability of the linkographic data, which was repeated and checked three times with ten days intervals.

The results have been presented systematically. First, each designers' design processes were presented through linkographs and related quantitative data to give an insight into the experiences in MR and physical design environments comparatively. A comparison was made over the coding schema, which was explained in Chapter 3 in detail to find answers the following research questions:

- How could MR effect the tinkering process of the user and what influenced most the users for reframing the problems to improve the solutions? (Tinkering)
- What are the advantages and disadvantages of MR design environment on productive thinking? (Productive Thinking)
- How is MR affecting the users' creative thinking abilities? (Creative Thinking)

- How could MR be supportive to understand 3D relationships and manipulating design elements through 3D perception? (Thinking in 3D)
- What could be the benefits of MR on finding ideas and searching for alternatives? (Idea Generation)
- What could be the possible effects of MR for designation necessary design components of solution ideas? (Providing Needs)
- How did the novice designers adapt the MR tool and learn to use basic abilities to design in the MR environment? (Adaptation and Usability)
- What is the most effective gesture-based manipulation for interaction with the design in MR? (Gesture-Based Manipulation)

After presenting the results based on the linkographic data, each designer's design processes were interpreted and discussed with observations and students' feedbacks. Then, findings have been stated and discussed to compare the design experiences in both environments in the context of the research problems.

## 5.1. The Results Based on the Linkographic Data

The protocol studies were based on several methods including Linkography, semi-structured interviews with the designers and observations on the design processes in both design environments, MR and Physical Environments, comparatively. Protocol Analysis was used as quantitative and qualitative data to compare the impacts of the physical and Mixed-Reality environments through design processes of novice designers. Also, the results of the semi-structured interviews and observations were used as qualitative resources. During the process of evaluation, each designer's design process was explored through linkography, observations, and the designers' own verbal statements during the design task and afterward during interviews. The metrics such as chunks, webs, link index, related verbal statements so on, as defined in Chapter 3, were detected and compared among two different design environments.

To express the results of Linkograpy, each linkograph of design processes were presented, therefore the chunks and the webs became visual. Link Index (L.I.) of each design process is calculated as a reference to the productivity of the design process and the leading point to the creative design process. Elapsed time, moves/min, link/min are also calculated to answer how Mixed-Reality Environment could be supportive of the design process of the first-year architectural design students in terms of decreasing the wasted time for craftsmanship.

The comments on the user experience of the designer with the new design tool were indicated to observe the first impressions on the MR in terms of the Basic Design education, and pedagogical effects on the first-year architectural design students.

### 5.1.1. Using Link Index (L.I.) Value for Design Productivity and Creativity

As stated before, in Chapter 3, link index value refers to the productivity level of a design process. However, the design researcher must be careful to use link index value during the evaluation of results. Since a high value of link index may not be always indicative of a productive or creative design. It also could be an indicator of a design process that includes several repetitive moves and initiative approaches for exploring alternative design solutions. On the other hand, the studies reviewed in Chapter 2, provide evidence that the search for alternative design solutions is usually supported by design educators to encourage creativity. Therefore, the link index values of the designers were evaluated considering the fact that the designers were inexperienced in design and also, it was the first time they used the developed design tool in an unfamiliar environment, MR.

Table 5.1. presents the four designers' link index values, the total number of the design moves, the total number of links, the ratio between the numbers of design moves and time, and the ratio between the numbers of links and time during the elapsed time according to design environments.

Table 5-1. *Link index values during the design processes*

| Designer | Design Environment | Total Moves | Total Links | Link Index (TM/TL) | Elapsed Time | Moves/ min | Links/ min |
|---|---|---|---|---|---|---|---|
| D1 | MR | 66 | 244 | 3.70 | 00:59:54 | 1.1 | 4.06 |
| | Physical | 39 | 88 | 2.26 | 01:07:38 | 0.58 | 1.31 |
| D2 | MR | 41 | 269 | 6.56 | 00:56:58 | 0.71 | 4.72 |
| | Physical | 41 | 120 | 2.93 | 00:54:49 | 0.74 | 2.18 |
| D3 | MR | 44 | 228 | 5.18 | 00:50:57 | 0.86 | 4.47 |
| | Physical | 31 | 137 | 4.42 | 00:49:15 | 0.63 | 2.79 |
| D4 | MR | 91 | 571 | 6.27 | 01:01:16 | 1.49 | 9.36 |
| | Physical | 40 | 152 | 3.80 | 00:51:02 | 0.78 | 2.98 |

As can be seen from Table 5.1. (above), D1's link index value in MR is higher (3.70) than in a physical environment (2.26). The design process in MR also includes more design moves and a significantly higher number of links compared to D1's design process in the physical environment. What is also interesting is that, in contrast to the elapsed time during the design process in MR (59'54") and in the physical environment (67'38"), the number of links per minute is also higher in MR than the physical environment. Despite the shorter duration of time spent in MR, the number of links per minute in MR is significantly higher than of the physical environment (59'54" vs 67'38"), indicating the high levels of productivity of D1 in MR. However, this may also mean that D1 could have explored alternative solutions or made much more repetitive design moves in MR than the physical environment. Therefore, the verbal protocols and the user's statements were examined to interpret the quantitative results adequately in the next section while comparing the two different design environments by means of qualitative data also.

As Table 5.1. shows, the total number of design moves for D2 are equal in both design environment (41). On the other hand, the numbers of links in MR (269) and physical environment (120) differ significantly. Herewith, the link index value of MR design process (6.56) is higher than the design process in the physical environment (2.93). The elapsed time during in the MR (56’58”) and in the physical environment (54’49” were proximate, however, the number of links per minute in the MR environment (4.72) is higher than the physical environment (2.18). Similarly, the results of the design protocols, which include higher number of link index value, indicated that the designer was more productive and creative the design process in the MR environment (6.56) than the physical environment (2.93), although, both design process includes the same amount of design moves (41). As can be seen in the figure below, the reason for the difference between the two-design process link index values is that the one in the MR environment involves more links between the design moves.

For D3, the total number of design moves in MR (44) is higher than the physical environment (31), as shown in Table 5.1. again. The design process in MR not also includes more links (228) than in the physical environment (137) but also presents a higher value for link index in MR (5.18) than in the physical environment (4.42). The design processes in MR (50’57”) and physical (49’15”) design environment are almost equal. Nevertheless, the number of links per minute is higher in MR (4.47) than the physical environment (2.79). These results signify that the design process in the MR environment with the developed design tool was a more productive design experience than in the physical environment with regular design tools.

For D4, the data in Table 5.1. shows that D4 made much more design moves in MR (91) than in physical design environment (40). Similarly, the design process in MR includes more links (571) than the design process in the physical environment (152). Therefore, the link index provides a significantly higher value in MR (6.27) than in the physical environment (3.80).

In summary, it can be seen from the data in Table 5.1. that all designers (D1, D3, D4) except D2, who made the equal number of design moves in both design environments, made significantly more design moves in MR with the developed design tool than the physical environment with regular design tools. On the other hand, all designers without any exception made more links between the design moves during their design processes in MR than the physical environment. However, as mentioned before in Chapter 3, comparing the design processes according to the number of moves and links is not correct considering the variabilities depend on the processes. Thus, the link index value became significant for this study. According to the link index value, the results indicate that all designers without any exception experienced more productive and creative design processes in MR design environment as using the developed design tool rather than physical design environment as using regular design tools.

### 5.2. Findings on the Potentials and the Limitations of the MR Design Environment for Basic Design

This section examines the protocol studies comparatively with the quantitative data which are the observations of the researcher, designers' comments during the design tasks, and interviews with the designers. As mentioned before in Chapter 3, the participants were 4 students who were at the end the first-year of architectural education at METU. They were novice designers and they were asked for use an unfamiliar design tool in an unfamiliar design environment, MR. Considering their lack of experience and the potential challenges to think-aloud fluently for them, linkographic results were preferred to be supported by these abovementioned qualitative data to conclude the potentials of the proposed design environment, MR, for Basic Design. The qualitative data was provided through the linkographs, observations of the researcher and the students' feedback.

The most obvious finding to emerge from the quantitative linkographic data was that all of the designers experienced more productive and creative design processes in the MR rather than the physical environment. However, the designers' comments during the design task and their answers to the interview questions were also presented remarkable data on their design processes in both design environment. Therefore, this section focuses on the comparison of the two-design environment in terms of each designers' experiences. In this section, the findings, which were provided by the developed mixed-methodology, have been listed and examined considering the research questions at the beginning of the study.

### 5.2.1. MR Increases Design Productivity by Eliminating Time-Consuming and Burdensome Necessities of the Physical Environment

The present study was designed to determine the effect of MR as a new design environment on the novice designer at the basic design studio. In this regard, the first results were the difference between the number of design moves and links among the two design environments. These results may support the hypothesis that the students waste of time for physical making with craft materials and they can have limited time for design exploration. Then again, these results, therefore, need to be interpreted with caution. There could be another explanation for the L.I values such as the designers' fixation moves. Herewith, the researcher's observations, the designers' verbal protocols, and feedback were presented to interpret these results appropriately.

To illustrate from D1' design processes, the linkographic data presented a higher value for the design process in the MR (3.70) than the design process in the physical (2.26) environment for D1. This result also was supported by the linkographs of the two protocol studies of D1. As shown in Figure 5.1., D1 experienced a more creative process in the MR environment as using the developed tool with regard to comparison on the link index values in both design environment. The linkograph belongs to MR experience of D1 shows more chunks and repetitive design moves than the physical experience. These data are also supported by the qualitative data includes the statements of D1.

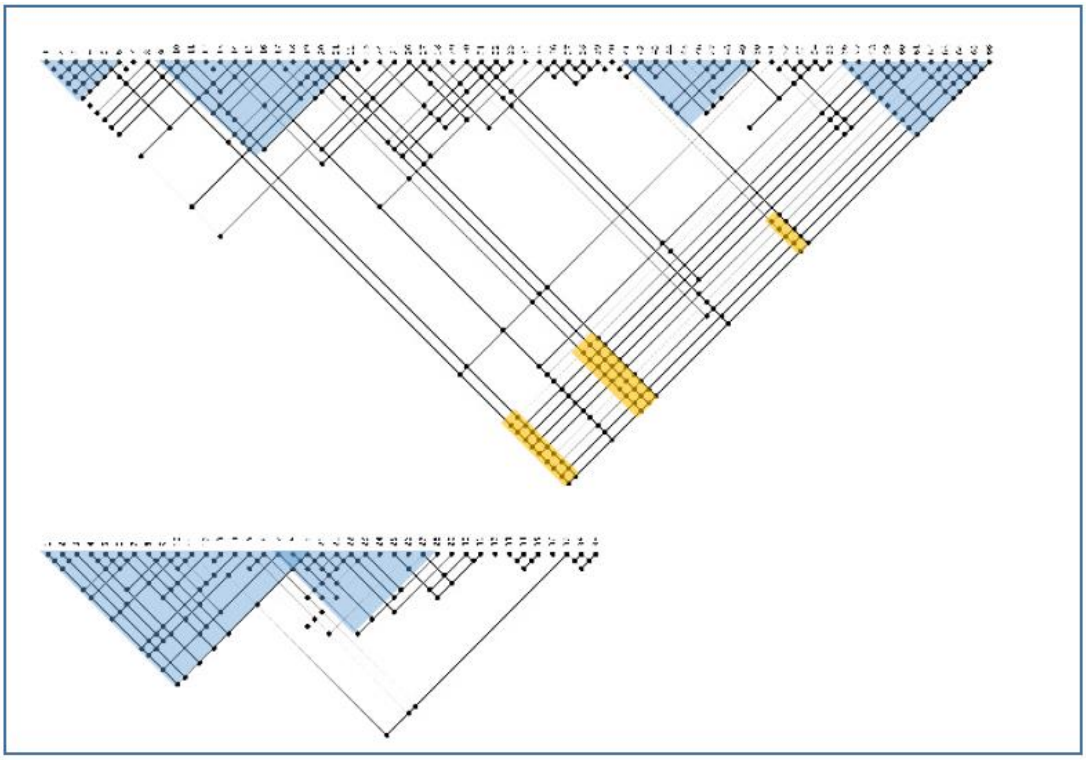

*Figure 5-1.* The Linkographs of the 2-design protocol belongs to D1

As can be seen from Figure 5.1., MR design experience includes more chunks and they are described as blue areas. Also, it can be seen that there are yellow areas, too. The data reported here appear to support the assumption that D1 tried to follow his/her initial ideas until the end of the design process, but this attempt was divided by the design moves, which was for fixation.

Turning now to the statements of the designer on this issue, D1 reported supportive evidence during the think-aloud in the MR experience.

> **M19** Like I said before, I have an idea of creating a core and locate the other elements around it, so I am trying to apply this idea with the groups now
> **M57** a little from that [fixes the snap points]
> **M58** Usually, I do not change my mind and insist to do what I find initially had in my mind

The reason behind D1's behavior was identified as his/her starts for designing all over again several times, according to the researcher's observation and the designer's statements during the interview. According to D1's protocol during the design process in MR, the verbal statements indicate that D1 had started to the design process all over again to do the initial idea of his/her.

> **M43** yes, I will delete this and start all over again
> **M49** It did not work as I want so starting all over again could be made more sense. Now I have 10 elements, but I could not…
> **M51** I will try to do the same thing
> **M54** I will do it again

What is interesting about the data in this figure is that the physical experience included fewer chunks, but bigger (Figure 5.1.) than the MR one and it was in the first half of the design process. According to the researcher's observations, D1 began to design with an initial idea for the design task, but the later design moves became irrelevant with the initial idea due to he/she was more focused to complete the task in time so made random design moves instead of trying again, generating alternative solutions, or tinkering on his/her initial idea. Besides, the reason of the lower number of moves was that D1 spent a lot more time to generate design elements and groups in the physical environment than MR because of the long and burdensome craftsmanship requirements as using regular design tools.

Another indicator of this finding was D2's responses to the interviews questions. D2 stated that:

> TQ1: I was slow at the beginning of MR experience, but it was easy to break something you did and start again when you were not satisfied with it. It reduces the time you spent. In physical model making, we make a great effort, so the idea of breaking it and start again makes us upset. It (MR) is comfortable psychologically, too. (Designer #2)

This statement also clarifies the fact that the designers could be anxious about wasting their time and effort in the physical environment, whereas they felt more comfortable in MR.

The indicators of the productivity of MR is also possible in the content of the other findings such as following one about idea generation.

### 5.2.2. MR Suggests Higher Possibilities to Explore New Designs Starting from Scratch and Support Idea Generation

Another important finding was that MR provokes the designers for a higher number of possibilities to explore new design ideas and a more creative attitude. Not only L.I but also percentages of critical moves in both directions indicated that MR design environment encouraged the idea generation during the design processes. Table 5.2. illustrates the percentages of the number of critical moves (%CM), the percentages of the number of critical moves have mostly forelinks (%CM>), and the percentages of the critical moves have mostly backlinks (%<CM) for each design processes of each designer in both design environment.

It can be seen in Table 5.2. that the design processes in MR reported significantly more %CM than the others in the physical environment. As mentioned in the literature review, the directions of the CMs have also great significance to detect the divergent and convergent thinking modes. As mentioned in the literature review, CMs> were accepted as the indicators of the divergent thinking, whereas <CMs were inferred to convergent thinking modes. Thus, the balance of the two different thinking modes refers to the creative thinking process. Herewith, the percentages of the CMs were calculated by defining the thresholds for each design protocol individually.

Table 5-2. *CMs' Distribution*

| Designer | Design Environment | % CM | % CM> | % <CM |
|---|---|---|---|---|
| D1 | MR | 12.12 | 7.57 | 4.54 |
| | Physical | 10.25 | 7.69 | 2.56 |
| D2 | MR | 12.19 | 12.19 | 0 |
| | Physical | 7.31 | 4.87 | 2.43 |
| D3 | MR | 9.75 | 4.54 | 4.54 |
| | Physical | 9.67 | 9.67 | 0 |
| D4 | MR | 10.98 | 8.79 | 2.19 |
| | Physical | 10.00 | 7.50 | 2.50 |

It can be seen in Table 5.2. that the design processes in MR reported significantly more %CM than the others in the physical environment. As mentioned in the literature review, CMs> were accepted as the indicators of the divergent thinking, whereas <CMs inferred to convergent thinking modes. Thus, the balance between the two different thinking modes refers to the creative thinking process. Herewith, the percentages of the CMs were calculated by defining the thresholds for each design protocols individually.

As a result, it can be seen from the data in Table 5.2. that without considering the directions, the design processes in MR have higher percentages of CMs than the design processes in the physical environment. On the other hand, examining the distribution of the link directions provided more information in detail. In the case of D1, the percentage of CM in MR (12.12) was calculated as more than the one that belongs to the physical environment (10.25). Besides, the link distributions were more promising to observe thinking modes. The distribution percentage of the <CMs for D1 in MR was %4.54 and CM> was %7.57. These numbers were quite different in the physical environment, which were %2.56 for <CM and %7.69 for CM>. This result may indicate that the MR environment not only has an impact on divergent thinking ability but also is able to provoke the convergent thinking ability.

For D2, the results differed. As can be seen from the data in Table 5.2., the percentage of CM in MR (12.19) was calculated a lot more than the one belonging to the physical environment (7.31). However, the link distributions presented interesting results for the thinking modes. All of the CMs in MR consisted of the CMs> only. Nevertheless, the distribution percentage of the <CMs for D2 in the physical environment was %2.43 and CM> was %4.87. On the contrary of D1's result, it was not possible to state that MR had any contributory effect on convergent thinking ability in this case. Still, these results support the idea that MR was more effective to trigger divergent thinking ability considering the number of percentages that belong to the two different design environments.

The results of the case for D3 were again encouraging to reading creativity through quantitative data. As shown in Table 5.2., the percentage of CM in MR (9.75) and the one in the physical environment (9.67) were almost equal and they did not indicate for any supremacy among the design environment. However, the link distributions suggested important findings on the balance between the divergent and the convergent thinking modes. The distribution percentage of the <CMs and the CM> for D3 in MR were %4.54, equally but all of the CMs in the physical environment (9.67) were the ones with only forelinks on the contrary of D2. These results, therefore, need to be interpreted with caution because having a balanced ratio between the percentages of CM> and <CM does not suggest that D3 had lack of divergent thinking ability. Quite the reverse, it means that D3 was able to shift between the modes of thinking more easily in MR rather than the physical environment. It would not be possible to state that if D3 had not had the almost equal values for %CMs. Besides, it can be seen from the linkographs of D3 in Figure 5.2. and Figure 5.3. that the MR design process produced a higher number of chunks with more link density than the physical design process.

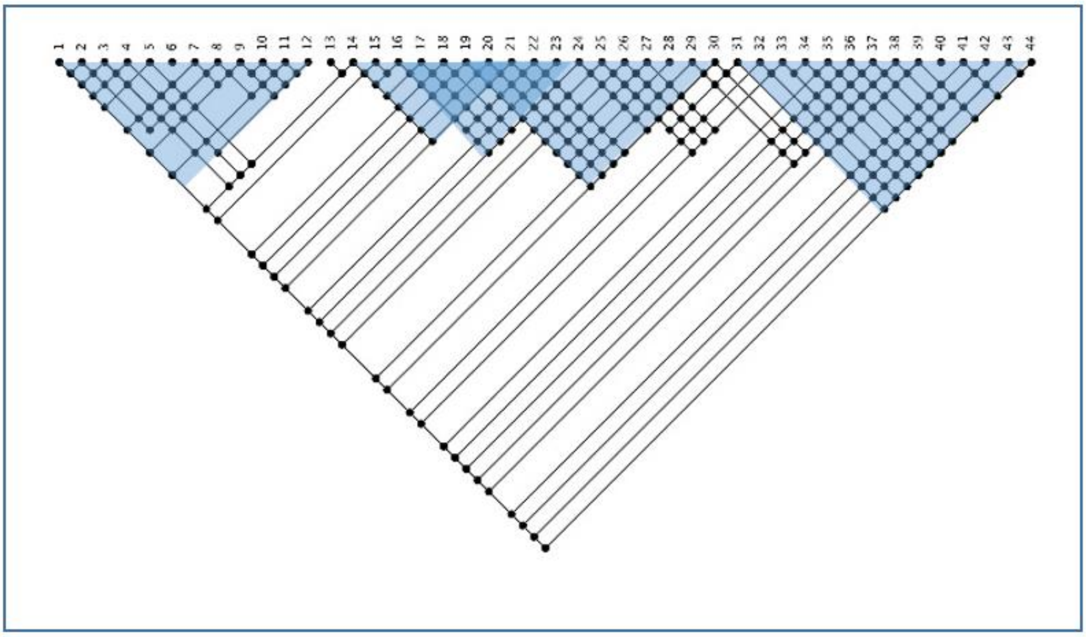

*Figure 5-2.* D3's linkograph in MR

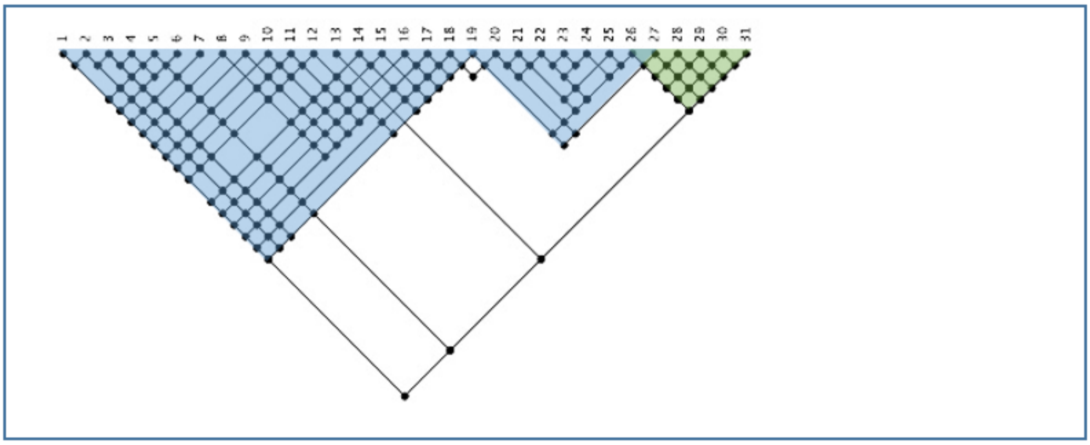

*Figure 5-3.* D3's linkograph in physical making

Finally, in the case of D4, the values of %CM in MR (10.98) and the one in the physical environment (10.00) were close numbers. The other values were also close enough so no significant differences were found between the design experiences in MR and physical environment. %<CM in MR was 2.19 and %CM> was 8.79. The values, which were 2.50 for %<CM and 7.50 for %CM>, did not differ so much for the design experience in the physical environment.

As mentioned in the literature review, CMs with forelinks refer to the divergent thinking and thusly seeking for alternative ideas. The qualitative data was also promising that the users had more motivation to start from scratch or try alternative solutions in the MR design environment rather than physical making. To illustrate, D2 said that:

> TQ2: It (physical making) did not go as well as I want because we are not able to know how it is going to before making. It could have last for two or three hours if I had attempted to break it and start all over again. (Designer #2)

According to D2's statement, it can be assumed that D2 had more encouragement for idea generation and manipulation with the MR design tool rather than the regular tools of the physical environment. D2 also emphasized that she/he had opportunity to try various grouping ideas and designed by using different groups as design components in MR, but the same possibility was not available with physical making and he/she had to work with only one type of group.

> TQ3: I have a chance to try different groups in MR. I had a different type of groups, but I could try only one type of group by model making. (Designer #2)

D3 also experienced working with alternative group ideas on the given design task. The excerpted verbal protocol (Table 5.3.) belongs to D3 indicates that 'playing' with the design elements and thinking on alternative ideas occurred during the MR design experience.

Table 5-3. *D3's excerpted protocol*

| | |
|---|---|
| M15 | 12:49 can I play with the scale as a group when I do this |
| M19 | 16:39 I'm currently trying to form a group of 2 squares and a pyramid. I turn the square so that there is space. they create such volume |
| M20 | 16:53 I'm making one more of it right now, I'll make two different versions |

The data from D4’s design protocols were also significant to prove that the designers were more motivated for exploring the design space and manipulation of the design elements. As can be seen in Table 5.4., D4 had attempted to undo and thinking on the design operations even at the almost end of the design process in M75-M77. On the other hand, Table 5.5. illustrates that D4 had to continue for the initial idea and did not have any attempt to modify design elements in the physical making, though it was the nearly beginning of the design process (M6-M7).

Table 5-4. *D4's excerpted protocols (MR)*

| | |
|---|---|
| M32 | 16:48 Let's grow this again. I've shrunk too much |
| M75 | 49:20 I don't know how I did it, but they all grew up, but I liked it |
| M76 | 49:41 anyway I will say undo |
| M77 | 50:34 I think I'll make another one - undo |

Table 5-5. *D4's excerpted protocols (Physical)*

| | |
|---|---|
| M6 | 03:46 I'm making these surfaces 2 cm below, and I'm gonna cut them out. |
| M7 | 06:19 There was no time for what I did, anyway. -continue to cut-. I will not change |

During the interview D4 also stated that:

> TQ4: It (MR) was really comfortable to undo. For example, I had made two different groups in MR and I did not like them, so I changed one of them a little bit. But I could not change in the physical making. (Designer #4)

Together these results provide important insights into positive effects of MR design environment for alternative idea generation and reduce the fear of design exploration.

### 5.2.3. Usability of MR Technology for Basic Design

Previous studies evaluating VR technologies in architectural education were limited in terms of usability and manipulation options. Therefore, another research question was focusing on the abilities of the novice designers to adapt the MR tool and learn to use basic abilities to design in the MR environment. The three of the four users had no experience in using any VR technology. Some of them also stated that they had no interest in using even daily technologies in their educational life or daily routines. Only D2 mentioned about his/her interest in digital tools such as Sketch-up and VR.

D1 stated during the interview that:

> TQ5: It was a little hard to manage it, but then I got used to it […] I would like to use this, (the developed design tool in MR) if I make myself get used to it. It needs to be practiced. (Designer #1)

Also, regarding the researcher's observation, these results suggested that D1 made more relevant design moves progressively. Nevertheless, D1 had another important point that was the relationship between the basic design course and material usage. D1 said that "It cannot provide the tactile sensation. I desired to touch the objects during the design process in MR".

As another fact that all designers emphasized their lack of experience in using the developed design tool, Microsoft HoloLens as HMD, and unfamiliarity for MR design environment. Moreover, D3 said that:

> TQ6: I felt more comfortable in physical making […] I had difficulties only for compounding the design elements, they could be joined from the edges in MR. Model making (physical) also requires more calculation, I cut the wrong spots. (Designer #3)

The results of this study also indicated that being familiar with using the design tool is important for the users in terms of making users comfortable. On the other hand, this issue could be discussed in the context of encouraging students to leave their comfort zones while designing.

Users had not experienced VR technologies before, but they got used to it easily. However, they wished to be more familiar to use VR technologies for design. To illustrate, D4 said that (TQ7) "it was not so hard to use, even I, as an unfamiliar person, got used to it quickly." D4 also stated during the interview that:

TQ8: I got used to it progressively […] I began to use fluently towards the middle of the design process, choose this, take that so and so… (Designer #4)

### 5.2.4. Ease of 3D Visual Perception, Thinking in 3D

Another significant assumption of the study was that MR may have positive effects on 3D thinking ability and ease the 3D visual perception during the design processes. The qualitative data from the verbal protocols and the statements during the interviews were promising to prove this assumption. The observations during the design processes were also presented as screenshots to support the idea of MR's impact on 3D thinking. To illustrate, as can be seen in Table 5.6., D2 had struggled during the design process in the physical making in terms of creating a 3D appearance (M39) and remembering the positions of the design elements (M38-M40-M41).

Table 5-6. *An excerpted protocol from D2's physical design process*

| | |
|---|---|
| M38 | 49:21 things are constantly changing; I don't want it here [but she didn't change] |
| M39 | 49:48 I want to make a little more 8 and go to the bottom so that it can get a more 3D appearance, it was very flat like this |
| M40 | 54:02 yes, I forgot where to put it |
| M41 | 54:08 was that? |

On the other hand, turn now to the excerpted verbal protocols during the D2's design process in MR in Table 5.7., it can be seen that when the designer had some difficulties to perceive the design elements, it was possible to manage design elements by changing position to catch a better perception. After stating that there was "chaos" as looking from the specific location (M28), D2 decided to change the spot where she/he stood.

Table 5-7. *An excerpted protocol from D2's MR design process*

| | |
|---|---|
| M28 | 51:22 there is a little bit **chaos** |
| M29 | 51:30 I will combine those when I remove these |
| M30 | 51:59 I will change from the back, here is mixed a lot |

These results from the D2's protocols show that MR design environment is promising to eliminate the cognitive loads of the physical making. This finding broadly supports the work of other studies in this area linking the VR technologies in design education with its decreasing influences on the designers' cognitive loads during the design processes.

Figure 5.4. below also shows that the designers had to make some effort to perceive the design in 3-dimensionally and thinking on 3D manipulations at the same time.

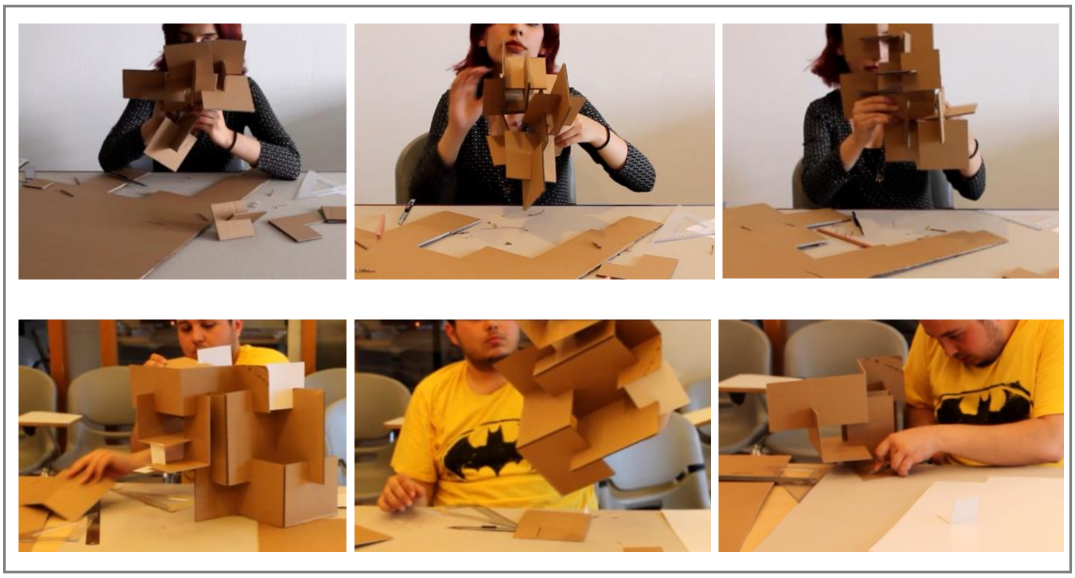

*Figure 5-4.* Designers during the physical making

As another fact that it was observed that the designers were able to use their body and hand-gestures without making extra effort to lift or turn the design elements. Instead of sitting constantly and struggling to find the correct perspectives of 3D thinking, they were able to move (Figure 5.5.) and work with 360 degrees around the design elements (Figure 5.6.).

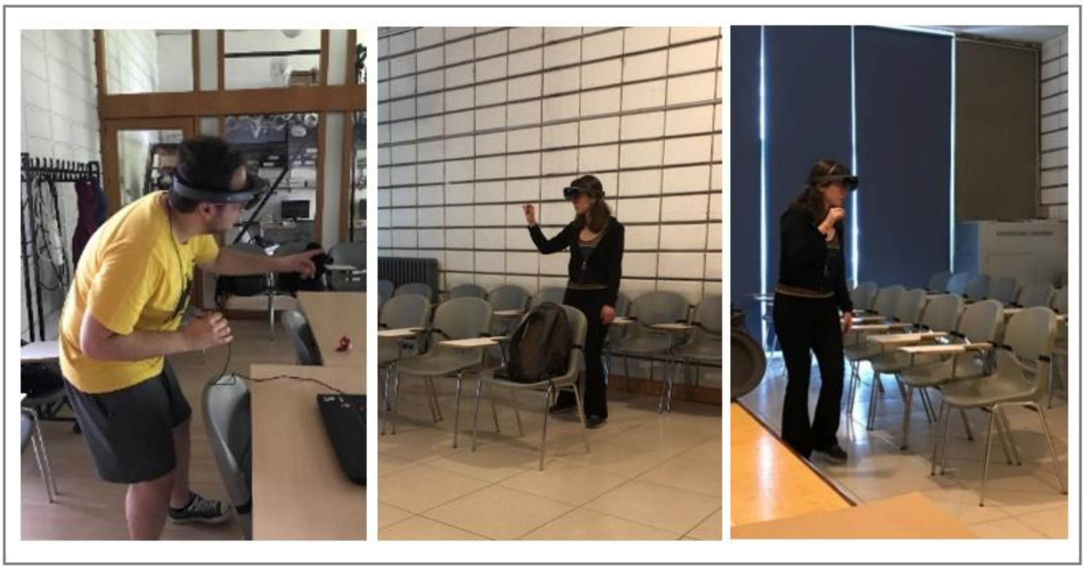

*Figure 5-5.* Designers while changing their positions

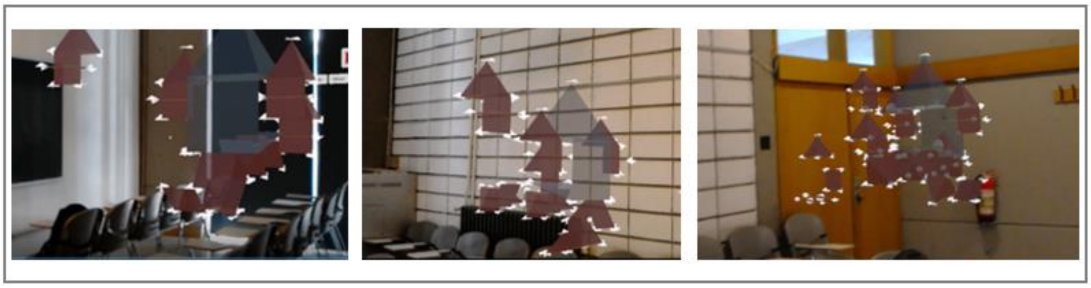

*Figure 5-6.* Panoramic view from D3's design process

One another advantage of working with 360 degrees was that designers were able to handle the design elements more easily. It can be observed in Figure 5.7. that D4 was able to relate and connect the elements precisely.

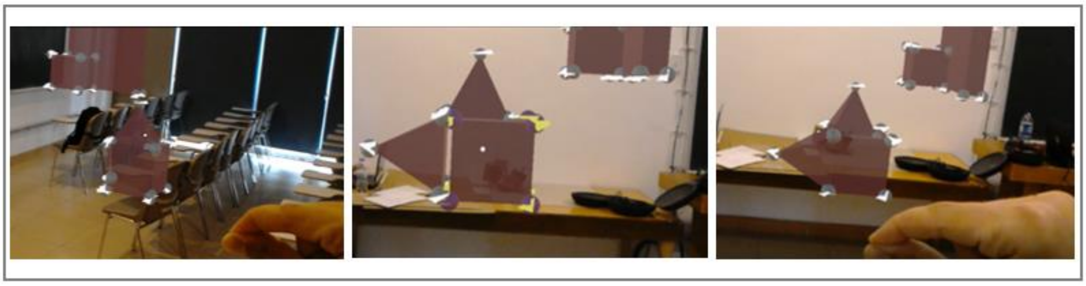

*Figure 5-7.* D4 work on precision in MR

D4 also said during the interview that:

> TQ9: I could see from all view easily that I cannot imagine, from the bottom, top, and all-around of it. It (MR) makes it really easy. (Designer #4)

D4 responded to the interview question on if he would like to use the MR design tool in the basic design studio that:

> TQ10: It would be better in terms of not wasting time, craft materials and perceiving easily. It would be much faster either case. (Designer #4)

*Figure 5-8.* D4 during the MR experience

### 5.2.5. Ease of Model Manipulation but the Use of Gestures Needs to be Improved and be More Intuitive

As mentioned in the literature review, previous studies on various levels of VR technologies, such as AR, AV, or MR, had limitations on real-time manipulations. Most of them need modeling with the computational design tools before transferring the data into VR devices. The developed tool for this study was aimed to allow real-time manipulations of the users in MR without the blessing of any computational design tool or data input. Herewith, the designers were asked to compare the MR and physical design environment in terms of the model manipulation ability.

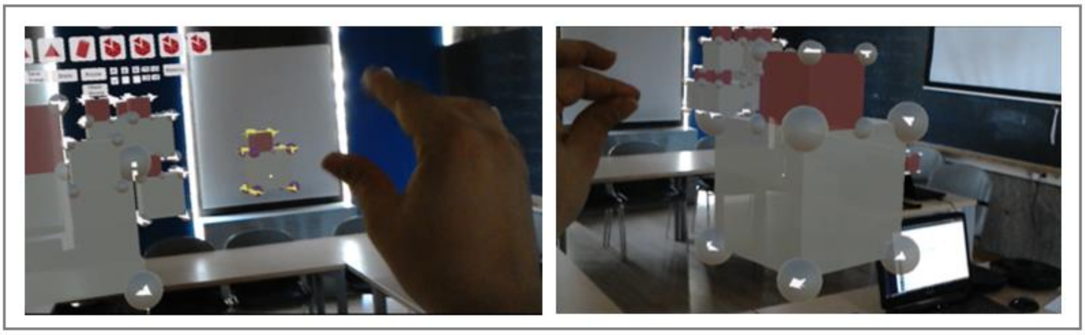

*Figure 5-9.* Gesture Using During the MR Design Process of D1

As can be understood in earlier findings, the designers were able to generate more ideas in MR than physical making. This result could only be possible by manipulating design objects in MR easier than the physical environment. Although MR design tool had caused some difficulties for the users due to lack of experience, the designers were more eager to fix the missing points of the sub-solutions or start again to seek for new alternative solutions. To illustrate, Table 5.8. shows that D3 had some technical problems because of failures based on the misuse of the design tool and lost one of the groups, which she/he designed previously (M35). Nevertheless, D3 did not give up on the group and tried to apply the same group idea again (M36).

Table 5-8. *An excerpted protocol from D3's MR process*

| | |
|---|---|
| M35 | 39:33 ohh… my middle group is gone |
| M36 | 40:32 I'm just trying to put what I lost in the middle of an element. I've tied the pyramids around the corners, and now I'm trying to do it again. |

It was also observed that pursuing design ideas or correcting design moves could be restricted in physical model making. Then again, the excerpted protocol, which belongs to D3's physical design process indicates that the designer continued to craftsmanship operations instead of fixing or improving the design elements and relations. M22 indicates that D3 made an improper or unsatisfying design decision but choose to complete the design task without fixing the mistake (M23) rather than making a new design element to achieve a more satisfying design solution.

Table 5-9. *An excerpted protocol from D3's physical making process*

| | |
|---|---|
| M22 | 26:47 I think on how to cut right now [cuts the material improperly for making an element] |
| M23 | 28:48 [cuts again instead of making a new element!] |
| M24 | 29:19 [tries to connect them again] |

D3 also indicated during the interview that:

> TQ11: I would like to use it (MR). For example, it could be tested for 2D basic design assignments. It would be useful on 3D ones too, and I can try my grouping ideas right away. (Designer #3)

This positive approach for using MR design tool could be accepted as the indicator of easy model manipulation with the developed design tool rather than regular design tools. A possible explanation for this might be that D3 was standing during all the design process in physical making and spent higher effort than the other designers. However, D3 was not the only user who supported the usage of MR design tool. All designers had similar statements on this issue and emphasized that they would like to use the developed design tool in MR with some improvements such as using some additional hand gestures, operations like folding, bending, or voice recognition to choose design operations instead of tapping.

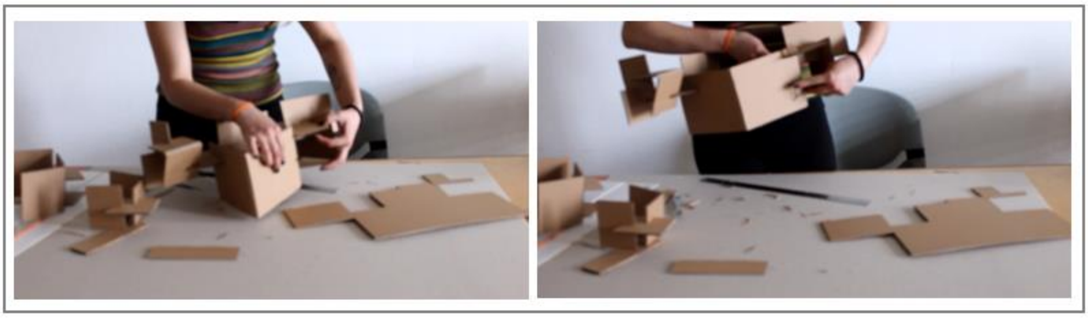

*Figure 5-10.* D3's physical model making

One of the significant observations was that the designers had to decrease their thresholds for being satisfied with their design solutions due to not making an extra effort in the physical environment. In the case of D4's verbal protocols, it can be seen several times that D4 was able to change the design decisions when the decisions were not so satisfying for him. It was observed that D4 generated alternative design solutions even when current solutions were satisfying enough in MR. On the contrary of MR design environment, D4 clearly stated that he had to give up his ideal solutions for the basic design problem several times in physical environment and did not want to improve his design even there was still time for it.

Table 5-10. *An excerpted protocol from D4's physical making*

| | |
|---|---|
| M22 | 40:31 At first, in my dream, I had to do white things in different sizes. So, these are shrinking among themselves, but the big ones are there again. I thought it was big white, median white, little white, but it would probably be the only white. |
| M23 | 40:52 It won't be able to form that much hierarchy properly but let me just say it was my dream. |
| M40 | 50:30 I'm finishing it because there's nothing I can do even if I have more time. My plan was to lay them around it again, I tried to do something like this by shrinking the size of it, but the volume did not. Maybe if I did a little more calculation |

### 5.2.6. Tinkering in MR Design Environment

As mentioned in the literature review, prior studies have noted the importance of tinkering on creativity and also tinkering was related with 'play' term during the exploration of alternative ideas and improvement on the design process. It is interesting to note that in all four cases of this study, the designers gave significant references for tinkering in the MR design environment. Moreover, it can be seen in the excerpted protocols in Table 5.11. and Table 5.12. that D3 and D4 actually used the word, ‘play’, several times while designing with the MR design tool to refer tinkering.

Table 5-11. *An excerpted protocol from D3's MR process*

| | |
|---|---|
| M15 | 12:49 can I **play** with the scale of a group when I do this |
| M16 | 13:45 [rotates a square -45 x axis] |

Table 5-12. *An excerpted protocol from D4's MR process*

| | |
|---|---|
| M3 | 00:23 I want to **play** with the proportions of it, so I have to say “scale” |
| M4 | 00:39 something like a little more rectangular prism |
| M7 | 05:31 Let's **play** with the proportions of the shape again, but let it be like a cube |
| M8 | 05:38 **or give it a try** -scales /3 |
| M9 | 05:56 /2 accidentally again-I did **something funny accidentally** |
| M25 | 14:44 Now I'm going to **play** with their dimensions, change their direction and start to combine |
| M26 | 15:09 I want to **play** with the dimensions of it |

The designers also emphasized this finding during the interviews while comparing the design experiences in the two different design environments. It could be useful to remember D2’s statement on the fear of changing the design ideas even if an alternative idea had been generated.[270] D4 was another designer who clearly stated that it was possible to try alternative ideas in the MR design environment on the contrary to the design process in the physical environment. D4 had to complete the design task despite the dissatisfying solution for the design problem.

[270] After the physical experience D2 said that “…it did not go as well as I want because we do not able to know how it is going to before making. It could have last for two or three hours if I had attempted to break it and start all over again.” (TQ2)

### 5.2.7. Time-Saver and Eco-Friendly Approach of MR

The final finding on eco-friendly and time saver features of MR design environment was not one of the research questions, which were designed at the beginning of the study. Surprisingly, all four designers commented additionally on the eco-friendly advantage of the MR environment. The main reason behind these comments of the designers was the fact that the architectural students usually have to use high-cost materials and spend long hours for model making in the physical environment by using regular design tools. Especially during the first year of the architectural design education, students have to spend extra laboring hours and deal with the extra cost of the wasted materials because of the lack of experience and not being able to use computational tools. Naturally, the idea of not wasting time, effort, and money for the burdensome basic design assignments attracted the participants as novice designers. One of the significant indicators of this finding was D1's statement during the interview. D1 said that:

> TQ12: They (architectural design educators) mention the importance of eco-friendly design but we consume a lot. Maybe it needs high-cost investment at the beginning, but it brings much more profitable outcomes in terms of energy and economy. It made me incredibly happy with regard to making me think about the damage to nature. (Designer #1)

D3 emphasized another advantage of the MR design tool compared to regular design tools. D3 stated that (TQ6) "Model making in the physical environment needs more calculation. I cut from the wrong points." This statement may also refer to the cognitive load of the physical environment. The reason for the time-saver feature of the MR design tool was emphasized before in the previous finding on 3D thinking as its decreasing impact on the cognitive loads of the users. Herewith, these results also suggest that MR reduces the time not only for craftsmanship but also calculation.

D4 had also similar responses to the question on the advantages of MR with D1. According to D4, using the MR design tool was more favorable than the physical tools in terms of saving time, not wasting material and so on. D4 emphasized that:

> TQ13: you can understand if your idea works or not (in MR) without cutting any craft material and spending long hours. (Designer #4)

This finding was unexpected and suggests that MR technology has an advantage in terms of saving nature and relieving the students of financial difficulties, too.

### 5.2.8. Design Fixation During Design Process in MR as a Negative Finding

One unanticipated finding was that the designers applied a lot more fixation during the design processes in MR than in physical making. As mentioned in the literature review, design fixation could be detected by reading the separated forelinks parts of the linkographs. The differences between the linkographs of MR and physical environments are highlighted with yellow color in Figure 5.11. and Figure 5.12. Upper sides of the figures show the linkographs belong to the MR experiences.

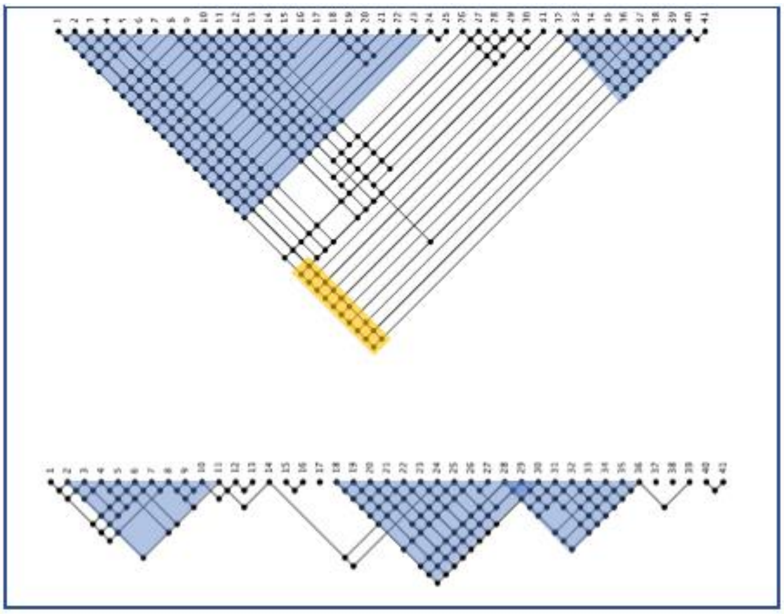

*Figure 5-11.* D2' linkographs

It can be seen in Figure 5.11. that D2 needed design fixation during the usage of MR on the contrary to the usage of regular design tools in physical making. Move 1 and Move 2 were the major design ideas of D2. D2 decided to use square-shaped design elements and right angles to relate them. Nevertheless, making the necessary transformations was hard to achieve during the earlier phase of the design process. Move 5 clearly states that D2 failed to accomplish the design ideas. Then, D2 succeeded to make the right transformations for the previously design ideas.

Table 5-13. *An excerpted protocol from D2's MR process*

| | |
|---|---|
| M1 | 00:04 The problem asks for 27 or 30 elements and should I use squares or is it up to me |
| M2 | 00:14 Then, I want to start with squares because I think right angles much more comfortable to work |
| M3 | 00:25 I will choose a square |
| M4 | 01:00 I want to rotate to achieve a 3d effect |
| M5 | 03:05 I couldn't because I can't be sure which axis should I choose to rotate |
| M6 | 04:00 hıhh [rotates +45 on x axis] |
| M7 | 04:55 Now I want to connect them with the right angle |

The reason of the yellow area, which refers to design fixation, that D2 was able to use the developed design tool more fluently and it was possible to work on the initial ideas to generate more design elements.

Table 5-14. *An excerpted protocol from D2's MR process*

| | |
|---|---|
| M27 | 51:15 OK, now we have 12 elements [relates the new group with the whole] |
| M28 | 51:22 there is a little bit chaos |
| M29 | 51:30 I will combine those when I remove these |
| M30 | 51:59 I will change from the back, here is mixed a lot |
| M31 | 52:31 now I will duplicate this group again |
| M32 | 52:58 I will make another group |
| M33 | 54:54 OK, let's make it bigger and locate |

The similar case was detected on the design process of D4. It can be seen in Figure 5.12. that D4 applied more than one design fixation during the MR design process.

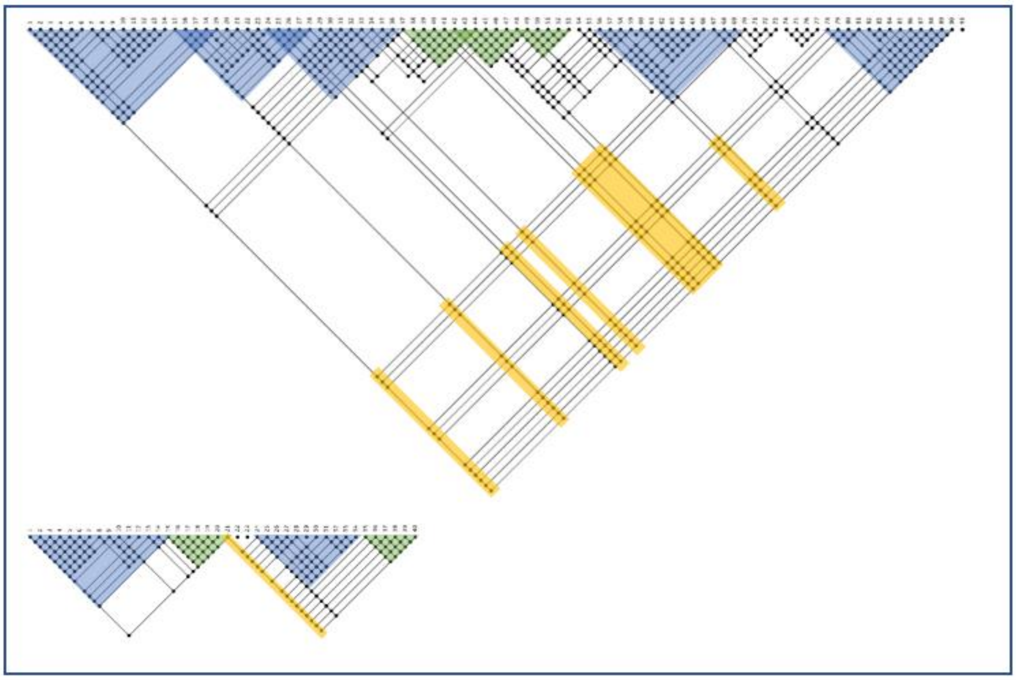

*Figure 5-12.* D4's linkographs

This finding was unexpected and suggests that the design tool requires practice before using for a design process. Each participant practiced the design tool before beginning the design process in MR. However, the students were much more familiar with the regular tools in the physical making. D1 also stated that:

> TQ14: I think I got more efficiency in the physical model making, but I'm more used to it since secondary school. I'm used to a pen, a craft knife. I know how to cut the cardboard, and I feel more comfortable. Obviously, I can’t start to use this (MR design tool) in a flash, the hand feels more comfortable. But maybe if I got used to this software, I'd love to use it. It was a very short experience for me to say it. I think the students would be more comfortable if they get used to it in the future. Of course, most things are a bit limited. It was good for basic design, but I don't know how to do it for advanced designs. When I made a mistake in this (physical model making), I could make small touch-ups on it. But I had difficulties while trying to put an object on top of another in MR because I wasn't used to it. But if I got used to it, I'd definitely use it.

# CHAPTER 6

# CONCLUSION

The present study was designed to determine the effect of MR as a new design environment on the architectural basic design. The aim of the research was to examine the potentials and the limitations of the Mixed-Reality environment and the developed design tool in comparison to the physical environment and regular design tools. In this regard, a mixed-methodology was developed to evaluate the new design environment in the context of the objectives of basic design education such as learning creative thinking, 3D thinking ability, design exploration, and so on. The scope of the developed methodology was evaluating and comparing both design environment through the cognitive outcomes. Herewith, a set of empirical studies were conducted on behalf of the accurate comparison among the MR design environment and physical making. The methodology was designed for an empirical study, consequently, this research presents itself as an experimental study, too rather than a concluded theory on the potentials of MR for the architectural basic design.

This chapter focusses on the conclusions on the empirical studied through the developed design tool and the mixed-methodology. Therefore, the main research findings have been summarized, the significant contributions of the study for the research field have been explained, and the limitations of the present study have been recognized and discussed. Eventually, the recommendations for further studies have been mentioned at the end of this chapter.

## 6.1. Outcomes of the Methodology on behalf of Investigating Potentials of MR for Basic Design

This study has found that generally, the MR design tool has positive effects on the design processes of the novice designers in the context of 3D basic design problems. One of the more significant findings to emerge from this study is that the motivational impact of the MR design tool on the first-year architectural students. The relevance of creative attitude is clearly supported by the current findings. The developed methodology succeeded to present appropriate quantitative and supportive qualitative data for evaluating the potentials and the limitations of the MR design environment. Therefore, this research has been one of the first attempts to thoroughly examine the cognitive contents of the design experiences in MR. The evidence from this study through the analysis of chunks, critical moves with forelinks and backlinks suggests that MR design environment offers a more enthusiastic environment to the novice designers for performing in a more creative attitude. These findings suggest that creativity, 3D thinking ability, visual perception, design productivity, design exploration by idea generation and tinkering process can be strengthened through using the MR tools for the basic design. Taken together, these findings suggest a role for MR in promoting architectural basic design studio mechanism.

This thesis also has provided a deeper insight into using Linkography on the novice designer with supportive qualitative data. Before this study, evidence of advantages using VR-based technologies in design education was only depending on the data derived from the surveying studies and they were mainly considering of the architectural design studios rather than a basic design studio. This project is the first comprehensive investigation of the cognitive aspects of MR usage for basic design through establishing a quantitative framework for detecting cognitive influences of MR as a type of VR technology. The methods used for this research on the potentials of MR in architectural basic design may be applied to other related studies through VR-based design tools elsewhere in the world.

The developed design too itself also contributed to the existing knowledge of VR technologies by providing expanded interaction abilities and gesture usage during the design sessions. The design tool minimized the restrictions on the users' natural movements and manipulations in comparison to the previous VR-based design tools. The new design tool is one of the first technology in terms of no requirement for earlier data input without assessment of any additional computational tool. The designers were able to generate and manipulate the design elements entirely by using the developed design tool solely.

## 6.2. The Limitations of the Research Study

The generalizability of these results is subject to certain limitations although the study is significantly promising on the potentials of the MR design environment in an architectural basic design course. For instance, the higher number of participants for the protocol studies would present a more generalizable conclusion for the potentials of MR usage in architectural basic design education. Due to the labor-intensive data analysis process of the methodology for only one researcher, the number of participants had to be restricted. Although the current study is based on a small sample of participants, the findings still suggest significant insights on MR usage for 3D basic design problems.

Secondly, the scope of this study was limited in terms of testing the design tool for only 3D basic design assignments based on the traditional basic design principles such as order, hierarchy, rhythm, balance, dominance, etc. Additionally, the manipulative operations presented by the design tool were still limited and did not include some sort of intuitive interactions such as folding and bending. Therefore, gesture-based manipulation has still need to be improved.

Another limitation was due to the duration of the design experiences and testing the MR design tool only with the novice designers who also had no training on the usage of the tool. The participants were purely unfamiliar to the design tool, the device

(Microsoft HoloLens) and the requirements of the think-aloud methodology. In spite of its limitations, the study certainly adds to our understanding of the VR-based design tool usage in architectural design education.

### 6.3. Suggestions for Further Studies

This research has resulted in many new questions in need of further investigation. Considering the limitations of the current study, further experiments, using a broader range of architectural design problems and a higher number of participants, could shed more light on the potentials of MR design environment for not only basic design studio but also advanced level architectural design studios.

The current study focused on the design processes of novice designers rather than the end product. As another suggestion, the duration of the empirical studies could be increased by using intervals in terms of comparing the end products of the two different design environments.

Thirdly, more information on the cognitive aspects of the MR would help us to establish a greater degree of accuracy on this matter and MR environment, which allows perceiving the physical and the holographic virtual environment at the same time, could be compared with the VR environment, which isolates the users from the momentarily physical world.

## REFERENCES


Acar, Aktan. "The Construction and Execution of Beginning Design Education". M. Arch, Middle East Technical University, 2003.

Aish, Francis, Wolfgang Broll, Moritz Stoerring, Ava Fatah, and Chiron Mottram. "An Augmented Reality Collaborative Design System". in Institution of Electrical Engineers Conference, 49-73. Hertsfordshire: IEE, 2004.

Akın, Ömer. A Cartesian Approach to Design Rationality. Ankara, Turkey: Middle East Technical University, Faculty of Architecture, 2006.

Akın, Ömer. "Creativity in Design". Performance Improvement Quarterly 7, no. 3 (1994): 9-21.

Akın, Ömer. Psychology of Architectural Design. London: Pion, 1986.

Akın, Şahin, Oğuzcan Ergün, İpek Gürsel Dino, and Elif Sürer. "An Immersive Design Environment For Performance-Based Architectural Design: A BIM-Based Approach.". in Goodtechs, 306-307. Reprint, Bologna: Association for Computing Machinery, 2018.

Alexander, Christopher. Notes on the Synthesis of Form. Cambridge, Massachusetts: Harvard University Press, 1964.

Angulo, Antonieta, and Guillermo Vasquez de Velasco. "Immersive Simulation of Architectural Spatial Experiences". in Blucher Design, 495-499. São Paulo: Blucher, 2014.

"ARCH 101 Basic Design". METU Academic Catalog. accessed 26 August 2019. https://catalog.metu.edu.tr/course.php?prog=120&course_code=1200101.

Archer, Leonard Bruce. Systematic Method for Designers. London: Council of Industrial Design, 1966.

Atman, Cynthia J., and Jennifer Turns. "Studying Engineering Design Learning: Four Verbal Protocol Studies". in Design Knowing and Learning: Cognition in Design Education, 37-60. Charles Eastman, Mike McCracken and Wendy Newsletter. Elsevier Science, 2001.

Azuma, Ronald T. "A Survey of Augmented Reality.". PRESENCE: Virtual and Augmented Reality 6, no. 4 (1997): 355-385.

Bayazıt, Nigan. "Investigating Design: A Review of Forty Years of Design Research". Design Issues 20, no. 1 (2004): 16-29. doi:10.1162/074793604772933739.

Belcher, Daniel, and Brian R. Johnson. "MxR: A Physical Model-Based Mixed Reality Interface for Design Collaboration, Simulation, Visualization, and Form Generation". in Silicon + Skin: Biological Processes and Computation, 464-471. Minneapolis: ACADIA, 2008.

Blom, Nicolaas, and Alfred Bogaers. "Using Linkography to Investigate Students' Thinking and Information Use During a STEM Task". International Journal of Technology and Design Education, 2018. doi:10.1007/s10798-018-9489-5.

"Buy Microsoft Hololens Development Edition - Microsoft Store En-SG". Microsoft Store. accessed 26 August 2019. https://www.microsoft.com/en-sg/p/microsoft-hololens-developmentedition/8xf18pqz17ts?activetab=pivot%3Aoverviewtab.

Chan, Chiu-Shui. "Cognitive Processes in Architectural Design Problem Solving". Design Studies 11, no. 2 (1990): 60-80. doi:10.1016/0142-694x(90)90021-4.

Chandrasekera, Tilanka. "Using Augmented Reality Prototypes In Design Education". Design And Technology Education: An International Journal 19, no. 3 (2014).

Ching, Francis D. K. Architecture: Form, Space, & Order. 3rd ed. Reprint, Hoboken: John Wiley & Sons, 2007.

Chu, Michael, Jane Matthews, and Peter E. D. Love. "Integrating Mobile Building Information Modelling And Augmented Reality Systems: An Experimental Study". Automation In Construction 85, no. 1 (2018): 305-316.

Craig, David Latch. "Stalking Homo Faber: A Comparison of Research Strategies for Studying Design Behavior". in Design Knowing and Learning: Cognition in Design Education, 13-36. Charles M. Eastman, Wendy C. Newstetter and M. McCracken. Oxford: Elsevier Science Ltd., 2001.

Cross, Nigel. "Creativity In Design: Analyzing And Modeling The Creative Leap". Leonardo 30, no. 4 (1997): 311. doi:10.2307/1576478.

Cross, Nigel. "Design Cognition: Results from Protocol and Other Empirical Studies of Design Activity". in Design Knowing and Learning: Cognition in Design Education, 79-103. Charles M. Eastman, Wendy C. Newstetter and M. McCracken. Oxford: Elsevier Science Ltd., 2019.

Cross, Nigel. Design Thinking: Understanding How Designers Think and Work. Oxford: Berg Publishers, 2011.

Cross, Nigel. Designerly Ways of Knowing. London: Springer, 2006.

Darke, Jane. "The Primary Generator and the Design Process". Design Studies 1, no. 1 (1979): 36-44. doi:10.1016/0142-694x(79)90027-9.

Davidson, James N., and Dace A. Campbell. "Collaborative Design in Virtual Space - Greenspace II: A Shared Environment for Architectural Design Review". in Design Computation: Collaboration, Reasoning, Pedagogy, 165-179. Tucson: ACADIA, 1996.

Denel, Bilgi. A Method for Basic Design. Ankara: Middle East Technical University, Faculty of Architecture, 1973.

Denel, Bilgi. Temel Tasarım ve Yaratıcılık. Ankara: O.D.T.Ü. Mimarlık Fakültesi Basım İşliği, 1981.

Dias, Miguel Sales, Pedro Santos, Nancy Diniz, L. Monteiro, R. Silvestre, and Rafael Bastos. "Tangible Interaction For Conceptual Architectural Design". In Augmented Reality Toolkit, The First IEEE International Workshop, 2002.

Dino, İpek Gürsel. "An Experimental Pedagogy of Concept Development in the Introductory Architectural Design Studio". Online Journal of Art and Design 5, no. 1 (2017): 1-23.

Dorta, Tomás, Gokce Kinayoglu, and Michael Hoffmann. "Hyve-3D and the 3D Cursor: Architectural Co-Design with Freedom in Virtual Reality". International Journal of Architectural Computing 14, no. 2 (2016): 87-102. doi:10.1177/1478077116638921.

Eastman, Charles M. On the Analysis of Intuitive Design Processes. Pittsburgh, Pa.: Carnegie-Mellon University, 1968.

Eastman, Charles M., W. Michael McCracken, and Wendy C. Newstetter. Design Knowing and Learning. Amsterdam: Elsevier Science B.V., 2001.

El-Khouly, Tamer, and Alan Penn. "On an Integrated Analytical Approach to Describe Quality Design Process in Light of Deterministic Information Theory". in Design Computing and Cognition, 1-20. Springer, 2012.

Ericsson, Karl Anders, and Herbert Alexander Simon. Protocol Analysis: Verbal Report as Data. Cambridge, Mass.: MIT Press, 1992.

Findeli, Alain. "Moholy-Nagy's Design Pedagogy in Chicago (1937-46)". Design Issues 7, no. 1 (1990): 4. doi:10.2307/1511466.

Findeli, Alain. "Rethinking Design Education for the 21st Century: Theoretical, Methodological, and Ethical Discussion". Design Issues 17, no. 1 (2001): 5-17. doi:10.1162/07479360152103796.

Fiorentino, Michele, Raffaele de Amicis, Giuseppe Monno, and André Stork. "Spacedesign: A Mixed Reality Workspace for Aesthetic Industrial Design.". in International Symposium on Mixed and Augmented Reality (ISMAR), 86-96, 2002.

Fletcher, Jack M. "Differentiating Characteristics of Creative Thinking". in Psychology in Education, with Emphasis on Creative Thinking, 321-380. Jack M. Fletcher. Garden City, NY: Doran & Company, 1934.

Fliegler, Louis A. "Levels of Creativity". Educational Theory 9, no. 2 (1959): 105-115. doi:10.1111/j.1741-5446.1959.tb01255.x.

Fröst, Peter, and Peter Warren. "Virtual Reality Used in a Collaborative Architectural Design Process". in IEEE Conference on Information Visualization, 568-573. IEEE Xplore, 2000.

Fuchs, Philippe, Pacal Guitton, and Guillaume Moreau. Virtual Reality: Concepts and Technologies. Boca Raton, FL: CRC Press, 2011.

Gero, John S. "Design Prototypes: A Knowledge Representation Schema for Design". AI Magazine 11, no. 4 (1990): 26-36.

Gero, John S. "Fixation and Commitment while Designing and Its Measurement". The Journal of Creative Behavior 45, no. 2 (2011): 108-115. doi:10.1002/j.2162-6057.2011.tb01090.x.

Gero, John S., and Udo Kannengiesser. "The Function-Behaviour-Structure Ontology of Design". In An Anthology Of Theories And Models Of Design, 263-283. Amaresh Chakrabarti and Lucienne T. M. Blessing. London: Springer, 2014.

"Gestures - Mixed Reality". Microsoft. accessed 26 August 2019. https://docs.microsoft.com/en-us/windows/mixed-reality/gestures.

Getzels, Jacob W., and Philip W. Jackson. Creativity and Intelligence: Explorations with Gifted Students. London: John Wiley, 1963.

Ghiselin, Brewster. The Creative Process. Los Angeles: University of California Press, 1952.

Goel, Vinod. Sketches of Thought. The MIT Press, 1995.

Goldschimdt, Gabriela. "Serial Sketching: Visual Problem Solving in Designing". Cybernetics and Systems 23, no. 2 (1992): 191-219. doi:10.1080/01969729208927457.

Goldschmidt, Gabriela. "The Designer as a Team of One". Design Studies 16, no. 2 (1995): 189-209. doi:10.1016/0142-694x(94)00009-3.

Goldschmidt, Gabriela. "The Dialectics of Sketching". Creativity Research Journal 4, no. 2 (1991): 123-143. doi:10.1080/10400419109534381.

Goldschmidt, Gabriela. Linkography: Unfolding the Design Process. Cambridge, Massachusetts: The MIT Press, 2014.

Goldschmidt, Gabriela, and Maya Weil. "Contents and Structure in Design Reasoning". Design Issues 14, no. 3 (1998): 85. doi:10.2307/1511899.

Gropius, Walter. "Teaching the Arts of Design". College Art Journal 7, no. 3 (1948): 160. doi:10.2307/773109.

Gruber, Hans Peter. "Afterword". in Beyond Universals in Cognitive Development. Praeger, 1980.

Guilford, Joy Paul. "The Structure of Intellect.". Psychological Bulletin 53, no. 4 (1956): 267-293. doi:10.1037/h0040755.

Gül, Leman Figen, Anthony Williams, and Ning Gu. "Constructivist Learning Theory in Virtual Design Studios". Computational Design Methods and Technologies: Applications in CAD, CAM and CAE Education, 2012.

Gürsoy, Benay. "The Cognitive Aspects of Model-Making in Architectural Design". Master of Architecture, Middle East Technical University, 2010.

Gürsoy, Benay, and Mine Özkar. "Is Model-Making Sketching in Design?". in Design Research Society International Conference on Design and Complexity. Montreal: Design Research Society, 2010.

Hatcher, Gillian, William J. Ion, Ross John Robert Maclachlan, Marion Marlow, Barbara Simpson, Nicky Wilson, and Andrew J. Wodehouse. "Using Linkography to Compare Creative Methods for Group Ideation". Design Studies 58 (2018): 127-152. doi:10.1016/j.destud.2018.05.002.

Itten, Johannes. Design and Form: The Basic Course at the Bauhaus. Reinhold Pub. Corp., 1964.

Jahn, Gwyllim, Cameron Newnham, Nick van den Berg, and Matthew Beanland. "Making in Mixed Reality". in Recalibration: On Imprecision and Infidelity, 88-97. Mexico City, 2018.

Kan, Jeff W.T., and John S. Gero. "Acquiring Information From Linkography in Protocol Studies of Designing". Design Studies 29, no. 4 (2008): 315-337. doi:10.1016/j.destud.2008.03.001.

Kan, Jeff W. T., and John S. Gero. "Using the FBS Ontology to Capture Semantic Design Information in Design Protocol Studies". in About: Designing - Analysing Design Meetings, 213-229. Janet McDonnell and Peter Lloyd. CRC Press, 2009.

Kara, Levent. A Critical Look at the Digital Technologies in Architectural Education: When, Where, and How?, 2015.

Kim, Nanyoung. "A History of Design Theory in Art Education". The Journal of Aesthetic Education 40, no. 2 (2006): 12-28. doi:10.1353/jae.2006.0015.

Kneller, George F. The Art and Science of Creativity. New York: Holt, Rinehart and Winston, 1965.

Ladovsky, Nikolai. "The Psycho-Technical Laboratory of Architecture". trans. Cooke Catherine Architectural Design 61, no. 9-10 (1991): 26.

Lang, Jon. "Öğrenciler için Mimarlığa Giriş: Temel Tasarım Dersini Yeniden Düşünmek". trans. Aytaç-Dural Tuğyan in Temel Tasarım / Temel Eğitim, 6. Necdet Teymur and Tuğyan Aytaç-Dural. Ankara: METU Faculty of Architecture Press, 1998.

Lawson, Bryan. How Designers Think. Architectural Press, 1980.

Lawson, Bryan. How Designers Think: The Design Process Demystified. Elsevier, 2006.

Lee, Ju Hyun, Ning Gu, and Michael J. Ostwald. "Architectural Design Using Algorithmic Scripting: An Application of Linkographic Analysis Techniques". in Cutting Edge: 47Th International Conference of the Architectural Science Association, 133-142. Hong Kong: The Architectural Science Association (ANZAScA), 2013.

McNeill, Thomas, John S. Gero, and James Warren. "Understanding Conceptual Electronic Design Using Protocol Analysis". Research In Engineering Design 10, no. 3 (1998): 129-140. doi:10.1007/bf01607155.

Milgram, Paul, and Fumio Kishino. "A Taxonomy of Mixed Reality Visual Displays". IEICE Transactions on Information Systems 77, no. 12 (1994): 1321-1329.

Milovanovic, Julie, Guillaume Moreau, Daniel Siret, and Francis Miguet. "Virtual and Augmented Reality in Architectural Design and Education: An Immersive Multimodal Platform to Support Architectural Pedagogy". in Future Trajectories of Computation in Design, 17Th International Conference, CAAD Futures. Istanbul, 2017.

Moholy-Nagy, László, and Daphne M. Hoffmann. The New Vision 1928 and, Abstract of an Artist. New York: Wittenborn, 1947.

Naylor, Gillian. The Bauhaus Reassessed. London: Herbert Press, 1985.

Neves, Ana Glória, Emília Duarte, and Diana Dias. "Basic Design Meets Virtual Reality: A Tentative Methodology". in Design Doctoral Conference, 104-111. Lisboa: IADE-U, 2016.

Neves, Ana Glória, Emília Duate, Diana Dias, and Magda Saraiva. "The Impact of a Virtual Reality-Based Tool on a Basic Design Rooted Discipline: Early Perceptions". in Design Doctoral Conference, 167-174. Lisboa: IADE-U, 2017.

Newell, Allen. On the Analysis of Human Problem Solving Protocols. Arlington: Computer Microfilm International, 1966.

Newell, Allen, and Herbert A. Simon. Human Problem Solving. Prentice-Hall, 1972.

Norberg-Schulz, Christian. Intentions in Architecture. Cambridge, Mass.: The M.I.T. Press, 1966.

Onur, Zeynep. "Mimarlık Eğitiminde İlk Yıl". in Temel Tasarım / Temel Eğitim. Ankara: METU Faculty of Architecture Press, 1998.

Özkar, Mine. Rethinking Basic Design in Architectural Education: Foundations Past and Future. New York: Routledge, Taylor & Francis Group, 2017.

Papert, Seymour. "Instructionism versus Constructionism". in The Children's Machine: Rethinking School in the Age of the Computer, 137-156. Seymour Papert. New York: Basic Books, 1993.

Pourmohamadi, Morteza, and John S. Gero. "Linkographer: An Analysis Tool to Study Design Protocols Based on FBS Coding Scheme". in 18Th International Conference on Engineering Design - Impacting Society through Engineering Design, 294-303, 2011.

Rauterberg, Matthias, Morten Fjeld, Helmut Krueger, Martin Bichsel, Uwe Leonhardt, and Markus Meier. "BUILD-IT: A Video-Based Interaction Technique For A Planning Tool For Construction and Design". In 5Th International Scientific Conference - WWDU '97, 175-176. Takorozawa: NORO Ergonomics Lab, 1997.

Ren, Jiang, Yingying Liu, and Zhicheng Ruan. "Architecture in an Age of Augmented Reality: Applications and Practices for Mobile Intelligence BIM-Based AR in the Entire Lifecycle". DEstech Transactions on Computer Science and Engineering, 2017. doi:10.12783/dtcse/iceiti2016/6203.

Resnick, Mitchel, and Ken Robinson. Lifelong Kindergarten: Cultivating Creativity through Projects, Passion, Peers, and Play. Cambridge: The MIT Press, 2017.

Rogers, Carl R. "Toward a Theory of Creativity". A Review of General Semantics 11, no. 4 (1954): 249-260.

Ross, Denman Waldo. "Design as a Science". Proceedings of the American Academy of Arts and Sciences 36, no. 21 (1901): 357.

Saranlı, Türel. "Başlangıçtan Bugüne Temel Tasarım". in Temel Tasarım / Temel Eğitim. Ankara: METU Faculty of Architecture Press, 1998.

Schnabel, Marc Aurel. "Framing Mixed Realities". in Mixed Reality in Architecture, Design & Construction. Springer, 2008.

Schieck, Ava Fatah gen, Alan Penn, Chiron Mottram, Andreas Strothmann, Jan Ohlenburg, Wolfgang Broll, Francis Aish, and Simon Attfield. "Interactive Space Generation through Play Exploring the Role of Simulation on the Design Table". International Journal of Architectural Computing 3, no. 1 (2004): 3-25. doi:10.1260/1478077053739612.

Schwartz, Howard S., and Donald A. Schon. "The Reflective Practitioner: How Professionals Think in Action.". Administrative Science Quarterly 32, no. 4 (1987): 614. doi:10.2307/2392894.

Seichter, Hartmut. "Benchworks Augmented Reality Urban Design". In 9th International Conference on Computer Aided Architectural Design Research in Asia. Seoul, 2004.

Seichter, Hartmut. "SKETCHAND+ A Collaborative Augmented Reality Sketching Application". in 8th Internationalconference on Computer Aided Architectural Design Research in Asia. Bangkok, 2003.

Simon, Herbert A. The Sciences of The Artificial. Cambridge: The MIT Press, 1969.

Taura, Toshiharu, and Yukari Nagai. Concept Generation for Design Creativity: A Systematized Theory and Methodology. London: Springer, 2019.

Ulusoy, Zuhal. "A Study of Perceptual Organization Principles as Related to Basic Design". Master of Architecture, Middle East Technical University, 1983.

van der Lugt, Remko. "Brainsketching and How It Differs from Brainstorming". Creativity and Innovation Management 11, no. 1 (2002): 43-54.

van der Lugt, Remko. "Developing a Graphic Tool for Creative Problem Solving in Design Groups". Design Studies 21, no. 5 (2000): 505-522.

Vidal, Rosario, Elena Mulet, and Eliseo Gómez-Senent. "Effectiveness of the Means of Expression in Creative Problem-Solving in Design Groups". Journal of Engineering Design 15, no. 3 (2004): 285-298. doi:10.1080/09544820410001697587.

Wang, Xiangyu, and Marc Aurel Schnabel. Mixed Reality in Architecture, Design and Construction. Dodrecht: Springer, 2009.

Wang, Xiangyu, Ning Gu, and David Marchant. "An Empirical Study on Designers' Perceptions of Augmented Reality within an Architectural Firm". Electronic Journal of Information Technology in Construction 13 (2008): 536-552.

Wang, Xiangyu, Do Hyoung Shin, and Phillip Sherwood Dunston. "Issues in Mixed Reality-Based Design and Collaboration Environments.". in Construction

Research Congress, Winds of Change: Integration and Innovation in Construction, 1049-1057, 2003.

Wei, Xiaodong, Dongdong Weng, Yue Liu, and Yongtian Wang. "Teaching Based on Augmented Reality for a Technical Creative Design Course". Computers & Education 81 (2015): 221-234.

# APPENDICES

## A. PROTOCOL TRANSCRIPTS AND LINKOGRAPHS

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN MIXED REALITY ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 1 (D1)

| | |
|---|---|
| M1 | 00:45 I choose a white cube as a start; I usually don't like colorful things a lot |
| M2 | 01:00 well, I am trying to move it |
| M3 | 01:12 It expenses before I do |
| M4 | 03:03 I can't get any closer |
| M5 | 03:13 I can't understand if the corners are connected or not, is there any change to see it? |
| M6 | 03:43 I got it |
| M7 | 03: 47 I am trying to snap the two cubes with different scales, but it is so sensitive |
| M8 | 04:29 Like I said, I like to work with cubes and I am thinking about something seems like pixels [relates the 2 cubes] |
| M9 | 04: 40 I thought a core at the center and other things, which form around the core |
| M10 | 04:49 But, I should make it bigger first |
| M11 | 05:32 I am saying "select" to select them both and then "save" to make them a group |
| M12 | 06:30 No, it is hard to select the buttons |
| M13 | 06:40 oh, it is "group save" |
| M14 | 07:07 There is a group idea in my head, but I hope it works |
| M15 | 07:17 It didn't happen, did it? |
| M16 | 08:28 [tries to relate the yellow cube with the group] |
| M17 | 08:53 Is there any other scaling options? |
| M18 | 09:05 I thought a lot of objects with miscellaneous dimensions |
| M19 | 09:28 Like I said before, I have an idea on creating a core and locate the other elements around it, so I am trying to apply this idea with the groups now |
| M20 | 09:47 I am trying to connect a big cube with some other smaller ones, but scaling is making it hard |
| M21 | 10:16 [relates the group with the yellow cube] |
| M22 | 10:35 mmmm [scales the group x5 on xyz axis] |
| M23 | 11:06 It is too big [undo]- I come back with "undo" I guess |
| M24 | 11:52 ok, now we are going to rotate it [rotates the group on x-axis +45] |
| M25 | 13:31 I chose but it doesn't make it white, I try another color [materials- white] |
| M26 | 13:59 I have a void like that now |
| M27 | 14:14 Something happened to an element in the group |
| M28 | 14:58 I saved and now I am going to make it "ungroup" |

| | |
|---|---|
| M29 | 16:00 now I have 6 elements |
| M30 | 16:26 Still I have only one group, actually just a part of a group but rotating is a little bit hard |
| M31 | 17:22 I made them a group but when I try rotating only one element can rotate |
| M32 | 17:45 yes, it worked |
| M33 | 18:27 Now it should disappear |
| M34 | 18:52 Void will appear automatically because of the vision |
| M35 | 20:11 I did one of them but have no clue how I did |
| M36 | 21:05 Let's try from somewhere else |
| M37 | 21:16 No, it doesn't work as I want |
| M38 | 23:29 Yes, it is a little slippery, but I think it is not a problem |
| M39 | 25:45 Is it overlapped, yes |
| M40 | 26:09 I have to move away from the things after selecting them-moves the new group2 |
| M41 | 26:12 hah, now I made them a group, let's try the rest of it |
| M42 | 27:05 I can't select them |
| M43 | 27:34 yes, I will delete this and start all over again |
| M44 | 27:38 I am saving into the slot |
| M45 | 27:56 What will I to start a new one |
| M46 | 27:58 Let me think about what kind of thing could be |
| M47 | 28:01 What if the group will be something like that to gain time |
| M48 | 28:05 I will try to group it; it will be good if it works |
| M49 | 28:07 It didn't work as I want so starting all over again could be made more sense. Now I have 10 elements, but I couldn't |
| M50 | 28:11 No, I am starting again |
| M51 | 28:27 I will try to the same thing |
| M52 | 29:25 OK- [scales a group on XYZ axis x3] |
| M53 | 31:50 I made a lot of "undo" |
| M54 | 32:02 I will do it again [loads new slot] |
| M55 | 35:50 [changes the relationship of the groups] It snaps directly itself |
| M56 | 36:33 I am using the existing groups; I couldn't make a new group [group1] |
| M57 | 37:40 a little from that [fixes the snap points] |
| M58 | 43:06 Usually, I don't change my mind and insist to do what I find initially had in my mind |
| M59 | 43:24 ooh, it is too big |
| M60 | 44:54 It is quite all right like that |
| M61 | 46:29 I hope it works [group1] |
| M62 | 46:55 [relates a new group with the whole] there is still only one group, but I got the cluster I want |
| M63 | 47:15 I feel too close to the image I want; it could be great if I could move it to the back but I can’t |

| | |
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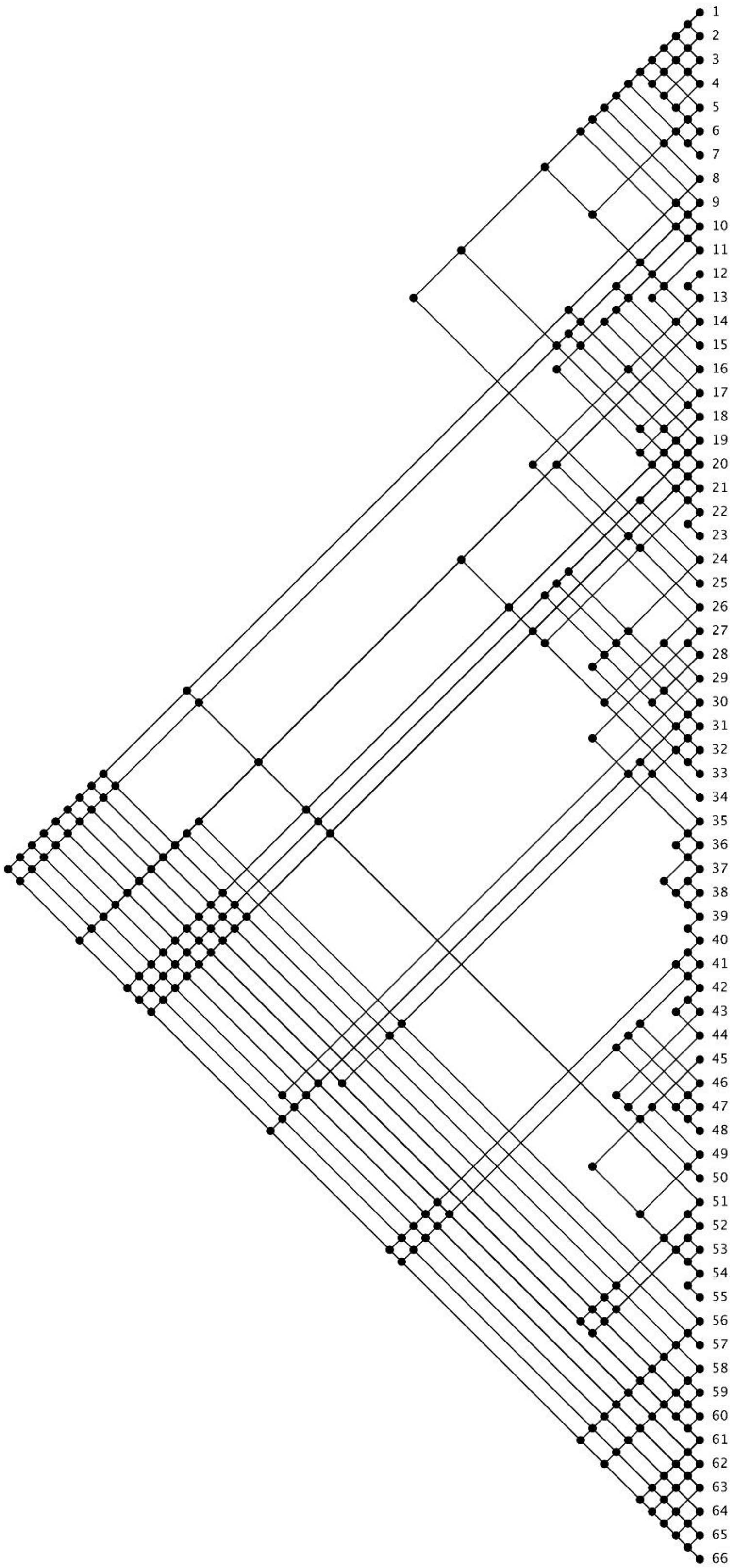
| M64 | 47:31 How many elements I have-counts |
| M65 | 48:35 [group1] |
| M66 | 49:14 [scales the new group on xyz axis x2] |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PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN PHYSICAL ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 1 (D1)

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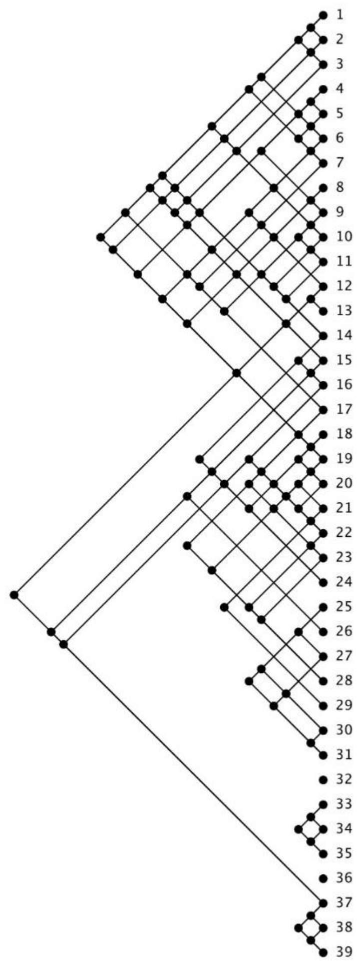
|---|---|
| M1 | 00:43 I will work with the basic geometries like the previous task, I will try to do something I hope it works |
| M2 | 02:30 Maybe not exactly a core but something end-to-end |
| M3 | 02:44 I will make 2 main bodies |
| M4 | 05:29 The idea is that… I will fold these to get different directions |
| M5 | 06:11 a little cutting |
| M6 | 06:37 now I will make another one but this one will be a little bigger |
| M7 | 09:05 I kept this one's width same because I raised the height |
| M8 | 09:18 I thought that making the difference with thickness because the theme is the hierarchy |
| M9 | 09:26 I will fold this one similarly (he begins to cut and fold) |
| M10 | 10:53 Now I should some way to locate them |
| M11 | 11:03 something like that |
| M12 | 11:19 and again, due to reach hierarchy, I will cut the biggest element from the thickest cardboard and cut other secondary elements from the thin cardboard |
| M13 | 11:53 now these ones stay here (stabilize the previous pieces) |
| M14 | 12:23 again I can use these L shape elements as rectangular, folded surfaces and double folded ones |
| M15 | 12:50 I have an idea like…with the growing distance color will remain but the material is going to be thinner and then the white elements will be there |
| M16 | 14:20 maybe I can fold much more time and as they get folded, we'll begin to see white and less folded elements |
| M17 | 14:40 I will try to raise the geometric and flat shapes |
| M18 | 17:12 the basic logic is based on the several folding operations but this one a little short, so I cut a new element twice as big |
| M19 | 17:27 relation and proportion are important, and I think enough for the basic design studio |
| M20 | 18:40 I scaled the last piece, I guess I will fold it twice |
| M21 | 18:53 It is annoying… It doesn't stay in right angle, so I think I will engage them like this [shows the 2 elements one on the top of the other] |
| M22 | 20:39 We will continue to this as adding others |
| M23 | 21:49 now, I changed the proportion of these elements. Basically, all of them are squares... play with the proportions and achieve different elements |
| M24 | 27:50 I count each folded parts of the elements as one element, so we have 10 elements, at least 1/3 |
| M25 | 28:12 there is no need to make it so big. It is already annoying, so I feel that I come to the end of this side. I will make something from the white one |
| M26 | 28:39 actually white color could become dominant and suppress the main elements, which I made from craft cardboard. so, I will cut them thinner |
| M27 | 29:09 If I make them smaller then maybe they could be in balance |

| | |
|---|---|
| M28 | 30:34 actually there is a systematic approach. Every element refers to another one like these heights and alignments. I measure but eyeball estimation |
| M29 | 31:32 I like to work with right angles. So, the voids over there will be narrow and gets less light |
| M30 | 33:37 I will make a surface to make stable that |
| M31 | 33:48 it should be stable |
| M32 | 37:12 I complete to work in this axis so now I will come towards this one |
| M33 | 37:24 Maybe I won't need this piece anymore [he gets another folded cardboard] |
| M34 | 37:36 actually I was thinking use these 2 as separately but now I think it is a better idea of diminishing one of them |
| M35 | 38:26 [tries to fit new elements] what if these will repeat? |
| M36 | 40:22 this one became distant [points an element] |
| M37 | 42:09 now we can get the secondary pieces |
| M38 | 53:46 it is too short |
| M39 | 59:42 this doesn't stay stable because of the long span; I will remove them |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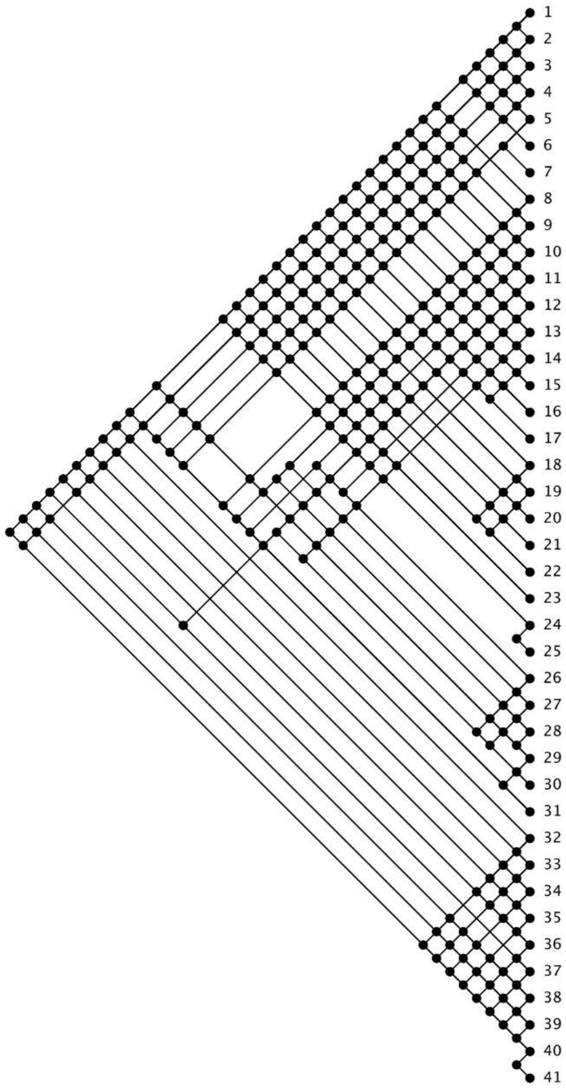
PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN MIXED REALITY ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 2 (D2)

| | |
|---|---|
| M1 | 00:04 The problem asks for 27 or 30 elements and should I use squares or is it up to me |
| M2 | 00:14 Then, I want to start with squares because I think right angles much more comfortable to work |
| M3 | 00:25 I will choose a square |
| M4 | 01:00 I want to rotate to achieve a 3d effect |
| M5 | 03:05 I couldn't because I can't be sure which axis should I choose to rotate |
| M6 | 04:00 hıhh [rotates +45 on x axis] |
| M7 | 04:55 Now I want to connect them with the right angle |
| M8 | 06:34 If I can rotate that I will make a group and it will end |
| M9 | 07:23 I compound this too [a square] |
| M10 | 07:29 Ok, now I will save it |
| M11 | 07:53 I will choose the same group again |
| M12 | 07:59 and I will rotate it in itself so I could make a rhythm and I am thinking on amplifying some of the group because we want an order hierarchically |
| M13 | 10:23 now I want to make a few more from that group in different heights |
| M14 | 11:27 OK, let's change the height of this one |
| M15 | 11:48 Can I scale in smaller proportions than the written ones here or just these are |
| M16 | 12:09 I made smaller one of my groups, now I will rotate it to combine differently |
| M17 | 16:41 I am taking another group again and I will change its size again |
| M18 | 21:02 I will amplify one more |
| M19 | 33:16 I will make one more [group1] |
| M20 | 35:13 anyway I will make it again [deletes the group accidently] |
| M21 | 35:37 ooh, one of the groups has gone too far |
| M22 | 38:39 OK, I am making a group again nothing else |
| M23 | 39:42 I made a new group and I will change its size and amplify it |
| M24 | 49:05 let's combine it too right away |
| M25 | 50:05 we have something that consists of 9 elements and another group, which includes 3 elements |
| M26 | 50:18 If I can combine them there will be 12 elements so I am trying to amplify it to combine later |
| M27 | 51:15 OK, now we have 12 elements [relates the new group with the whole] |
| M28 | 51:22 there is a little bit chaos |
| M29 | 51:30 I will combine those when I remove these |
| M30 | 51:59 I will change from the back, here is mixed a lot |
| M31 | 52:31 now I will duplicate this group again |
| M32 | 52:58 I will make another group |
| M33 | 54:54 OK, let's make it bigger and locate |
| M34 | 54:59 No, it is not ok |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PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN PHYSICAL ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 2 (D2)

| | |
|---|---|
| M1 | 00:49 I want to work with the right angles again |
| M2 | 00:55 first, I will draw a few elements. I want to catch a rhythm orderly grow to achieve hierarchy |
| M3 | 01:09 I will start with 8 cm |
| M4 | 02:51 now 10 cm to grow it gradually |
| M5 | 03:01 Also I want to change the shape because I want to catch a similarity between the elements |
| M6 | 03:40 I will just make differences in their sizes |
| M7 | 04:58 now I have 4 pieces of 10*10, 4 pieces of 8*8 squares ad I want to one 12*12 square too |
| M8 | 06:15 now I will cut them let's see how to combine them |
| M9 | 09:46 now the project doesn't want me to use glue, but I have to combine them somehow so that I can create volume so I can try to open the small notches and put them together. |
| M10 | 10:03 and I think of combining it from the same place so that it can be read |
| M11 | 10:14 maybe I can combine these together to form binary groups, and there can be a hierarchy of these as they grow |
| M12 | 11:44 maybe I can try to combine a small one and a big one |
| M13 | 11:49 It's too big |
| M14 | 11:53 the same size merged better |
| M15 | 11:58 this combination can come up to half because it's not so solid |
| M16 | 12:29 Yes, it is better now |
| M17 | 12:31 now if I add one on top of it, a volume will slowly begin to form. |
| M18 | 12:40 maybe there will be a big duo in the center and the focus will be there, small elements can be added around it |
| M19 | 12:48 I will combine these two (12*12 2 squares, measure for connection points) |
| M20 | 13:28 [thinks on another relations] even so... |
| M21 | 13:48 I decided to put it in the center - 12 * 12 squares group- the others will turn around |
| M22 | 13:51 I combine these because I want it to shrink slowly, not suddenly |
| M23 | 14:42 these are my duo (8*8,10*10,12*12-3 groups) |
| M24 | 14:45 I will combine them (10*10 squares) |
| M25 | 17:28 combining them in this way, now on this side and on this side began to form gaps |
| M26 | 17:51 I will combine this in the middle of it (3rd group 8*8) |
| M27 | 18:40 accidentally cut them all I will start over |
| M28 | 22:03 I want it all around the big one, I want it to shrink when the previous one is connected, so I look where I can position it. |
| M29 | 23:59 I'm going to make another group this way. one in the middle |
| M30 | 24:08 then I can start trying the others around you |
| M31 | 28:13 I'll put this around the big one |

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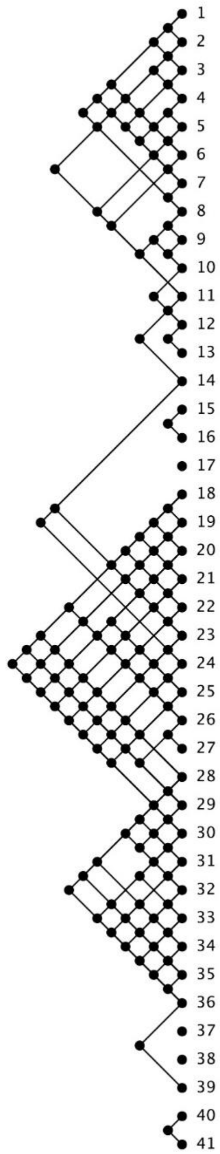
|---|---|
| M32 | 35:30 I will start with the smallest |
| M33 | 35:50 I'm going to need more of these because I put four groups around the middle one and I want to keep it going. |
| M34 | 36:00 so I'll put 4 of them around the median ones. both ready to do the others soon |
| M35 | 37:58 Now I'm starting to place the little ones |
| M36 | 44:24 I'm going to do a little more 8 now |
| M37 | 48:41 I want to count my elements -counts the elements – now 18 |
| M38 | 49:21 things are constantly changing; I don't want it here [but she didn't change] |
| M39 | 49:48 I want to make a little more 8 and go to the bottom so that it can get a more 3D appearance, it was very flat like this |
| M40 | 54:02 yes, I forgot where to put it |
| M41 | 54:08 was that |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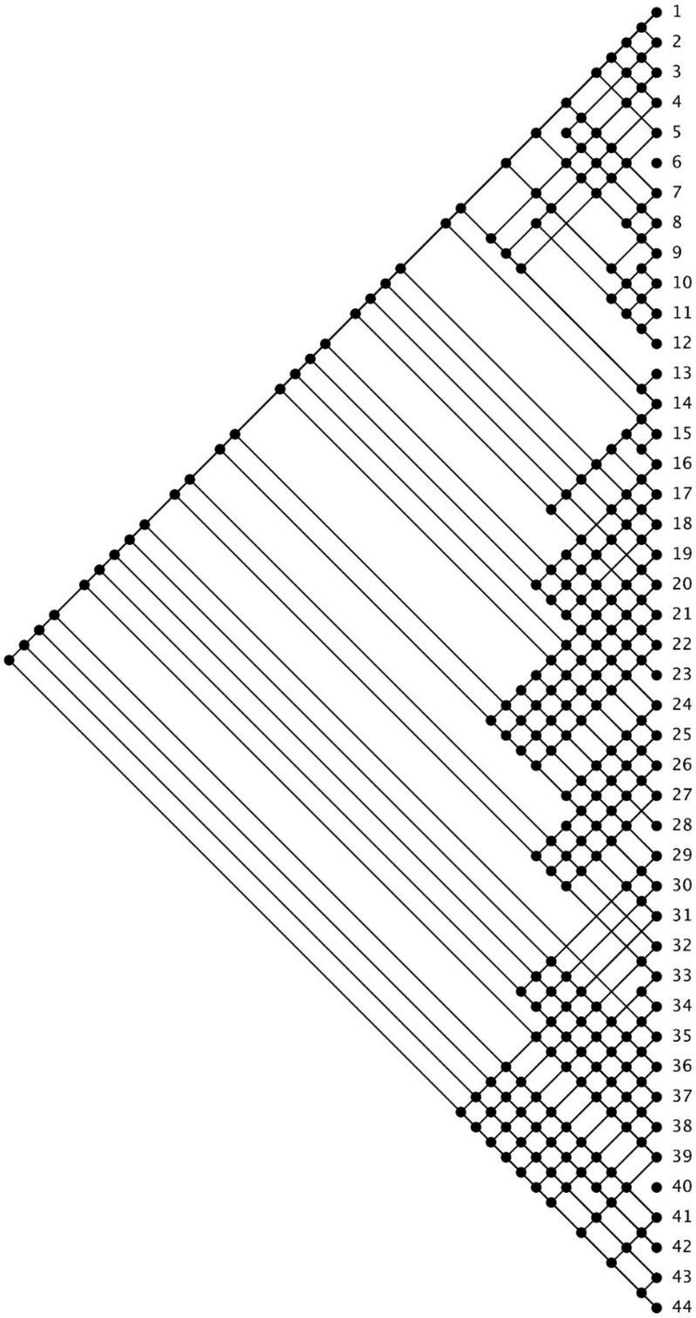
PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN MIXED REALITY ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 3 (D3)

| | |
|---|---|
| M1 | 00:10 then let's create groups |
| M2 | 00:17 groups consist of 3 elements |
| M3 | 01:39 Here I got the pyramid, square and circle-moves the pyramid- |
| M4 | 01:58 I'll replicate this group in such a way that I can position them somehow and create volume |
| M5 | 02:14 I'm giving up the circle, I'll erase it |
| M6 | 02:28 accidentally deletes the square -ahh |
| M7 | 03:04 I'll try to rotate it now |
| M8 | 04:30 I will choose another axis right now, but |
| M9 | 06:07 I'm still trying to group |
| M10 | 06:27 these are joining corners, aren't they, okay, now |
| M11 | 06:34 moves the other square and tries to relate-hıh |
| M12 | 08:26 I'm going to change the scale of it now but well |
| M13 | 10:27 yes, I lost what I did-load the slot accidentally |
| M14 | 12:41 connects the square and the pyramid |
| M15 | 12:49 can I play with the scale as a group when I do this |
| M16 | 13:45 rotates a square -45 x axis |
| M17 | 15:10 relates the 2 squares |
| M18 | 16:23 relates the square with the pyramid |
| M19 | 16:39 I'm currently trying to form a group of 2 squares and a pyramid. I turn the square so that there is space. they create such volume |
| M20 | 16:53 I'm making one more of it right now, I'll make two different versions |
| M21 | 22:27 now I've created 2 groups I'll save and multiply them |
| M22 | 24:07 I'm trying to choose the oblique |
| M23 | 26:19 connects the all 3 elements again |
| M24 | 26:30 I try to select and group 3 elements again |
| M25 | 27:23 I made group 2 |
| M26 | 28:36 I want to duplicate my last group |
| M27 | 29:58 rotates a group 2 times in x axis +45 |
| M28 | 30:04 scale x2 in XYZ axes -I increased the size of one of the group |
| M29 | 30:47 [changes the relation]-I'm trying to connect the pyramids from the corners |
| M30 | 31:03 tries to relate another group with the other 2 bonded groups |
| M31 | 32:17 changes the connection of the latest group with the whole-I couldn't put it right around the corner, but I think my purpose is clear. |
| M32 | 35:31 rotates the new group +45 2 times in axis x – I'm currently trying to rotate a group |
| M33 | 37:13 chooses the z-axis to rotate- now I'm trying to rotate the group on another axis |

| | |
|---|---|
| M34 | 37:39 Isn't it taking back the direct process – undo |
| M35 | 39:33 aa my middle group is gone |
| M36 | 40:32 I'm just trying to put what I lost in the middle of an element. I've tied the pyramids around the corners, and now I'm trying to do it again. |
| M37 | 41:07 but I can't see I'm going to change the color of it |
| M38 | 41:18 material – soft yellow |
| M39 | 43:38 tries a new relation for that group |
| M40 | 44:52 moves the separate elements- I am cleaning |
| M41 | 45:27 tries to connect the biggest group again in a new way |
| M42 | 46:14 changes again the relation between 2 groups |
| M43 | 46:30 connects the rotated group with the biggest one |
| M44 | 49:47 moves and relate another group with the biggest one |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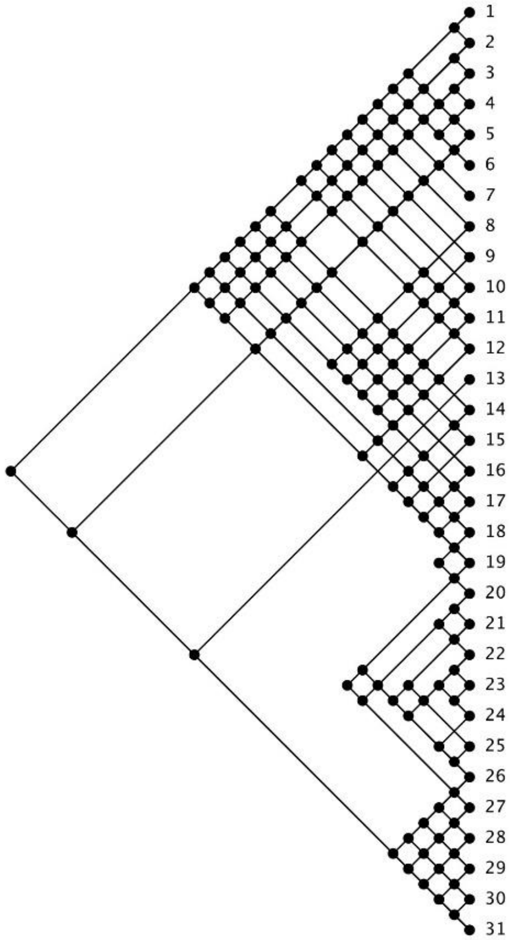
PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN PHYSICAL ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 3 (D3)

| | |
|---|---|
| M1 | 00:15 now I'll try to do something similar to what I just did |
| M2 | 00:28 but it's going to be a little more difficult because I don't use glue |
| M3 | 02:08 folds the cardboard |
| M4 | 04:13 connects the 4th element |
| M5 | 04:28 I thought about two kinds of groups. It's one of the groups, but I can make it a little smaller. These will be added to each other to create a volume |
| M6 | 04:52 cuts the 4th element to make it smaller |
| M7 | 05:17 cuts the 3rd element to make to smaller too |
| M8 | 08:04 connects the new elements |
| M9 | 09:12 connects the 3 new elements |
| M10 | 12:22 connects the elements |
| M11 | 13:26 connects the new groups |
| M12 | 13:55 now I'm planning this as a group of the biggest elements - shows the biggest group - they're all repeating each other, this will be as much as possible with all the other elements, the groups |
| M13 | 14:09 checks and fixes the connections |
| M14 | 15:38 connects the new elements |
| M15 | 16:47 connects the new groups with each other |
| M16 | 21:58 connects the new elements to make a new group |
| M17 | 22:10 connects the new groups -I made one of the smallest group |
| M18 | 22:24 I will start to combine now – checks the connections of a medium group |
| M19 | 22:46 I want to combine these with different angles (small and the biggest group) |
| M20 | 25:14 I will combine them in this way- connects the big one and the small one |
| M21 | 25:32 eventually they will move from a different place |
| M22 | 26:47 tries to relate them – I think how to cut right now |
| M23 | 28:48 cuts again instead of making a new element! |
| M24 | 29:19 tries to connect them again |
| M25 | 32:55 connects the groups- I tried to use angles similar to those in both |
| M26 | 34:33 cuts for the new connections – now I'm placing the 3rd small group |
| M27 | 40:51 Now I've put the small group, I'll do one more. There were groups repeating each other, the biggest one in the middle, in some way in contact with all the others. The smallest two are articulated in only one plane, and the other two of the other intermediate lengths are connected in two places |
| M28 | 41:44 I'm going to make a more medium-sized group that connects two of the groups. |
| M29 | 44:47 connects the new elements to make a group |
| M30 | 48:22 it's over – connects the last element |
| M31 | 48:29 so here are 5 of a group, repeating each other, the biggest one in the middle, others around it |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PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN MIXED REALITY ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 4 (D4)

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| M1 | 00:06 first I want to create a group of myself |
| M2 | 00:18 for example, let me choose a cube |
| M3 | 00:23 I want to play with the proportions of it, so I have to say “scale” |
| M4 | 00:39 something like a little more rectangular prism |
| M5 | 01:12 it is a little more like a plate |
| M6 | 03:04 now I want to make a group |
| M7 | 05:31 Let's play with the proportions of the shape again, but let it be like a cube |
| M8 | 05:38 or give it a try -scales /3 |
| M9 | 05:56 /2 accidentally again-I did something funny accidentally |
| M10 | 06:21 What shall we do now |
| M11 | 06:32 I'll make it a little bigger because it's too small |
| M12 | 06:45 x5 has grown now |
| M13 | 06:49 x3 grew too much |
| M14 | 07:21 moves the new cube near to the other cube- these were more or less the same size |
| M15 | 07:25 now I want to be hierarchical not only in size but also in the differentiation of geometric objects, so I will add something sharp to this group |
| M16 | 08:31 changes the relation between cube and pyramid – hıh |
| M17 | 08:35 let's increase the size of it -scales a pyramid x2 |
| M18 | 08:51 now I want to rotate it so that I can place it on its side, not on top |
| M19 | 09:23 scales pyramid x2 – It's too big |
| M20 | 09:50 Now I have to make an account. I want the pointed tip to look at me, what should I do |
| M21 | 10:08 rotates a pyramid (scaled/3) on the x-axis -45-aa 45 but I have to rotate 45 more |
| M22 | 10:53 I just decided to shrink the cube I just made |
| M23 | 11:05 hmm how much smaller, 2 times smaller |
| M24 | 13:19 OK, I have a group like this |
| M25 | 14:44 Now I'm going to play with their dimensions, change their direction and start to combine |
| M26 | 15:09 I want to play with the dimensions of it |
| M27 | 15:19 but without changing the proportions, so I left all axis actively |
| M28 | 15:31 I have a very small element right now |
| M29 | 15:36 it seemed like it would be easier to combine them all if I could get more than one size from the same group and throw them left and right |
| M30 | 16:04 then let me bring one more from the same group |
| M31 | 16:11 for example, divided by 2 or 3 |
| M32 | 16:48 Let's grow this again. I've shrunk too much |
| M33 | 16:56 Now I have 2 of the same size from the 1st group, I will throw it to the left again |
| M34 | 17:14 Since we have a number to reach, let's produce some more of these small groups. |
| M35 | 18:44 Anyway let me continue-group 1- I brought one more from the first group |
| M36 | 19:01 I'll shrink it again-scales / 3-okay |
| M37 | 19:20 I have three of the small group. Two more now. I used 11 elements anyway |
| M38 | 19:37 I thought what can I do without producing by memory |
| M39 | 19:50 I have produced one more in the same group, but larger |
| M40 | 21:11 I'm just producing 1 more of the middle size 1 group I just made |
| M41 | 21:23 counts the elements |
| M42 | 21:49 maybe I start to group or merge groups within itself, so I'm going to rotate |

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| M43 | 22:19 now I will merge them-select |
| M44 | 23:44 Now I've started to put those small and medium sizes around the big one. |
| M45 | 23:55 I'm going to change the direction at the same rate to use similar relationships, but this time look at the other side |
| M46 | 29:24 How to place - tries to relate |
| M47 | 29:34 looking out the little cubes get-ah stop, it was nicely settled-hah-fixes the snap points |
| M48 | 31:26 should I grow this |
| M49 | 31:40 scales the group 2 x3 XYZ axes– it's too big |
| M50 | 32:08 In the 2nd group, it turns out that one of the pyramids is not well placed. I noticed when I accidentally increased the dimensions |
| M51 | 32:24 Let me resize. -scales / 5- very small |
| M52 | 33:00 I want to select and enlarge this again. too small |
| M53 | 34:10 actually something like that hmmm |
| M54 | 34:11 that group wasn't very good, I want to get it out - I threw it right - moves the group 2 |
| M55 | 34:29 let me place the groups I have created before |
| M56 | 35:21 connects the group with the whole-i did something like that |
| M57 | 35:46 let me do one more of this |
| M58 | 35:50 Now to do something that looks at me like this... just rotate around the y-axis |
| M59 | 36:02 accidental scales / 2- no, I've shrunk |
| M60 | 36:12 enlarge all x2 |
| M61 | 37:23 let's just turn around y-scales / 2 |
| M62 | 37:34 I didn't want to shrink. -x3 - good luck |
| M63 | 38:23 something interesting happened but I liked it |
| M64 | 38:32 I did it unintentionally, but can I do the same again |
| M65 | 39:44 changes his position to see- I want to copy what I accidentally do |
| M66 | 43:33 OK. I put |
| M67 | 43:52 moves the original group- I want to select it and change its direction |
| M68 | 45:51 probably not exactly catching up, but I still thought of replicating these elements and lining them around |
| M69 | 46:09 even though I never use this group- moves the group 2 |
| M70 | 47:27 it was hanging in the air. the latest group |
| M71 | 48:01 I did the undo command |
| M72 | 48:45 let me shrink it |
| M73 | 48:55, in fact, it could stay that way. let me shrink a few things one of the groups |
| M74 | 48:58 aa... no such not-moves it to the previous position |
| M75 | 49:20 I don't know how I did it but they all grew up but I liked it |
| M76 | 49:41 anyway I will say undo |
| M77 | 50:34 I think I'll make another one - undo |
| M78 | 51:56 I wonder how many elements I used |
| M79 | 52:03 chooses an element- just want to rotate around y |
| M80 | 52:31 eh… something started to form |
| M81 | 53:15 I got 15 degrees, but I didn't want to. Undo |
| M82 | 53:50 I want to rotate this one |
| M83 | 55:53 moves it away, and scales on XYZ axes / 2- I got it down, I got angry |
| M84 | 56:02 duplicates the scaled element |
| M85 | 56:16 moves the other one and relate it with the whole |
| M86 | 56:43 moves the cube element and relate it with the previous scaled element and the whole |

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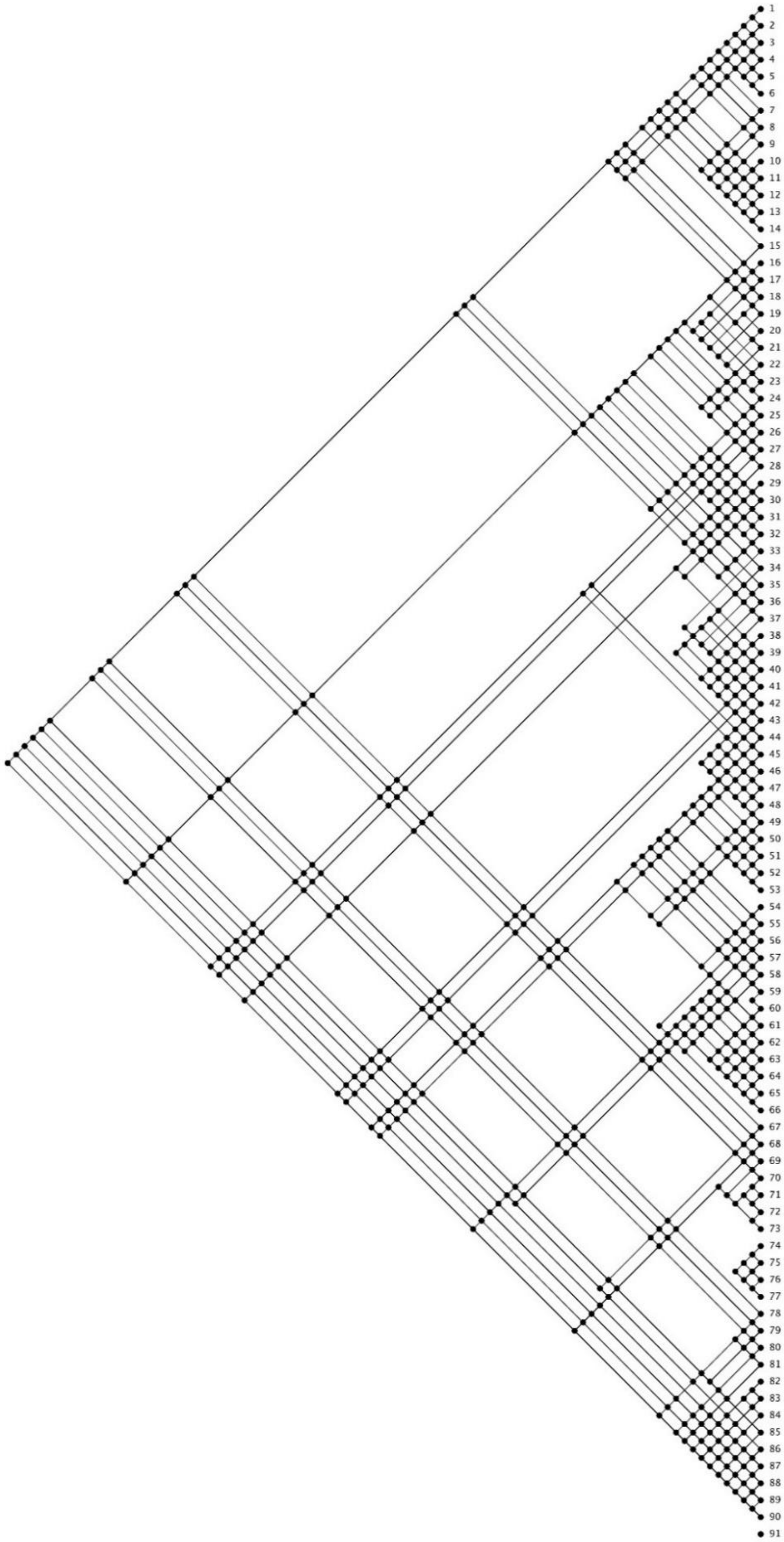
| M87 | 56:48 the last cube and put it there - cube |
| M88 | 57:27 I added 2 more elements-group 1-I brought it from the first group |
| M89 | 57:38 let's make smaller- scales xz axes /5 |
| M90 | 58:30 moves and relates the newest group with the whole |
| M91 | 59:09 ok let's make a color change as the last move, I never thought -selects group 2 and yellow |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PROTOCOL TRANSCRIPT AND LINKOGRAPH OF BASIC DESIGN TASK IN PHYSICAL ENVIRONMENT-DESIGN PROTOCOL OF DESIGNER 4 (D4)

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| M1 | 00:10 first of all, I want to use 2 colors so that it would be more comfortable to achieve hierarchy |
| M2 | 00:25 I want to make cubes again, I think that if I make such transitions and opened places between them, it will be without the use of glue. |
| M3 | 00:50 now to make an element to our cube (measures to make an element) |
| M4 | 00:53 It will be 12 cm-measures |
| M5 | 01:25 counts- and measures- There will be 6 surfaces. If all four surfaces are protruding, if they fit together, maybe I can handle it without using glue. |
| M6 | 03:46 I'm making these surfaces 2 cm below, and I'm going to cut them out. |
| M7 | 06:19 There was no time for what I did, anyway. -continue to cut-. I will not change |
| M8 | 11:09 Now I'm talking about those other surfaces I'm going to do with protruding ones - measures on the white cardboard |
| M9 | 15:27 All of this won't take so long, I just thought of making a few white cubes. then cut the surfaces from the other and merge. |
| M10 | 19:12 cuts to make new elements-. I am cutting now |
| M11 | 19:49 Am I going too slow? -cutting |
| M12 | 29:24 I will be very sorry if it does not fit. - connect to the elements but couldn't |
| M13 | 31:02 connects the 3rd element with others |
| M14 | 31:49 connects the 4th element with the other 3 |
| M15 | 32:10 I started to combine now but I want to make different cartons. I'll do it directly without clicking the cube because it takes a lot of time or else |
| M16 | 33:32 I'm going to cut big and small pieces, but these elements will be plain. I'm thinking of putting it on the places I left. |
| M17 | 37:08 I identified several rectangles of different sizes and cut a lot of them. again, I will try to combine them with similar relationships for the theme of hierarchy. |
| M18 | 39:05 connects it to the whole |
| M19 | 39:17 connects another element with the whole and relate it with the previous one |
| M20 | 39:52 connects another element |
| M21 | 40:17 Now I tried to group it myself. I cut 3 different size shapes. I divided it from big to small. I've grouped them together in different ways each time, but I keep thinking the elements around the white one. |
| M22 | 40:31 At first, in my dream, I had to do white things in different sizes. So these are shrinking among themselves, but the big ones are there again. I thought it was big white, median white, little white, but it would probably be the only white. |
| M23 | 40:52 It won't be able to form that much hierarchy properly but let me just say it was my dream. |
| M24 | 41:11 measures to make new elements-How many did I get over there? 10 |

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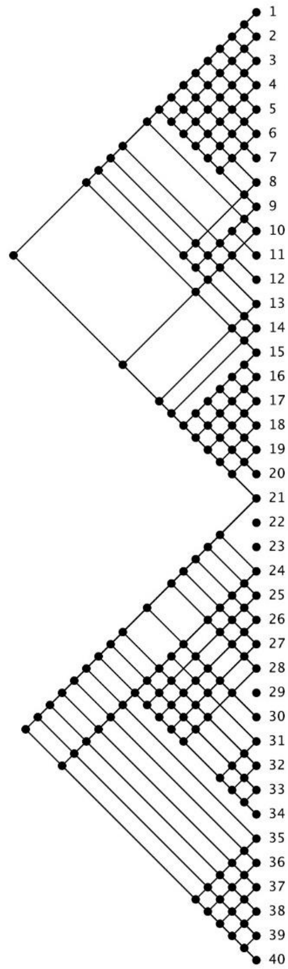
| M25 | 41:26 2 more -measures |
| M26 | 42:12 I will do the same as I just did. I'll combine large, medium, small, different colored ones within each other and position them around white-cuts |
| M27 | 43:27 connects them with the whole again |
| M28 | 43:53 connects a group with the white one |
| M29 | 44:18 When this assignment was first given, I experienced the same thing as I did, again. I'm so focused on doing something that I forgot to create a void - try to connect a new element with the whole but it didn't work |
| M30 | 44:32 cuts and fixes. For example, if I cut these (2nd group) according to that, it would have created something more defined, but let's see. |
| M31 | 45:15 connects an element to complete the group |
| M32 | 45:49 connects it with the white one |
| M33 | 47:35 connects an element to complete another group -it doesn't look like something has come up |
| M34 | 48:10 connects it and complete another group |
| M35 | 48:55 cuts- I'll cut another piece. it will be smaller than all |
| M36 | 49:20 adds it to a group |
| M37 | 49:43 adds it to another group |
| M38 | 49:58 adds it to another group |
| M39 | 50:15 add it to another group |
| M40 | 50:30 I'm finishing it because there's nothing I can do even if I have more time. My plan was to lay them around it again, I tried to do something like this by shrinking the size of it, but the volume did not. Maybe if I did a little more calculation |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## B. THE TRANSLATIONS OF THE SEMI-STRUCTURED INTERVIEW QUOTATIONS

TQ1: I was slow at the beginning of MR experience, but it was easy to break something you did and start again when you were not satisfied with it. It reduces the time you spent. In physical model making, we make a great effort, so the idea of breaking it and start again makes us upset. It (MR) is comfortable psychologically, too. (Designer #2)

TQ1: (En iyi yanı) ben biraz yavaştım başta ama el alışkanlığı olunca yaptığın bir şeyi bozabilirsin içine sinmediği an. Çok kısaltıyor zamanı. Mesela maket olarak yapıyoruz, bu kadar emek veriyoruz. İnsanın böyle içi gidiyor bozarken. Orda sürekli, Sketchup'ta da öyleydi sürekli değiştirip bozabiliyorsun ve çok zaman kazandırıyor ve aynı psikolojik olarak da daha rahat. Böyle 5 saat uğraştım bunu mu bozacağım oluyor normalde bunda öyle değil 1 saat falan. (Tasarımcı #2)

TQ2: It (physical making) did not go as well as I want because we are not able to know how it is going to before making. It could have last for two or three hours if I had attempted to break it and start all over again. (Designer #2)

TQ2: Mesela bu hiç istediğim gibi gitmedi çünkü bilemiyoruz denemeden nasıl olacak ve bunu bozmaya kalksam yine bir iki-üç saat sürekli bozup yapmak lazım. (Tasarımcı #2)

TQ3: I have a chance to try different groups in MR. I had a different type of groups, but I could try only one type of group by model making. (Designer #2)

TQ3: MR'da farklı gruplar deneme şansım oldu mesela farklı gruplar vardı ama maketle yaparken tek bir grup denedim. (Tasarımcı #2)

TQ4: It (MR) was really comfortable to undo. For example, I had made two different groups in MR and I did not like them, so I changed one of them a little bit. But I could not change in physical making. (Designer #4)

TQ4: Geri dönmek açısından çok rahattı. MR'da 2 grup yapmıştım mesela birini beğenmedim biraz değiştirdim ama burada devam ettim değiştiremedim. (Tasarımcı #4)

TQ5: It was a little hard to manage it, but then I got used to it […] I would like to use this, (the developed design tool in MR) if I make myself get used to it. It needs to be practiced. (Designer #1)

TQ5: Daha önce kullanmadığım için biraz zorlandım başta ama sonra alıştım […] Ama kendimi belki bu yazılıma alıştırsam kullanmayı çok isterim. (Tasarımcı #1)

TQ6: I felt more comfortable in physical making […] I had difficulties only for compounding the design elements, they could be joined from the edges in MR. Model making (physical) also requires more calculation, I cut the wrong spots. (Designer #3)
TQ6: Elde daha rahattım […] burada (physical making) birleştirmede zorlandım orda ucundan birleşebiliyordu. Maketi yaparken daha çok hesaplama yapmak gerekiyor yanlış yerleri kestim. (Tasarımcı #3)

TQ7: It was not so hard to use, even I, as an unfamiliar person, got used to it quickly. (Designer #4)

TQ7: Bence yine de rahattı ben çok haşır neşir olmadığım halde rahat kullanabildim. (Tasarımcı #4)

TQ8: I got used to it progressively […] I began to use fluently towards the middle of the design process, choose this, take that so and so… (Designer #4)

TQ8: İlerledikçe çok alışmaya başlamıştım […] Ortalarda çok rahattı alışmaya başlamıştım bunu seç bunu al falan. (Tasarımcı #4)

TQ9: I could see from all view easily that I cannot imagine, from the bottom, top, and all-around of it. It (MR) makes it really easy. (Designer #4)

TQ9: Hayal edemediğim açılardan çok kolay sürekli görebildim altından üstünden etrafından. Çok büyük kolaylık sağlıyor… (Tasarımcı #4)

TQ10: It would be better in terms of not wasting time, craft materials and perceiving easily. It would be much faster either case. (Designer #4)

TQ10: Vakit, malzeme ve daha rahat görmek açısından iyi olurdu. Daha hızlı olur her türlü. (Tasarımcı #4)

TQ11: I would like to use it (MR). For example, it could be tested for 2D basic design assignments. It would be useful on 3D ones too, and I can try my grouping ideas right away. (Designer #3)

TQ11: İsterdim. Mesela 2 boyutlu ödevler için hemen tutup denenebilir. 3 boyutlularda da işe yarar hemen grupları deneyebilirim. (Tasarımcı #3)

TQ12: … They (architectural design educators) mention the importance of eco-friendly design but we consume a lot. Maybe it needs high-cost investment at the beginning, but it brings much more profitable outcomes in terms of energy and economy. It made me incredibly happy with regard to making me think about the damage to nature. (Designer #1)

TQ12: … hem israf açısından iyi çünkü hem eko-friendly tasarım diyorlar hem çok fazla tüketiyoruz. Belki ilk başta buna daha büyük yatırım gerekir ama geri dönüşü daha karlı olur hem enerji hem ekonomi açısından diye düşünüyorum. Beni çok mutlu etti bu açıdan böyle bir şey olması doğaya verilen zararı da düşürmesi açısından. (Tasarımcı #1)

TQ13: …you can understand if your idea works or not (in MR) without cutting any craft material and spending long hours. (Designer #4)

TQ13: …burada (MR) o kadar kesip hatta malzeme de harcamadan, vakit harcamadan yapmaman gerektiğini görebilirsin o açıdan çok daha avantajlı. (Tasarımcı #4)

TQ14: I think I got more efficiency in the physical model making, but I'm more used to it since secondary school. I'm used to a pen, a craft knife. I know how to cut the cardboard, and I feel more comfortable. Obviously, I can't start to use this (MR design tool) in a flash, the hand feels more comfortable. But maybe if I got used to this software, I'd love to use it. It was a very short experience for me to say it. I think the students would be more comfortable if they get used to it in the future. Of course, most things are a bit limited. It was good for basic design, but I don't know how to do it for advanced designs. When I made a mistake in this (physical model making), I could make small touch-ups on it. But I had difficulties while trying to put an object on top of another in MR because I wasn't used to it. But if I got used to it, I'd definitely use it. (Designer #1)

TQ14: Makette daha çok verim aldım bence ama buna daha çok alışığım ortaokuldan beri. Kaleme, maket bıçağına alışkınım. Maket kartonunu nasıl keseceğimi biliyorum artık o yüzde daha rahat geliyor. Pat diye buna geçemem açıkçası el daha rahat geliyor.

Ama kendimi belki bu yazılıma alıştırsam kullanmayı çok isterim. Bu benim için çok kısa bir deneyimdi bunu söylemek için. İleride öğrenciler buna alışıp gelse daha rahat ederler bence. Tabi birçok şey biraz da sınırlı basic design için iyi ama ileri tasarımlar için nasıl olur bilmiyorum. Bunda yaparken bir hata yapınca hemen üstünde küçük rötuşlar yapabiliyordum ama onda alışık da olmadığım için üst üste getirmeye çalışırken bile zorlanıyordum baştan deniyordum. Ama alışsam kesinlikle kullanırım. (Tasarımcı #1)