AN EVALUATION OF SKETCHING IN EARLY CONCEPTUAL DESIGN PROCESSES: PHYSICAL AND IMMERSIVE ENVIRONMENTS

by
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AN EVALUATION OF SKETCHING IN EARLY CONCEPTUAL DESIGN PROCESSES: PHYSICAL AND IMMERSIVE ENVIRONMENTS

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ABSTRACT

AN EVALUATION OF SKETCHING IN EARLY CONCEPTUAL DESIGN PROCESSES: PHYSICAL AND IMMERSIVE ENVIRONMENTS

New technologies are increasingly being recognized for their potential to be as effective in the early conceptual design process as they are in various industries and disciplines. This study focuses on the evaluation of physical and immersive environments in the sketching process. It examines the impact of sketching different environments on the early conceptual design process. A comprehensive sketching study ranging from paper-based and digital in the physical environment to VR (Virtual reality) and AR (Augmented reality) in the immersive environment was conducted with experiments involving 8 participants. The processes were conducted through protocol studies, and evaluations were performed using methods of protocol analysis and design conversation elements. The collected data was transformed into linkography graphics and analyzed based on content and evaluation criteria. Following the experiments, questionnaires were distributed to gather insights about participants' experiences in both the physical and immersive environments. According to the results of the experiment, the comparison between the physical and immersive environments showed that the design movements were more effective and the design processes were more impactful in the immersive environment. When evaluating the physical environment in terms of analog and digital based, it was observed that design productivity was more efficient in the analog based compared to the digital based, as indicated by numerical data. Upon evaluating the immersive environments individually, it becomes apparent that design productivity tends to be more efficient in AR based than in VR based. This observation is interpreted as a positive factor enhancing the designer's contextual interaction within the immersive AR environment. At the same time, the design process in the AR based was seen to provide dimensional consistency by enabling the production of 1/1 scale outputs. Although physical and immersive environments have different purposes and users in architectural or industrial design disciplines, it is predicted that the active use of immersive environments in the production of design will become more widespread in the near future. Immersive environments allow designers to produce their designs in a three-dimensional (3D) space that more accurately represents the final sketch, allowing for refinement and a better understanding of scale, proportion and spatial relationships.

ÖZET

ERKEN KAVRAMSAL TASARIM SÜREÇLERİNDE ESKİZİN DEĞERLENDİRİLMESİ: FİZİKSEL VE ÇEVRELEYİCİ ORTAMLAR

Yeni teknolojiler, çeşitli endüstrilerde ve disiplinlerde olduğu kadar erken kavramsal tasarım süreçlerinde etkili olma potansiyelleri nedeniyle giderek daha fazla tanınmaktadır. Bu çalışma, eskiz sürecinde fiziksel ve çevreleyici ortamların değerlendirmesine odaklanmaktadır. Farklı ortamlarda yapılan eskiz süreçlerinin erken kavramsal tasarım sürecindeki etkisini incelemektedir. Fiziksel ortamda kağıt tabanlı ve dijitalden başlayarak, çevreleyici ortamda Sanal Gerçeklik (VR) ve Artırılmış Gerçeklik (AR) kullanılarak kapsamlı bir eskiz çalışması, 8 katılımcıyla yürütülen deneylerle gerçekleştirilmiştir. Süreçler, protokol çalışmaları aracılığıyla yürütülmüş ve değerlendirmeler, protokol analizi yöntemleri ve tasarım konuşma unsurları kullanılarak gerçekleştirilmiştir. Toplanan veriler, bağlantı grafiği grafiklerine dönüştürülmüş ve içerik ve değerlendirme kriterlerine göre analiz edilmiştir. Deneylerin ardından, katılımcıların fiziksel ve çevreleyici ortamlardaki deneyimlerini anlamak için anketler dağıtılmıştır. Deneyin sonuçlardan elde edilen sayısal verilere göre, tasarım hareketlerinin çevreleyici ortamda daha etkili olduğunu ve tasarım süreçlerinin çevreleyici ortamda daha etkili olduğunu görülmektedir. Fiziksel ortam kendi içerisindeki süreç analizine bakıldığında, tasarım üretkenliğinin analog temelli ortamda dijital temelli ortama göre daha etkili olduğu gözlenmiştir. Çevreleyici ortamlar kendi içerisinde değerlendirildiğinde, tasarım üretkenliğine ait sayısal verilerin, AR temelli ortamda VR temelli ortama göre daha yüksek olduğu görünmektedir. Bu gözlem, tasarımcının çevreleyici AR ortamında bağlamsal etkileşimini artıran olumlu bir etken olarak yorumlanmıştır. Aynı zamanda, AR temelli tasarım sürecinin 1/1 ölçekli çıktıların üretilmesine imkan tanıyarak boyutsal tutarlılık sağladığı görülmüştür. Mimarlık veya endüstriyel tasarım disiplinlerinde fiziksel ve çevreleyici ortamların farklı amaçları ve kullanıcıları olmasına rağmen, tasarım üretiminde çevreleyici ortamların etkin kullanımının yakın gelecekte daha yaygın hale geleceği öngörülmektedir. Çevreleyici ortamlar, tasarımcılara nihai çizimi daha doğru bir şekilde temsil eden üç boyutlu bir alan içerisinde üretme imkanı sağladığından söz edilebilmektedir, bu sayede ölçek, oran ve mekansal ilişkilerin daha iyi anlaşılmasına ve geliştirilmesine katkı sağladığı düşünülmektedir.

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LIST OF SYMBOLS/ABBREVIATIONS

2D	2 dimensional
3D	3 dimensional
AR	Augmented reality
CACD	Computer-aided conceptual design
CAVE	Cave automatic virtual environment
CM	Critical move
HMD	Head mounted display
IE	Immersive environment
PE	Physical environment
VR	Virtual reality

1. INTRODUCTION

In the early conceptual design process, the designers concretize the ideas in their mind with external representations. At this stage, designers use lines in different sketching media to represent a design problem that is being addressed for the first time. In this context, the representational environments of sketching attract attention. It is envisaged that sketching in different tools/environment will influence the design process. In this situation, traditional sketching environments and immersive environments are examined.

Developments in computer technologies, as in almost every field of science and art, have created a tendency to re-evaluate design environments, especially in the 21st century. Sketching has become possible in traditional paper-based environments as well as technology-active environments. The most prominent example of this is the recent developments in immersive virtual and augmented reality technology. These developments have brought new technologies to the design world. The sketching environments created by these technologies are also different from the traditional ones and offer new possibilities. The differences between these new design environments and the traditional ones have been investigated both theoretically, through literature research, and by setting up a comprehensive experimental environment to explore their contributions and potentials in practice.

There is no comprehensive study of sketching from analog and digital in the physical environment to Virtual Reality (VR) and Augmented Reality (AR) in the immersive environment. For this reason, the sketching environments realized in the study were not categorized according to the tools used, but according to the possibilities they offer and the designer's interaction with the environment. What differentiates the environments is also the variety of tools or high-tech technologies.

It is important to analyze the designer's actions and ideas in order to identify similarities, differences or highlights between the design processes in different environments. These environments can offer different potentials to the designer in the development of the ideas generated. Therefore, this study investigates the contribution of physical and immersive environments to the sketching process. In response to this, the aim of the study is to explore the potential of environments in visual thinking.

The research is based on a comparison of design productivity and interaction with context. This involves observing the design process in different sketching environments and analysing the results of the experiments. The results of the experiments were evaluated using protocol analysis and design conversation elements. The study overlays these two different methods and makes them readable on a single graphic.

1.1. THE PURPOSE AND SCOPE OF THE THESIS

In the conceptual phase of architectural design, designers brainstorm to generate different ideas for a specific design problem. These ideas are presented as external representations using various methods. Three-dimensional physical models, digital models, and sketches are some of these methods. This study focuses on the production of sketches in the concept phase of the architectural design process.

The aim of this research is to understand the relationship between the environments used and the process by analyzing the designers' design processes. For this reason, the subject will be approached as physical (analog, digital) and immersive (virtual reality, augmented reality) environments. The thesis aims to investigate what architectural designers think about the production processes in these environments and how they relate to these environments. It aims to understand which environments support visual thinking skills, their activities in production processes, and how the design process is structured. It aims to analyze the relationship between design environments and design thinking from the following perspectives.

- How they interact with sketching in physical and immersive sketching environments; to show what design issues they address in this process based on two basic environments.
- To identify the differences/similarities using analog and digital media as two different media covered by the physical sketching environment.
- As two different environments covered by the immersive sketching environment; to reveal the differences/similarities on the basis of VR and AR supported environment.

1.2. THE METHOD OF THE THESIS

In this thesis, a protocol study was carried out to analyse the design process. The sample group in the study was defined as 8 architectural designers with at least a Bachelor's degree. In order to ensure that the level of sketching experience of the participants would influence the experimental process, a preliminary interview was conducted with the designers. For this reason, graduates and experienced designers were preferred. The experimental environment was defined as the front of the Faculty of Fine Arts at Yeditepe University Kayışdağı Campus. A total of 8 designers participated in the experiment and were expected to work on the design problem in 2 different environments physical and immersive. These two different environments have been divided into two different parts. In fact, that is divided into within itself two but totally four different environments the physical environment as analog and digital, immersive as VR and AR. Participants were given 10 minutes for each session in the environment and two equivalent design tasks for two different environments: a book-sharing stand and a bus station. The reason for this was to ensure that the participant was not influenced by the decisions made in the previous environment. The distribution of participants is detailed in section ‘’Distribution of Participants’’. Prior to the experiment, the participants were given a 5-minute briefing to be informed about the sessions. This information included the importance of thinking aloud for the study in the context of protocol studies. The phase after the experiments continued as follows: Transcribing the data obtained from the recordings of the protocol studies in order to visualize them with the linkograph method [1, 2, 3] separating them as design movements, determining the connections between the movements and creating linkographs, re-evaluating the design movements and evaluating the design movements with the design conversation elements method [4], creating graphics. Analysing the participants through the created graphics. Compare design productivity within and between environments according to graphs.

1.3. THE STRUCTURE OF THE THESIS

This study first analyses the place and importance of the early concept phase in the design process. It then discusses the design tools and environments used in this phase. In order to investigate the importance of different environments in the design process, a design

environment was constructed and experiments were conducted with the participants. The design processes in the environments were followed up by protocol studies. The data on the participants' experiences in different design processes are analysed. The dissertation consists of four main chapters. The first chapter presents the problem, theoretical framework, structure and methodology of the thesis. The second chapter presents the theoretical background of sketching in early conceptual design processes. In the fourth chapter, sketching experiments were carried out in different environments, and then analyses were made on the basis of participants, and then comparisons were made on the basis of environments. The fifth chapter concludes the thesis with final evaluations.

The second chapter begins by discussing the role and historical development of sketching in the early design phase. The use of analogue and digital based sketching tools for two or three dimensional sketching in the early design phase is examined. In addition, virtual and augmented reality based sketching tools that have emerged in the historical process are also examined. In the next section, a general evaluation of the aforementioned tools is made for the research and the classification of the environments is determined by looking at the environments in which they are used. In other words, sketching in physical and immersive environments and its place in previous studies will be examined.

In the third chapter, in order to understand the impact of physical and immersive environments on the sketching process, these sketching environments were divided into two sections and experimental environments were realized. The subheadings of these two main sections are physical sketching tool, analogue and digital, and immersive tool, VR and AR. General information about the evaluation and analysis methods of the experimental process was then given. These methods are carried out in protocol studies and analysed using linkographs and design conversation elements.

The fourth section includes linkographs with design conversation elements and individual analyses of two different environments where each of the 8 participants entered the ekiz experiment separately from the physical and immersive environment. After the participants' analyses, the study is concluded with the fifth section, after the evaluation of each environment in itself, the evaluation of the two main environments as analogue-digital within the physical environment and VR and AR within the immersive environment, and the evaluation of all environments together.

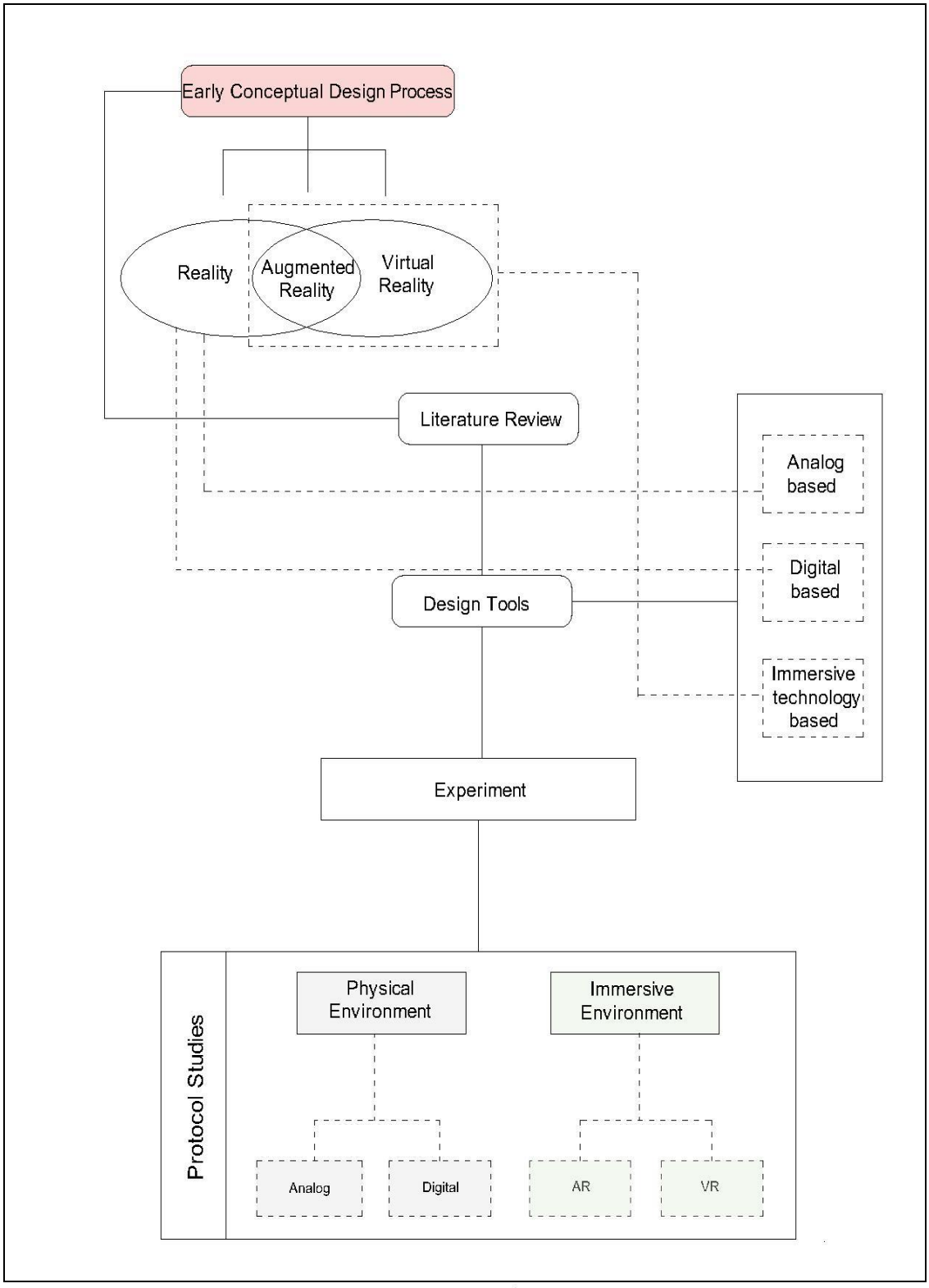


Figure 1.1. Structure of the thesis.

2. THEORETICAL BACKGROUND OF SKETCHING IN THE EARLY CONCEPTUAL DESIGN PROCESSES

The early conceptual design process is the first of the design development cycle and can involve important decisions. In this process, designers generate solutions to the design problem in different ways. The sketches and models created in the first process of design are accepted as 'thinking by doing' and 'designing', as they provide coordination between the brain and the eyes [5]. In this phase, designers determine the direction of the next design process, incubate creativity, and embody most of the values in design artefacts [6].

Sketching and conceptual design are two inseparable actions for most designers [7,8,9]. According to Goldschmidt [10], sketching is an extension of daydreaming. In terms of human cognition, sketching promotes the dialectical process between a sufficiently specified and consistent physical form and abstract, conceptual, and propositional knowledge [10,11]. Sketching helps designers see and understand the shapes they are working with, and is a tool for communicating with others. [12]. For this reason, Schön and Wiggins [13] refer to sketching as a tool that allows the designer to communicate between himself /herself and the tools. For this reason, the sketch made by the designer about a specific design problem serves as a tool to communicate with himself and his environment. Herbert [14] emphasizes that sketching is not only an appropriate strategy for solving design problems but also a "main thinking tool" for the designer and that the designer should "interact with sketching". Therefore, designers should not only "crystallize" their thoughts on paper, but also interact and collaborate with a sketch [15]. Michael Graves [16] explains that the sketch serves as a tool for discovery and emphasizes that a sketch is the starting point for synthesis in design. Designers make discoveries by analyzing the visual clues provided by their sketches; they use the visual clues in their sketches to improve and develop the design [17]. Just as writing is the best way to discover and analyze our thoughts, sketching has the same role as design thinking[18].

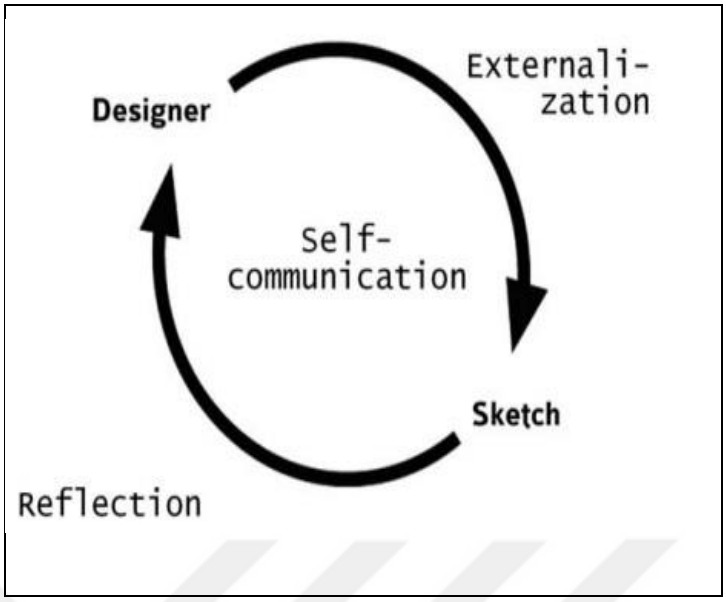


Figure 2.1. Sketching as a process of externalization [19].

According to these views, conceptual sketches in the early process of design allow designers to create representations by expressing what is in their heads. In addition, the sketch is seen as the primary tool between the designer's mind and the designer's heart in the conceptual phase of design. The sketch is a kind of carrier to express the designer's design intentions and ideas. Freehand, is often done quickly compared to other design processes and is not intended to be a final product. Schön and Wiggins [13] state that the cycle of design and exploration in sketching is a strong phenomenon, that designers always work with a media/medium, that it requires visual communication, and that they draw new conclusions from each sketching. For this reason, media and tools attract attention to the creation of the sketch. External representations such as sketches are influenced by environmental factors during design [20]. These can be categorized according to the designer's interaction with the physical environment or the capabilities of the tools. At the same time, existing technologies can also be involved in the design process. The tools used in the design process influence the design perspective [21]. For this reason, the effects of design environments created with different tools on the design process and designers' approaches to this process were considered worthy of research.

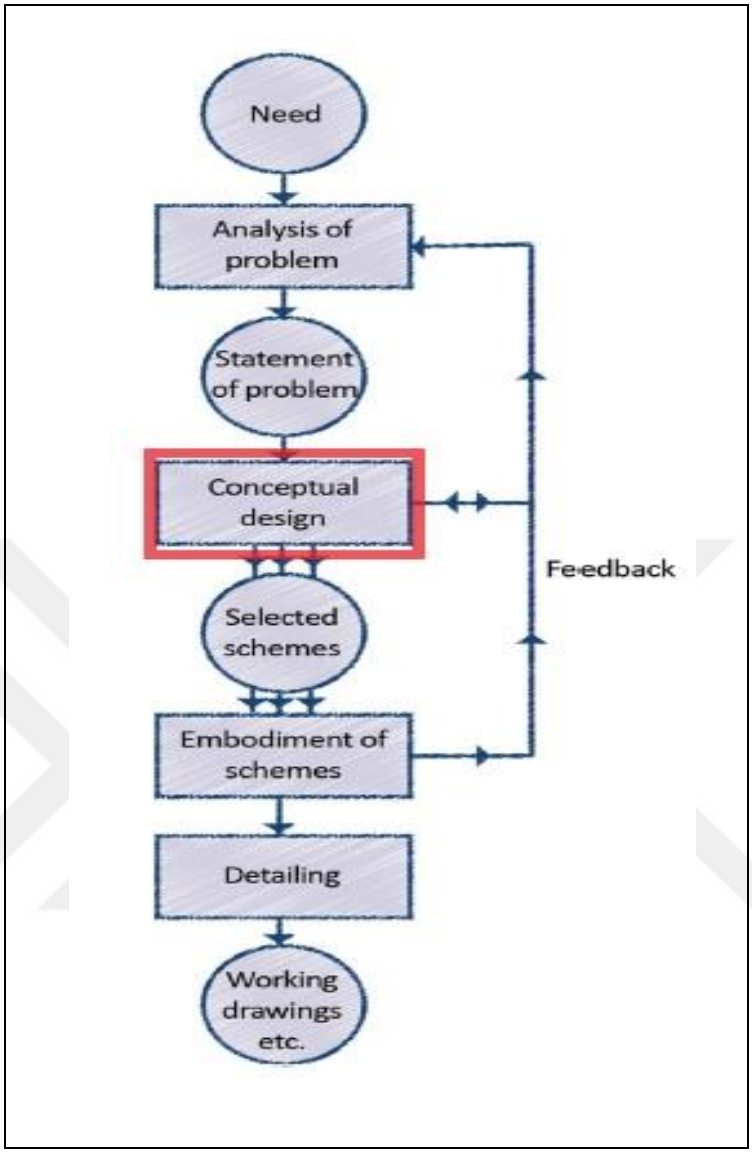


Figure 2.2. The role of conceptual design [22].

Within this information, the early conceptual design process has different objectives depending on the discipline. These objectives are shaped first by the need and then by the problem analysis, and the reason for the importance of conceptual design in the overall design process is that it influences the main decisions as shown in Figure 2.2 [22]. In this context, the early conceptual design process creates an intuitive and heuristic semi-rational problem-solving environment. It plays a role in transforming different images in the mind into external visual representations. It is effective in creating collective compositions with different perceptions and assumptions and, in addition, it can be seen that mental activities are active.

2.1. SKETCHING TOOLS

According to sketches history, the first known examples of sketching can be accepted as sketching/paintings on cave walls. In the 14th century, it can be said that the importance of sketching increased even more with the widespread use of paper. It can be seen that various studies have been carried out on the possibilities offered by the use of different sketching tools for designers to produce and present ideas [23].

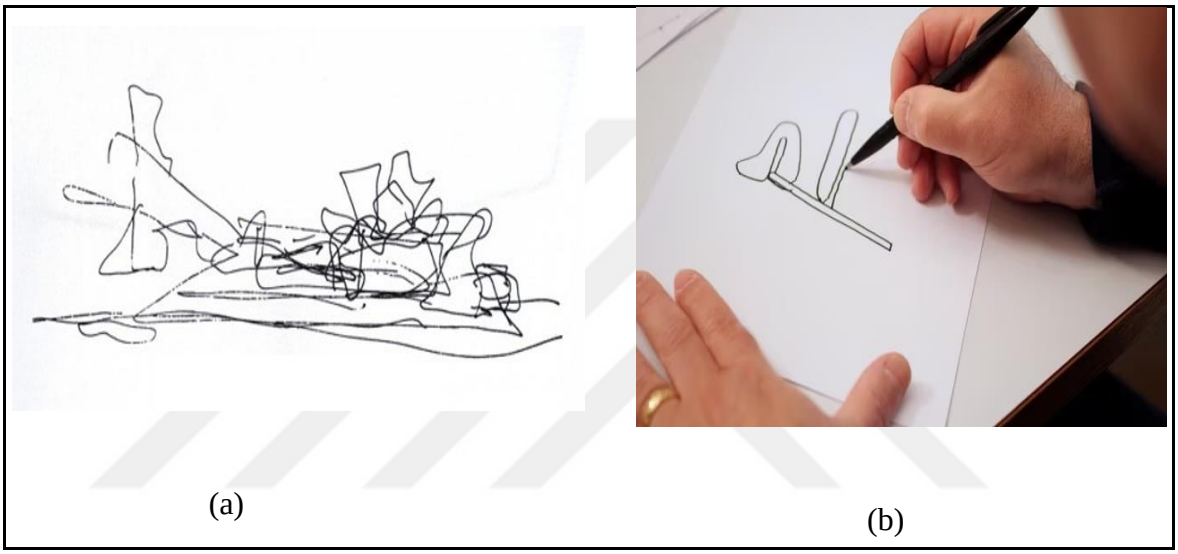


Figure 2.3. (a) Frank Gehry's Sketch Guggenheim Bilbao Museum [24] , (b) From Khodi Feiz is skething with pen and paper [25].

The tools used in the sketching process also vary according to the use of designers in different sectors and disciplines. Considering the current state of design tools, these tools can be classified as analog and digital. Designers can transform their ideas into 2D or 3D external representations by using analog and/or digital tools. Various studies have been conducted on the effects of analog and digital tools on the early design process [26, 27, 28, 29, 30]. It uses sketching to transfer the visual information imagined by the designer to paper [31,10,3]. Looking at examples of paper-based sketching from the 19th and 20th centuries, we can see that it is often used by designers (Figures 2.3).

Another example of anologue tools used in design is the 3D printing pen shown in Figure 2.4. Looking at the structure of the tool, it can be said that it is suitable for making sketches in the early conceptual design process. Unlike paper-based sketches, 3D printing pens can

also be used to create 3D sketches. A 3D printing pen can be used to create three-dimensional objects by extruding heated plastic filament, as opposed to traditional pen and paper drawing. In addition, it has been found that this method can be used to create sketches in different colours.

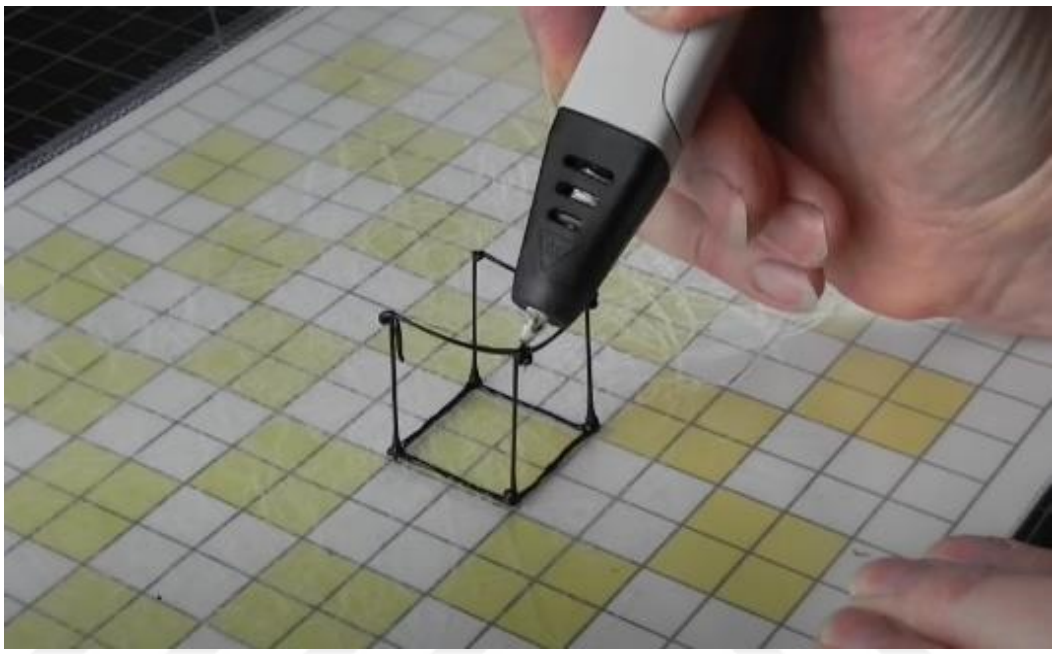


Figure 2.4. Sketching with 3D printing pen.

In the 1950s, when the foundations of today's modern computers were being laid, the first ideas for computer-based sketching environments began to emerge with the digitization of information. The emergence of the digital sketching tablet (Figure 4), now used in the early design process, dates back decades with Sutherland's invention of the 'sketchpad' in 1964 (Figure 2.5). Since the 1980s, digital information processing methods have diversified. In addition, computer graphics has provided designers with different visualization techniques. Over time, design informatics research and the establishment of a computer-aided conceptual design (CACD) system became an important issue [32]. This forms the basis of the digital tools used in design.

Figure 2.5.Sutherland’s Sketchpad [33].

Computers have been portable for a quarter of a century [34]. However, 2D digital tablets have become more common in the design environment. With these digital tablets, sketching can be done directly on a digital screen using a finger or a digital pen. There are also sketching tablets that are connected to any digital screen. However, these tablets are not visible on the sketch surface and require a digital screen (Figure 2.6).

(a)

(b)

Figure 2.6. (a) Sketching with digital tablet [23] , (b) XP Pen for sketching [35]**.**

Following on from these developments in the 1990s, the possibilities offered by virtual reality (VR) and augmented reality (AR) technology have made 3D sketching systems more accessible today. The current basis for this is based on Sutherland's Head Mounted Display (HMD) system developed in 1968. This HMD had a 40° field of view and was a crude optical system. The system shown in Figure 2.7, was heavy enough to be suspended from the ceiling [36]. Therefore, although the first versions of HMDs did not become widespread research tools, the use of new-generation HMDs has become widespread in recent years with the re-emergence of VR systems. The two main methods of creating visual stimuli in virtual reality are HMDs and immersive displays [37]. This new generation of HMDs is less expensive and more portable than their predecessors [38]. These new generation and also advanced HMDs have technological features such as much higher resolution, wider field of view, and integrated audio systems [39]. Therefore, they are able to fulfill the requirements of VR rendering (visual stimuli, body tracking, and binaural sound systems) even on their own without additional equipment [40].

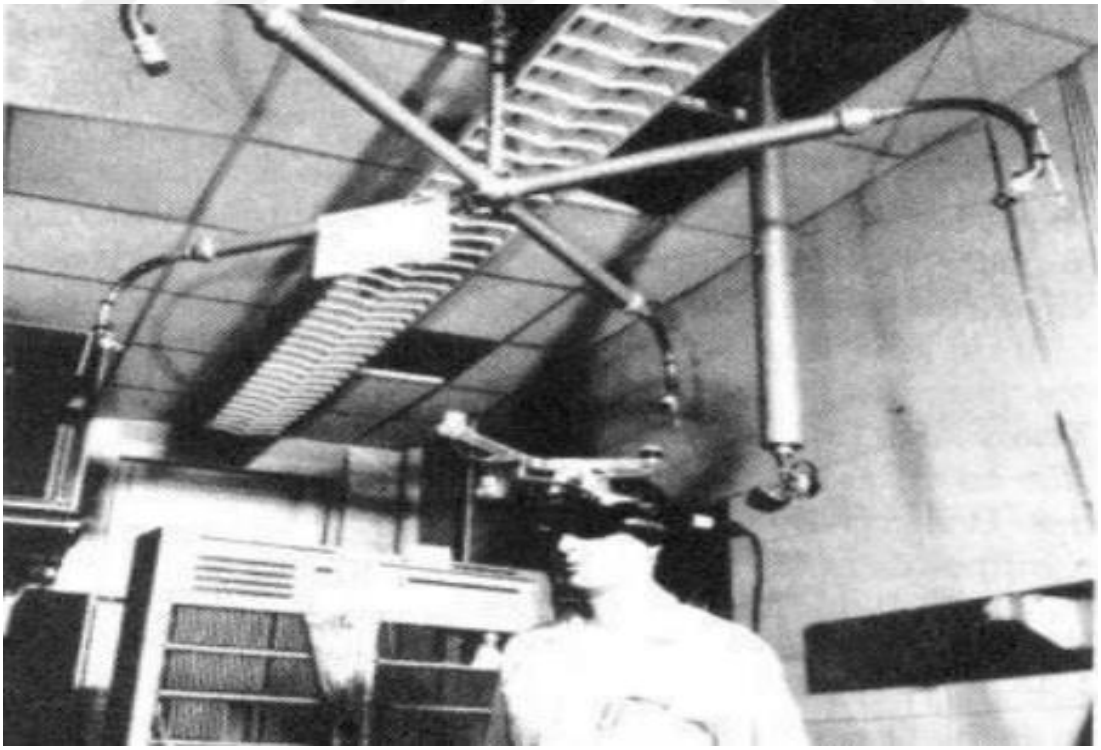


Figure 2.7. Sword of Damocles HMD VR system [36].

VR and AR allow the user to perceive and interact with tactile systems, sensors, cameras, and similar devices [21]. While some systems use simple hand gestures as "input" [41], others use freehand tools to create visually rich and aesthetic sketches and drawings [42]. Studies have been conducted on the use of these tools in the design process [43, 44, 45, 46]. As seen in the studies, HMD & controller, interactive pen-based immersive technology tools are used for sketching. Several studies have also been conducted on the use of HMD as a sketching tool in design [44].

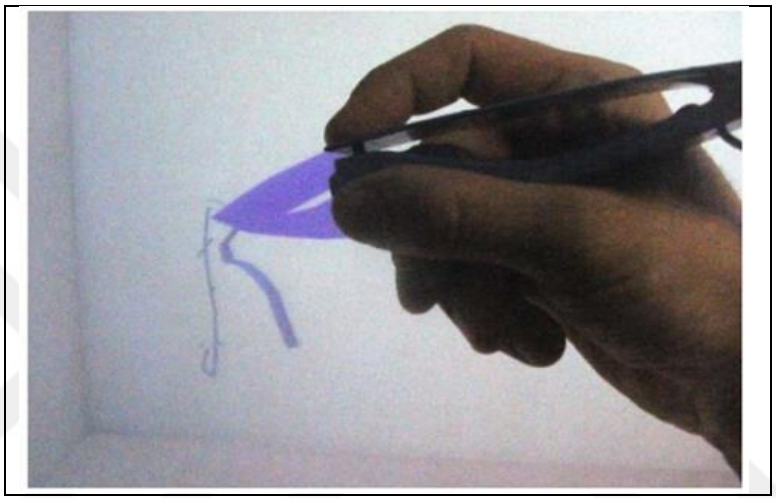


Figure 2.8. Sketching with Hybrid pen [19].

In addition, as shown in Figure 2.8 , some studies have been conducted using immersive technology with an interactive pen [19]. It can be seen that the tools used in these examples can be directly related to the early design process.

(a) (b)

Figure 2.9. Interactive pen with immersive technologies [47].

2.2. SKETCHING ENVIRONMENTS

When observing the historical process of sketching tools, it is predicted that if the they used in the early design process are combined with an appropriate environment, they can open the door to the development of new methods and create new paradigms. Within this framework, an examination of the characteristics of the environments in which designers sketch shows that there are physical and immersive environments. The differences between the two environments were investigated.

In the physical environment, it is seen that sketching can be done without any support such as virtual reality or augmented reality. In this process, the designer is directly related to the environment while sketching. In the immersive environment, VR and AR technologies are effective. Technologies such as virtual reality and/or augmented reality offer the designer the opportunity to share this experience with a wide range of experiences. In this way, the environment in which the design is made can be characterized as an immersive environment.

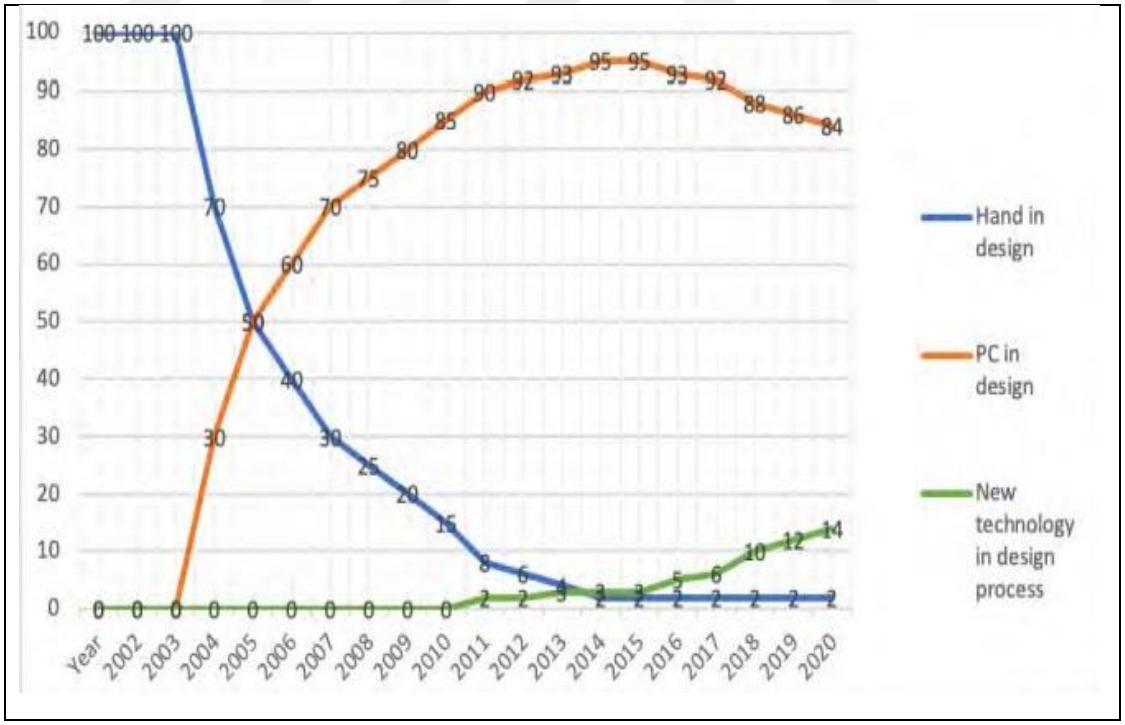


Figure 2.10. Using different environments to sketch by year [23].

A study by Dzurilla & Achten covering the years 2000 - 2022 asked designers about their use of sketching media. As a result of this research, the use of computer-based tools in design

has increased and the use of hand sketching has decreased. It was also observed that the use of new technologies such as VR and AR in the design process increased after 2011 (Figure 2.10). When reviewing the literature, there are various studies that compare sketching in physical and immersive environments, but it is seen that there is no comprehensive study comparing physical and immersive environments created with different possibilities and their general comparison with each other.

2.2.1. Physical Environment

In the physical environment, it can be seen that sketching can be done with analog tools such as fingers, pens, and brushes, as well as digital-based tools such as digital tablets or sketching tools such as sketch tablets. In a physical environment, the designer can produce 2D or 3D sketches depending on the analog or digital tool used. When reviewing the literature, various studies have been conducted to compare analog and digital based environments [5, 48]. As an example of one of the environments where analog tools are used, in Figure 2.11 (a), a sketch made with a pencil on a flat board can be given. In Figure 2.11 (b), the designer is using a digital tablet in a physical environment.

(a) (b)

Figure 2.11. (a) Sketching in a physical environment with analog tools [23], (b) Sketching in a physical environment with digital tools.

In addition to this, Picasso's sketches made with miniature light bulbs in a dark room in 1949, as shown in Figure 2.12, can be cited as an example of sketching in a physical environment. In this study, a dark room was used as a physical environment and it can be seen that dozens of sketching were created using this method [48].

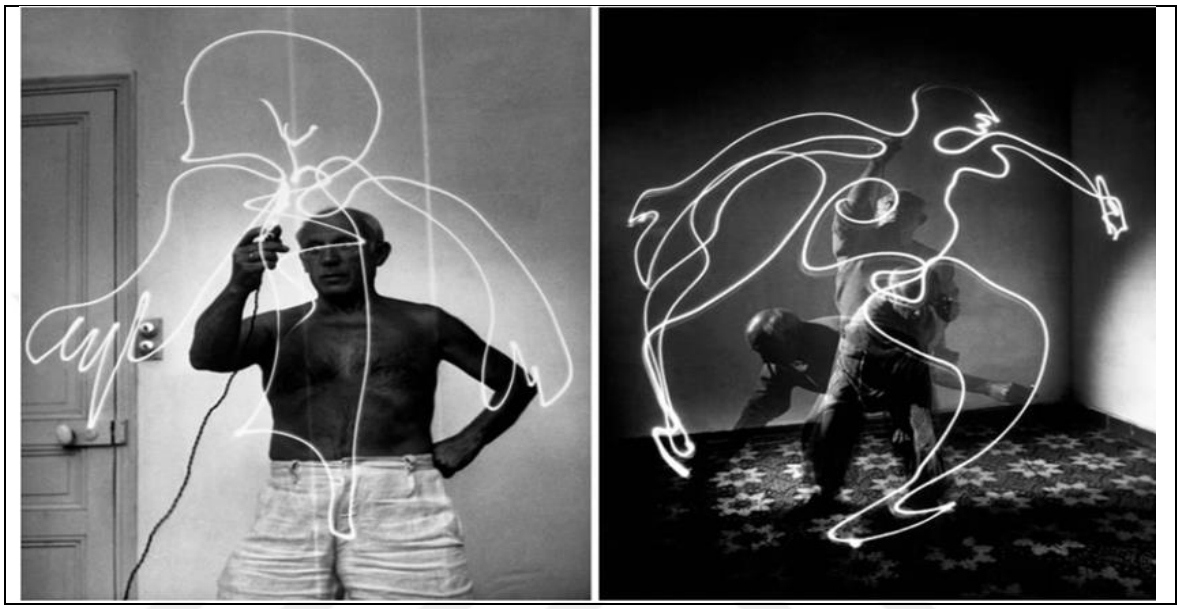


Figure 2.12. Picasso’s light drawings [49].

Another example of 3D sketching in a physical environment is the 3D printing pen. While the designer is in the early process of design in their environment, they can use the 3D pen to transform the thoughts in their head into external representations. While designers can use the 3D-printing pen for free sketching in space, it is also seen that they develop a sense of skill through practice [50]. This is due to the use of free body and hand movements when sketching in the physical environment. As can be seen in Figure 2.13, the design can be done with a 3D printing pen, which is an analogous tool. Similarly, a smaller scale but more directly mediated method can be achieved by using a 3D printing pen [51], which removes the plastic from the pen. The 3D printing pen can be used to create much larger shapes than traditional 3D printers, which can only produce objects of equivalent size while allowing for complex shapes. In this respect, it can be said that it is suitable for producing sketches in the conceptual phase of architectural design.

Figure 2.13. (a) Sketching with a 3D-printing pen [52], (b) Sketch produced with 3D printing pen [53].

2.2.2. Immersive Environment

The term 'immersion' in 'immersive environment' can be used to describe a continuous computational view of the system that is larger than the human field of view. The designer's perception of being in an environment represented by the display is called presence [54], and the designer's sense of presence and dominance in the environment is supported by these computational images.

It can be said that the immersive environment became available with the existence of VR technology in the mid-1980s. CAVE (Audio Visual Experience Automatic Virtual Environment) systems can be mentioned as the first immersive environment. According to early CAVE designers, the name CAVE is both an acronym for CAVE Automatic Virtual Environment and a reference to Plato's allegory of the cave [55]. The idea of being in a virtual "cave" or enclosed space where the user can explore and interact with the virtual world from different angles gave rise to the word "cave". Users can experience virtual worlds as if they were physically there because of the immersive design of a CAVE.

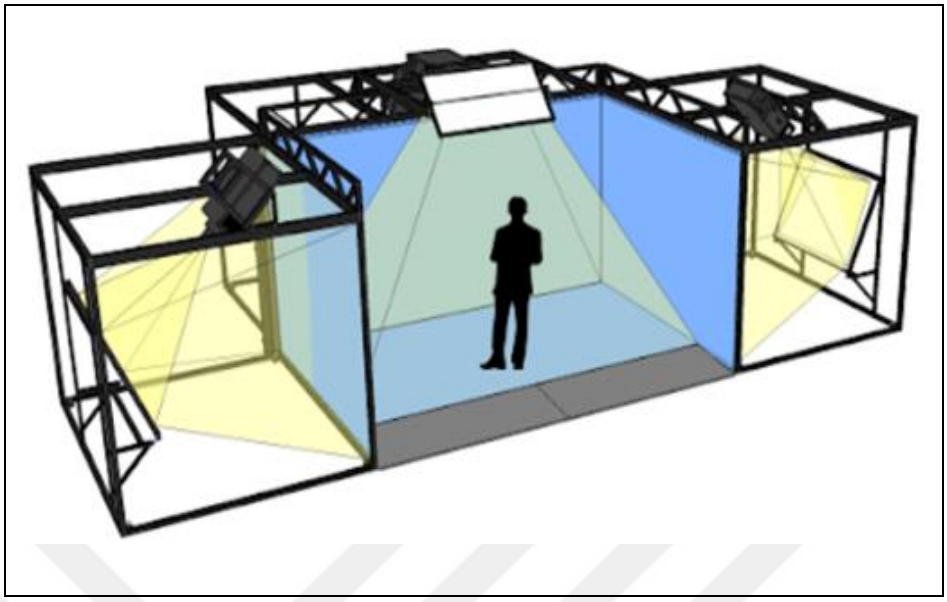


Figure 2.14. A three-sided typical CAVE system [56].

CAVE can be characterized as a box-shaped room and is used to simulate the depth of the walls by means of multiple projectors on three surfaces and glasses with stereo shutters as shown in Figure 2.14. The resulting visuals change in real-time according to the user's viewing angle, providing immersion [55]. These displays do not only have to be CAVE, but also large curved displays, so-called dome displays, are used to provide immersive virtual environments [57]. An example of this type of system is shown in Figure 2.15.

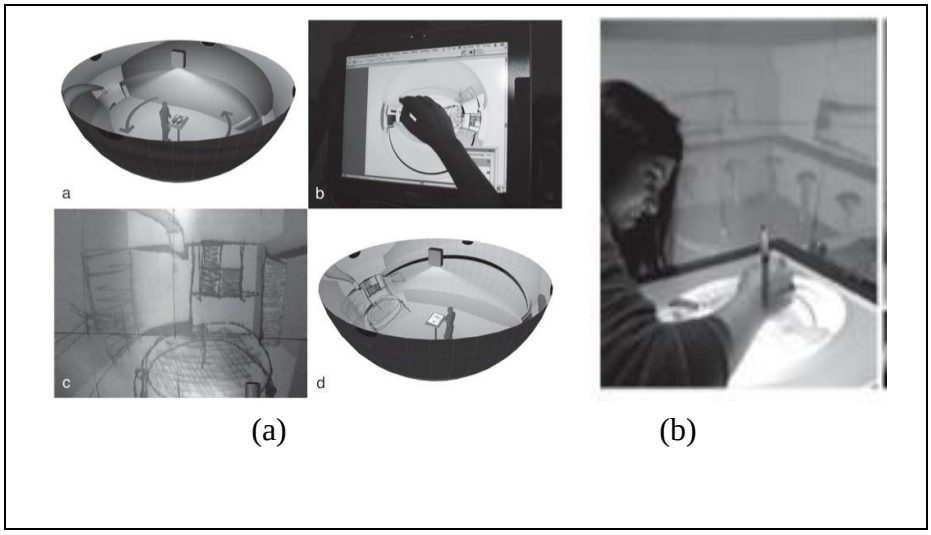


Figure 2.15.(a) Curved screen in the immersive environment, (b) iDVR system: Panoscope + Interactive pen display mounted on a pivoting table [58].

In addition to these systems, it is seen that various designs are made in immersive environments with HMDs today. HMD is a dual-screen display that is worn on the designers' heads and placed in front of their eyes [59]. These displays show different views of the virtual environment to provide stereoscopic visual stimuli to increase the sense of presence.

(a) (b)

Figure 2.16. (a) Sketching in an Immersive environment with VR, (b) Sketching in an immersive environment with AR [47].

Designers in immersive environments can have a shared, all-encompassing vision of a situation that may or may not actually exist because immersive environments provide immersion and presence [45]. The designer who can perceive their presence in an immersive environment is actually in a close connection with the outside world. In the meantime, it makes the designer's need to interact with real-scale artefacts relevant. Some studies have shown that the immersive environment supports the understanding of 3D artefacts [60, 61]. When previous studies are analyzed; it can be said that designers in IE generally stand out with their ability to make 3D sketching (Figure 2.17). In addition, some previous studies have mentioned that immersive 3D sketching supports cognition and thinking to simplify spatial perception [19, 62, 63].

Figure 2.17. Sketching in an immersive environment with Hyve3D [64].

In light of this information, the early design processes in different environments based on the designer's interaction with the environment were found to be worthy of analysis. While the immersive environment with VR allows 3D sketching, it is seen that with augmented reality technology it becomes possible to make 3D and 1/1 scale designs in interaction with the real environment. In the context of this information, immersive environments include elements that stimulate the senses and create an experiential effect for producing sketches in the conceptual design process. It is therefore envisaged that immersive environments will allow designers to experience virtual worlds as if they were physically there. For this reason, four different design environments were designed with two different possibilities under two main environments. In order to analyse the process, experiments with the participants were planned within the framework of an appropriate methodology.

3. RESEARCH METHODOLOGY AND MATERIAL

The research methodology and materials section of the thesis describes the conditions under which the experiments will take place, the content of the different environments, the content of the specific design tasks, the distribution of participants and the methodology for conducting each experiment. First, the conditions of the design environments and the design tools used to create them are described. This is followed by a description of the design tasks given to the participants in the experiment and their characteristics. As each designer participates in two design sessions in two different environments, two design tasks are defined. Therefore, the experimental settings in which the designers will participate and the distribution of the design tasks are given. This chapter contains information about the designers who participated in the protocol studies as part of the thesis, the design tasks given, the recording and observation, and detailed information about the procedure. The procedures applied to the participants during the protocol studies are indicated. Finally, the last title of this part describes the methodology of the thesis and then describes the methods of analysis of the experimental environments. With this information it was possible to analyse the processes of the experimental sessions carried out with the participants.

There are various methods for analyzing thinking in the design process. Within the framework of this study, the aim is to analyze the experiment processes verbally and visually. In studies conducted in the field of design thinking, data is usually collected using the 'thinking aloud' method. In this way, the designer expresses their thoughts during the design process and provides the researcher via data about the process. It is also possible to use the participants' behavior, body movements, attitudes, emotions and similar expressions as data to understand the process more fully during the design process.

This process is recorded and data is collected by 'thinking aloud' as the participants search for solutions to the given design task while sketching. These collected data are the participants' expressions about the design and the actions related to these expressions. In this context, actions and expressions are divided into design protocols.

3.1. THE EXPERIMENT ENVIRONMENTS

Within the study, two main environments (PE and IE) were realized as physical and immersive. Under the two main environments, four different environments were structured with different tools/technologies and different features. The physical environment was divided into analog and digital. Experiments in the analog section were conducted with pen& paper; experiments in the digital section were conducted with a digital pad-digital pen using a sketchbook app. In the immersive environment, a headset& controller called Oculus Quest 2 was used as a tool. The Gravity Sketch app was used for sketching with a headset& controllers. The environments were classified under VR and AR technologies as in shown in Figure 3.1.

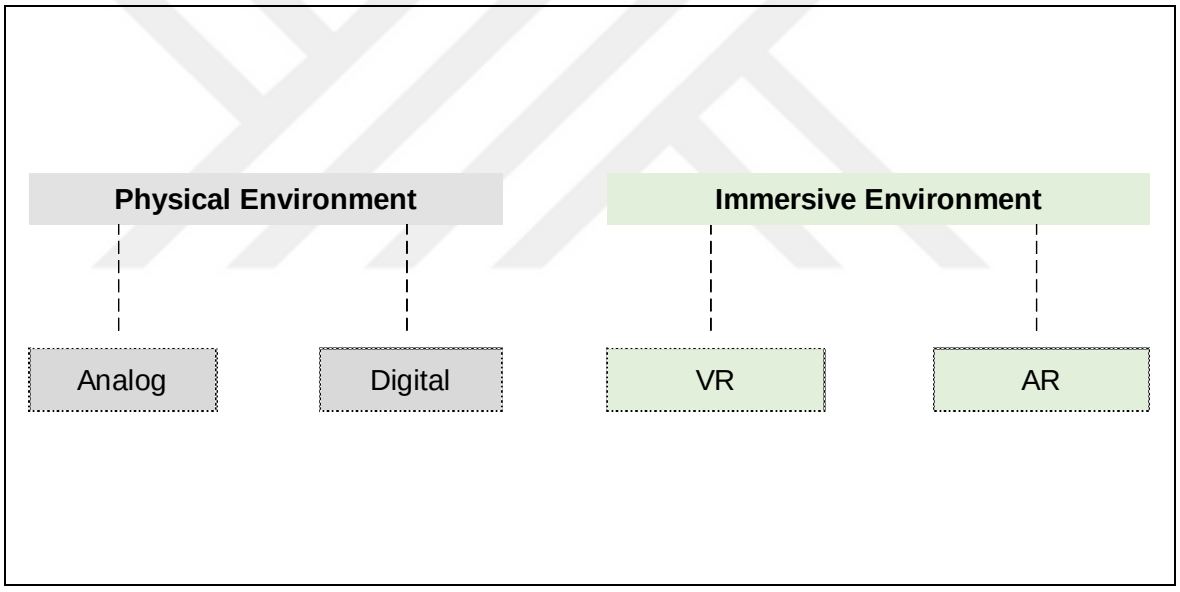


Figure 3.1. Setting up experiment environments.

In the physical and immersive sketching experiment environments, a camera and voice recorder were placed to observe the designers' movements and record their conversations. In the pen & paper and digital tablet experiments in the physical environment, the designer's movements were recorded by a camera, while in the immersive environment, the designer's movements were recorded by the screen recording feature of the Oculus Quest 2 device. The sketching experiment was conducted on different days to accommodate the participants' work and schedules, as well as the weather conditions for sketching outdoors. In addition, communication between the participants before and after sketching was prevented.

3.2. IDENTIFIED DESIGN TASK

The sketch experiments were carried out on the campus of Yeditepe University. The experimental area can be described as the front of the Faculty of Fine Arts and the cafeteria building. The area is where the ring road passes and stops on the campus. It is also located in an area where circulation is active due to its corner point. Satellite images and visuals related to the experiment area are shown in the Figure 3.2. Considering the scope of the study, each participant will enter two different design sessions. Moreover, two equivalent design tasks are planned so that participants can enter the other session without being influenced by their decisions in the previous design session. The design tasks should be formally and structurally equivalent in order to provide equal conditions for the participants and to make objective comparisons. Therefore, design tasks are determined as book-sharing stand and bus station are proportionally similar.

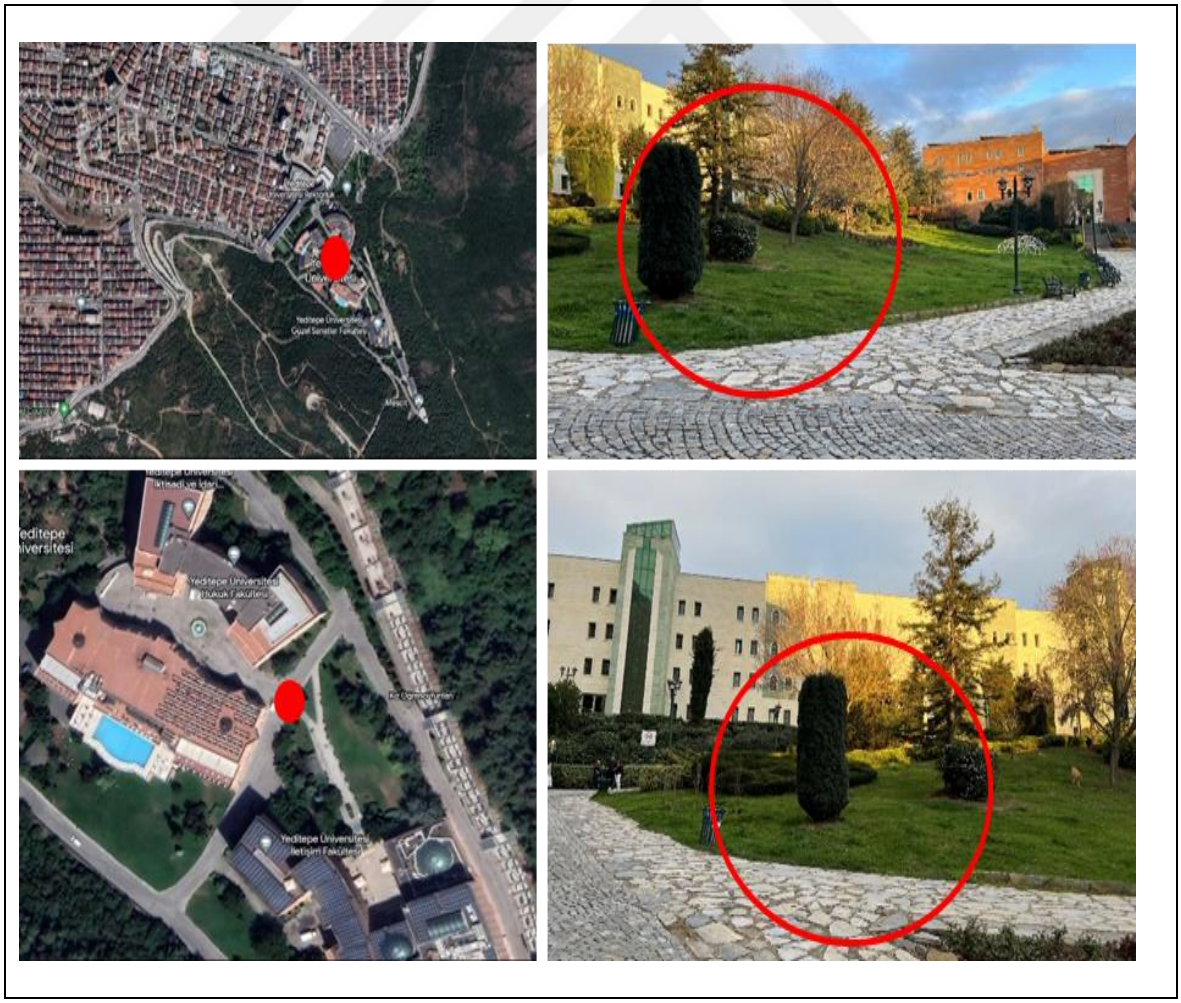


Figure 3.2. Satellite images and visuals related to the experiment area.

In general, the equivalent features have been defined in the concept design as shown in Table 3.1. The list of requirements for the design tasks takes into account the needs of people. The maximum overall dimensions of the structures are approximately 2 m wide, 3 m long, and 2.6 m high. Both design tasks require a protective cover and describe a semi-open space. Besides, the bus station would have a brochure holder, seating for three, and a timetable, and the book-sharing stand should have bookshelves, seating for three, and a billboard.

Table 3.1. Features of the design tasks given to the participants.

Design Tasks	**Dimensions**	**List of Requirements**		
Bus Station	≅ 2- 3- 2,6	Brochure holder/stand	Seating for 3 people	Timetable
Book-sharing Stand		Bookshelves	Seating for 2 people	Billboard

3.3. DISTRIBUTION OF THE PARTICIPANTS

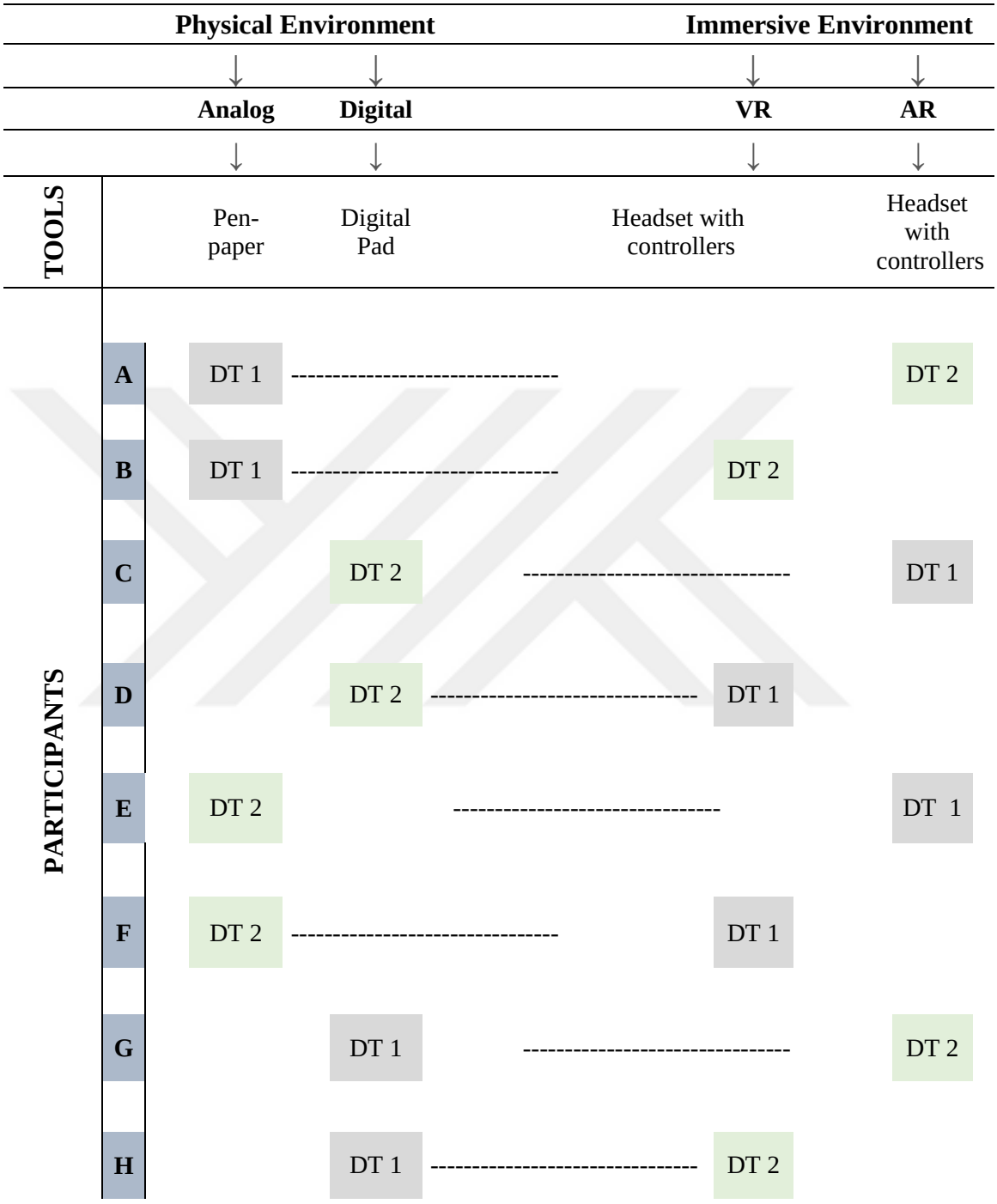
Sketching experiments were conducted with 8 designers to explore the use of sketching tools in physical and immersive environments in the design process and their impact on design thinking in this process. Participants preferred to be designers with at least a Bachelor's degree. Apart from this, no common educational background was sought among the participants. However, consideration was given to ensuring that participants had experience of sketching. Information on the general characteristics of the designers who participated in the study is summarized in the Table 3.2.

Participants sketched using pen and paper or a digital tablet in a physical environment. They then sketched using a headset and controllers in VR or AR in an immersive environment. Participants in both design sessions used two different design tools. The distribution of participants is shown in Table 3.3.

Table 3.2. Features of Participants.

Participant	Age	Graduation Year	Job Experience (year)	Sketching Experience (year)
A	24	2022	1	10
B	25	2021	2	6
C	27	2019	2	10
D	38	2018	5	9
E	24	2021	1	4
F	25	2020	3	7
G	29	2018	5	10
H	25	2020	3	6

Table 3.3. Distrubition of Participants.



*Design Task 1 (**DT 1**) :Bus Station
*Design Task 2 (**DT 2**): Book Stand

3.4. THE METHODOLOGY OF THE EXPERIMENTS

The experiments involved 8 designers with at least a bachelor's degree and experience in sketching. Each designer participated in two design sessions, and a total of 16 design sessions were conducted. Each design session was limited to approximately 10 minutes. Before the experiments, the characteristics of the tools to be used were explained with a three-minute slide presentation.

A list of requirements for the design tasks was then given. Participants were asked to think aloud before starting the experiment. A two-minute think aloud experiment was conducted before the sketching experiment. In some cases, thinking aloud may not be sufficient to capture the participants' design behavior. Therefore, video recordings were also made. After the design session, the recorded voices were transcribed and written down. After 16 design sessions, the recorded voices were transcribed. After transcription, the design behaviours were created and the connections between the behaviours were examined. Linkographs were then created and matched to the design conversation elements. As part of the study, two different methods were created and presented on a graph as shown in Figure 3.3. Firstly, the graph showing the relationship between design conversations elements and design loops is defined by red dots and dashed lines. The next graph, shown with black dots and solid lines, is a linkograph, which contains the links between design moves.

Protocol studies are often used to understand and quantitatively evaluate the design process [44, 65]. Protocol analysis draws on cognitive science and is generally based on thinking aloud. In protocol studies, analysis is usually carried out using the linkograph method. In this study, the data was analyzed using the linkograph method. The study compared the interaction times and design productivity in the session, taking into account the movement, connection models, and design conversation elements in the diagrams.

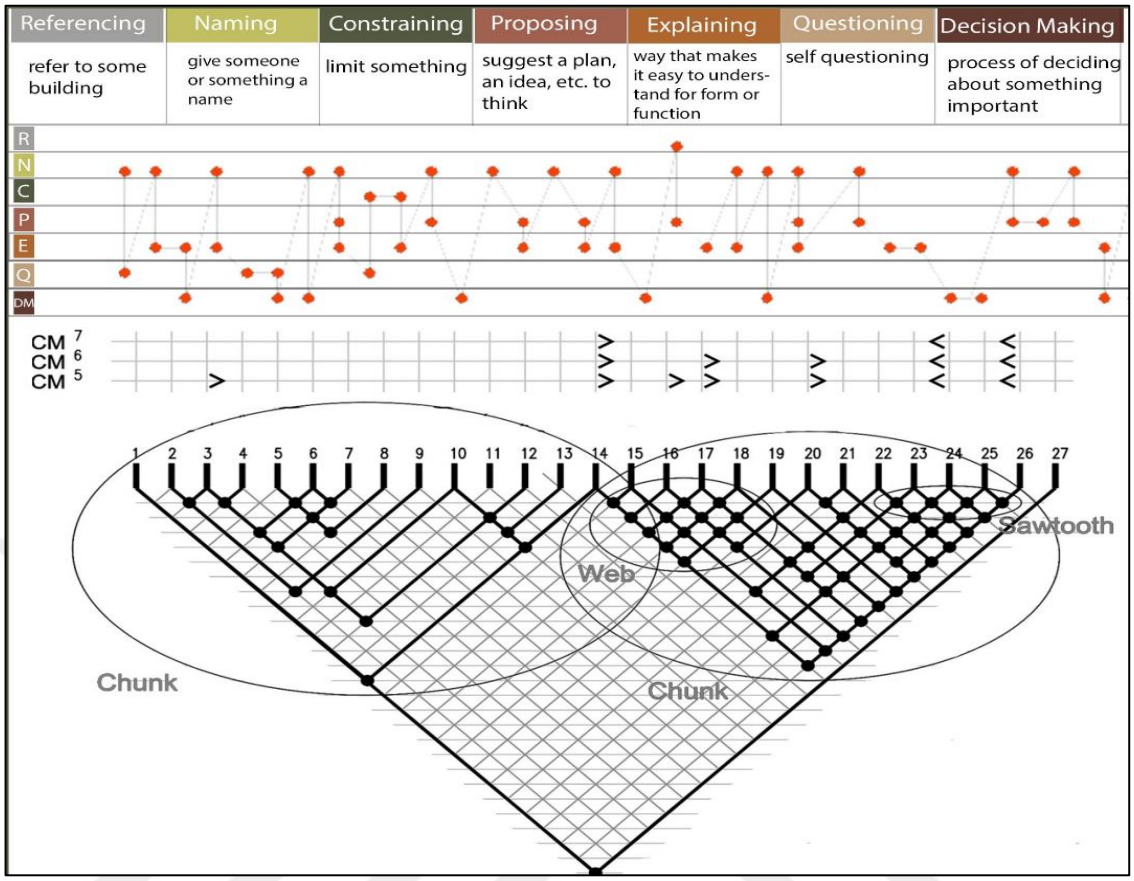


Figure 3.3. Produced graphs with linkographs and elements of design conversation.

3.5. THE ANALYSIS OF EXPERIMENT

It is well known that there is more than one research method for studying the design process. According to Cross, one of these basic research methods is 'protocol studies'. Protocol studies, one of the formal methods of conducting design research, are realized by recording the protocols and related movements of the designer working on the design project through thinking aloud [66]. The concepts of perception, attention, mind and language are central to these studies [67]. The most commonly used experimental research method for analysing the design process is protocol analysis. This method is considered to be the most accurate method that can be used to reveal the hidden cognitive activities of designers [68]. Protocol analysis, which is an experimental research method based on observation, allows the qualitative data in the design process to be transformed into measurable data in order to evaluate the designer's behavior. The ability to represent the design process with numerical data is important because it allows the process to be analyzed and different design processes

to be compared. Such studies, which focus on the knowledge stages of the designer, are concerned with observing how the information that reaches the individual is processed and how it is transformed into a reaction [67]. In this context, protocol analysis studies gain importance in order to observe the difference or similarity of the reaction of different designers to the common information coming from external sources in the face of the design problem.

3.5.1. Protocol Analysis Method

Protocol analysis is one of the experimental methods widely used in the field of cognitive psychology, which analyses design activities consisting of sequential reasoning in order to understand design thinking and process. It is an effective method used to study the cognitive activities and problem-solving behaviors of designers in the design process. Protocol analysis, which is an experimental and observational research method, enables the quantitative structuring of qualitative data during design movement to assess the designer's behavior [67]. Design protocols are obtained by an audio-visual recording of the designer's speech and sketching actions during the design process. Different protocol study methods have been tried to record these actions and to understand the cognitive processes the designer is involved in while solving problems. In think-aloud research, the participant simultaneously expresses all the thoughts that go through his or her mind while trying to solve a well-defined problem. Obtaining real-time verbal data in this way provides a better representation of the participant's thought processes than the introspective approach. Think aloud originally used voice recorders to accurately capture verbal utterances. With the use of video cameras, it is possible to conduct more comprehensive protocol studies by recording both verbal and visual data.

Another way of obtaining data in protocol studies is retrospective protocol analysis. This method does not require the participant to think aloud while solving problems. After the design process, the participant is shown the video recording and asked to comment retrospectively on what he/she thought and did during the design process. With this method, there is a risk that the designer will express new potential thoughts that come to his/her mind while watching the recording of his/her process, instead of expressing what he/she thought during the design process [69].

Within the scope of the thesis, the protocol analysis method was used, in which the design process is expressed aloud. As this method is oriented towards process- and content-oriented research, it allows the evaluation of design steps. The data obtained from the protocol studies were analyzed using the linkograph method developed by Goldschmit and compared with the design conversation elements developed by Dorta et al.,[4]. By analyzing the resulting linkograph and loops, the effects of using different design tools in the design process at the early conceptual process of design on design productivity are examined.

3.5.2. Linkograph

The linkograph is a linear representation that shows design movements and the connections between these movements. Essentially a modified version of the matrix, the linkograph is a form of directional representation from the beginning to the end of the design process, although there is no directional sign [70]. The linkograph can be seen as an extended representation of the small problem fragments and design ideas that the designer focuses on during the design process. The links between design movements allow both partial analyses and a holistic analysis of the entire design process. It is at this point that the designer's thought process can be observed. Analyzing the design moves and connections allows a more detailed analysis of the design process. According to Goldschmidt [70], the linkograph is basically defined as the order in which successive design moves are shown with numbers, the order in which the designer's name is shown if there is more than one designer, the grid lines in the background on which the links are shown, the horizontal lines showing the distance between the links, the order in which critical design moves are shown Figure 3.3. The design movements are separated according to the moments of change of thought. This allows the design process to be understood. Whether there is a connection between two design moves is determined by the content of the moves. The design is analyzed by asking whether each design move is related to the content of the previous moves. The connections between the design moves that make up the design process are shown as nodes in the linkograph and form pattern. Design moves in linkograph are defined with different names according to the number, distance, distribution, and pattern of the connections they produce.

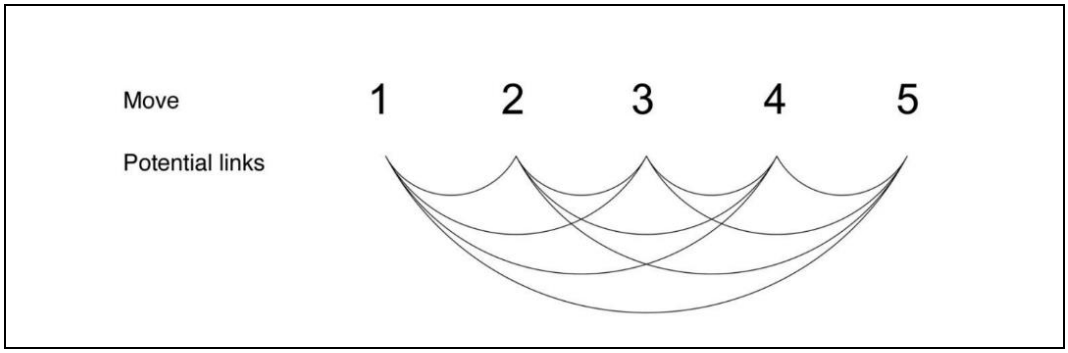


Figure 3.4. Number of tests required to test the connections between five moves [70].

The connection state between the movements is controlled backwards. Therefore, move 1 shown in Figure 1 has a forward connection for move 2 while move 2 has a backward connection for move 1. The backward connection is indicated by a "<" sign, while the forward connection is indicated by a ">" sign. While backward links keep a record of how a move has occurred, forward links carry clues of future movements [71]. Goldschmidt associates the relation of forward and backward connections with the design process with the place of "divergent" and "convergent" thinking styles in problem solving. Goldschmidt states that backward connections between design movements represent convergent thinking and forward connections represent divergent thinking and associates the ability to switch quickly between these two ways of thinking with creativity (productivity) in the design process [70].

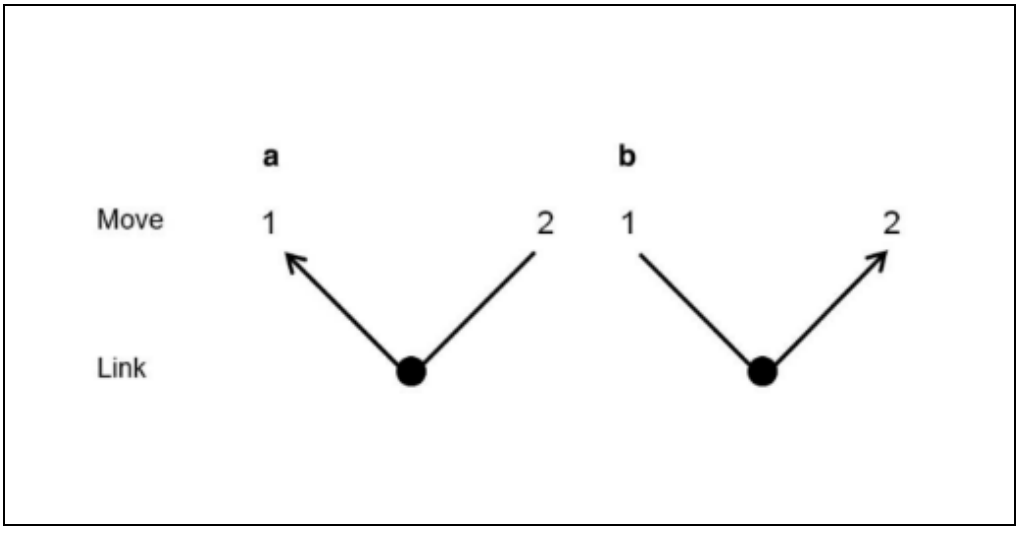


Figure 3.5. Connection between moves 1 and 2 [70].

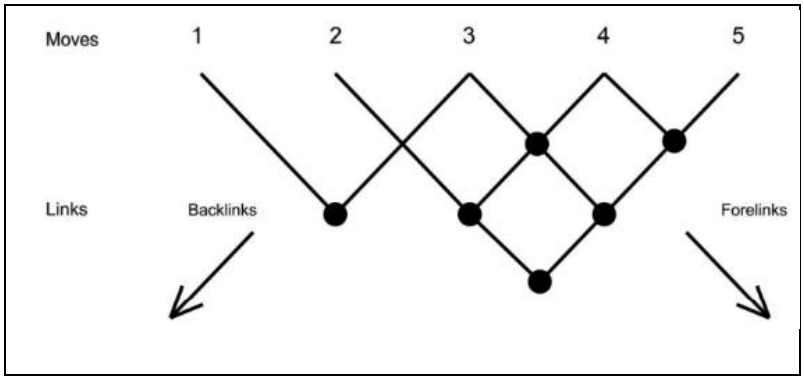


Figure 3.6. Connection graph with five moves and six connections [70].

The movements defined by Goldschmidt are as follows.

Orphan: It defines the movements that have never been mentioned before and have never been brought up in the design process. It is possible to be seen in every design process, but Goldschmidt stated that it is more likely to be seen in inexperienced designers.

Unidirectional: Defines moves that have only forward or backward connections. If the first and last moves are connected, these are unidirectional connections. Moves that produce backward connections are based on the previous thought. Moves that produce forward connections show that the design idea is being supported and developed with new ideas.

Bidirectional: Moves that produce both forward and backward connections between design moves are defined as bidirectional moves. It shows that a design idea is related to any moves before and after it. Bidirectional moves show that rapid changes are made between two different types of reasoning defined as convergent and divergent thinking [70].

Critical: It defines the moves that create a connection between the design moves up to the determined threshold value. In order to identify critical moves, the threshold value must first be determined. A threshold value between approximately 10% and 12% of the total number of moves allows the design process to be evaluated [70]. Critical moves can be decided either by looking at the total number of links produced in each direction or the number of links produced in only one direction. If the number of critical moves with connections in both directions is to be calculated, moves that produce connections in two directions should be counted twice. The critical moves are denoted as "CM" and the threshold number of connections as "t". Critical moves reaching the threshold number of connections in the backward direction are denoted as "<CMt", critical moves reaching the threshold number of

connections in the forward direction are denoted as "CMt>", critical moves reaching the threshold number of connections in both directions are denoted as <CMt>.

Goldschmidt states that critical moves have a direct relationship with design productivity. The designers questioning the design problem backward or forwards show that they produces various alternatives because they aims to solve the specific problem and tries to reach the solution. Critical moves that contain divergent and convergent thoughts play an important role in understanding the way of thinking and evaluating productivity.

The lines formed by the connection nodes in the linkographs on the graphic form various patterns. These connection patterns are important for the evaluation of the design process. Goldschmidt defined these patterns as chunk, web, and sawtooth track [70,71].

Chunk: Connected moves in the chunk show that the related features and possible results of the problems are cross-examined. It can be defined as a series of analyses of sub-problems whose scope is limited when solving a design problem.

Web: It occurs when a large number of connections are produced between a relatively small number of moves. It is shown as short and dense sections of a few moves in which a particular topic is examined in depth and its aspects are woven together to make sure that they are compatible with each other.

Sawtooth: It can be considered as a reaction to what has just been said or done, rather than a holistic point of view where the thinking at a particular point is linear. At least four movements are included.

3.5.3. Elements of Design Conversation

At the beginning of an early conceptual design process, before any physical representation, there are words that express the designer's thinking [4]. To externalize an idea verbally and visually [1], designers link qualitative and vague mental images and external representations in a continuous interaction [72]. In this way, designers are involved in the brainstorming process. Typically, designers see more in their sketches and physical models than they realize when they design them [73]. They often work with new information about the design

task, making assumptions and tentative decisions that need to be revisited, because this early conceptual process is the basement of the whole design process.

Within these definitions, it is accepted that design conversation elements do occur. In this context, it can be said that the concepts of referencing, naming, constraining, proposing, explaining, questioning, and deciding to play a role in determining the structure of the design process. In this way, it can be said that it plays a guiding role in examining how the design process is shaped and between which concepts it is associated.
These processes in the early design process form a short ideation loop, as shown in Figure 3.7, in which the designer thinks aloud [4]. To evaluate the design conversation from the beginning to the end of the loops, Dorta et al. present three elements of the conversation. These elements have been developed as collaborative ideation loop, collaborative negotiation, and collaborative movement. However, in this study, it was planned that each participant would work alone on the specific design task. Therefore, only the concept of the ideation loop is included. An ideation loop is usually based on familiar design moves such as naming, constraining, negotiating, deciding, and acting [4].

First, designers will start by naming the design object or the specific element they are considering. They will then constrain the design task with its requirements and limitations (time, dimensions, and other constraints). They will express verbal meanings associated with visual images. This category is about proposing, explaining, and questioning. The designer would decide on a proposal they have presented or change their mind. This is the end of thinking aloud. This process constitutes an ideation loop. Dorta et al. mentioned that the structure of a basic ideation loop takes different forms. In general, however, the main element for the end of a loop can be considered decision-making. Naming is defined as referring to a building, constraining is to limit something, proposing is to propose a plan, an idea, etc. thinking, explaining is to make it easy to understand for form or function, questioning is to question oneself, the decision-making process of deciding about something important. They also mentioned that the tool used in the design process influences this process and the way the designer thinks in the process. This suggests that design processes carried out in different environments may reveal different dynamics.

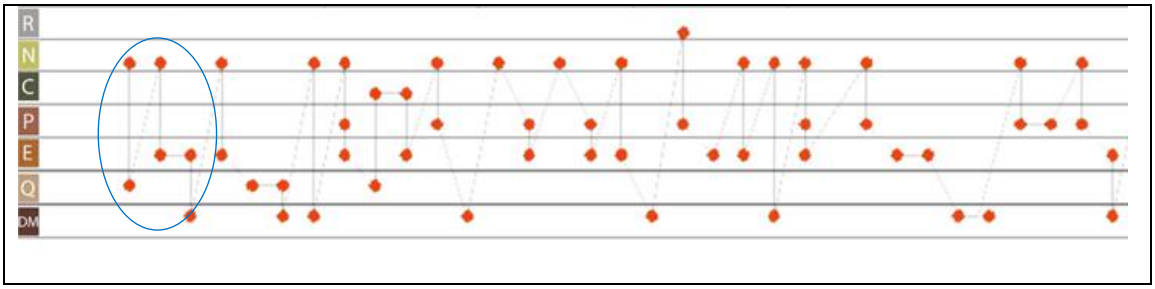


Figure 3.7. Example of ideantion loop according to design conversation elements[4].

3.6. PROCEDURES APPLIED TO PARTICIPANTS

The first of the procedures to be applied to the participants is to inform them of the explicit consent text in accordance with ethical rules. This text includes the information that audio and recordings will be made during the experiment. It provides information about the purposes of storage and use of the recordings. It guarantees that the participant's data will be protected in accordance with the European Union's General Data Protection Regulation (GDPR) [74]. After the participants signed the consent form, the following sequence was followed

(a) First, a preliminary interview was conducted to understand the general characteristics of the participant, such as age, gender, information about the degree, previous experience and experience in sketching.

(b) Preliminary presentation of the experiment; information about the content of the protocol study.

(c) Preliminary presentation of the tool/technique to be developed and brief training on its contents for five minutes.

(d) Think aloud experiment; explain the think-aloud method to the participant.

(e) Informing the participant about the design task, examining the given design task and asking and answering questions (which design tool and which design problem the participant will be working on is indicated in Table 3.3).

(f) Allow the student about 10 minutes to understand the design task, taking into account the criteria given in the design task.

(g) After the experimental sessions, ask the participant for feedback in two different environments.

In addition to these procedures, the participants were prevented from exchanging information with each other before or during the experiment.

4. EVALUATION OF THE EXPERIMENT

A total of 16 design sessions were conducted, with each participant attending two design sessions. Figure 4.1 shows four participants sketching in an physical environment with analog. Figure 4.2 shows four participants sketching in a physical environment with digital. Figure 4.3 shows four participants sketching in an immersive environment with VR. Finally, Figure 4.4 shows four participants sketching in an immersive environment with AR.

Linkographs with design conversation elements were created by considering the participants' voices and sketches, as shown in previous parts of the thesis, during the experiment. To analyze each session, the total number of movements, the total number of connections, the connection index, the critical movement number, and the critical movement ratio were analyzed according to the linkograph graphs. Study movement loops were created during design, as in Dorta et al. [4]. However, as their study deals with collaborative design and analyses two-way dialogues, the elements that would be suitable for a single-participant design environment were taken as a reference. In the diagram, which is divided into design movements, words have been referenced according to the content of the movements.

Figure 4.1. Participants in PE with analog.

Figure 4.2. Participants in PE with digital.

Figure 4.3. Participants in IE with VR.

Figure 4.4. Participants in IE with AR.

4.1. ANALYSIS OF THE DATA OBTAINED

This section presents the participant-based analyses of the protocol studies conducted with 8 designers who participated in the research. Each participant's design process was visualised using the linkograph technique and design conversation elements, one of the protocol analysis methods. After the design experiments, the recordings and voices were first transcribed. The design sessions were divided into design movements, each of which is ten seconds based on audio and video recordings. In addition, to create the linkographs, each design movement was examined in relation to the previous movements to establish connections between them. In order to obtain information regarding the general structure of the design process and the efficiency and productivity of the design process, the following procedures were used in the analyses.

- A linkograph representation of each participant's design process was created and general data such as the number of design moves, number of links, link index (LI) were determined.

- Critical movements were identified and the relationship of critical movements with the sketching situation was indicated. Critical movements can be unidirectional (forward or backward) (CM>, <CM,) as well as forward and backward (bidirectional) (<CM>). Bidirectional critical movements are counted twice. In order to determine a design movement as a critical movement, a common value was not required for all participants as a threshold value. Goldschmidt stated that it would be ideal for the threshold value to be selected to produce approximately 10-12 per cent of the total number of critical movements in the design process (Goldschmidt, 2014b, p.58). In this context, while determining the threshold value, designers' connection indices and critical movement potentials at different threshold values were taken into consideration.
- Sawtooth and chunk were identified as connection patterns and the number of connections included in the patterns were calculated.
- In order to compare the design productivity, the design productivity value was determined by summing the connection index (LI) and critical movement ratio (CM). These ratios are calculated as follows.

  Link Index (LI): Total Number of Connections / Total Number of Movements

  Critical Movement Rate: <CM⁴> moves / Total Moves
- The value obtained by summing these ratios indicates that the designers' design productivity were used for comparison.
- After all these graphs based on the linkograph method were completed, matching was made with the design conversation elements on the graphs divided into design moves. Afterwards, the ratios of these elements are given in Table 4.2. This table includes the ratio of the design conversation elements to the overall ratio on participant basis. It has been explained in the previous sections that conversation loops are formed depending on these elements during the design process. The number and characteristics of the loops are given in the following sections and in the graphs of the participants. Design conversation loops usually start with Naming and end with Decision Making. A design move may contain more than one design conversation element. Accordingly, in the following sections, the number of loops is also included in the sections where the environments are compared.

Participant A in PE;

The graphic and sketch of Participant A's design process in the physical environment (PE) is shown in Figure 4.5. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant A produced a total of 19 movements and 26 links in the physical environment with analog. The link index, determined by the ratio of the total number of links to the total number of movements, was 1.4. Considering the links of the movements, the threshold was set at 3. The total number of forward and backward CM3s is 4. The ratio of this to the whole design process is 21%. Participant A's productivity values shows in Table 4.1

Chunk: Participant A’s linkograph, was not observed in a physical environment with analog.

Sawtooth: Participant A; M1-8 (9), M12-16 (5) were observed as a total of %73 in the physical environment with analog. Table 4.1 shows the productivity values of participant A in PE.

Table 4. 1. Participant A's productivity values in PE with analog.

A	**Number of Moves**	**Number of Connection**	**Link Index**	**CM Number**	**CM Number (%)**
PE with Analog	19	26	1,4	4	21

Participant A's number of design conversation elements is shown in Table 4.2. The total loop of the physical environment was in seven average minutes. Participant A spent 0% of the time referencing, 42% naming, %4 constraining, 4% proposing, %25 explaining, 4% questioning, and 21% decision making in the physical environment. The number of design conversation element loops was observed to be 5 (M1-M6, M7, M8-M14, M15-M17, M18-M19) in the PE with analog. It can be seen that the loops start with intensive naming. Towards the end of the design, it ended with decision making by giving short explanations. Participant A's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.3.

Table 4. 2. Participant A’s number of design conversation elements PE with analog.

A	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with Analog	0	42	4	4	25	4	21

Table 4.3. Example of segmentation of participant A in PE with analog session.

Timeline	**Move No**	**Participant A in PE with analog**
00:00:10	M1	Now first of all, because I want to understand the area a little bit, I try to draw it like this, I see. This is the area on the plan plane. I'm going to express the tree like this. That there's a dustbin like this. And I need to work in this area.
00:00:20	M2	Then, if we think that there is a book sharing and a sitting area for two people, it is actually a more comfortable area.
00:00:30	M3	Because there is a place in nature and I think that there can be a stand where you can sit and sit next to it, especially from the ground and so on.
00:00:40	M4	It sounds like it could be something that fits the shape of the tree that wraps the tree.
00:00:50	M5	Therefore, I can design the stand in a more oval shape in front of it.
00:01:00	M6	They can also use it as a table, and you know, there can be something underneath where there can be a bookcase next to it.

Participant A in IE;

The graphic and sketch of Participant A's design process in the immersive environment (IE) is shown in Figure 4.6. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant A produced a total of 13 movements and 18 links in the immersive environment with AR. The link index of the design process is 1.4. The ratio of this to the whole process is 15 %. Considering the links of the movements, the threshold was set at 2. The total number of forward and backward CM3s is 2. Participant A's productivity values shows in Table 4.4

Chunk: In the linkograph of participant A, M1-M12 (13), a chunk pattern appeared between them in the immersive environment with AR. It has been observed that the participant has an idea of the structure and necessity of the "top cover".

Sawtooth: Participant A; M1-M13 (14) were observed as a total of %100 in the immersive environment with AR.

Table 4. 4. Participant A's productivity values in IE with AR.

A	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with AR	13	18	1,4	2	15

Participant A's number of design conversation elements is shown in Table 4.5. Participant A spent 0% of the time referencing, 29% naming, %14 constraining, 0% proposing, %21 explaining, 0% questioning, and 36% decision making in the immersive environment. The total loop of the immersive environment was in four average minutes. The number of design loops was observed to be 4 (M1-M3, M4-M7, M8-M10, M11-M12) in the IE with AR. Participant A’s one minute think aloud section from the participant's approximately ten minute design process is given in Table 4.6.

Table 4. 5. Participant A’s number of design conversation elements IE with AR.

A	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with AR	0	29	14	0	21	0	36

Table 4.6. Example of segmentation of participant A in IE with AR session.

Timeline	**Move No**	**Participant A in IE with AR**
00:00:10	M1	That's why I'm dropping it further than I am. Can I walk, by the way?
00:00:20	M2	I mean. Uh-huh. You can walk very lightly. You've got your own blue area down there in that area. I've framed it out, but I've got
00:00:30	M3	I'm not very happy with it, so I'm taking it back.
00:00:40	M4	I'll try to start a bit lower, closer to the ground.
00:00:50	M5	I'm trying to make an area that leans towards the tree. In an oval shape.
00:01:00	M6	Again, I wanted to have a covering area inside myself.

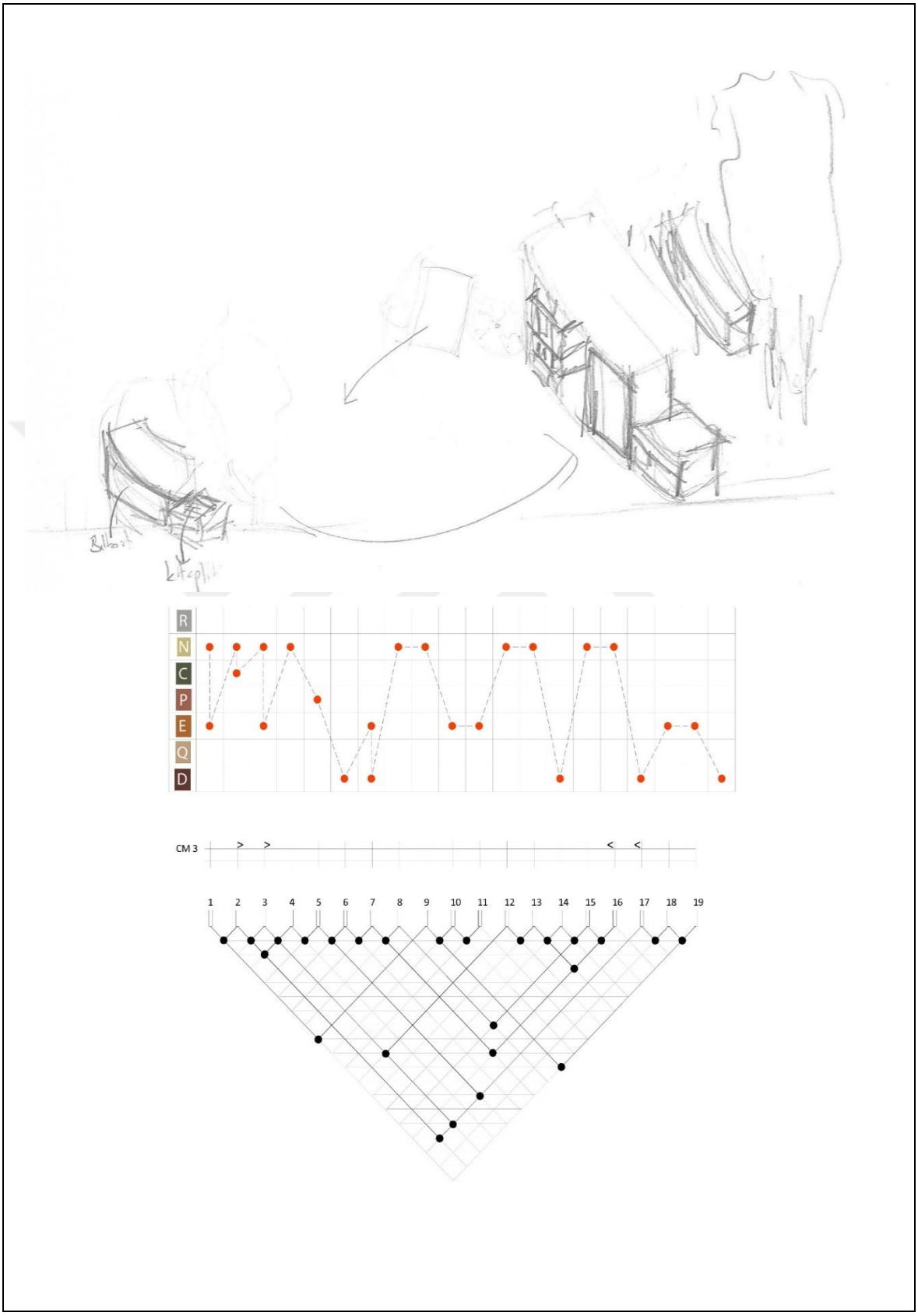


Figure 4.5. Sketch and graph of Participant A in PE with analog.

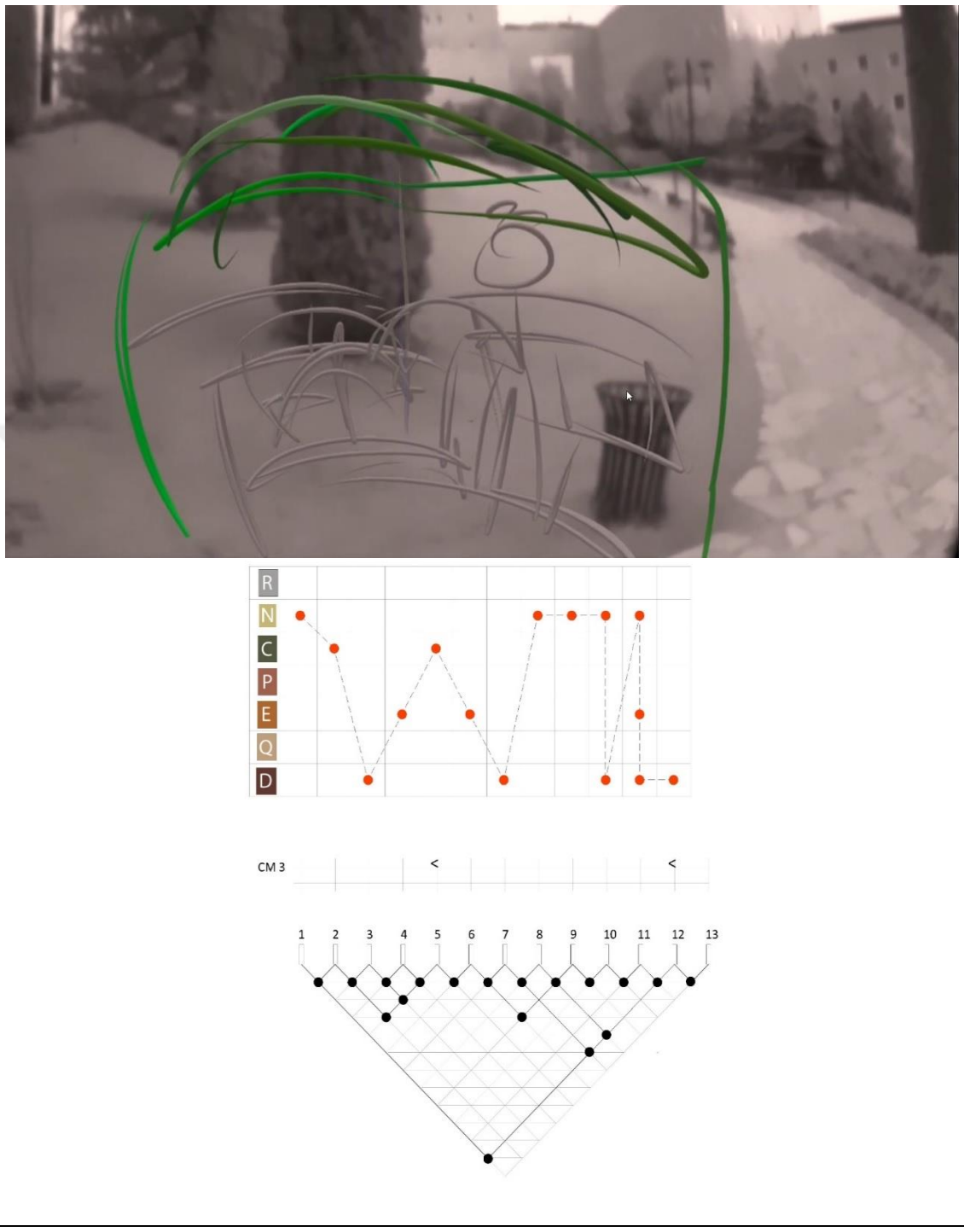


Figure 4.6. Sketch and graph of Participant A in IE with AR.

Participant B in PE;

The graphic and sketch of Participant B's design process in the physical environment (PE) is shown in Figure 4.7. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant B produced a total of 38 movements and 64 links in the physical environment with analog. The link index of the design process is 1.7. Considering the links of the movements, the threshold was set at 5,6 and 7. The total number of forward and backward CM5, CM6, CM7 are 9. The ratio of this to the whole process is 24%. Participant B's productivity values shows in Table 4.7.

Chunk: In the linkograph of participant B, M4-M9 (6), a chunk pattern appeared between them in a physical environment with analog. It was observed that the participant mentioned that it should be a semi-open space. It can also be said that among these movements there are new ideas about the orientation of this space.

Sawtooth: Participant B; M5-M10 (6), M29-M34 (6) were observed as a total of 32% in the physical environment with analog.

Table 4. 7. Participant B's productivity values in PE with analog.

B	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
PE with analog	38	64	1,7	9	24

Participant B's number of design conversation elements is shown in Table 4.8. The total design process of the PE with analog was in nine average minutes. The number of design loops was observed to be 15. The number of design loops was observed to be 15 (M1-M3, M4-M12, M13-M16, M17-M18, M19, M20-M22, M23, M24-M26, M27-M29, M30-M32, M33-M34, M35, M36, M37, M38). In addition participant B spent, 0% of the time referencing, 25% naming, %7 constraining, 8% proposing, %25 explaining, 10% questioning, and 25% decision making in the PE with analog.

Participant B's one-minute think aloud section in PE, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.9.

Table 4. 8. Participant B’s number of design conversation elements PE with analog.

B	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with analog	0	25	7	8	25	10	25

Table 4.9. Example of segmentation of participant B in PE with analog session.

Timeline	**Move No**	**Participant B in PE with analog session**
00:00:10	M1	Okay, the bus is on the other side. How come? Why does it stop here?
00:00:20	M2	Yes, it is. At first, I'm going to look at a 3D dimension to get a sense of the dimensions. To the corner to see what it could be.
00:00:30	M3	Aren't these dimensions too small?
00:00:40	M4	Yes, they are.
00:00:50	M5	It's round the corner, so it's gotta be where the entrances to this one meet. But I think that's the main building. Let's see if there's an entrance from there, but is there an exit from that building?
00:01:00	M6	It's going to be a place that's open on three sides. Semi open place.

Participant B in IE;

The graphic and sketch of Participant B's design process in the immersive environment (IE) is shown in Figure 4.8. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant B produced a total of 29 movements and 37 links in the immersive environment with VR. The link index of the design process is 1.3. Considering the links of the movements, the threshold was set at 3 (CM3) and 4 (CM4). The total number of forward and backward CM3 and CM4 is 9. The ratio of this to the whole process is 31%. Participant B's productivity values shows in Table 4.10

Chunk: In the linkograph of participant B, M3-M24, a chunk pattern appeared between them in an immersive environment with VR. In fact, the participant worked on the position of the "billboard" in this interval. It was observed that this billboard should contain more than one advertisement and should be electronic.

Sawtooth: Participant B’s linkograph was not detected in the immersive environment with VR.

Table 4. 10. Participant B's productivity values in IE with VR.

B	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with VR	29	37	1,3	9	31

Participant B's number of design conversation elements is shown in Table 4.11. The total loop of the immersive environment was in nine average minutes. The number of design loops was observed to be 10 (M1-M7, M8, M9, M10-M13, M14-M19, M20, M21, M22, M23-M26, M27-M29) in the PE with VR. Looking at the graphs, the loops generally started with the naming. In addition, the first loop started with the naming and contains the seven moves. In this respect, it is the most intensive loop compared to the others. Participant B spent, 2% of the time referencing, 33% naming, %13 constraining, 7% proposing, %20 explaining, 2% questioning, 22% decision making in the immersive environment.

Participant B's one-minute think aloud section in IE, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.12.

Table 4. 11. Participant B's number of design conversation elements IE with VR.

B	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with VR	2	33	13	7	20	2	22

Table 4.12. Example of segmentation of participant B in IE with VR session.

Timeline	Move No	Participant B in PE with VR session
00:00:10	M1	OK. Two by three by two point six again. That one's drawing too thick.
00:00:20	M2	Now we have an area like this here.
00:00:30	M3	In this area, we will now have bookshelves, there will be a seating area for two people, in that seating area for two people, people who will most likely shop for books inside.
00:00:40	M4	And there will be a billboard. Now the billboard will be outside. Because I don't know what angle we're supposed to be looking at.
00:00:50	M5	This has to be a completely enclosed space. Because there's going to be books, and the books have to be sheltered. It's right round the corner.
00:01:00	M6	But the big area of this is the main line this time, to see this. Okay, it's actually three metres of space.

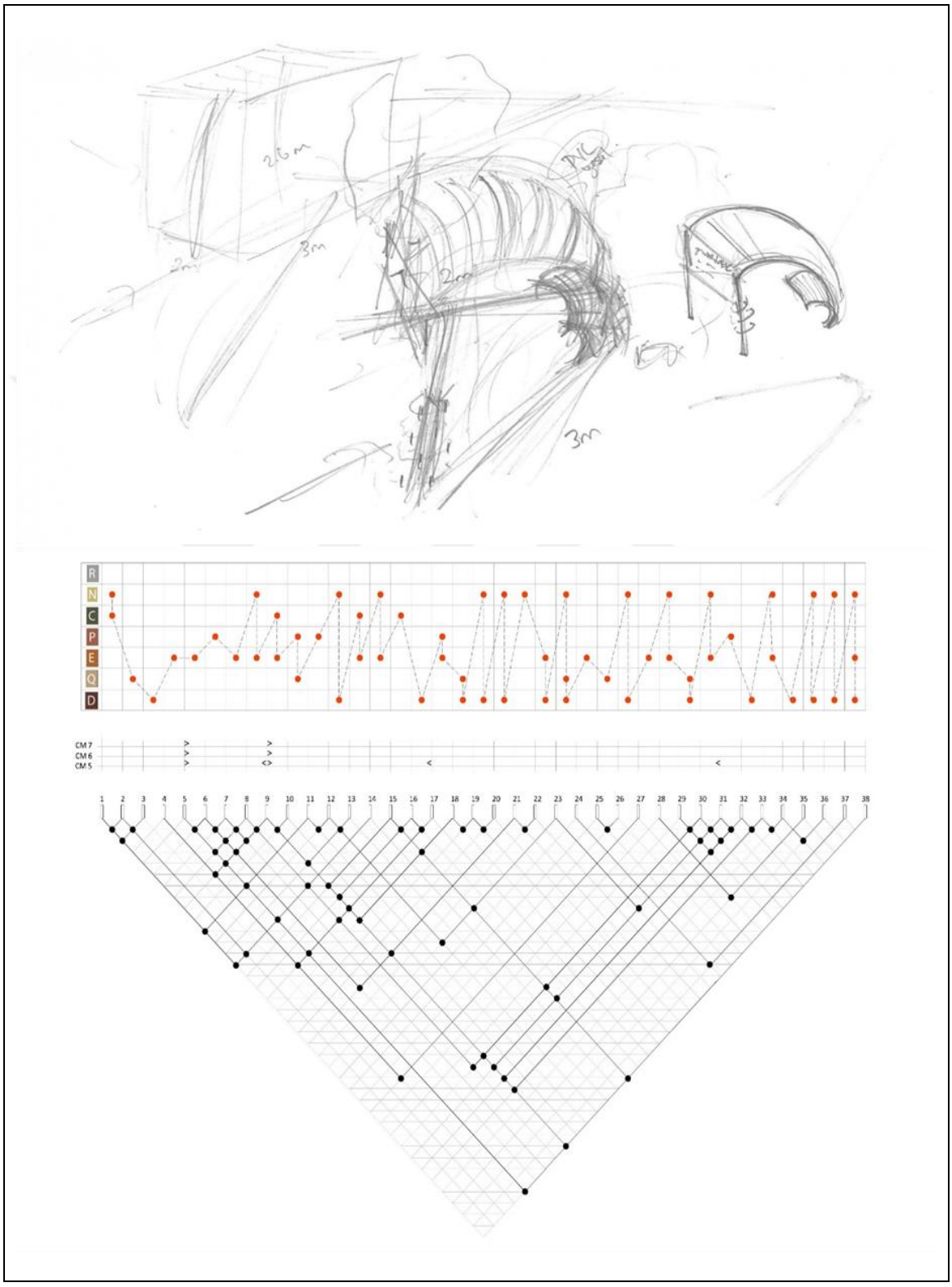


Figure 4.7. Sketch and graph of Participant B in PE with analog.

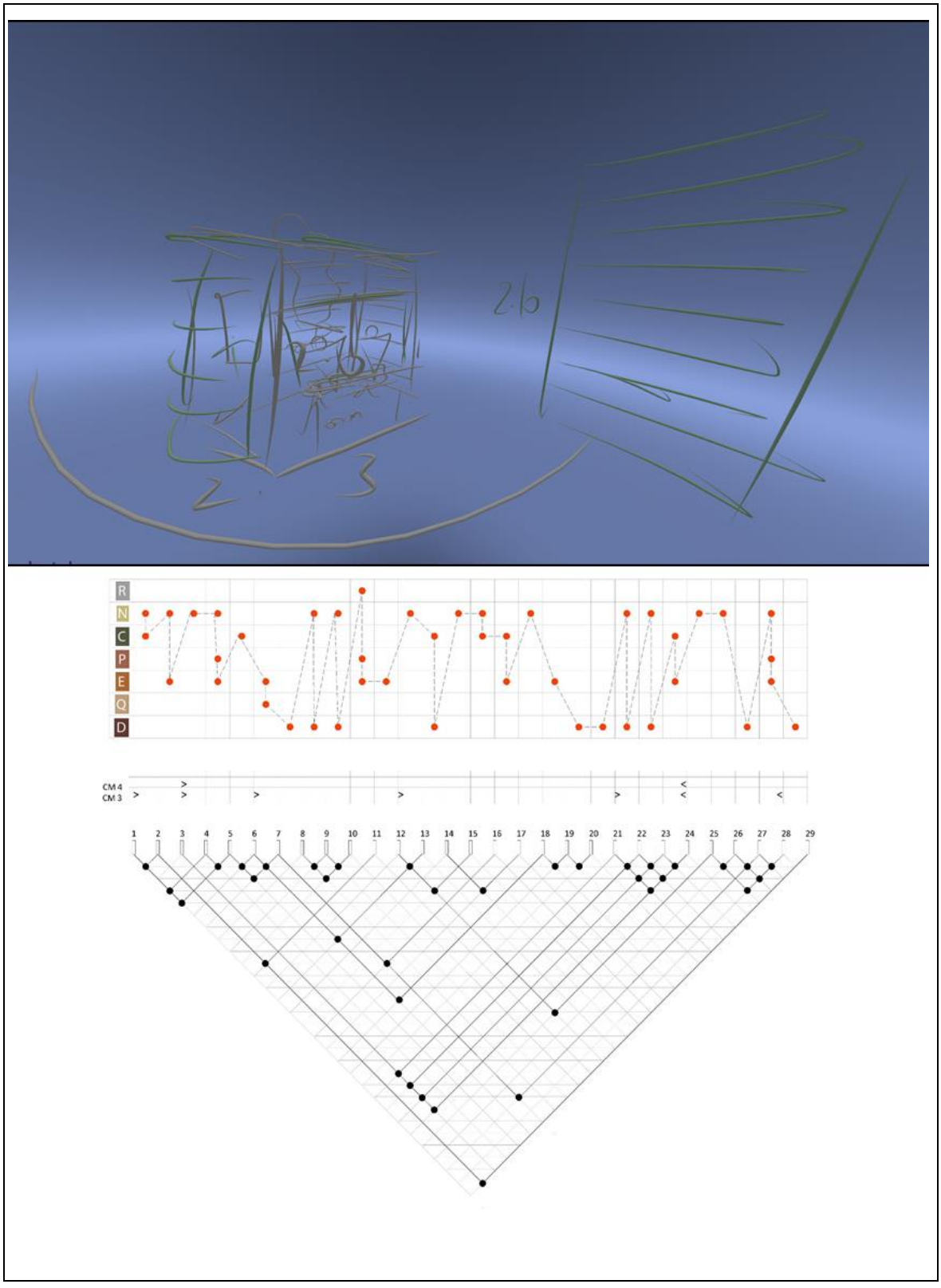


Figure 4.8. Sketch and Graph of Participant B in IE with VR.

Participant C in PE;

The graphic and sketch of Participant C's design process in the physical environment (PE) is shown in Figure 4.9. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant C produced a total of 23 movements and 28 links in the physical environment with digital. The link index of the design process is 1.2. Considering the links of the movements, the threshold was set at 3 (CM3) and 4 (CM4). The total number of forward and backward CM3 and CM4 are 10. The ratio of this to the whole process is 43%. Participant C's productivity values shows in Table 4.13.

Chunk: In the linkograph of Participant C, M1-M22, a chunk pattern appeared between them in a physical environment with digital. Between these movements it was observed that the participant was generally working from the idea that the building elements should be 'inviting' as the building is located at a transition and intersection point.

Sawtooth: Participant C’s linkograph was not detected in the physical environment with a digital.

Table 4. 13. Participant C's productivity values in PE with digital.

C	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
PE with digital	23	28	1,2	10	43

Participant C's number of design conversation elements is shown in Table 4.14. The total loop of the PE with digital was in nine average minutes. Participant C spent, 0% of the time referencing, 29% naming, %5 constraining, 20% proposing, %10 explaining, 10% questioning, 27% decision making in the physical environment. Looking at the graphs, the number of design conversation element loops was observed to be 11 (M1-M2, M3-M5, M6, M7, M8, M9, M10-M11, M12, M13-M19, M20-M21, M22-M23) in PE with digital. In general, the loops started with the naming and the most intense loop occurred between M13 and M19. Participant C was thinking aloud during this time about new suggestions for the

design in the design area. Participant C's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.15.

Table 4. 14. Participant C’s number of design conversation elements in PE with digital.

C	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with digital	0	29	5	20	10	10	27

Table 4.15. Example of segmentation of participant C in PE with digital.

Timeline	**Move No**	**Participant C in PE with digital**
00:00:10	M1	I think this place is just such a transition area. Since it's a point that everyone frequents, we need to position it in such a welcoming way. we can do something like this…
00:00:20	M2	OK, OK. So now I'm saying that this is an area where people will sit. Hm. Then let's do something like this.
00:00:30	M3	Over there, now this one is two metres wide. One of them, for example...
00:00:40	M4	Let's do something like this. Let's position part of it here. Three metres high like this? No. Anyway, three metres L...
00:00:50	M5	It's like this. I don't understand. What's three metres? Something like this, anyway. Like this. Like this. It's not very good.
00:01:00	M6	I want to have shelves like this here. Let's draw an area where people can sit between these shelves. Over there like this

Participant C in IE;

The graphic and sketch of Participant C's design process in the immersive environment (IE) is shown in Figure 4.9. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant C produced a total of 16 movements and 21 links in the immersive environment with AR. The link index of the design process is 1.3. Considering the links between the movements, the threshold was set at 3 (CM3) and 4 (CM4). The total number of forward and backward CM3 and CM4 are 13. The ratio of these to the whole process is 81%. The productivity values of participant C are shown in Table 4.16.

Chunk: In the linkograph of Participant C, M1-M6, a chunk pattern appeared between them in an immersive environment with AR. Between these movements, it was observed that the participant usually worked on the general structure of the building and the closed top of the bookshelves.

Sawtooth: Participant C; M3-M7 (5) were observed as a total of 31% in the immersive environment with AR.

Table 4. 16. Participant C's productivity values in IE with AR.

C	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with AR	16	21	1,3	13	81

Participant C's number of design conversation elements is shown in Table 4.17. The total loop of the immersive environment was in five average minutes. Participant C spent, 0% of the time referencing, 29% naming, %0 constraining, 15% proposing, %18 explaining, 6% questioning, 32% decision making in the immersive environment. The number of design loops are 10 (M1-M2, M3, M4, M5-M7, M8-M9, M10-M11, M12, M13, M14, M15-M16). Participant C generally completed the requirements of the design task between M1 and M5. In the following design moves, it was observed that new design suggestions such as charging box, rubbish bin, heater, ashtray were brought. Participant C's one-minute think aloud

section, including the first six design moves from the approximately five-minute design process, is shown in Table 4.18.

Table 4. 17. Participant C's number of design conversation elements in IE with AR.

C	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with AR	0	29	0	15	18	6	32

Table 4.18. Example of segmentation of participant C in IE with AR.

Timeline	Move No	Participant C in PE with AR session
00:00:10	M1	First of all, we need to build a bus stop here.
00:00:20	M2	There's a tree here, you know. Let's make an area like this. Now, one okay.
00:00:30	M3	One like this. Session location
00:00:40	M4	Such a sitting place for three triples of three people. of course.
00:00:50	M5	Okay. On the back of this, there should be a screen with the bus times on it.That the bus will arrive at this time and that time. Again, this is a waiting area, so let's cover it up like this.
00:01:00	M6	I've got it all covered. And then I think these seats should be heated. Because the distances are very long at school. The incoming may get cold while waiting here.

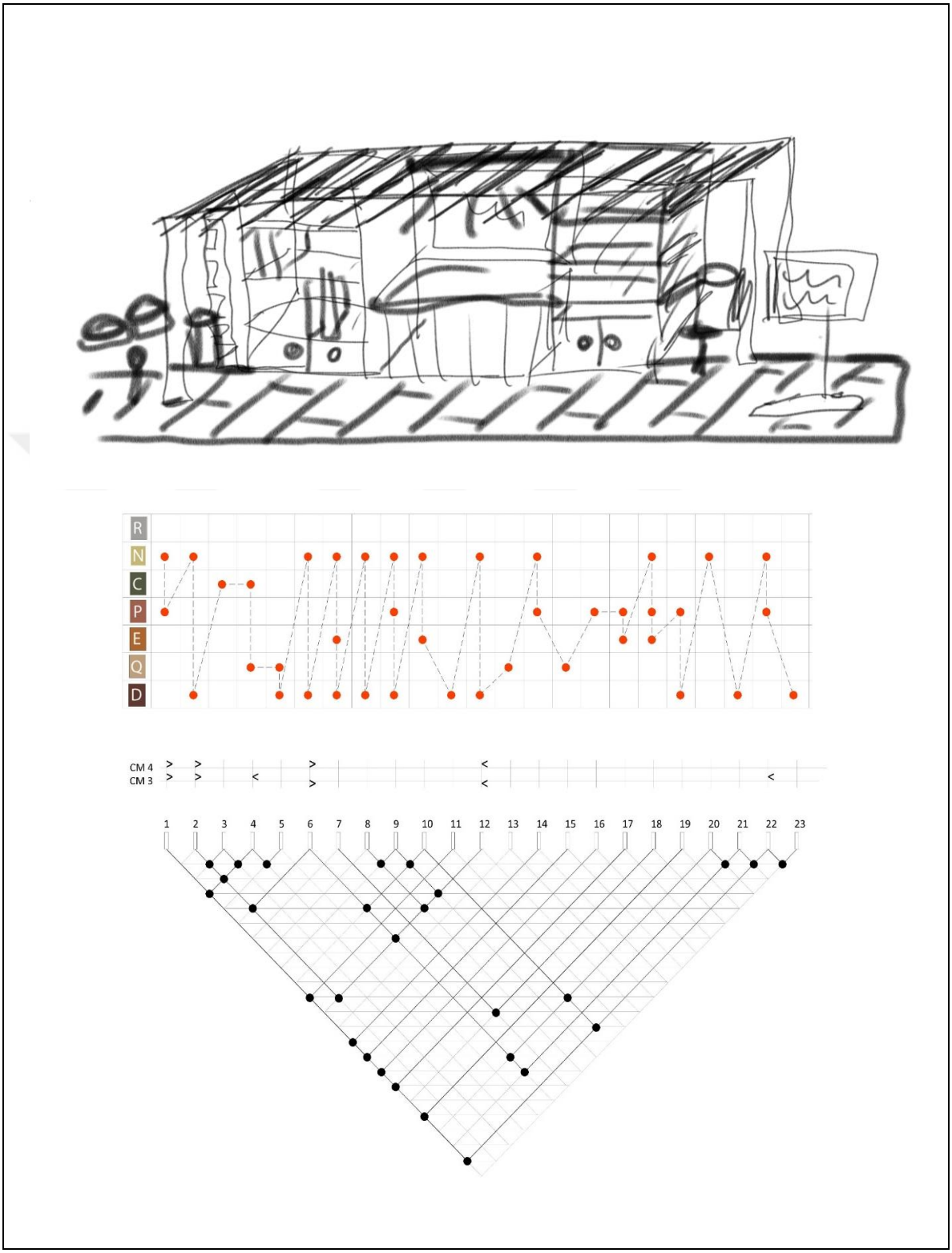


Figure 4.9. Sketch and Graph of Participant C in PE with digital.

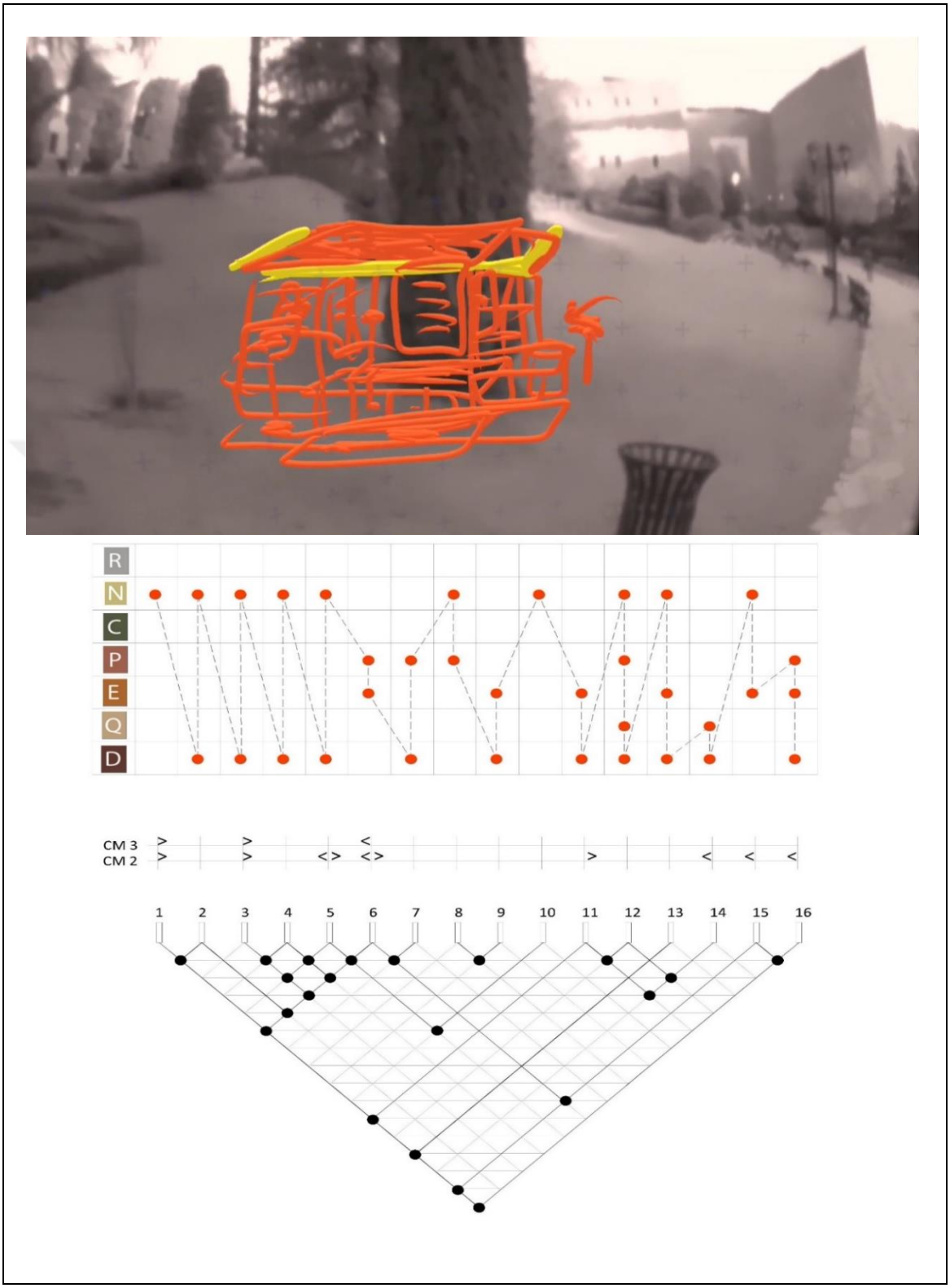


Figure 4.10. Sketch and Graph of Participant C in IE with AR.

Participant D in PE;

The graphic and sketch of Participant D's design process in the physical environment (PE) is shown in Figure 4.16. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant D produced a total of 40 movements and 54 links in the physical environment with digital. The link index of the design process is 0.7. Considering the links of the movements, the threshold was set at 4(CM4) and 5(CM5). The total number of forward and backward CM4s and CM5s is 6. The ratio of this to the whole process is 15%. Participant D's productivity values shows in Table 4.19.

Chunk: not observed.

Sawtooth: Participant D; M1-M6 (6), M12-M17 (6), M22-M26 (5), M29-M33 (5), M36-M40 (5) were observed as a total of %67 in the physical environment with digital.

Table 4. 19. Participant D's productivity values in PE with digital.

D	**Number of Moves**	**Number of Connection**	**Link Index**	**CM Number**	**CM Number (%)**
PE with digital	40	54	0,7	6	15

Participant D's number of design conversation elements is shown in Table 4.20. Participant D spent, 2% of the time referencing, 28% naming, %5 constraining, 18% proposing, %23 explaining, 6% questioning, 18% decision making in the physical environment. Participant D's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.21.

Table 4.20. Participant D’s number of design conversation elements in PE with digital.

D	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with digital	2	28	5	18	23	6	18

Table 4.21. Example of segmentation of participant D in PE with digital.

Timeline	Move No	Participant D in PE with digital session
00:00:10	M1	A stand like this. Now once two metres two two two three metres two point six metres. This one for example
00:00:20	M2	width, length and height, right? Uh-huh. Okay. [chuckles] Okay, if I came up with it on my own, okay. Under the fluffy tree.
00:00:30	M3	That tree. Let's think about it. First of all, we have a road. Right? Let's choose this one
00:00:40	M4	Let's do something first. I don't like the road, I'm driving again. That's a criterion.
00:00:50	M5	I'm trying to find the appropriate tool. Which, for example, this thick, not thick enough, I need to draw a thick line. I'm looking for that tool,
00:01:00	M6	Let this be our road. Those who pass this way will both sit. While waiting for someone, let's find a colour here. Let's find a different colour.

Participant D in IE;

The graphic and sketch of Participant D's design process in the immersive environment (IE) is shown in Figure 4.11. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant D produced a total of 36 movements and 61 links in the immersive environment with VR. The link index of the design process is 0.6. Considering the links of the movements, the threshold was set at 4 (CM4). The total number of forward and backward CM4s is 8. The ratio of this to the whole process is 22%. The number of design loops is 11 (M1-M3,M4-

M6,M7,M8-M12,M13-M17,M18-M22,M23-M28,M29-M32,M33,M34-M35,M36-40) in PE with digital. Participant D's productivity values shows in Table 4.22.

Chunk: In the linkograph of Participant D, M16-M21 (5), a chunk pattern appeared between them in an immersive environment with VR. Among these movements, it was observed that the participant generally developed the top cover of the building and worked on its size.

Sawtooth: Participant D; M4-M13 (10), M16-M22 (7), M31-M36 (6) were observed as a total of %64 in the immersive environment with VR.

Table 4.22. Participant D's productivity values in IE with VR.

D	**Number of Moves**	**Number of Connection**	**Link Index**	**CM Number**	**CM Number (%)**
IE with VR	36	61	0,6	8	22

Participant D's number of design conversation elements is shown in Table 4.22. Participant D spent, 2% of the time referencing, 20% naming, %6 constraining, 8% proposing, %25 explaining, 4% questioning, 35% decision making in the immersive environment. The total loop of the immersive environment was in ten average minutes. The number of design loops observed was 15 (M1-M4,M5-11,M12,M13,M14-M17,M18-20,M21,M22-M23,M24,M25-M27,M28-M29,M30-31,M32-M33,M34-M35,M36) in IE with VR. Participant D's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.24.

Table 4.23. Participant D’s number of design conversation elements in IE with VR.

D	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with VR	2	20	6	8	25	4	35

Table 4. 24. Example of segmentation of participant D in IE with VR.

Timeline	Move No	Participant D in IE with VR session
00:00:10	M1	And then keep going. Okay, that's it. That's it, that's it. That's it. That's it. Two, two metres. Let's do it like this. Two metres, three metres.
00:00:20	M2	It's crooked here. Let's enlarge this
00:00:30	M3	I took it like this. I put it two metres by three metres like this. I see.
00:00:40	M4	It's beautiful. Like this. That's it. That's it. Now I'm scaling what I'm doing. Two metres will be three metres.
00:00:50	M5	Two metres is two hundred per cent. This tells me the percentage. Now let me think of it as an area where I can sit. Let's make it three metres, three metres, three metres.
00:01:00	M6	Let's change the colour. Let's choose a colour. Yes, a colour like this

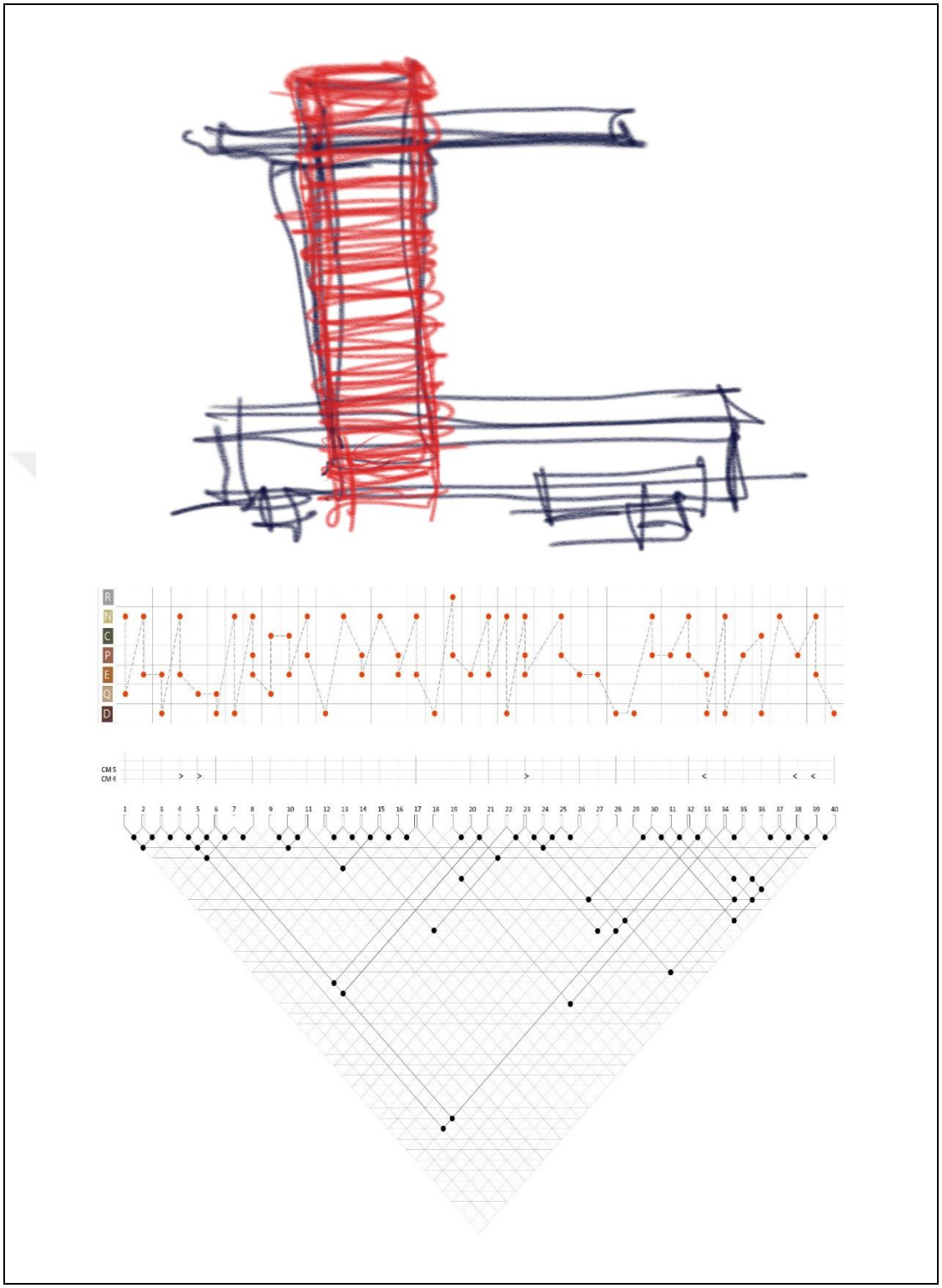


Figure 4.11. Sketch and Graph of Participant D in PE with Digital.

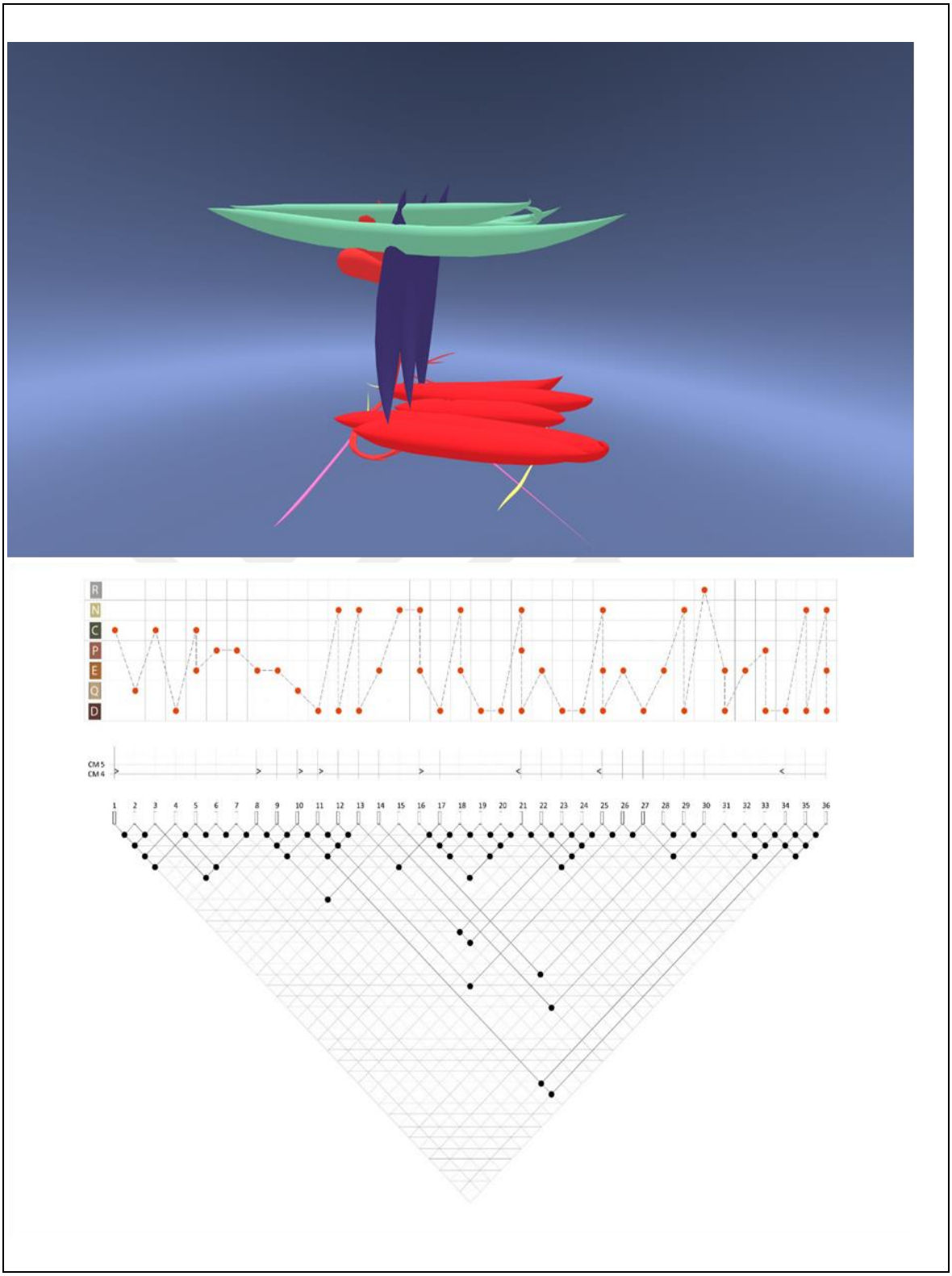


Figure 4.12. Sketch and Graph of Participant D in IE with VR.

Participant E in PE;

The graphic and sketch of Participant E's design process in the physical environment (PE) is shown in Figure 4.11. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant E produced a total of 15 movements and 22 links in the physical environment with analog. The link index of the design process is 1.5. Considering the links of the movements, the threshold was set at 2 (CM2) and 3 (CM3). The total number of forward and backward CM2s and CM3s is 10. The ratio of this to the whole process is 67%. Participant E's productivity values shows in Table 4.25.

Chunk: In the linkograph of participant E, the chunk pattern is not observed in physical environment with analog.

Sawtooth: Participant E’s linkograph was not detected in the physical environment with analog.

Table 4.25. Participant E's productivity values in PE with analog.

E	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
PE with analog	15	22	1,5	10	67

Participant E's number of design conversation elements is shown in Table 4.26. Participant E spent, 0% of the time referencing, 29% naming, %4 constraining, 11% proposing, %25 explaining, 4% questioning, 29% decision making in the physical environment. The total loop of the physical environment was in five average minutes. Participant A's one-minute think aloud section, including the first six design moves from the approximately five-minute design process, is shown in Table 4.3.

Table 4.26. Participant E’s number of design conversation elements in PE with analog.

E	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with analog	0	29	4	11	25	4	29

Table 4. 27. Example of segmentation of Participant E in PE with analog session.

Timeline	Move No	Participant E in PE with analog session
00:00:10	M1	There's a level difference there. On the road coming from the side. on the road. I said, you know, why is the denim difference like this? an upper cover on that side so that it doesn't rise"
00:00:20	M2	and a green roof garden, bees, bees and so on, maybe seasonal plants in bloom. That's why I'm saying that if we had a slope like this, like a side view here. And if it goes like this...
00:00:30	M3	This is how the bus station comes from here. No, the other way round, of course. If it came like this. If it opens up from the slope in more organic forms.
00:00:40	M4	I couldn't draw that on the road.
00:00:50	M5	There's one more thing like this here. We have a big tree here, redwood.
00:01:00	M6	came from this slope. We need a pole to carry it, we need something here, in here. A seat here, a seat there, a slab there, of course.

Participant E in IE;

The graphic and sketch of Participant E's design process in the immersive environment (IE) is shown in Figure 4.12. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant E produced a total of 17 movements and 24 links using AR in the immersive environment. The link index of the design process is 1.4. Considering the links of the movements, the threshold was set at 2 (CM2) and 3 (CM3). The total number of forward and backward CM2s and CM3s is 14. The ratio of this to the whole process is 82%. Participant E's productivity values shows in Table 4.28.

Chunk: In the linkograph of participant E, the chunk pattern is not observed in immersive environment with AR.

Sawtooth: Participant E’s linkograph was not detected in the immersive environment with AR.

Table 4.28. Participant E's productivity values in IE with AR.

E	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with AR	17	24	1,4	14	82

Participant E's number of design conversation elements is shown in Table 4.29. Participant E spent, 10% of the time referencing, 20% naming, %0 constraining, 5% proposing, %10 explaining, 5% questioning, 50% decision making in the immersive environment. The total loop of the immersive environment was in five average minutes. The number of design loops observed was 8 (M1,M2-M4,M5-M6,M7,M8,M10,M11-M14,M15-M17) in IE with AR. Participant E's one-minute think aloud section, including the first six design moves from the approximately nine-minute design process, is shown in Table 4.30.

Table 4.29. Participant E’s number of design conversation elements in IE with AR.

E	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with AR	10	20	0	5	10	5	50

Table 4. 30. Example of segmentation of Participant E in IE with AR session.

Timeline	**Move No**	**Participant E in IE with AR session**
00:00:10	M1	Next to the tree... I started to draw something here again... Such a top cover
00:00:20	M2	Let me take it back a little bit. I mean, I'm suggesting a semi-enclosed place right now.
00:00:30	M3	Now that we're at school, I'm thinking of doing something a little more suitable for the forms at school, you know, those ridiculous triangular pediments and stuff like that?
00:00:40	M4	I'd like to decorate an entrance door like this.
00:00:50	M5	(redrawing the general outlines from the carriers)
00:01:00	M6	There are trees at the back. I drew them. Ok, I made such an entry here (similar to school's building forms)

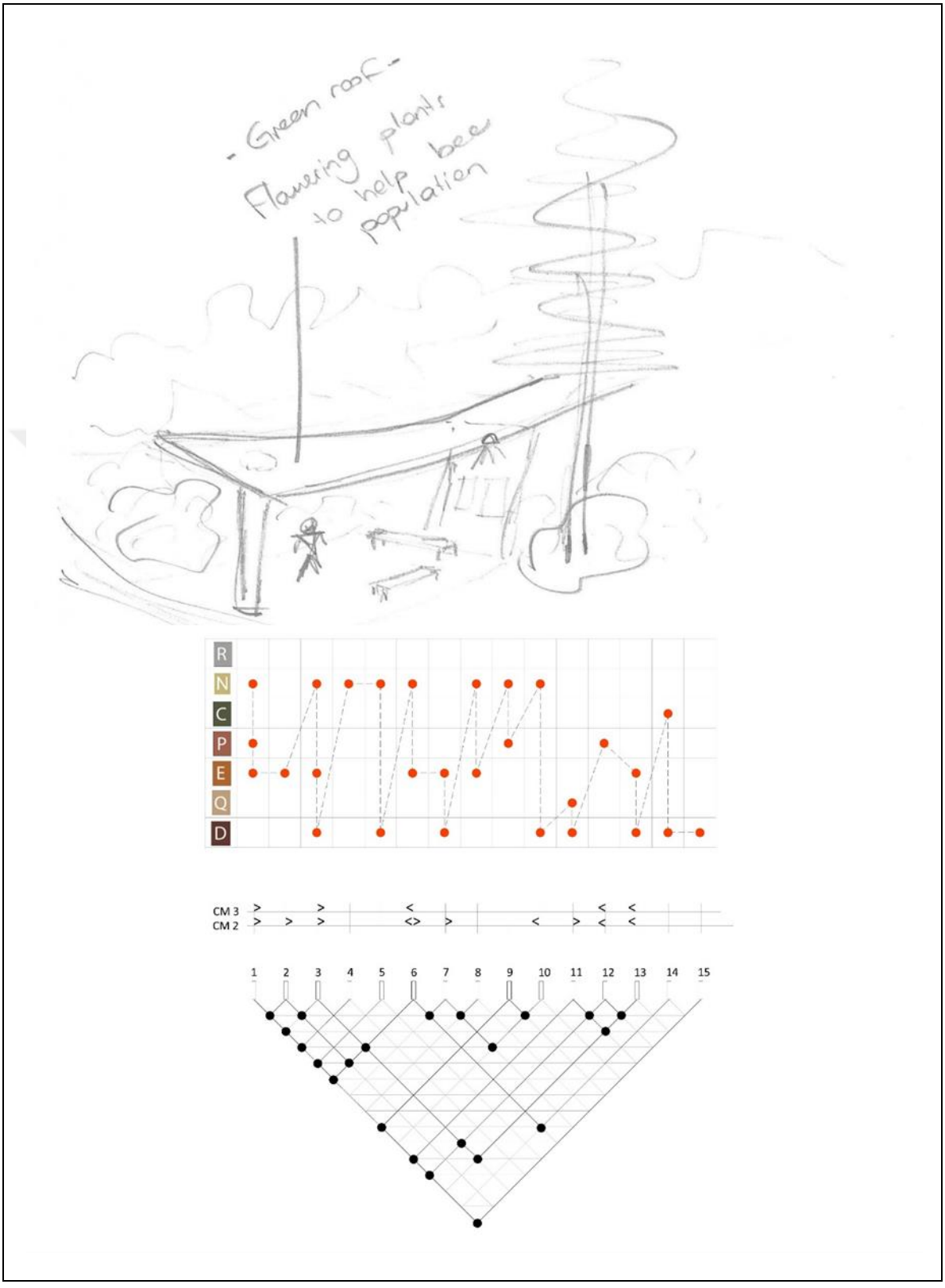


Figure 4.13. Sketch and Graph of Participant E in PE with analog.

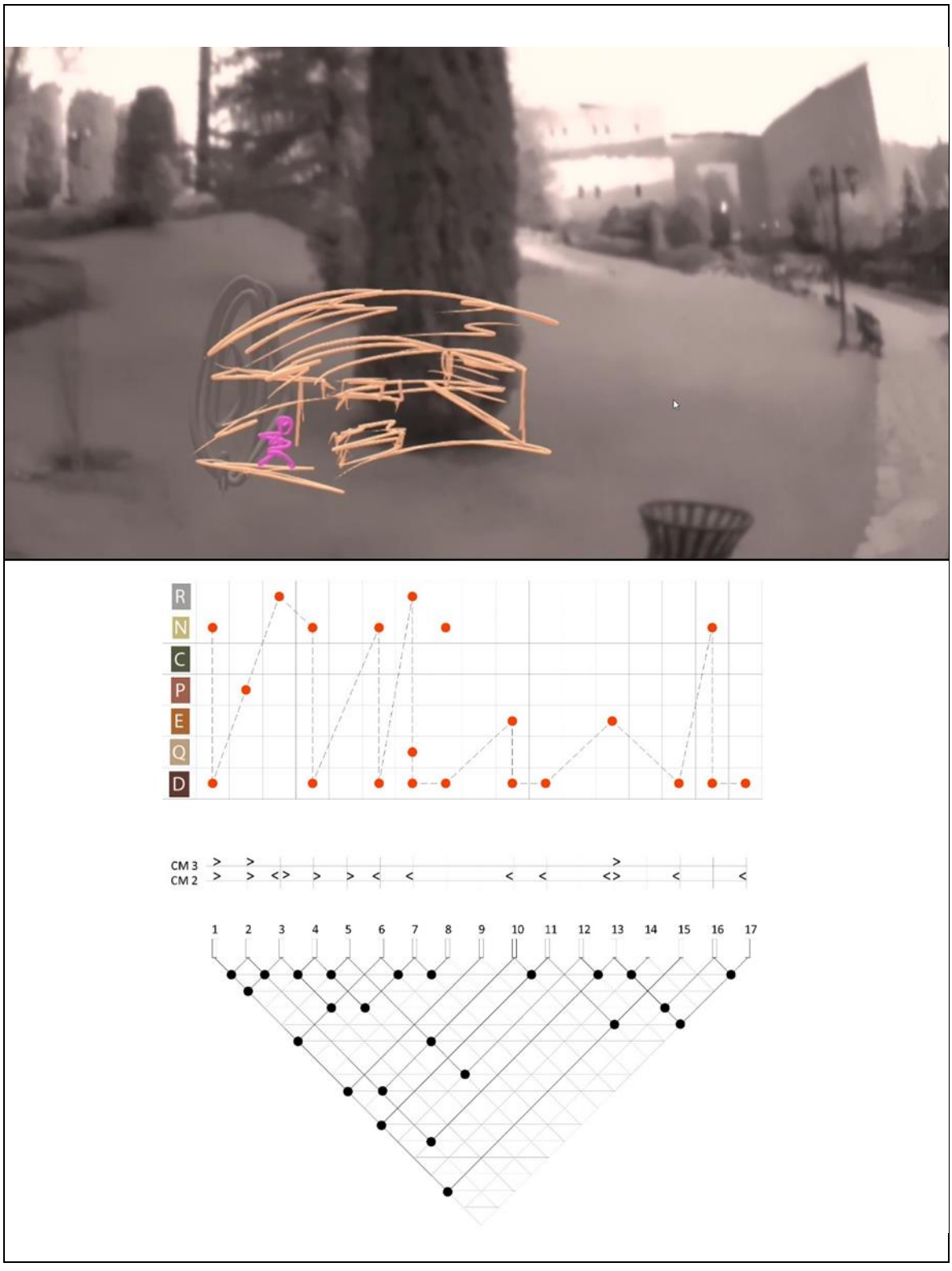


Figure 4.14. Sketch and Graph of Participant E in IE with AR.

Participant F in PE;

The graphic and sketch of Participant F's design process in the physical environment (PE) is shown in Figure 4.15. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant F produced a total of 20 movements and 25 links in the physical environment with analog. The link index of the design process is 1.8. Considering the links of the movements, the threshold was set at 3 (CM3). The total number of forward and backward CM3s is 11. The ratio of this to the whole process is 55%. Participant F's productivity values shows in Table 4.31.

Chunk: In linkograph of Participant F, M6-M11 (5) a chunk pattern appeared between these movements. During these movements, the participant identified wooden slats on which to place brochures and then suggested that these slats could be transformed into a seat.

Sawtooth: Participant F; M6- M11 (6) were observed as a total of %64 in the physical environment with analog.

Table 4.31. Participant F's productivity values in PE with analog.

F	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
PE with analog	20	35	1,8	11	55

Participant F's number of design conversation elements is shown in Table 4.32. Participant F spent, 0% of the time referencing, 29% naming, %12 constraining, 6% proposing, %15 explaining, 6% questioning, 32% decision making in the physical environment. The total loop of the physical environment was in seven average minutes. The number of design loops observed was 9 (M1-M6, M7, M8, M9-M11, M12-M14, M15, M16, M17, M19-M20) in PE with analog. In general, participant F thought aloud about the material of the bookshelves, which were made of wooden slats. Participant F's one-minute think aloud section in PE, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.33.

Table 4.32. Participant F's number of design conversation elements in PE with analog.

F	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with analog	0	29	12	6	15	6	32

Table 4. 33. Example of segmentation of participant F in PE.

Timeline	Move No	Participant F in PE with Analog session
00:00:10	M1	Well, then. Let me see the measurements. Two, three, height two six. Then I'll draw it two metres high. I'll draw a foot of sixty centimetres.
00:00:20	M2	Standard. Do I need to take these measurements? Like, for example, the one I wrote down here.
00:00:30	M3	Two thousand sixteen. Then I draw two shelves at the top, sixty by sixty by sixty-two. Two metres wide.
00:00:40	M4	The height is left at a very nice twenty. One twenty down, sorry. We've got one root height left. Then we'll have a full stand of three metres.
00:00:50	M5	It's useless. Useless. I got out of there, but then this deep part...
00:01:00	M6	Have him draw the depth we're going to put a couch underneath, a two-seater. Let me start this a little bit further back. The bookcase and the seating area will be in the same place at the same time.

Participant F in IE;

The graphic and sketch of Participant F's design process in the immersive environment (IE) is shown in Figure 4.16. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant F produced a total of 13 movements and 20 links in the immersive environment with VR. The link index of the design process is 1.5. Considering the links of the movements, the threshold was set at 3 (CM3). The total number of forward and backward CM3s is 6. The ratio of this to the whole process is 46%. Participant F's productivity values shows in Table 4.34.

Chunk: it was not observed

Sawtooth: Participant F; M6- M10 (5) were observed as a total of %38 in the immersive environment with VR.

Table 4.34. Participant F's productivity values in IE with analog.

F	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with VR	13	20	1,5	6	46

Participant F's number of design conversation elements is shown in Table 4.35. Participant F spent, 4% of the time referencing, 36% naming, %0 constraining, 8% proposing, %24 explaining, 0% questioning, 28% decision making in the immersive environment. The total loop of the immersive environment was in four average minutes. The number of design loops observed was 7 (M1, M2-M5, M6-M7, M8, M9-M10, M11-M12, M13) in IE with VR. Participant F's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.36.

Table 4.35. Participant F’s number of design conversation elements in IE with VR.

F	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with VR	4	36	0	8	24	0	28

Table 4. 36. Example of segmentation of participant F in IE.

Timeline	Move No	Participant F in IE with VR session
00:00:10	M1	First rectangular like this. Closed on all sides. I've drawn a stop where it won't rain. Like this. Then I drew a stall here
00:00:20	M2	And in order to make it more aesthetically pleasing in appearance, I create it not as a glass ceiling but with such wooden notes. Like this. Even these wooden slats are slanted slats like this
00:00:30	M3	It can let in light when it needs to. But it's rainproof. Because my hand is in the opposite direction. Like this. And then you can put the shelves
00:00:40	M4	I even do it like this. Behind it, I make it completely closed. Behind it, I continue these wooden wests in this way. Again, in order to provide a visual integrity in order to be compatible with each other, all of the wooden horses
00:00:50	M5	I'm going down like this. Like this. The ice ancestors above and below serve no purpose. They're just
00:01:00	M6	As for the ones in the middle, I make such data like this. I give a very thin thickness between them that you can put a brochure. And I give height.

Figure 4.15. Sketch and Graph of Participant F in PE with Analog.

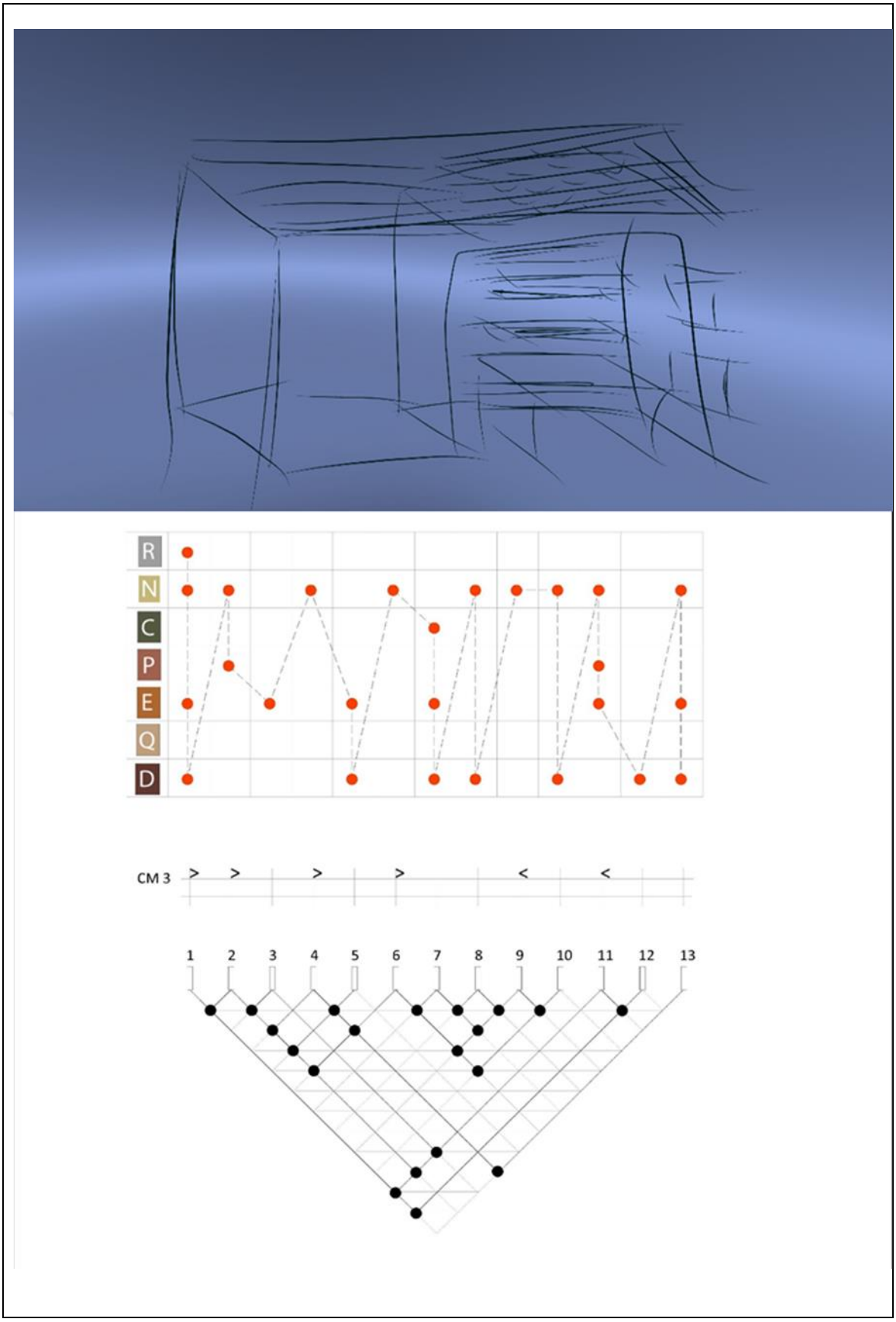


Figure 4.16. Sketch and Graph of Participant F in IE with VR.

Participant G in PE;

The graphic and sketch of Participant G's design process in the physical environment (PE) is shown in Figure 4.17. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant G produced a total of 36 movements and 48 links in the physical environment with digital. The link index of the design process is 1.3. Considering the links of the movements, the threshold was set at 4 (CM4) and 5 (CM5). The total number of forward and backward CM4s and CM5s is 3. The ratio of this to the whole process is 8%. Participant G's productivity values shows in Table 4.37.

Chunk: It was not observed

Sawtooth: Participant G; M8- M14 (7) were observed as a total of %19 in the physical environment with digital.

Table 4.37. Participant G's productivity values in PE with digital.

G	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
PE with digital	36	48	1,3	3	8

Participant G's number of design conversation elements is shown in Table 4.38. Participant G spent, 0% of the time reference, 32% naming, %2 constraining, 9% proposing, %32 explaining, 11% questioning, 14% decision making in the physical environment. The total loop of the physical environment was in average minutes. The number of design loops observed was 6 (M1-M6, M7, M8-M12, M13-M15, M16, M17-M23, M24-M36) in PE with digital. Participant G 's design loops included that more than one design conversation elements. Because of this, loops have many design moves and it is intensive. Participant G's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.39.

Table 4.38. Participant G's number of design conversation elements in PE with digital.

G	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with Digital	0	32	2	9	32	11	14

Table 4. 39. Example of segmentation of participant G in PE.

Timeline	**Move No**	**Participant G in PE with Digital session**
00:00:10	M1	First of all, let's define the area.
00:00:20	M2	Let me draw a buckthorn tree
00:00:30	M3	That's where the road leads. It's a bit of a fix. There's these
00:00:40	M4	Now, don't forget to draw these. Anything can happen. It gets messy. Yes, it does. Now. I have such a green area. I have a tree here.
00:00:50	M5	Let's play a little in the corner. What have we got? Two, three, two point six.
00:01:00	M6	Two metres wide. Three metres tall. No. Two point six. Depth. Three metres? It will be something you can sit in.

Participant G in IE;

The graphic and sketch of Participant G's design process in the immersive environment (IE) is shown in Figure 4.18. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant G produced a total of 20 movements and 30 links in the immersive environment with AR. The link index of the design process is 1.5. Considering the links of the movements, the threshold was set at 3 (CM3) and 4 (CM4). The total number of forward and backward CM3s and CM4 is 9. The ratio of this to the whole process is 45%. Participant G's productivity values shows in Table 4.40.

Chunk: In linkograph of participant C, M3-M10 (8) a chunk pattern appeared in an immersive environment with AR. Among these movements, the participant wanted to establish a relationship with the tree in the area he designed. It can be mentioned that he made various suggestions about the upper cover and seating unit.

Sawtooth: Participant G; M5- M10 (6) were observed as a total of %30 in the immersive environment with AR.

Table 4.40. Participant G's productivity values in IE with AR.

G	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with AR	20	30	1,5	9	45

Participant G's number of design conversation elements is shown in Table 4.41. Participant G spent, 0% of the time referencing, 34% naming, %0 constraining, 17% proposing, %10 explaining, 7% questioning, 31% decision making in the immersive environment. The total loop of the immersive environment was in average minutes. The number of design loops observed was 7 (M1-M5,M6-10,M11-M13,M14,M15,M16-M17,M18-M20) in IE with AR. Participant G's one-minute think aloud section, including the first six design moves from the approximately ten-minute design process, is shown in Table 4.42.

Table 4.41. Participant G's number of design conversation elements in IE with AR.

G	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with AR	0	34	0	17	10	7	31

Table 4. 42. Example of segmentation of participant G in IE.

Timeline	Move No	Participant G in IE with AR session
00:00:10	M1	Firstly, I have again specified the environment
00:00:20	M2	Now I actually wanted to do something organic. Because I can't be in front of me at the moment, I have described the space in front of me again
00:00:30	M3	It's actually a sloping area. I want to make it a little greener. I mean, I want it to be integrated with that green rather than a school.
00:00:40	M4	Ha. Although I did it about like this in the sketch I made with a digital tablet. But a little more so that people can sit on all sides....
00:00:50	M5	(sketcing a sitting area)
00:01:00	M6	(sketching the top cover)

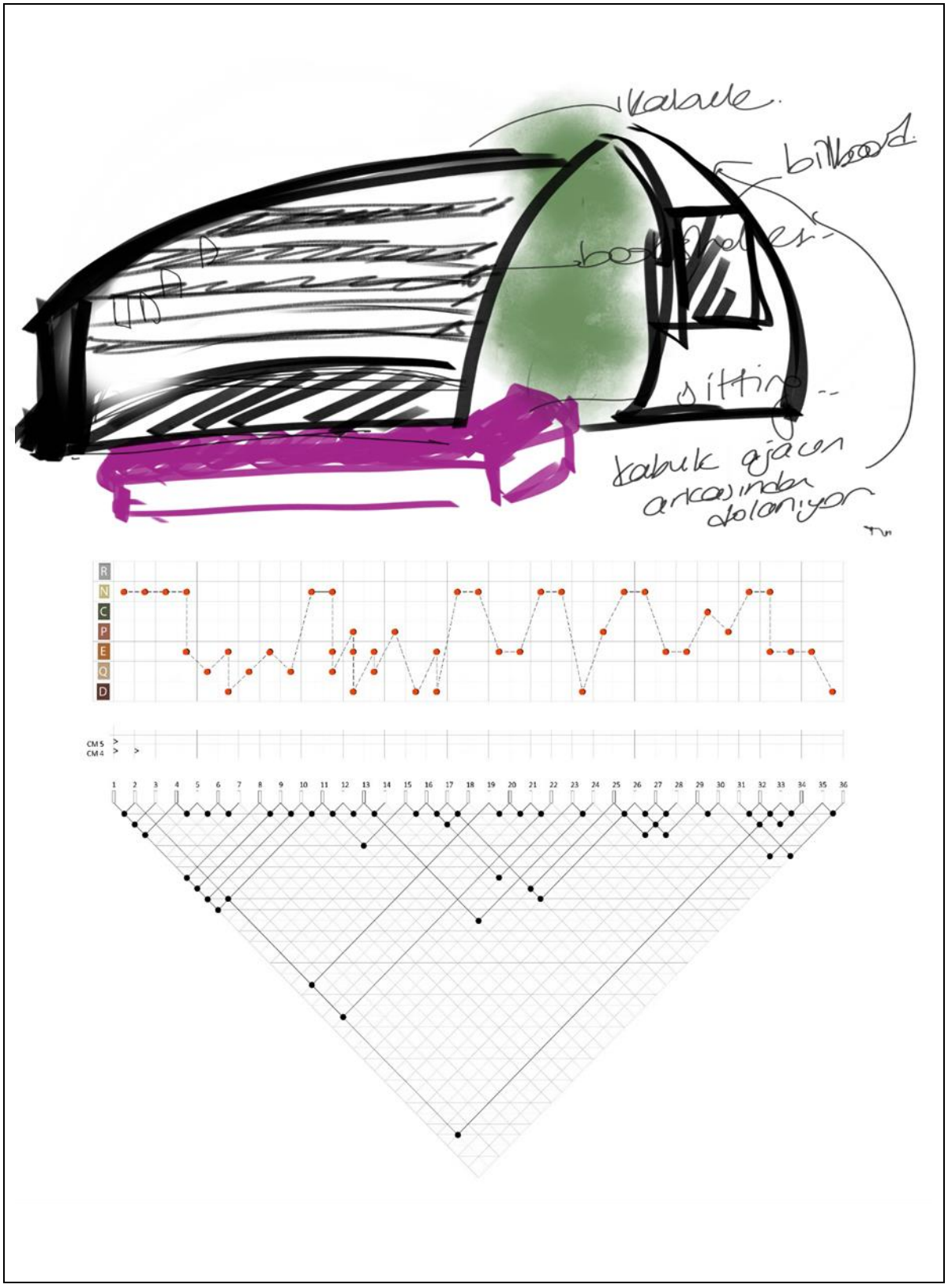


Figure 4.17. Sketch and Graph of Participant G in PE with Digital.

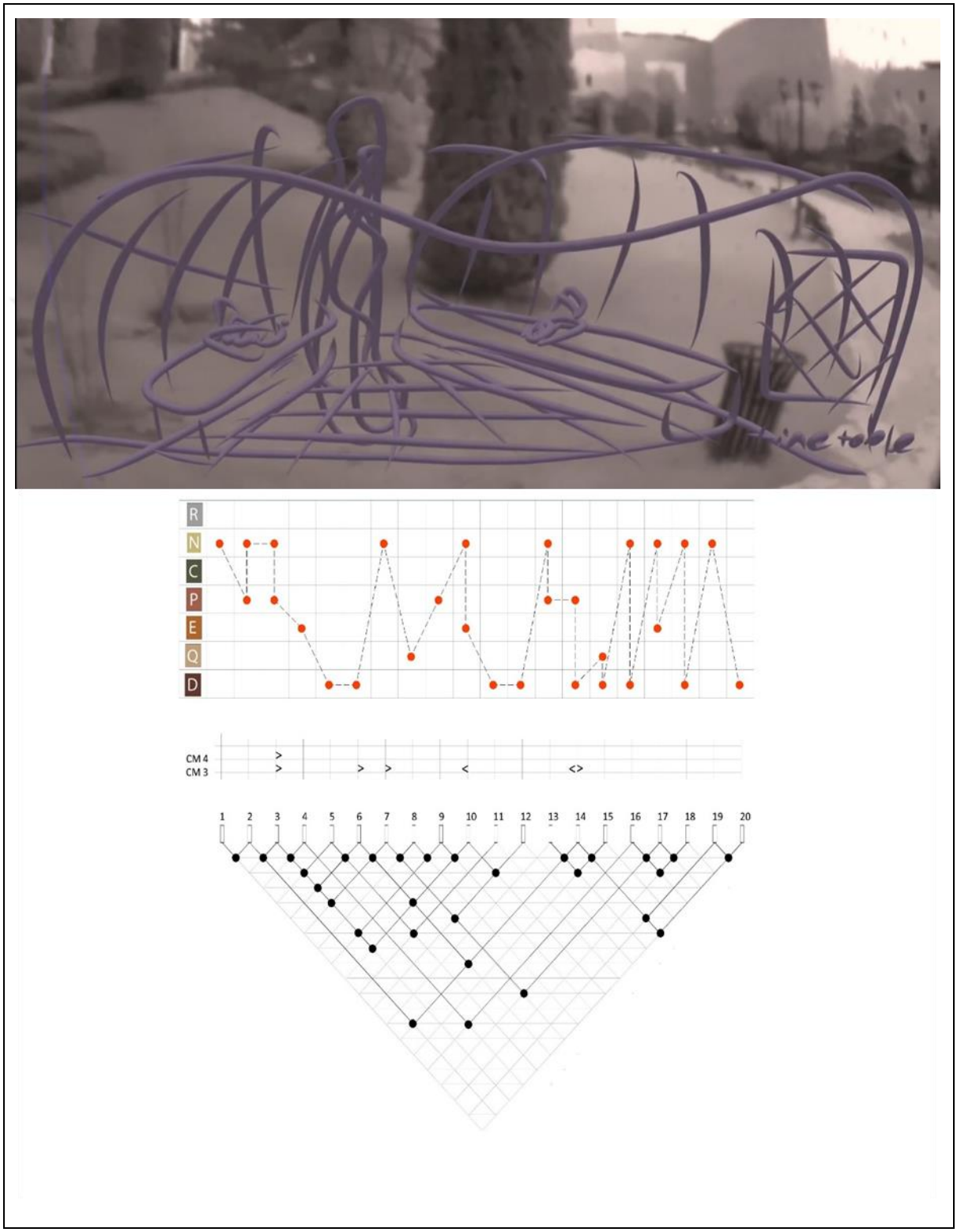


Figure 4.18. Sketch and Graph of Participant G in IE with AR.

Participant H in PE;

The graphic and sketch of Participant H's design process in the physical environment (PE) is shown in Figure 4.19. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant H produced a total of 16 movements and 19 links in the physical environment with digital. The link index of the design process is 1.2. Considering the links of the movements, the threshold was set at 3 (CM3). The total number of forward and backward CM3s is 3. The ratio of this to the whole process is 19%.

Chunk: It was not observed.

Sawtooth: Participant H’s linkograph was not detected in the physical environment with digital.

Table 4.43. Participant H's productivity values in PE with digital.

H	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
PE with digital	16	19	1,2	3	19

Participant H's number of design conversation elements is shown in Table 4.44. Participant H spent, 0% of the time referencing, 29% naming, %4 constraining, 11% proposing, %25 explaining, 4% questioning, 29% decision making in the physical environment. The total loop of the physical environment was in five average minutes. The number of design loops observed was 6 (M1-M5, M6-M8, M9, M10-M11, M12-14, M15-M16) in PE with analog. Participant H's one-minute think aloud section, including the first six design moves from the approximately five-minute design process, is shown in Table 4.45.

Table 4.44. Participant H's number of design conversation elements in PE with digital.

H	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
PE with digital	0	29	4	11	25	4	29

Table 4. 45. Example of segmentation of participant H in PE.

Timeline	Move No	Participant H in PE with digital session
00:00:10	M1	Let's imagine a place like this. A road like this, actually, at this height.
00:00:20	M2	we have a tree here. A tree.
00:00:30	M3	Next to it is this light...
00:00:40	M4	A lamp. A light lamp like this.
00:00:50	M5	We need to set up a station here at work.
00:01:00	M6	Something like this

Participant H in IE;

The graphic and sketch of Participant H's design process in the immersive environment (IE) is shown in Figure 4.20. While the linkograph includes the connection between design movements and critical movements, the graphic with red dots above includes the design conversation elements and the loop between them.

Participant H produced a total of 17 movements and 27 links in the immersive environment with VR. The link index of the design process is 1.6. The total number of CM is 4. The ratio of this to the whole process is 24%. Participant H's productivity values shows in Table 4.46.

Chunk: M4-M8, a chunk pattern appeared in an immersive environment with VR. Among these movements, it can be said that the participant worked on a table where two people can sit. It was observed that he was working on the idea that the top of this table should be closed and for information purposes at the entrance.

Sawtooth: Participant H's linkograph was not detected in the immersive environment with VR.

Table 4. 46. Participant H's productivity values in IE with VR.

H	Number of Moves	Number of Connection	Link Index	CM Number	CM Number (%)
IE with VR	17	27	1,6	4	24

Participant H's number of design conversation elements is shown in Table 4.47. Participant H spent, 10% of the time referencing, 29% naming, %4 constraining, 11% proposing, %25 explaining, 4% questioning, and 29% decision making in the immersive environment. The total loop of the immersive environment was in five average minutes. The number of design loops observed was 6 (M1-M5, M6-M8, M9, M10-M11, M12-14, M15-M16) in IE with VR. Participant H's one-minute think aloud section, including the first six design moves from the approximately five-minute design process, is shown in Table 4.48.

Table 4.47. Participant H’s number of design conversation elements in IE with VR.

H	Referencing	Naming	Constraining	Proposing	Explaining	Questioning	Decision Making
IE with VR	10	20	0	5	10	5	50

Table 4. 48. Example of segmentation of participant H in IE.

Timeline	Move No	Participant H in IE with VR session
00:00:10	M1	Okay. [laughs] So let's think of a square space.
00:00:20	M2	and then we'll think of a place like a wall with books.
00:00:30	M3	With shelves on top...
00:00:40	M4	Let's think of a table for two.
00:00:50	M5	Table like this.
00:01:00	M6	where people can sit and read a book.

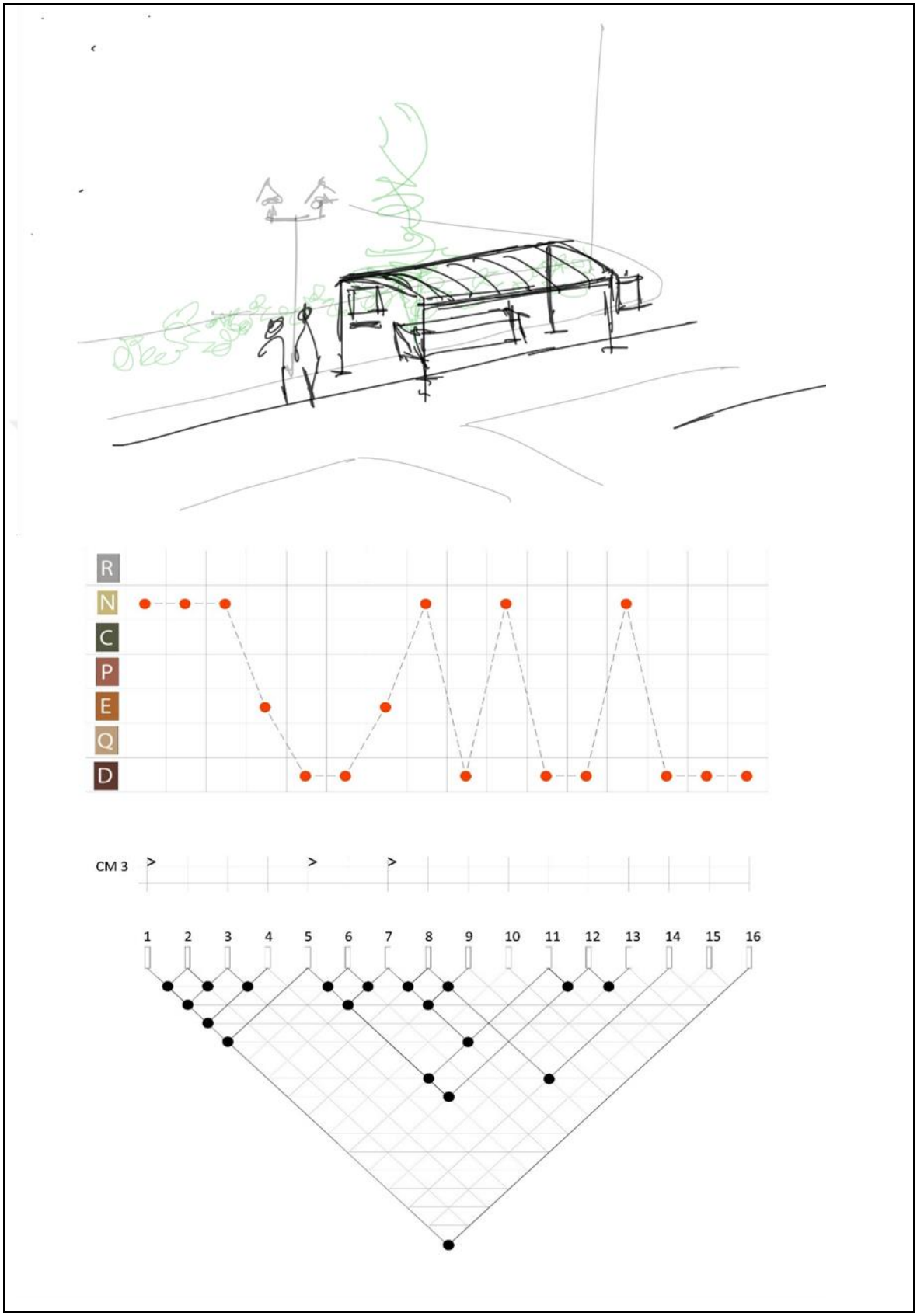


Figure 4.19. Sketch and Graph of Participant H in PE with Digital.

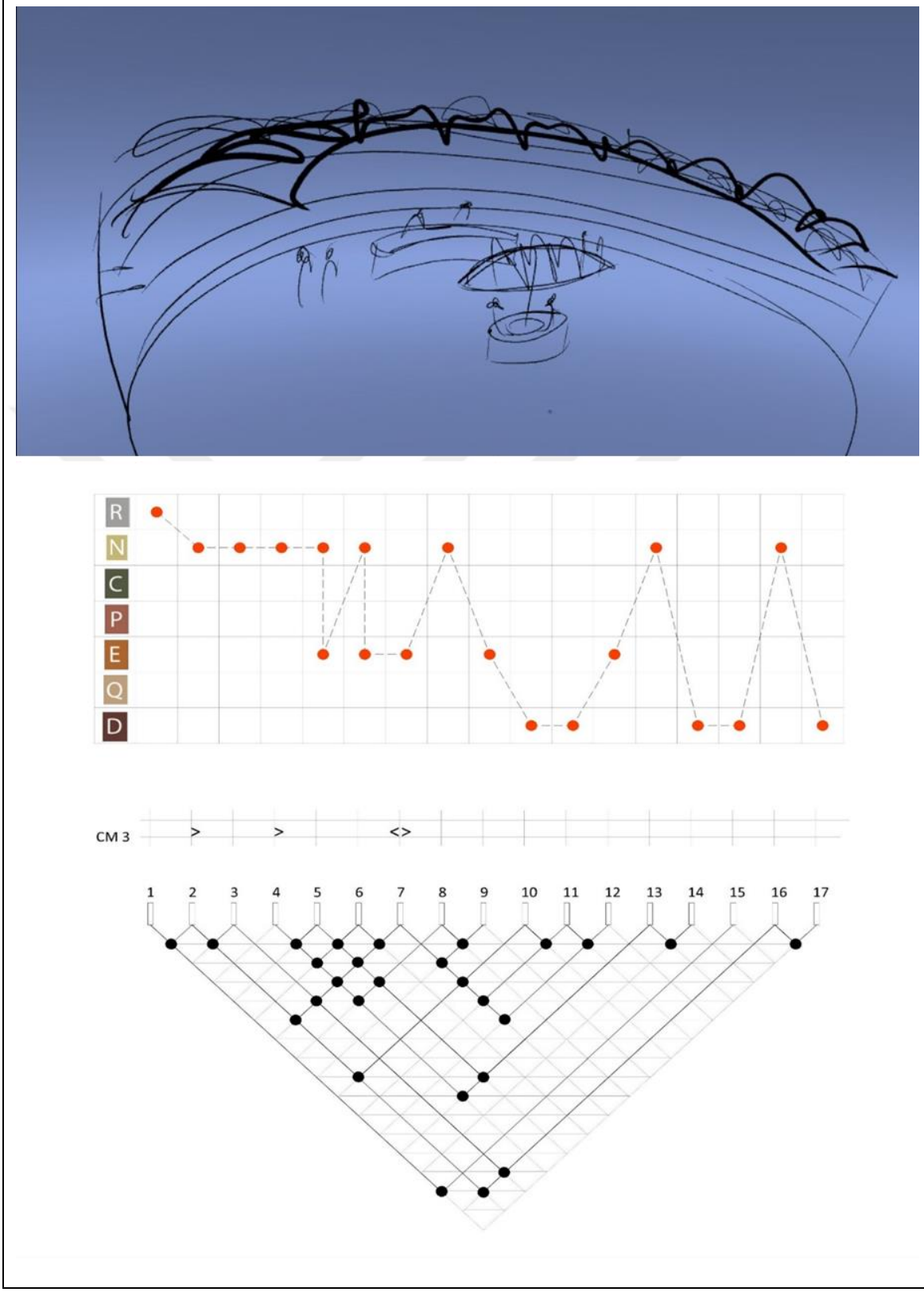


Figure 4.20. Sketch and Graph of Participant H in IE with VR.

Within the framework of this study, in both the physical environment and the immersive environment protocols, there is a situation of dense connection generation (6 connections with 4 consecutive movements) between a relatively small number of movements. However, as Goldschmidt (1990) stated about the "web" pattern, the situation of generating 12-13 connections consisting of 7-8 consecutive movements were not observed. This may be due to the fact that the elements of the design tasks in the study were relatively undeveloped, as the study was carried out in the early design phase. Each participant was asked 8 questions about the experimental environments they had designed after the two sessions. The questions are listed in Table 4.49.

Table 4.49.Questions asked to participants after the experiment.

Q1:	When you start sketching in conceptual design, which environment do you tend to use for your future designs?
Q2:	What conceptual design environments/tools will you use in your future design work?
Q3:	What conceptual design environments/tools do you recommend to your colleagues?
Q4:	What environment do you prefer to support creativity in design?
Q5:	Which environment do you feel most comfortable in for early concept design?
Q6:	Would you prefer to use these experiment environments set up for the conceptual design phase in later design phases? If so, which one would you prefer to use in the further design phase?
Q7:	Which environment do you prefer to better express your design ideas?
Q8:	Which environment limited your design thinking?

According to the participants' answers, the tables. realised that the graphs Table 4.50 shows the general distribution of responses between the physical and immersive environments. Table 4.51 shows the distribution of the participants' answers according to the environments, divided into two and four in total within the physical and immersive environments.

When evaluating within the physical and immersive environments: When the answers to the question " When you start sketching in conceptual design, which environment do you tend to use for your future designs?" were analyzed, five of the participants stated that they would prefer to use the physical environment. In the answers given to the question " What conceptual design environments/tools will you use in your future design work?", five of the participants stated that they would prefer physical environment. In the question "What conceptual design environments/tools do you recommend to your colleagues?", six participants stated that they would recommend the immersive environment and two people would recommend the physical environment to other colleagues. In response to the question "Which environment do you prefer to support creativity in design?'', three participants answered that physical environment supports creativity, while five participants answered that immersive environment supports creativity. When asked "Which environment do you feel most comfortable in for early concept design", four participants mentioned the physical environment and four participants mentioned the immersive environment. It was observed that the preference for the two environments was at the same level. Would you prefer to use these experiment environments set up for the concept design phase in later design phases? If so, which one would you prefer to use in the further design phase?'', five participants mentioned physical and three participants mentioned immersive. Participants who said physical environment generally mentioned that they would prefer an immersive environment for the early design phase. After starting the design in the immersive environment in the early design phase, they stated that it was more appropriate to develop it in the physical environment. When asked "Which environment do you prefer to better express your design ideas", six participants mentioned that the immersive environment improves their ideas in the design process, while two participants mentioned that the physical environment is more developer. When analyzing the answers to the question "Which environment limited your design thinking?", four participants answered that the physical environment limited their design thinking, while four participants answered that the immersive environment limited their design thinking.

Table 4.50. Graphs within PE and IE.

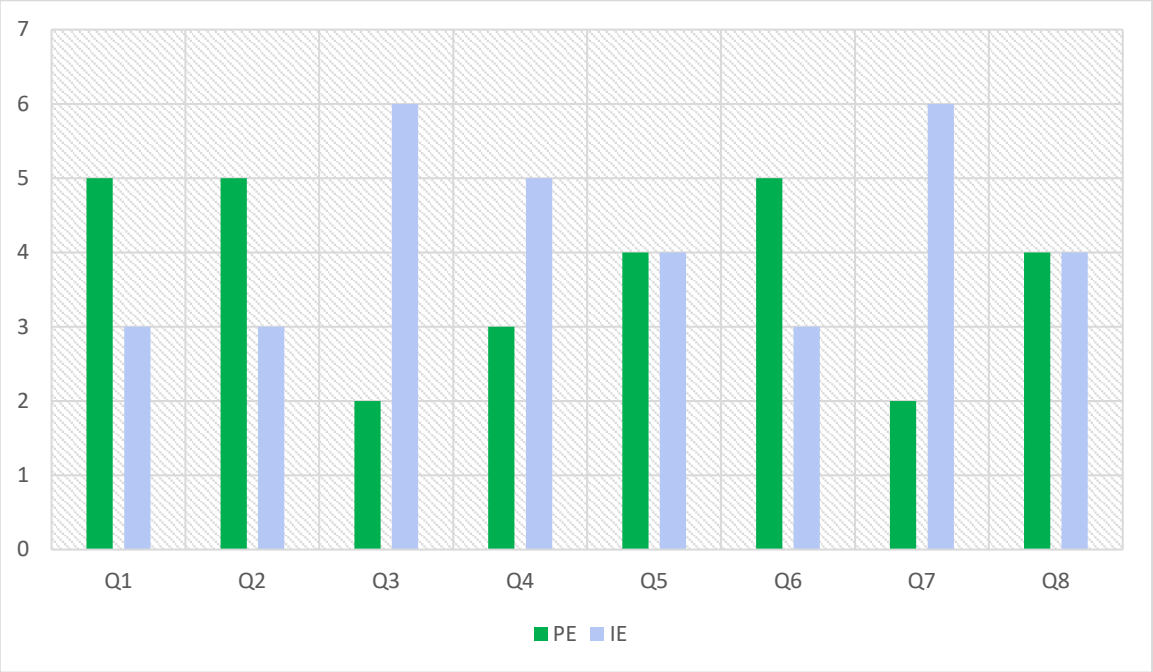
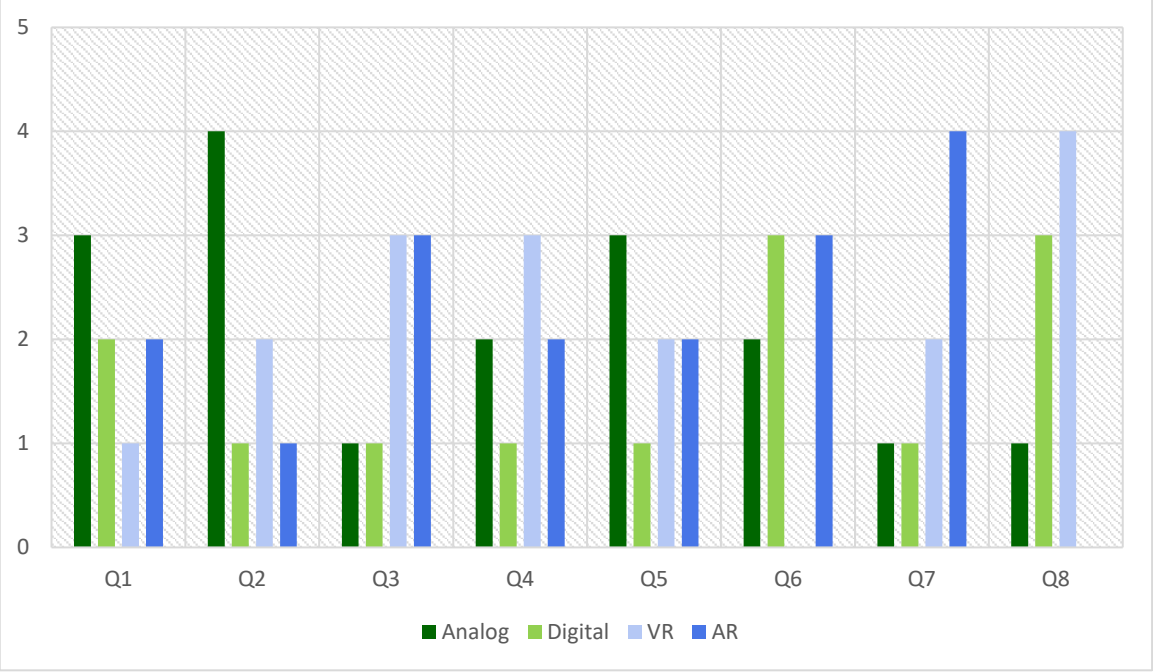


Table 4.51. Graphs within PE with analog or digital and IE with VR or AR.



The distribution of answers given to the questions after the experiment in the physical and immersive environments was also analyzed, as shown in the figure. Looking at the responses to Q1, it was observed that three participants responded as analog and two participants responded as digital. Overall it was observed that one participant answered as VR and two participants answered as AR. Four participants answered Q2 as analog and one as digital. Looking at the total responses to the same question, it was observed that two participants answered as VR and two participants answered as AR. Q3 was answered by one participant as analog and one participant as digital. It can be said that three participants answered the same question as VR and three participants as AR. Looking at Q4, two participants answered analog and one participant answered digital. It was observed that three participants answered the same question as VR and two participants answered as AR. It can be said that three participants answered Q5 as analog and one participant answered as digital. It was observed that two participants answered the same question as VR and two participants answered as AR. Q6 was answered as analog by two participants and as digital by three participants. The same question was not answered as VR and three participants answered as AR. When analyzing the responses to Q7, one participant answered analog and one answered digital. The same question was answered as VR by two participants and as AR by four participants. Finally, one participant answered Q8 as an analog and three as digital. It can be said that four participants answered the same question as VR, while it was observed that there were no participants who answered as AR.

4.2. RESULTS OF THE EXPERIMENTS

The analyses by participant were carried out one after the other in the section ‘’4.1. Analysis of the data obtained’’. With reference to the detailed analyses in that section, the results of the environment-based experiments are described in this section. The status of each environment and the results of the experiments with each other are described in this part.

4.2.1. Evaluation of each environment

Linkographs with design conversation elements were created by looking at the participants' design moves during the experiment. To analyze each session, the total number of

movements, the total number of connections, the connection index, the CMs, and the CMs ratio were evaluated according to the linkograph graphs. When the PE is evaluated within itself, it is seen that the CM rate is higher in design processes using PE with analog. This shows that designers produce rich connections with each other in this process mostly PE with analog. When the link index and CM ratio totals, which are used to interpret design productivity, are analyzed, it is seen that the designers have a more productive and creative process in the sketches produced with PE with analog.

Table 4.52. CMs ratio.

CM (%) Total			
PE with analog	PE with digital	IE with VR	IE with AR
166	86	146	201

Table 4.53. Design productivity ratio.

Design Productivity (CM+ Link Index)			
PE with analog	PE with digital	IE with VR	IE with AR
173	90	128	230

Table 4.54. Total design conversation elements loops according to environment.

PE with analog	PE with digital	IE with VR	IE with AR
36	32	37	30

When the IE is evaluated within itself, it is seen that the IE with VR produces less CM than the IE with AR. This shows that the IE with AR is rich in connectivity and has movements that support productivity. This result is also supported when the CM rate and link index are collected in order to interpret creativity.

The PE is assessed by analog and digital. The referencing is seen on the digital with a low rate according to the overall situation. One participant sketching with a digital made a reference during the design. The naming rates are generally quite close. The rate of limiting expressions is higher PE with analog. The rate of proposing is higher in PE with digital. The rates of explaining are the same. The rate of asking questions is higher in the PE with digital. It can be seen that the rate of decision-making is higher in the PE with analog. In addition, the total number of loops in the PE with analog is higher than the number of loops in the PE with digital. This shows that creativity and productivity are more effective in PE with analog.

The IE is evaluated as AR and VR. It can be seen that the rate of referencing is higher in the IE with AR. This may be related to establishing a relationship with the context or being influenced by the surrounding structures or building elements. The naming rate is quite close and the use of constraining expressions is higher in the environment with VR. This may be because the designers are sketching on a completely virtual ground. The proposed rate is higher in the IE with AR. The reason for this may be the desire to support the sketch with new suggestions due to the better relationship with the sketch in the IE. The explaining rate is higher in the IE with VR, which may be related to the inability to establish a relationship with the environment and the designer's desire to use explanatory expressions while trying to get the sketch accepted. The rate of asking questions to oneself is higher in the environment with AR. This may be related to the designer's focus on finding problems rather than solving them, encountering more problems with a one-to-one scale drawing close to reality, and asking themselves questions. The rate of decision-making is fairly close in both environments but is higher in the environment with AR.

When looking at the design conversation elements' loops, the number of loops IE with VR is more than IE with AR. The reason for this is that in IE with VR, it is observed that the designer's effort to express them is greater. The reason for this can be interpreted as an inability to establish a relationship with the ground and the context. In AR, most users immersed themselves in the environment and formed long-lasting meaningful, regular loops. Participants are actually in a physically continuous and strong interaction in the IE with AR. This may be due to the interactive nature of the environment. Participants were observed to be more practice-oriented than language oriented. The method has a number of limitations due to the fact that it does not include gesture data and only processes data related to design conversation elements.

4.2.2. Evaluation within physical/immersive environments

Looking at CM in link graphs in two different environments, PE and IE, it can be seen that there are more CM in the IE. Moreover, when looking at the ratio of the CM+ link index, it's shown that the IE rate is higher in PE. This shows that design productivity is higher in the IE. While orphan moves were found in the link graphs in the PE (not connected to previous and subsequent moves), no orphan moves were found in the experiments in the IE. A large number of links (web) with a small number of movements is more common in the IE. The situation of not approaching the design linearly, i.e. with a holistic perspective (sawtooth), is more common in the physical environment. In addition, when the post-experiment opinions of 8 participants were examined, responses were obtained that supported this conclusion. When asked which environment allowed them to develop their design more, and which environment supported their creativity more, they generally gave answers based on the experimental area in the IE.

When evaluating the PE and IE, it’s shown that the ratio of referencing in an IE is more than in the PE. This could be because designers wanted to relate the real environment to the design they created. It can also be seen that questioning is more intense in PE. It can be said that designers are more decision-oriented than questioning when designing in an IE.

Table 4.55 shows the number of design conversation elements by looking at the graphs in PE and IE. When analysing the graphs of the design conversation elements, while the referencing is 2 in the PE, it is 19 in the IE. Naming is 215 in the PE, it is 222 in the IE. Constraining is 41 in the PE, it is 33 in the IE. Proposing is 87 in the PE, it is 64 in the IE. Explaining is 179 in the PE, it is 138 in the IE. Questioning is 54 in the PE, it is 29 in the IE. Decision making is 194 in the PE, it is 285 in the IE.

Table 4.55. The number of design conversation element loops PE and IE.

	Referencing	**Naming**	**Constraining**	**Proposing**	**Explaining**	**Ouestioning**	**Desicion Making**
PE	2	215	41	87	179	54	194
IE	19	222	33	64	138	29	285

The post-experiment interviews showed that the IE could be used more effectively than the PE for the concept phase. In addition, most participants in the post-experiment interviews stated that the design process would be more productive and creative after increasing their interaction in IE. In addition, participants have been shown to move around their designs as they sketch in IE to get different perspectives. They were also shown sketching the majority of shapes at sizes that fit their bodies. Users attempted to walk through, sit on and look under their drawn forms. Overall, finding solutions, externalizing, testing, and expressing ideas can be said to be easier to sketch with IE.

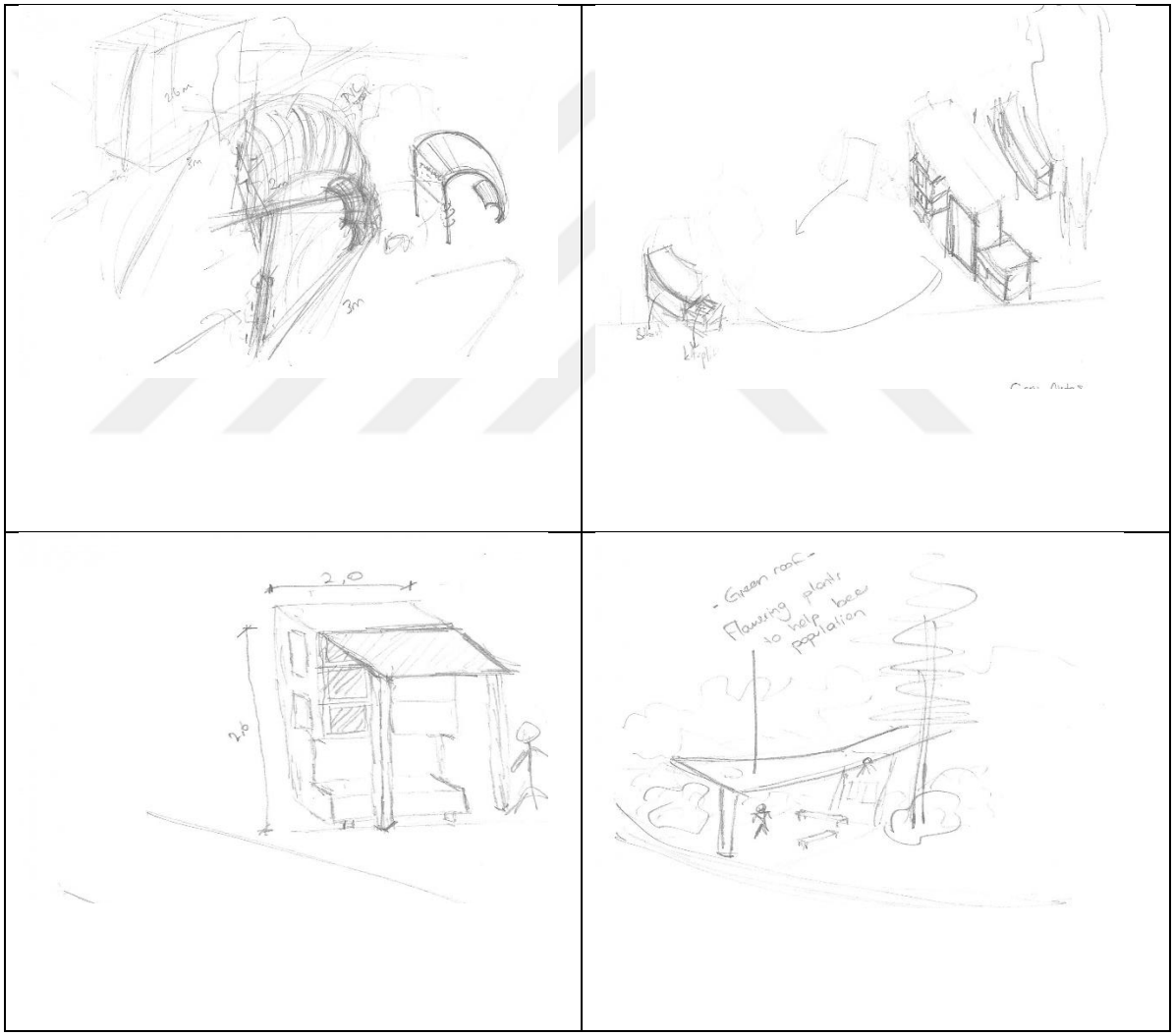


Figure 4.21. Participants' sketches were produced in PE with analog.

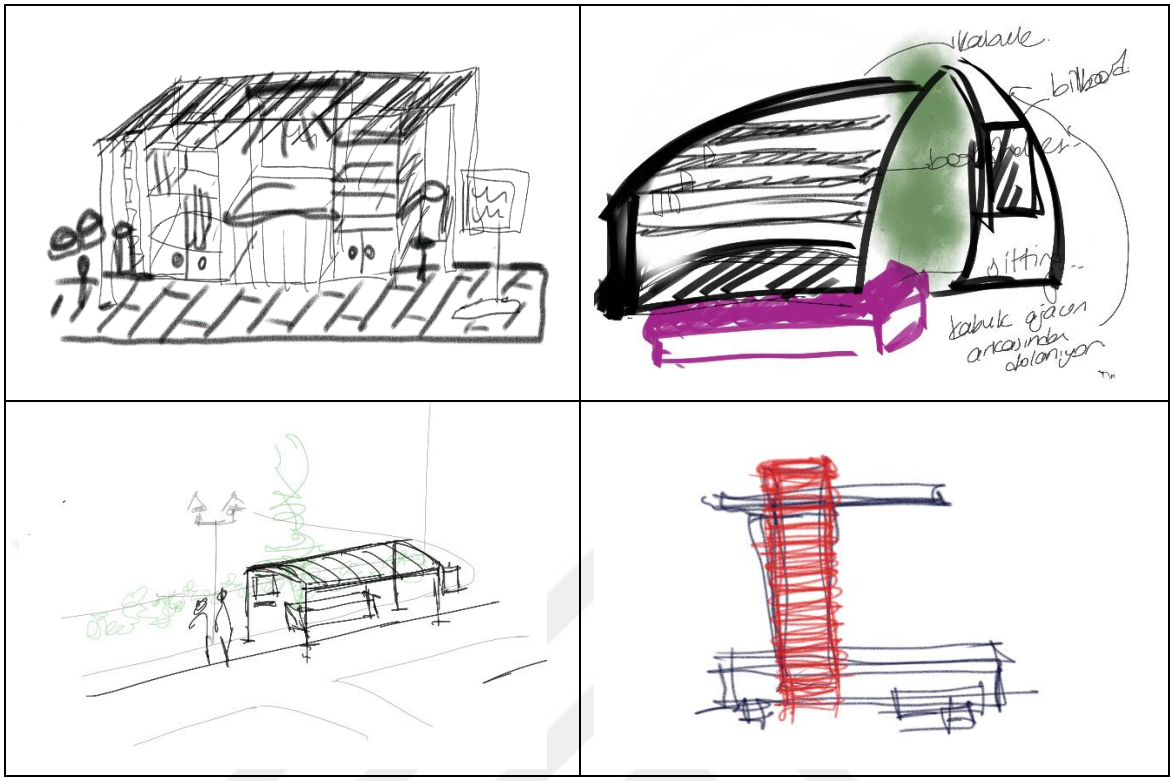


Figure 4.22. Participants' sketches produced were in PE with digital.

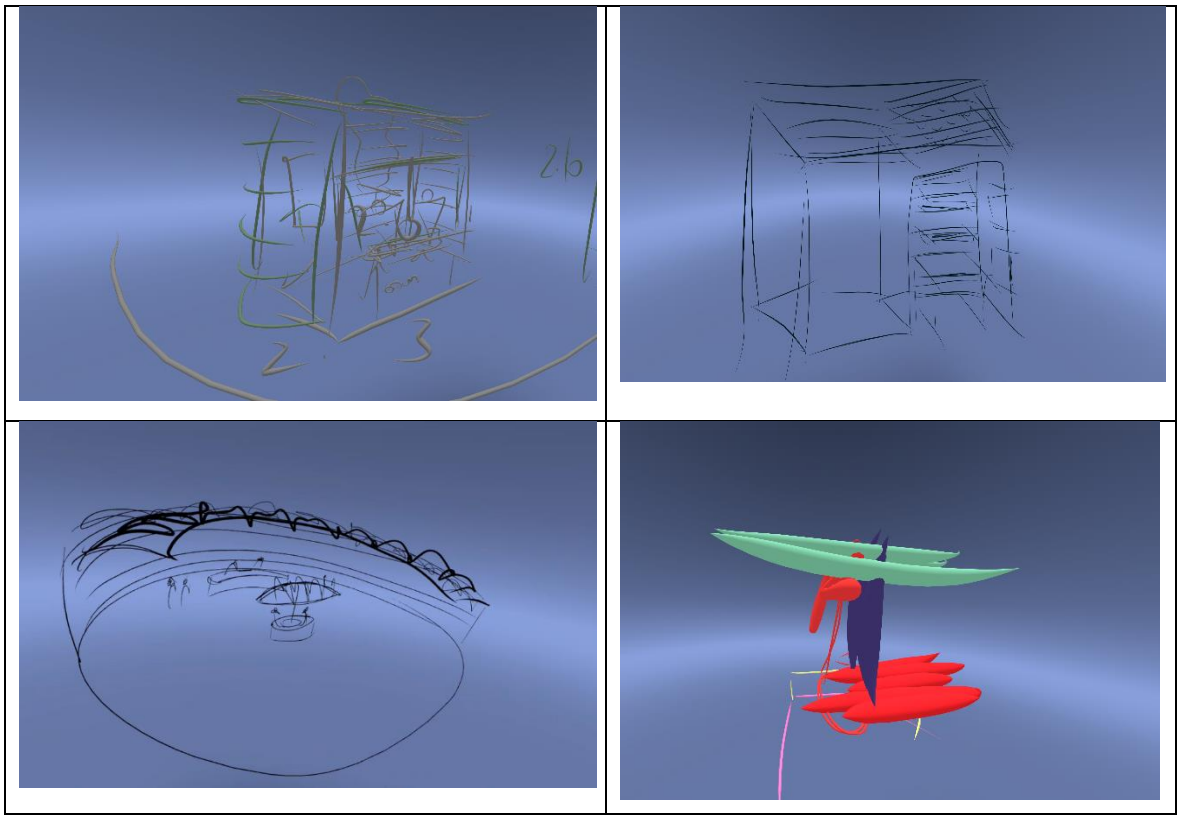


Figure 4.23. Participants' sketches were produced in IE with VR.

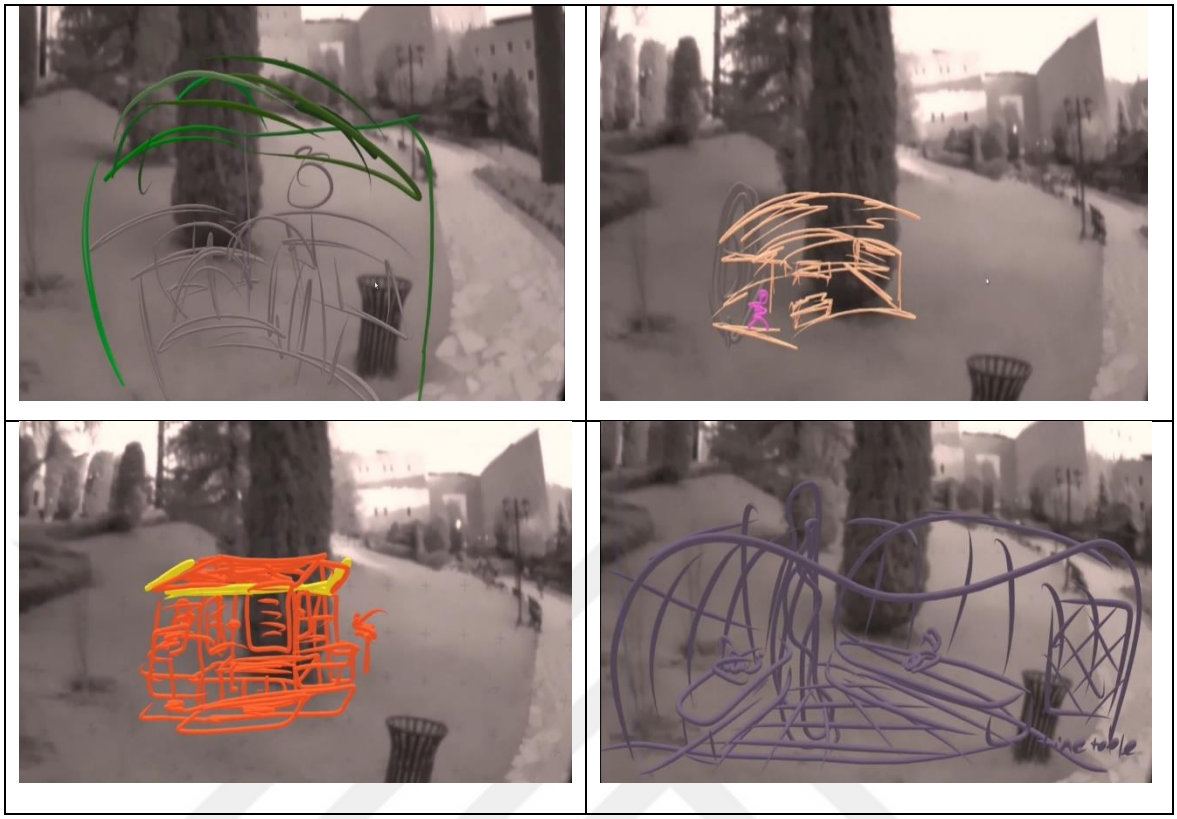


Figure 4.24. Participants' sketches were produced in IE with AR.

4.2.3. Evaluation of environments together

The priority is the general evaluation between the experiments, in the IE with AR it is noteworthy because the relationship with the environment was never interrupted, when evaluated with the design conversation elements, they moved immediately to the decision making after a short explanation. Looking at the areas where the CMs are intense in the linkographs, it can be seen that they are generally related to the idea of establishing a relationship with the tree. The designers often talked about creating a seating area around the tree during the design process. In the later design moves, the backward moves usually occurred while trying to establish a relationship with the tree.

When comparing the PEs within themselves, the number of CMs is higher for analog than for digital. Accordingly, it can be seen that the participants who sketched in the PE with analog had a more productive and creative process than those who sketched in the PE with digital. In addition, the content of the design moves suggests that the participants in the PE with analog found it easier to express themselves during the early conceptual design process.

When analysing the graphs of the design conversation elements, this result is supported. It can be said that the number of loops in PE with analog is higher than in PE with digital. While referencing was never seen in the PE with analog, it was seen 2 times in the PE with digital. While naming is 125 in the PE with analog, it is 117 in the PE with digital. Constraining is 26 in the PE with analog and 15 in the PE with digital. Proposing is 29 in the PE with analog and 58 in the PE with digital. Explaining is the same in both environments and is 90. Questioning is 23 in the PE with analog and 31 in the PE with digital. While the rate of decision making is 107 in the PE with analog, it is 87 in the PE with digital. It can be seen that the rates of asking questions and decision making are opposite. Therefore, in the PE with analog more decision makings were made and more loops were formed. In the PE with digital more questionings were asked and more open-ended thinking occurred. Table 4.56 shows the number of design conversation elements by looking at the graphs in PE.

Table 4.56. The number of design conversation elements loops PE with analog and digital.

	Referencing	**Naming**	**Constraining**	**Proposing**	**Explaining**	**Ouestioning**	**Desicion Making**
PE with analog	0	125	26	29	90	23	107
PE with digital	2	117	15	58	90	31	87

When comparing the IEs, the ratio of CMs in the environment with AR to the IE with VR is quite high. The loop was generally between explanation and decision. Another conclusion regarding the design conversation elements is that referencing was very rare throughout the experiment. Only one participant created a design idea by referring to the building shapes in the environment in the IE with AR. It can also be seen that the ratio of decision making in the environment with AR to the IE with VR is high. This shows that the designers relate better to the context in the IE with AR. In this respect, it can be seen that the IE with AR has positive effects in terms of 3D thinking and 3D application. In the IE with AR, they considered various factors in terms of making suggestions and references about the buildings in the surrounding area, suggesting green plants in the surrounding area, and establishing a relationship with animals during the experiment. In addition, as the design area is located where the ring road of the surrounding area passes by, they had the opportunity to experience a dynamic space. These factors seem to contribute positively to the designer's potential to make new suggestions.

Generally, analog and digital in PE, IE with AR, they generally considered various factors in terms of making suggestions and references about the buildings in the surrounding area, making suggestions about the green plants in the surrounding area, and establishing a relationship with animals during the experiment. As a limitation in IE with VR, participants had difficulty in establishing a relationship with the sketching area because the area was not visible in the IE with VR and they were in an area completely disconnected from the sketching area.

Table 4.57 shows the number of design conversation elements by looking at the graphs in IE. When analysing the graphs of the design conversation elements, referencing is 7 in the IE with VR, it is 10 in the IE with AR. Naming is 109 in IE with VR, it is 113 in the IE with AR. Constraining is 28 in the IE with VR, it is 10 in the IE with AR. Proposing is 28 in the IE with VR, it is 37 in the IE with AR. Explaining is 79 in the IE with VR, it is 59 in the IE with AR. Questioning is 11 in the IE with VR, it is 18 in the IE with AR. Lastly, decision making is 136 in the IE with VR, it is 149 in the IE with AR.

Table 4.57. The number of design conversation elements loops IE with VR and AR.

	Referencing	**Naming**	**Constraining**	**Proposing**	**Explaining**	**Ouestioning**	**Desicion Making**
IE with VR	7	109	19	28	79	11	136
IE with AR	10	113	14	37	59	18	149

5. CONCLUSION

This research was initiated to contribute to the understanding of how environments can be used to play an active role of sketching in the early conceptual design process. This study aims to contribute to the literature on the interaction between designer and environment in the production of sketches in environments and the effectiveness of design in technology-assisted environments. Previous studies have investigated design processes in environments that are embedded in physical environments and include analogue and digital based tools. However, a comprehensive investigation ranging from analogue and digital based within a physical (analogue, digital) environment to immersive (VR and AR) environments has not been undertaken. Therefore, to explore the potential of the sketching process, physical environments were set up as analogue and digital, immersive environments were set up as VR and AR, and sketching experiments were conducted with participants. Therefore, this study elaborates on sub-environments covered by fundamental settings, namely physical and immersive environments. Through this approach, interactions between designers and environments are explored across these four distinct contexts. In this phase, 8 designers participated in the study, with each participant placed within one of the physical (analog, digital) and immersive environments. Each designer completed two design tasks that were deemed equivalent. The experiments were conducted using protocol studies, and the collected data were analyzed through linkography and design discourse analysis methods.

When the observed the participants in experiment sessions, the analogue sketches show that the participants have better hand-finger coordination. When sketching with the digital based , the relationship between the screen and the wrist sometimes interrupted the sketching, but in general one of the most striking features of the digital based in physical environment is that they can easily highlight the structural element they want to emphasise in the sketch by increasing the line thickness. In VR based, participants had to constantly describe the sketch area during the design process. It was observed that the desire to establish a relationship with the ground and the sketch area was constant throughout the design. This experiment shows that designers establish a better relationship with the context in an AR based. In this respect, an AR based has a positive effect on 3D thinking and 3D application. This also shows that when supported with numerical data, designers can use their processes more efficiently in the early design phase.

When the considering the results of the analysis and the overall conditions of the two primary environments according to numerical datas, it can be said that the design process in the immersive environment is more efficient. On the other hand, upon examining the numerical data within the physical environment, it was observed that participants were more efficient in the analog-based environment compared to the digital-based one. In the immersive environment (VR and AR), it was observed that participants in the VR-based environment were completely independent of time and space. Therefore, according to data analyses in the immersive environment, higher efficiency can be attributed to the use of AR in comparison to VR. Additionally, after all experimental sessions were completed, participants were questioned about the experiment. In response, participants stated that the experiences using AR in the immersive environment were more efficient from a procedural perspective.

The headset utilized as a sketching tool in the immersive environment posed limitations during the experimentation due to its usage under sunny conditions. The lenses experienced glare from the sun, resulting in visual distortion and complicating the tracking of control mechanisms. Consequently, in order to derive efficient outcomes from the research, sketching experiments were predominantly conducted during cloudy conditions and closer to sunset hours. Furthermore, within the immersive environment, the device portrays the real surroundings in black and white while sketching, leading to a slightly altered perception of the actual environment for the designer. Moreover, when designing in the immersive environment, the dimensions of the assigned design tasks were established to be closely aligned with human scale dimensions. It is anticipated that undertaking work on a one-to-one scale would become challenging for design problems of larger scales.

The research conducted within the scope of the thesis and the obtained data are of a pilot study nature. It is anticipated that future studies will enhance the reliability of results by increasing the number of participants. Additionally, it is envisaged that comparing data from designers with higher levels of experience, in contrast to the participants in the pilot study, could contribute to the comparative analysis. The results obtained from the study contribute to the definition of the research problem and subsequently add to the existing literature for future endeavors. This study has been carried out to elucidate the relationship between the designer and the environment and to compare different contexts, with the data elucidating the interaction between the environment and the designer and this comparison is executed through different environments. The concept of 'early conceptual design stages in different

environments' will influence the use of these environments and encourage their combined utilization. Therefore, based on the experimental outcomes and the feedback from participants, these potentials should be explored in depth, and the contributions of novel immersive environments should be deliberated upon. Furthermore, the applicability of such a study as a conceptual framework for future projects can be explained by the fact that the outcomes can be analyzed alongside protocol analysis and design conversation elements in the same context. Thus, it offers a research methodology for scholars studying such investigations and paves the way for forthcoming projects. The fundamental question posed by this study, the concept of 'early conceptual design stages in different environments,' is expected to diversify the use of these environments and, in some instances, promote their combined usage.

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APPENDIX A: ETHICS COMMITTEE APPROVAL FORM

T.C.
YEDİTEPE ÜNİVERSİTESİ REKTÖRLÜĞÜ

12.04.2023

Sayı : E.50532705-302.14.01-1523
Konu : Zeynep Selcen Narin Kurul Onayı

İLGİLİ MAKAMA

Üniversitemiz Fen Bilimleri Enstitüsü Mimarlık Yüksek Lisans Öğrencisi Zeynep Selcen Narin'in, Dr. Öğr. Üyesi Faruk Can Ünal danışmanlığında gerçekleştireceği ''An Evaluation of Sketching in Early Conceptual Design Processes: Physical and Immersive Environments'' başlıklı araştırmasının Beşeri Bilimler etik standartlarına uygunluğuna ilişkin Yeditepe Üniversitesi Beşeri ve Sosyal Araştırmalar Etik Kurulu Onayı ekte sunulmuştur.

Gerekli iznin verilmesi hususunu bilgilerinize arz ve rica ederim.

İmza
Prof. Dr. Fatma Yeşim EKİNCİ
Rektör a.
Rektör Yardımcısı

Ek: Etik Kurul Onayı.pdf

Bu belge, güvenli elektronik imza ile imzalanmıştır.
Belge Doğrulama Adresi : http://belgedogrulama.yeditepe.edu.tr/bg.aspx?id=6D62AC6A-0DAA-42F6-ABB6-502CEFEF3177

Yeditepe Üniversitesi 26 Ağustos Yerleşimi, İnönü Mahallesi Kayışdağı Caddesi 34755
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Kep Adresi : yeditepeuniversitesi@hs03.kep.tr

Bilgi İçin: Suat ANAR
Unvan: Öğretim Üyesi
Telefon No: (0216) 578 00 00

Figure A.1. Ethics Committee Approval Form

APPENDIX B: CONSENT FORM

INFORMED CONSENT FORMS AND INFORMATIONS SHEETS

This informed consent form is for architectural designers invited to participate in research MSc thesis entitled " An Evaluation of Sketching Processes in Physical and Immersive Environments''.

Name of the Researcher: Zeynep Selcen Narin

Name of the Supervisor: Assist. Prof. Dr. Faruk Can Ünal

Name of Organization: Graduate School of Natural and Applied Sciences, Yeditepe University, İstanbul

Name of Project and Version: An Evaluation of Sketching Processes in Physical and Immersive Environments, MSc Thesis
This Informed Consent Form has two parts:
• Information Sheet (to share information about the study with you)
• Certificate of Consent (Signature those who agreed to participate) a full copy of the informed Consent Form will be given to participants

Part I: Information Sheet

Introduction
This informed consent form is for architectural designers with at least three years of experience and who are invited to participate in research MSc thesis, titled " An Evaluation of Sketching Processes in Physical and Immersive Environments".
This research explores the evaluation of the sketching process in conceptual design in the early stage of architectural design. Initially, you will be informed and invited to be part of this research. This consent form may contain words not understood. Do not hesitate to ask the researcher to stop and take time to explain while reviewing the information.

Purpose of the research
This study will consider on investigating design productivity in different design environments and designers' interactions in context. Also, this research focuses on the evaluation of the physical and immersive virtual environment in the sketching process. With the development of XR technologies, the contribution of the immersive virtual environment to the architectural design process will be explored. The significance of the study lies in the physical environment, from paper-based and digital media, to immersive. There is a lack of comprehensive work on the sketching process leading up to VR and AR in the medium.

Type of research intervention
This research will involve your participation in that will take approximately forty minutes including interview about your background and five minutes' interview for feedback.

Participant Selection
You are being invited to take part in this research because we consider that your experience as architectural designer can contribute much to our research of sketching in early conceptual design stage.

Participation Type
Participation in this research is entirely voluntary. In addition, participants will not be provided any incentive to take part in the research.

Procedures
There are two design tasks and you will be asked to produce sketches in two different sketching environments. You will be given the design task and specification written before the session starts. You are requested to participate in a think-aloud activity while sketching. It is important the clearly and understandable talking. You can also answer questions about the research that you might have.
The experiment will take place in Yeditepe University Campus, and there will be no one else at the experiment place except researcher during this experiment.

Data Protection
This consent form prepared the considering The EU General Data Protection Regulation (GDPR) governs. Audio and video recordings will be stored on a separate hard disk for 2 years, anonymizing the participants. They will be stored encrypted and transcripts of participant data will be used for qualitative evaluation. It will be used in theses and publications.

Confidentiality
The research being done in the community may draw attention and if you participate you may be asked questions by other people in the community. We will not be sharing information about you to anyone outside of the research team. In addition, the recorded information is confidential and no one other than the thesis supervisor, will have access to the recordings. The information that we collect from this research project will be kept private. Any information about you will have a number on it instead of your name. Only the researchers will know what your number is and we will lock that information up with a lock and key.

Sharing the Results
During the study, information shared with the research team will not be shared with anyone outside the team and nothing will be attributed to you by name. The information obtained from this research will be shared with participants and the public. Following the experiments, the results published in M.Sc. thesis so that other interested people may learn from the research.

Right to Refuse or Withdraw
Participants do not have to take part in this research if they do not wish to do. Participants will be given to an opportunity at the end of the feedback section about the experiment (not what was said during the experiment) to review participant's remarks. If participant do not agree with researcher's notes or if researcher did not understand correctly, participants have right to modify or remove parts of those.

Who to Contact
If there are any questions, the researcher can be contacted now or later. To be asked later, contact the following: Zeynep Selcen Narin, +905543998407, zeynepnarinn98@gmail.com
This proposal has been reviewed and approved by Yeditepe University Human and Social Research Ethics Committee, whose task it is to make sure that research participants are protected from harm.

Part II: Certificate of Consent

I am voluntarily taking part in this project.

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study.

Name of Participant…….

Signature of Participant …….. Date …….

Statement by the researcher/person taking consent

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

A copy of this ICF has been provided to the participant.

Signature of Researcher taking the consent…….. Date…….

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Figure B.1. Consent form before the experiment