ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A STUDY WITH ARCHITECTS ON THE USE OF GESTURES WITH AND WITHOUT SPEECH FOR REPRESENTING SHAPES

M.Sc. THESIS

Ayşe IŞKIN TÖRE

Department of Informatics

Architectural Design Computing Programme

MAY 2015

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

JESTLERİN KONUŞMA İLE KONUŞMASIZ OLARAK ŞEKİLLERİN TEMSİLİ İÇİN KULLANIMI ÜZERİNE MİMARLARLA BİR ÇALIŞMA

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Ayşe IŞKIN TÖRE, a **M.Sc.** student of ITU **Institute of / Graduate School of Science Engineering and Technology** student ID **523101003**, successfully defended the **thesis/dissertation** entitled "**A Study with Architects on the Use of Gestures with and without Speech for Representing Shapes"** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my husband,

FOREWORD

First and the foremost, I would like to express my deepest gratitude and thanks to my supervisor, Lect. Dr. Elif Sezen Yağmur-Kilimci who always supported me with her patience, advice and motivation. This thesis would not have been achieved without her valuable thoughts and guidance.
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I present my special appreciation to all participants of the studies.

May 2015 Ayşe IŞKIN TÖRE
(Architect)

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ABBREVIATIONS

CAD	**:** Computer Aided Design
3D	**:** Three Dimensional
P	**:** Participant

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A STUDY WITH ARCHITECTS ON THE USE OF GESTURES WITH AND WITHOUT SPEECH FOR REPRESENTING SHAPES

SUMMARY

Conceptual design occupies a crucial place in architectural design process. Designers tend to quickly express, convey and externalize their design ideas to the external world. At the same time, they want to make them visible with the purpose of working on them. Thus, when these ideas became visible, architects could have the opportunity to think about, inspect and improve them.

Using hands while explaining a spatial problem frequently can be observed in architectural statements and design communication, because of the rapid and intuitive nature of the hand motions-gestures. Gestures have a significant role in explaining spatial information very quickly and effectively, because they are spatial. Furthermore, gestures are very suitable mediums for expressing 3D representations, because they occupy a 3D space, and they are three-dimensional by nature. Accordingly, gestures have been studied in various fields, but particularly in spatial domain. Two of these fields constituted a source of motivation for this thesis. The first one is 'use of gesture in design communication' and the second one is 'gesture as input medium in HCI' (human computer interaction).

In this thesis, -instructed- hand gestures that architects used in modeling a given set of shapes/configurations were investigated by an empirical study for exploring their gestural modeling behavior and understanding (1) how the shapes were modeled by gestures, (2) to what extent architects can represent a shape/form via gestures, (3) what shape/form information was conveyed via gestures and/or speech. This investigation was executed under two different circumstances, which are gesture-only and gesture-plus-speech. In the gesture-only circumstance, participants were requested to model sixteen shapes/configurations by using their gestures and were not allowed to speak. In the gesture-plus-speech circumstance, participants were requested to model another set of sixteen shapes/configurations with their gestures and were informed that they can speak if they like to.

All of these studies' data were gathered via camcorders and observations were analyzed by segmenting to the protocols with regards to the gestures produced. In consequence of all these investigations, gestures, which were produced by the participants during the modeling process, were analyzed to seek answers to the research questions. During the analyses, some simple sketches of the represented shapes/configurations were also drawn while videotapes of the participants were being watched in order to seek whether the shapes/configurations can be fully captured from the videos. In these qualitative analyses, it was observed that architects generally exhibited some similar behaviors during the modeling of similar forms. Some participants generated gestural models, which contain all of the shape information holistically. If shape was not modelled as giving all the data about its'

characteristic features, it was difficult to understand whole shape from the videos. It was observed that there were several gesture-speech mis-matches produced by the participants during the gestural modeling process where information given by speech was different than what was rendered by the hands yet in other cases, speech was often found to give complementary information about distance, size and/or measure of the physical models efficiently.

Finally, a comment can be added that participants tried to find the correct word and to form a meaningful sentence mentally while generating gesture-speech models in the gesture-plus-speech phases. Because of this process, their hands hung in the air and they hesitated about the next motions of their hands. So, if speech was dysfluent, gesture was interrupted as well. However, in the gesture-only phases, a great majority of the participants' gestural models were more holistic, complete and fluent.

As a result of these investigations and analyses, it can be suggested that gestural modeling via hand motions can be a representative and communicative medium between architects to a certain extent. Architects can model some primitive shapes with their gestures and they can be encouraged for using gestures in design communication for representing some primitive shapes. For the case of human computer interaction, with the technological developments in the near future, it might be possible to define some shapes/configurations to a computer system via gestures.

JESTLERİN KONUŞMA İLE KONUŞMASIZ OLARAK ŞEKİLLERİN TEMSİLİ İÇİN KULLANIMI ÜZERİNE MİMARLARLA BİR ÇALIŞMA

ÖZET

Kavramsal tasarım, mimari tasarım sürecinde ve tasarım temsilinde oldukça önemli bir yere sahiptir. Tasarımcılar bu süreçte, düşüncelerini dış dünyaya çok hızlı bir şekilde iletmek, ifade etmek ve dışsallaştırmak isterler. Bu tasarım düşüncelerini görünür kılmak için, onları kristalize etmek-belirginleştirmek amacı güderler. Böylece, bu dışsallaştırma süreci aracılığıyla, belirgin hale gelen fikirleri üzerinde düşünme, onları inceleme ve geliştirme imkanına sahip olurlar. Bu sayede, görünür olan bu fikirleri ve tasarım niyetlerini meslektaşları ile tartışabilirler.

Bu tip işbirlikçi tasarım tartışmaları gerçekleştirilirken, uzamsal bir problemin açıklanması sırasında ellerin kullanılması, sıklıkla gözlenen bir durumdur. Bunun sebeplerinden biri, bu el ve kol hareketlerinin, yani jestlerin çok hızlı ve sezgisel olarak gelişen doğasıdır. Jestler, mekan-zamansal bilginin, özellikle 3 boyutlu mekan bilgisinin temsili için, oldukça uygun ve elverişli birer araçtır. Bu önemli rolden kaynaklı olarak, jestler pek çok araştırma çalışmasına konu olmuşlardır. Bu çalışma alanlarından ikisi, bu tez için motivasyon kaynağı teşkil etmektedir. Bunlardan birincisi, iş birlikçi tasarım süreçlerindeki anlatımlarda ortaya çıkan jestlerin ve konuşmaların, şekil bilgisinin dış dünyaya aktarılmasında ne derecede kullanılabileceğidir. Başka bir deyişle, bu jestlerin tek başına veya konuşma ile birlikte, mimarların kendi arasındaki iletişim sırasında düşünce aktarımında hızlı, açıklayıcı ve destekleyici bir temsil aracına dönüşüp dönüşemeyeceğidir. İkincisi ise bu jestlerin tek başına veya yine konuşma ile birlikte, üç boyutlu şekillerin modellenmesi sırasında kullanımıyla, doğal bir kullanıcı arayüzü için girdi aracına dönüşebilme potansiyelidir. Yani, jest ve konuşmanın, bu kavramsal şekil modelleme verisinin bilgisayara aktarılması ve tanıtılmasında, temsili bir araca dönüşüp dönüşemeyeceğidir. Bu iki farklı bakış açısıyla gerçekleştirilecek olan incelemenin, her iki bilimsel araştırma alanına da önemli katkı sağlayacağı düşünülmektedir. Bu perspektiften yola çıkılarak, tezin temel amacı, üç boyutlu kavramsal şekil modellemesi sırasında -jest ve söz kullanmaya yönlendirilmiş olan- mimarların, jestleriyle ve konuşmalarıyla sergiledikleri davranışların keşfedilmesi ve araştırılmasıdır. Mimarların el hareketleriyle modelleme davranışının araştırılması çerçevesinde bu çalışmada, mimarlara bazı fiziksel modeller verilerek, bunları jestlerle ve konuşarak anlatmaları istenilmiştir. Bu çalışmanın ön çalışması olarak da iki pilot çalışma gerçekleştirilmiştir. Tüm çalışma süreçleri video ile kaydedilmiştir. Çalışmaya dair gözlemler, her bir katılımcının her bir şekil için ürettiği jest modelleri dikkate alınarak segmentlere ayrılmıştır.

Ana deneysel çalışma öncesinde gerçekleştirilen birinci pilot çalışma, 2 mimar katılımcı ile, 22 adet üç boyutlu fiziksel maket kullanılarak yürütülmüştür. Katılımcılardan onlara birer birer verilen üç boyutlu fiziksel maketleri detaylıca incelemeleri ve sonrasında bu maketleri jest+konuşma ile anlatmaları, diğer bir

ifadeyle üç boyutlu uzayda modellemeleri istenmiştir. Birinci pilot çalışma sonucunda yapılan analizlere ve çıkarımlara göre, kullanılan üç boyutlu fiziksel maketler ve çalışmanın metodu revize edilmiştir. Birinci pilot çalışmadan çıkarılan derslerle, fiziksel maketlerin birbirleriyle belirli bir oransal ilişkiye sahip olması, aynı zamanda daha bütüncül, temiz ve iyi üretilmiş olmaları gerektiği sonucuna varılmıştır. Ayrıca, sonraki pilot çalışmaya konuşmanın yasaklandığı bir fazın da dahil edilmesine karar verilmiştir.

Sonrasında, yeniden hazırlanan 35 adet fiziksel maket ile ikinci bir pilot çalışma gerçekleştirilmiştir. Bu ikinci pilot çalışmaya, 2 mimar olmayan katılımcı ve 1 mimar katılımcı eşlik etmiştir. Bu çalışmada, 2 mimar katılımcıya iki farklı fazda maketler anlattırılmıştır. Birinci katılımcı, birinci durumda 35 maketi sadece elleriyle, ikinci durumda hem elleri hem de konuşmalarıyla modellemiştir. İkinci katılımcı ise, birinci fazda elleri ve konuşmalarıyla, ikinci fazda da sadece elleriyle 35 maketi modellemiştir. Devamında, bu iki katılımcının, video verileri, maketler ekranda görünmeyecek şekilde Camtasia Studio 8 adlı video işleme programında gerekli kesintiler yapılarak hazırlanmıştır. Her iki katılımcının maket videoları, morfolojik ve kavramsal olarak birbirine benzerlik teşkil eden parçalar her iki grupta da yer alacak şekilde, biri sesli diğeri sessiz, iki gruba ayrılmıştır. Sonrasında, üçüncü mimar katılımcıya bu iki grup video, iki faz halinde izletilmiştir ve ondan, izlediği el hareketi-jest modellerinden, gerçek maketlerin eskizlerini yapması istenmiştir. Bu ikinci pilot çalışma sırasında ilk iki katılımcıya, 35 maket her iki durumda da modelletildiği için, maketleri öğrendikleri ve ikinci fazda daha iyi anlattıkları gözlenmiştir. Bu öğrenme etkisi nedeniyle, üçüncü deneysel çalışmada maketlerin de iki farklı grup halinde anlattırılması gerektiği sonucuna varılmıştır. Bu çalışmada, mimar katılımcıya eskiz yaptırılmasının sebebi, ilk iki katılımcının jest modellemelerinin ne derece anlaşılabilir olduğuna bakılabilmesidir. Bu sayede, farklı bir katılımcı maketleri hiç görmeden, başka birisinin anlatımıyla, gerçeğe yakın bir şekilde eskizler üretebiliyorsa, bu jest+konuşma verileri doğal bir kullanıcı arayüzü için bilgisayara girdi sağlayabilir, ayrıca mimarların kendi arasındaki iletişimde de destekleyici temsili bir araç olarak katkı sağlayabilir motivasyonları elde edilmiştir.

Üçüncü ana deneysel çalışma ise, 4 mimar katılımcı ile gerçekleştirilmiştir. Maketler, bir önceki deneyde kullanıcıların modellemekte en çok zorlandığı ve en karmaşık olan 3 maket göz ardı edilerek, morfolojik olarak ve karmaşıklık seviyesi bakımından her iki gruptaki maketler eşdeğer olacak biçimde, 16’ şar maket içeren iki gruba ayrılmıştır. Öğrenme etkisini ortadan kaldırmak için, her bir katılımcıya her bir maket bir kere anlattırılmıştır. Katılımcılara maketler, sadece-jest ve jest+konuşma fazı olarak iki fazda modelletilmiştir. Maket grubu sırası ve sözlü-sözsüz anlatım sırası belirli bir permütasyon mantığında, tekrar etmeyecek şekilde düzenlenmiştir.

Jestle modelleme süreçleri sırasında ortaya çıkan sözsel ve el hareketli anlatımların incelenmesi ve karşılaştırılması için düzenlenen, ‘sadece jest fazı’ ve ‘jest+konuşma fazı’ sayesinde, jestle ile iletilen bilgiye, konuşma ile iletilen bilgiye ve son olarak da jest+konuşma ile iletilen bilgiye, ayrı ayrı bakılabilmesi amaçlanmıştır. Bunlardan yola çıkarak, jest ile konuşmanın birbirini tamamlayıcı doğası sebebiyle, konuşmanın da jest ile birlikte, üç boyutlu mimari kavramsal şekil modellemesi için doğal bir kullanıcı arayüzü olup olamayacağı da araştırılmıştır. Konuşmanın, ‘jest+konuşma fazı’nda şekillerle ilgili sayısal bilginin ve ölçülerin iletilmesinde yoğun olarak kullanıldığı gözlenmiştir. Konuşmanın bu katkısına rağmen, çalışmalar sırasında, çeşitli jest-konuşma uyumsuzlukları da gözlenmiştir. Bu uyumsuzlukların, katılımcıların aynı anda hem şekli öğrenmeye çalışıp, hem onu elleriyle modellemeye gayret ederken, diğer yandan da sözlü olarak verecekleri bilgiyi kararlaştırmaya çalıştıkları için ortaya çıktığı görülmüştür.

Tüm bu çalışmaların sonucunda, üç boyutlu modelleme süreci sırasında sergilenen el hareketleri-jestler analiz edilmiştir. Öncelikle, dört katılımcının bütün maketler için ürettiği sesli ve sessiz jest videoları, katılımcıların modelleme davranışlarını analiz etmek açısından gözlemlenmiştir. Ardından, mimarların şekilleri modellerken sergiledikleri benzerlik ve farklılıklar analiz edilmiştir. Son olarak da, tüm sesli ve sessiz jest videolarında, jestle ve konuşma ile iletilen bilgiyi araştırmak amacıyla, hem yapılan jest modelleri hem de sözlü tanımlamalar birebir metne dökülmüştür, hem de her bir şekil için, iletilen bilgi analizleri yazılarak çıkarılmıştır. Modelleri anlatan katılımcılar dinlenirken, onların anlatımları üzerinden basit eskizler yapılmıştır. Bu analizler, tamamen deneyimsiz, koşullanmamış ve çıplak bir gözle yapılmaya çalışılmıştır, başka bir deyişle modelleri önceden bilme durumu göz ardı edilerek geçekleştirilmiştir. Çalışmanın güvenilirliğini kontrol etmek amacıyla, maketleri daha önceden hiç görmemiş, dışarıdan bir gözlemciye de seçilen 32 adet jest modelleme videosu izletilerek, bu videolardaki modellemelerden anlayabildikleri ile, gerçek şekiller hakkında eskiz yapması istenmiştir. Bu videolar, dört katılımcının sadece-jest ve jest+konuşma fazında ürettikleri jest modellerinden, her bir katılımcının birkaç sesli ve sessiz videosunu içerecek biçimde oluşturulmuştur. Sonrasında, bu dış gözlemcinin eskizleri, gözlemci olarak analizler yapıldığı sırada aynı şekilleri izlerken üretilen eskizler ile, benzerlik bakımından karşılaştırılmıştır.

Bu nitel analizlerde, mimarların benzer formları modellerken benzer davranışlar sergiledikleri gözlemlenmiştir. Bazı katılımcıların bazı şekilleri, bütün veriyi aktaracak şekilde bütüncül olarak modellediği gözlemlenmiştir. Analizler sırasında, jest modelleri, şekille ilgili tüm veriyi içerecek biçimde üretilmediyse, ilgili modelin anlaşılmasında ve şekillerle ilgili doğru eskizlerin üretilmesine güçlükler çekilmiştir. Yani katılımcıların şekillerle ilgili yeterli ve doğru bilgiyi aktarmasının, şeklin anlaşılmasında ve eskizinin üretilmesinde önem arz ettiği söylenebilir. Eğer katılımcı model yaparken, jest-konuşma uyumsuzluğu sergilediyse, yapılan eskizlerde karmaşa yaşanmıştır ve modelin eskizi doğru biçimde üretilememiştir. Bu uyumsuzluklara rağmen, katılımcıların ürettiği jest modelleri izlenip, analiz edildiğinde ve bu sırada üretilen eskizler ile dış gözlemcinin aynı jest modelleri için ürettiği 32 adet eskiz karşılaştırıldığında, 32 adet şeklin yaklaşık olarak yüzde sekseninin doğru biçimde anlaşılabildiği ve eskizinin yapılabildiği görülmüştür.

Bu çalışmalar ve erişilen veriler sonucunda, jest ile üç boyutlu modellemenin, mimarlar arasında ve bir bilgisayar arayüzüne girdi sağlamak amacıyla, basit şekillerin ifade edilmesinde açıklayıcı ve destekleyici bir iletişim aracı olabileceği kanısına varılmıştır. Fakat, şekiller karmaşıklaştıkça; yani daha fazla sayıda yüzeyden oluşmaya başladıkça ya da daha kompleks mekansal ve oransal ilişkiler içermeye başladıkça, katılımcıların şekilleri jestleriyle modellenmekte zorlandıkları gözlenmiştir. Ayrıca, çeşitli jest-konuşma uyumsuzluklarına rağmen, konuşmanın çoğunlukla şeklin niceliği, ölçüleri ve şekillerin adları ile igili etkili ve doğru bilgi vermekte büyük rolü olduğu gözlenmiştir. Son olarak, jest-konuşma fazında, konuşma sırasında katılımcıların doğru kelimeyi bulmaya çalışırken ya da cümle kurma uğraşı verirken, ellerinin kısa süreçler halinde havada asılı kaldığı ve jest modelinin kesintiye uğradığı belirtilebilir. Buna rağmen sadece jest fazında ise katılımcıların modellerinin büyük çoğunluğunun oldukça bütüncül ve akıcı biçimde kurgulandığı ve daha kısa sürede, hızlıca üretildiği söylenebilir.

1. INTRODUCTION

People mostly tend to gesture as they talk. It is frequently observed that while working on a spatial task, gesture production becomes more visible and increases (Morsella & Krauss, 2004; Marrin & Olsen, 2013; Trafton et el., 2006; Atit et al., 2013; Hostetter & Sullivan, 2011; Wesp et al., 2001; Chu & Kita, 2011, 2012; Allen, 2003; Bergmann & Kopp, 2006). This might be partly because, gestures are great for "capturing visuospatial content" because of their "visuospatial form" (Wagner et al., 2004) and they can represent actions in space because they are actions in space (Jamalian et al. 2013). So, they can represent spatial information very naturally and quickly by nature.

Gestures can convey substantive extra information, which is not conveyed in speech (Church and Goldin-Meadow 1986; Schwartz and Black 1996). "Gestures are free to take on forms that speech cannot assume and are consequently free to reveal meanings that speech cannot accommodate." and they participate in communication supportively as a part of intentional communicative act (Goldin-Meadow, 2003). So, they support speech process with this additional information and they present some different information from speech freely. Thus, the listener understands the speaker better.

A similar situation can be observed in some spatial tasks, speaker's gesture usage positively effects the understandability of the spatial issues by listeners. For instance, in assembly of a simple object, if communicator produces gestures while exhibiting and explaining the assembly process to recipient, the recipient could understand and learn better by means of gestural instructions (Lozano & Tversky, 2007).

Tendency to produce gestures when talking about spatial information can be widely observed in the context of architectural design. Architects tend to produce gestures while explaining or describing their design ideas or a design to others as observed in collaborative design meetings, presentations or in empirical studies. (e.g. Bekker et al. 1995; Yağmur Kilimci, 2010; Alaçam & Çağdaş, 2014). For instance, while describing design of masses in a building, architects frequently produce several gestures as holding these masses with hands and these gestures often exhibit spatial relations and locations of these masses and enrich architects' descriptions by conveying extra comprehending information in addition to speech.

While architects frequently use hand gestures in their communications, they do not use gestures in their own thinking processes in the same vein. Architects' main thinking tools are diagrams, sketches, analog and digital models. They externalize their thoughts with these representations. One of the reasons of their not using gestures as a representational medium for thinking might be that what is rendered by the gestures disappear simultaneously and cannot be captured in a real-time fashion. But, if it could be captured and digitally modelled in a real-time fashion, architects could simultaneously see and review a digital model of the entities they render via their gestures. In such a case, creating digital models of the entities that architects visualize in their minds would be much faster than creating them by using conventional input devices and using the modeling tools provided in the digital modeling environment. Such a fast creation of digital models via gestures could benefit architects thinking processes by reducing the time spent for externally modeling the entities visualized in mind and providing a faster visual feedback to the architect.

Indeed, until now there has been an extensive amount of research on the use of gestures as means for interacting with computer systems, particularly in the field of human computer interaction (HCI). Several studies have been carried on gestural inputs, which allow people to interact with products and systems using hand motions such as giving 'start, stop, pass, pause, volume up-down' etc. commands to a TV with hand motions (Lenman et al. 2002) or interacting with some computer games (Loviscach, 2009), military (Lebron, 2013) or medical applications (Wachs et al. 2006) etc.

Also, there has been one line of research focused particularly on study of gestures as means for defining shape information. For example, Horvath et al. (2003) developed a -hand motion language- tool for modeling and manipulating shapes. They defined some specific hand motions and called this specific language as HML (Hand Motion Language). They constituted a specific language contains some special words and sentences defined by hand motions. Their results indicated the potentials of a HML in shape conceptualization. Varga (2008) studied about the topic of hand motion based spatial shape design. She focused on the transfer of design data to the computer and she produced some digital conceptual models via hand movements. She developed several algorithms and used some input devices and HML for transferring data to the computer. Varga compared a CAD based modeler system with a HML based modeler system and she reported that participants were enjoyed about using HML modeler system more than CAD modeler system. Zaman (2010) studied on the transfer of the hand motions used in the model making process to the computer. He developed a design environment employing the hand motions used in model making process and defined several hand gestures that are used in the modeling process to the computer. He worked on hand motion capturing and he presented a set of algorithms. This study defined hand motions used in model making process to computer with a certain categorized way. Vinayak et al. (2013) presented an interaction system as called “Shape-It-Up”. They studied on intelligent generalized cylinders (IGC) on the concept of shape creation, shape modification and shape manipulation with hand gestures. They designed a prototype involves human skeletal tracking and hand-posture classification using the depth data provided by a low-cost depth sensing camera (Microsoft Kinect). This study shows that it is possible to generate, modify and manipulate cylinders with hand motions through a virtual slab, so this could also apply to other shapes. It can be deduced from these research studies that shape information can be acquired from hand gestures and further studies could be performed with help of several technological developments.

As, human hand has a very complex structure. Five fingers of the hand have a great variety of motion abilities. There have been so much complex motions and operations of the hand. So, recognition of these complex elements-fingers and these complex motions is a challenging issue for HCI. Because of that, so far studies on gestures have worked with a set of predefined hand motions and postures. So specific hand motions should be predefined to the computer like a certain language and several algorithms should be generated. Different from all these studies, there was a more developed input device -Kinect- in Shape-It-Up. Kinect is a system, which enables people to control the environment without remote control, mouse or a controller. “With a 3-D human motion capturing algorithm, Kinect enables interactions between users and a game without the need to touch a controller” (Han et al., 2013). So Vinayak et al. (2013) took the advantage of this Kinect technology for generating shapes by means of taking gestural input directly without the need for extensive training and they implemented this study with cylinders in the study of Shape-It-Up.

Thus, until now several prototype systems and algorithms have been developed for generating digital shape models or transferring hand motion data -used in the model making process or while describing a shape- to computer. In all these research studies except Shape-It-Up, researchers have studied with predefined gestures and certain languages for shape-modeling studies at their age because of some recognition problems.

At this point, we should touch on the issue of gesture input devices, especially three-dimensional ones. Here, we can see wired gloves, bodily and visual sensor-devices, depth-aware cameras, stereo cameras etc. Here, bodily input devices cause some movement restrictions and people mostly do not prefer wearing external devices on their hands or bodies. Cameras sometimes can have some motion capturing problems resulting from diversity of human motions. But, a great variety of technological developments have been carried on nowadays, especially for capturing gesture with using minimal external devices.

There is a growing number of research in HCI, for developing gestural interfaces. This research and the technological developments point that there would be such interactive interfaces, which can recognize freehand gestures naturally and spontaneously without any need of physical input devices (hand gloves, markers etc.). As such, there would not be a need for predefined gestures (preconditioned-previously taught to the computer and people) or a training process in the future.

Accordingly, it seems that in the near future it would be possible to capture the space occupied by hands and translate the shapes/configurations rendered by the movements of the hands to a computer system. At this point, the question comes to mind, whether and to what extent shapes/forms can be modeled via gestures.

This thesis presents an empirical study conducted to explore gestural modeling behavior of the architects while modeling shapes via gestures under two different circumstances with or without speech. In the context of this study, research questions were formulated as follows;

(1) How the shapes were modeled by gestures under each of the circumstances?

(2) To what extent architects can represent a shape/form via gestures under each of the circumstances?

(3.1) What shape/form information was conveyed via gestures under the gesture-only circumstance?

(3.2) What shape/form information was conveyed via gesture and/or speech under the gesture-plus-speech circumstance?

By addressing these issues, it aims to provide insight to the ‘gesture researches in HCI’ and ‘use of gestures in design communication’. In other words, this exploration can shed light on two different issues. The potential of gesture and speech as representational mediums for architects in defining shapes/configurations to a computer system as well as describing them to others in the context of collaborative design meetings, presentations etc.

To find answers of these questions, two preliminary pilot studies and a main empirical study were conducted in this thesis. In the main study, participants were requested to generate shape models by using their hands. Various 3D physical models were given to them and the participants were asked to re-model these objects with their hands only or hands and speech together. They were informed about their gestures should be the first priority medium for their gestural statements as different from co-speech gestures that are produced spontaneously while speaking. In other words, it was expected from them to give the maximum information with their hands more than their speech thus, our priority was hand motions. This process was conducted in the experimental design so it was not in the nature environment. Participants were asked to do that in that manner. The purpose of this unnatural approach was that to look for how architects would behave, if they know they could use their hands in the spatial problem definitions and also if they were aware of the hand gesture usage can provide an extra information to their representations. In this case, we looked at what kind of statements could be observed? Could architects improve and enrich their representations via hand gestures?

The rest of this thesis is organized in four chapters. The first chapter is the literature review about co-speech gestures used in collaborative studies, also spatial representational gestures used in design communication and several input gestures used in HCI. The second chapter presents the design of the study. It first explains two pilot studies with their participants, procedures, materials and their implications to design of the main empirical study. Then it presents the main empirical study with participants, procedure and materials. Then it outlines the analysis method of the main empirical study. The third chapter discusses the all of the detailed analyses and results of the main empirical study. Lastly, chapter 5 summarizes the conclusions, recommendations and further studies about this significant topic.

2. LITERATURE REVIEW

> Gestures are not just movements and can never be fully explained in purely kinesic terms. They are not just the arms waving in the air, but symbols that exhibit meanings in their own right. They have a meaning that is freely designated by the speaker. (McNeill, 1992)

There have been several gesture definitions. For instance, Kendon (1981) stated that the word 'gesture' means "distinct bodily action that is regarded by participants as been directly involved in the process of deliberate utterance". McNeill (1992) arranged Kendon's different kinds of gestures and named "Kendon's Continuum". Here, Kendon's categorization was that *gesticulation*, *speech-linked gestures*, *emblems*, *pantomime* and *sign language*.

McNeill (1992) defines gesture as "movements of the arms and hands and are closely synchronized with the flow of speech". He classifies gestures as; *beats, iconics, metaphorics and deictics* (McNeill, 2005). *Beats* are the rhythmic gestures which occur with beat time of the hand. They are hand movements like up and down or back and forth. *Iconics* are gestures which "present images of concrete entities and/or actions". So, depiction of a circle by drawing its' shape in the air or behaving like grasping an object with hand or showing a direction with hand can be accepted as iconic gestures. *Metaphorics* are gestures which can present "images of the abstract". Here people use space for representing abstract ideas like holding an 'idea' or 'memory'. They are similar to iconic gestures but they contain a semantic content. *Deictics* are gestures that mostly occur like pointing somewhere with index finger. Sometimes, deictic gestures can be used with other parts of the body such head, nose, elbow, feet etc. Krauss et al. (1996) terms these gestures as '*lexical movements'* and Ekman & Friesen (1969) names them as '*illustrators'* (Alibali, 2005). Furthermore, there was a *representational gesture* expression in Kita's chapter (Kita, 2000) as "*Representational gestures* are defined here as iconic gestures and abstract deictic gestures (McNeill 1992)". Moreover, Alibali (2005) defines representational gestures as "gestures that convey semantic content by virtue of shape, placement or motion trajectory of the hands". Rauscher et al. (1996) indicate that representational gestures are obtained from spatially encoded knowledge and serve to build the spatial relations that will be expressed in speech.

These different gesture definitions have an important place in the literature, but the gestures which were elicited in this research study were called generally as ‘representational gestures’. This study focuses on these **representational gestures** which are **iconics**-refer to directions, proportions, spatial relations (near, parallel, contiguous, horizontal, vertical, etc.), subtraction and additional operations or geometry of shapes, **deictics**-point a special path, direction and size or they depict a part of the shape and **metaphorics** beside the representational gestures-refer to abstract ideas such information which acquired before like explaining an idea which does not have a physical form or waving hands in the air while trying to retrieve a word from memory. Along the present study, participants were instructed to generate representational gestures for shape description and the experimental studies were executed from this point of view and these representational gestures were henceforth called ‘**gestures**’, unless indicated otherwise.

Gestures are produced in a great variety of conditions such as mental rotation and geometric shape motion tasks (Chu & Kita, 2009); when giving directions (Allen, 2003); when describing a picture from memory (Wesp et al, 2001); recall of spatial information (Morsella & Krauss, 2004; Chong et al. 2013); when talking about spatial topics (Lavergne & Kimura, 1987); when grounding mental representations in action (Beilock & Goldin-Meadow, 2010); during the lexical retrieval and information packaging processes (Alibali et al. 2000); in word retrieval (Krauss & Hadar, 1999); in revealing and changing thought (Goldin-Meadow & Wagner, 2005); in assembling a simple object (Lozano & Tversky, 2007); in collaborative discussions (Becvar et al. 2008). These gestures are mostly used with speech and speakers produce them spontaneously, than they are named as co-speech gestures. They sometimes turn into language, sometimes work alongside language (Goldin-Meadow, 2006). In scope of this study, as indicated before there were two different viewpoints, so gesture studies in literature will be explained according to these two fields as co-speech gestures used in collaborative studies and input gestures used in HCI.

2.1 Co-Speech Gestures Used in Collaborative Studies

Collaborative studies generally elicit co-speech gestures. In this context, several research studies will be explained. In Lozano and Tversky's assembly task (2007), they aimed to seek evidence that gestures benefit both communicators and recipients. They performed two experiments; one of them was conducted with communicators and the other one was conducted with recipients. Communicators explained to the recipients how to assemble a simple TV cart, using speech with gestures or gestures alone. Communicators' explanations were videotaped and these videotapes were watched to the recipients. The study reached these results, communicators learned assembly better while using gestures alone. They made fewer assembly errors in this gesture-only condition than gesture and speech condition. "Recipients understood and learned better from gesture-only instructions than speech-only instructions". Gestures helped to communication because they conveyed action information directly. Gestures themselves were not informative but "they helped communication because they facilitated speech". Lozano and Tversky interpreted that gestures were better than words because they carried embodied knowledge. They attributed effectiveness of the gesture-only conditions on the extra attention of communicators and recipients. Communicators paid extra attention in the gesture-only condition because they knew that they had to convey all information with their hands and they tried to be sure about giving clear and explicit explanations for the assembly process. On the other hand the recipients also paid extra attention while watching the gesture-only videotapes because they knew that they could acquire whole information from only communicators' hands.

In another example Yağmur-Kilimci's research study (2010), participants were not instructed about using gestures during their 3D mental visualization practices but they substantially produced gestures, such as pointing to relative locations in space or depicting the shape of an element. In this research study, she focused on the architects' mental visualization skills and examined their mental visualization performance through several practices. It was observed that participants rendered an invisible 3D small scale of the visualized building or building space and sometimes they gestured as walking in the related building. An external reviewer was requested to review video segments of the participants' verbal descriptions in order to seek reliability. Besides, she analyzed video records of each participants' verbal descriptions for examining what kind of information was expressed with speech and also gesture. She mentioned that participants defined the building components with speech and they depicted their locations in space by using their gestures. So, they defined spatial entities by way of gestures. She deduced from the observations of this study, “These gestures were an integral part of the visualization process in that they supported the creation of the imagistic models… Their gesture models were helping them to concretize their imagistic models, the dimensions of the space and the components in the external space” (Yağmur-Kilimci, 2010).

In Alaçam and Çağdaş’s study (2014), they performed a thirty-minutes case study which consisted two phases with two post-graduate architecture students. They explored the role of embodied bodily experience within the frame of abstract and conceptual ideas. The aim of this study was to explore presence of iterative patterns in the iconic and deictic gestures during the modeling process. The first participant was asked to examine four physical models which were produced with different types of production. Than in the second phase, the second participant was asked for generating 3D models of these physical objects in digital media by way of the gestural and verbal instructions of the first participant. The first participant described all of the physical models to the second participant by using ones gestures and speech. Whole modeling process videos were analyzed by using McNeill’s deictic and iconic descriptions. According to the results of this study, iconic gestures were used generally for depicting the relation of the small components or spatial information and they were accompanied by speech. They observed that discussion of the spatial features of the models in the computer screen remained limited according to the discussions which carried out in physical space. And also, it can be said that nature of gestures used during digital modeling process turned into deictic gestures. Gestures were used for not only description of a shape geometry but also for generation time of an action. They aimed to answer this specific question; why and how digital media interfaces were insufficient in the process of conceptual and abstract idea generation along the early phase of design.

In Becvar et al.’s study (2008), they examined use of the representational gestures for the formulation of scientific theory during collaborative discussions in a biochemistry lab. They found that representational gestures were frequently used to reference, modify and embody special parts such as models, diagrams and graphs.

They commented that representational gestures were used for description of the information which was not conveyed with language. They used the term “embodied” to refer to representational forms. They collected experimental data in the duration of weekly laboratory meetings and training laboratory hours. They used video recording techniques to collect data. They collected case study data from weekly lab meetings of a biophysics research and training laboratory at the University of California by video recording method for this project. Participant constructed the hand model firstly, later she could adapt and modify the molecular model as it was still there in the air and communicated with the group members by her gestural models.

2.2 Input Gestures Used in HCI

There have been several research studies in the way of gesture acquisition or recognition context in HCI. In this thesis, gesture studies which concern about design, shape modeling or CAD technologies will be exemplified only. Because, focus of this research study is nature of the gestures which will be provided an input to the computer in scope of the gesture-based interaction more than gesture recognition.

“Hand motion is one of the most natural ways for designers to express their shape concepts for computers and to communicate with each other during the shape conceptualization (Varga et al. 2004). In this context, HML can be explained firstly (Horvath et al. 2003). HML is a hand motion language tool for 3D shape conceptualization and design of shapes. Horvath et al. (2003) defined a set of specific hand motions and called them as HML (hand motion language). One purpose of defining this language was to minimize its dependences on temporal, morphological and spatial variances (Varga, 2008). In the scope of HML, they produced several geometric words, procedural words, identification words, positioning words, connectivity words, scaling words, and assembling words. Their results indicated potentials of a HML in shape conceptualization process. However, there were some problems to illustrate, the amount of shape details was too much and there were some limitations about memorizing the complex hand motion sequences by the test persons. Test persons performed better the simple objects according to the compound and hybrid ones. They reached the solution that with the help of the hand movements, time spent in CAD programs decrease. Moreover, the conceptual models, which were produced with HML, were more flexible and creative when compared with CAD software.

Words	Descriptions	Signs
Plane	Specifies a planar surface as halfspace	
Cylinder	Specifies a cylindrical surface as halfspace	
Cone	Specifies a conical surface as halfspace	
Sphere	Specifies a spherical surface as halfspace	
Ellipsoid	Specifies a ellipsoidal surface as halfspace	
Free form	Specifies arbitrary free form surface as halfspace	

Figure 2.1 : Geometric Words of HML (Horvath et al. 2003).

Varga (2008) investigated hand motion based spatial shape design. She focused on the transfer of design data to the computer interface and she produced digital conceptual models via hand movements. She compared a CAD based modeler system with a HML based modeler system and she reported that participants were enjoyed when using HML modeler system more than CAD modeler system. Besides, HML based modeler system was a more easier and interactive system according to CAD modeler system in the way of interacting with the shape generation and manipulation process. This study showed that hand motion usage in shape modeling can be an enjoyable and helpful medium for designers and this issue can be searched with different viewpoints in the future.

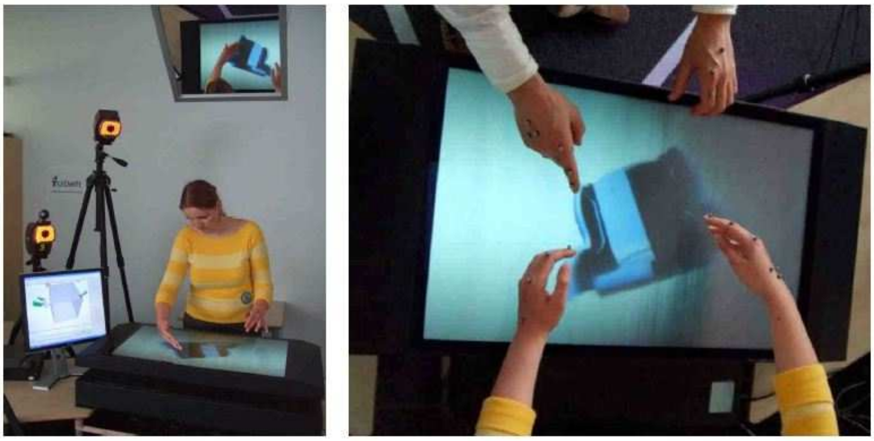

Figure 2.2 : Using HML in Conceptual Shape Design (Varga, 2008).

Zaman (2010) studied on the transferring of the hand motions data -which are used in the model making process- to the computer aided inteerface. He categorized the actions according to the fundamental features of hand motions and "proposed a recognition schema to be processed in the digital platform". He developed a design environment employing the hand motions used in model making process. He defined several hand gestures that are used in the modeling process to the computer. He worked on hand motion capturing and presenting a set of algorithms. This study supports the idea that hand motions used in model making process can be defined to computer with a certain categorized way via a certain classified hand motion repertoire.

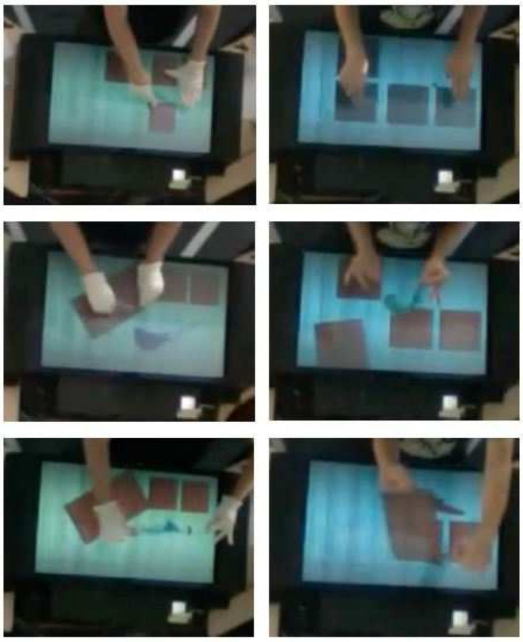

Figure 2.3 : Session of Modeling Experiment (Zaman, 2010).

Vinayak et al. (2013) presented an interaction system and developed an interface as called “Shape-It-Up”. They used Kinect technology in this study. They studied on intelligent generalized cylinders (IGC) on the concept of shape creation, shape modification and shape manipulation with hand gestures. This study showed that it is possible to generate, modify and manipulate cylinders with hand motions through a virtual slab, so this could also apply to other shapes. They emphasized the potential of moving the interactions from a conventional desktop based CAD environment to a NUI (natural user interface) enabled spatial environment.

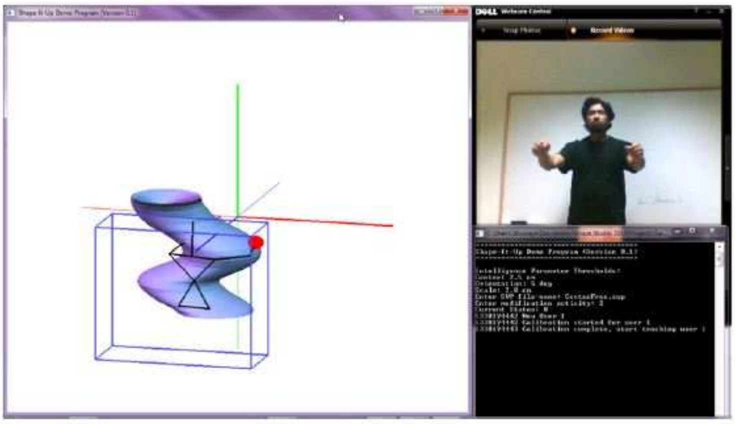

Figure 2.4 : Shape It Up User Interface (Vinayak et al. 2013).

There have been several prototype systems and algorithms. They have been developed for generating digital shape models or transferring hand motion data -used in the model making process or while describing a shape- to computer. In all these research studies except Shape-It-Up, focus for shape modelling with hand motions is mostly working with predefined gestures or certain languages, which were taught, to the people or the computer previously. We performed our study with the aim of discussing the gestural shape modelling with natural and spontaneous hand motions. Participants executed this study without learning any certain gestural language. They modeled the shapes with their spontaneous gestures.

With the help of technological developments, hand motion capturing technologies will be improved to the extent that the spatial movements of the hands could be captured in a real time fashion by an interface that will capture and model the hand motions while architects are representing their designs with their hands. The space that hand renders will be recognized and translated into 3D models. It would be possible to create a digital model capturing the space occupied by motion of the hands.

In the light of these experimental studies, we came up with an idea to study about exploring the gestural modeling behavior of architects with the purpose of understanding; to what extent various shapes/forms can be represented via gestures and what shape/form information can be expressed by gestures. We aimed to provide insight to the 'gesture researches in HCI' and 'use of gestures in design communication'. We formulated this study from the perspective of the architectural design. There were not such research study, which was directly unfolding architects' shape modelling behavior via gestures and speech by way of certain designed geometrical forms and configurations in the architectural design communication. At this point, this study would provide a different contribution to the field of the architectural education and practice by means of the design communication.

On the other hand, we restricted the content of this study to some certain basic 3D configurations. There have been much more complex forms and shapes used in this study for testing the challenging point, but we did not include any architectural building or very complex-detailed 3D physical model in the test materials.

Furthermore, this study was not arranged with any predefined gestures or certain languages, because we wanted to investigate and reveal; how architects would model shapes with their hand motions naturally and spontaneously and if they would know they can use their hands for representing shape information, how they would behave while describing shapes with their hand motions-gestures? As far as, we should highlighted that; there is no such a research study in this field, which was using this type of an experimental setup and directly conducted with the architects on the purpose of exploring the gestural modeling behavior of them.

3. DESIGN OF THE STUDY

This chapter discusses the main empirical study designed with 5 architect participants to address the research questions formulated in chapter 1. It was expected from the participants to generate explanatory 3D gestural models for various configurations of several 3D physical models. Before this main study, two preliminary pilot studies were conducted in this thesis. This chapter first outlines two pilot studies conducted with different participants, materials and procedures, then discusses the implications of these studies to the main research study. Later, it presents the main empirical study with participants, materials and procedure. Then it presents the analysis approach and the path followed during the observations.

For all these research studies, some important points were explained to the participants. They were first acclimated to the experimental setting by talking and giving solely essential information to them. They were not especially informed about the aim and approach of the study with the purpose of keeping their minds and hands clear. Several questions were posed to the participants for being sure whether participants understood the study and the procedure. When they were ready to model shapes, the testing process began.

Participants were informed about that they would generate gestural models for an external observer with the aim of a re-modeling process through their statements and videos. It was told to them that their gestural models will be shown to an external participant and (s)he will re-model the configurations according to their gestural model videos. Because of this motivation, they tried to represent the most necessary and comprehensive information about the 3D physical models with their hands and speech. Participants were also informed about that visibility of the 3D physical configurations was a proposed situation for modeling, so they did not have to keep the 3D physical model in their working memory during the modeling act. It was mentioned to participants that the base plane of the physical models can be ignored, they are asked to focus only 3D physical models.

3.1 Pilot Studies

Section 1 – The First Pilot Study:

The first pilot study was carried out to search the feasibility of the architects' gestural modeling act and availability of the -produced- 3D physical models' types-features for the modeling process. One purpose of this pilot study was to investigate whether the production methods of the shapes can affect the participants' gestural modeling act or style. One other purpose was to search whether there were considerable results and experimental data for analyzing the architects' gestural modeling behavior. Here participants were asked to study a series of 3D physical forms –quickly produced with hands- and configurations of them with the aim to describe them to a third person via hand movements and gestures. One reason of including 'a third person' in the study was to motivate participants for generating good gestural models and the other reason was to look at the comprehensibleness of the gestural statements by a third person who did not see the real models before.

The first pilot study was conducted with two architects from Architectural Design Computing Program of Istanbul Technical University. Twenty-two 3D physical models were given to the participants in a regular turn and they were allowed to examine every physical object (**Figure 3.1**). Then it was asked them for generating gestural models of these physical objects with their hands and gestures. The whole examining and modeling processes were recorded via two camcorders, one positioned opposite of the participant, the other one was the right side of them. Every participant studied alone and asked her/him to explain the given 3D physical configurations via hands motions. There was no time limit and they were allowed to speak, also encouraged about talking. But it was expected from them to giving the maximum information with their hands.

This study was a feasibility research, so 3D physical models were generated quickly. Here, these models were produced as containing some basic components such as, one piece and multi-pieces linear configurations, flat surfaces, single and double curved surfaces, volumetric elements, some primitive shapes and several configurations of them. Also, various subtractive and additional forms were included in these configurations (**Figure 3.1**).

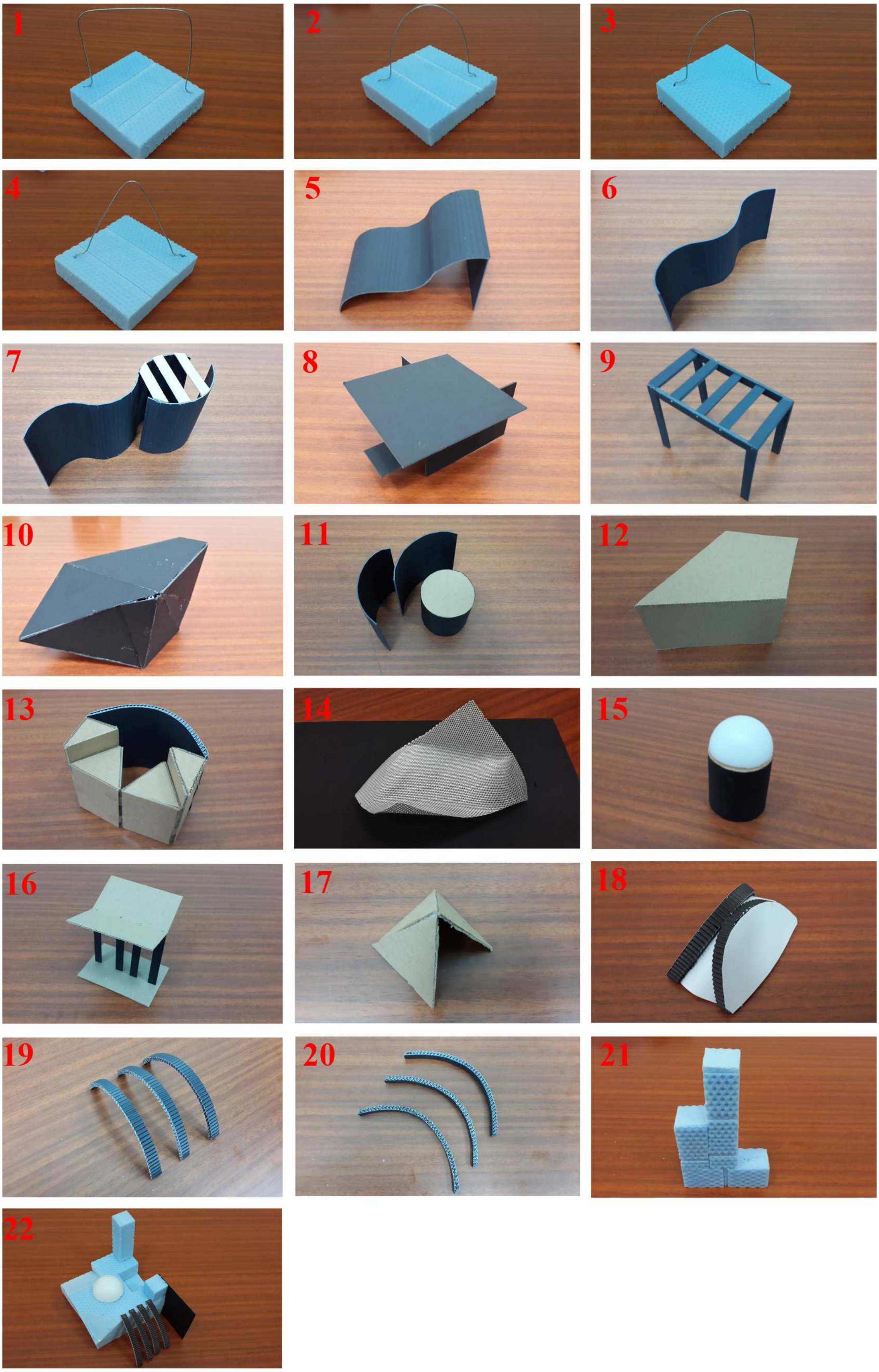

Figure 3.1 : Configurations of the First Pilot Study.

Implications of the first pilot study:

During this pilot study, several significant implications were noticed. According to these implications, design of the main experiment was revised. First, it was observed that participants were aware of level and material differences of objects. If an object has a fragmental composition, they began to model it part by part, sometimes it could be deceptive for the holistic structure of the object. Therefore, it was decided that 3D physical models should be more holistic, well-produced and proportioned. It was observed that they generated certain gestural models for certain 3D physical models, so several different configurations were included in the physical models. These implications raised awareness about the required correct 3D physical models and the whole experiment process.

There was another significant observation that whether or not the physical model big or small, participants modelled all the configurations according to their gesture space. They generally modelled objects bigger than the real ones. So, the size of the 3D physical models were revised in consequence of the participants' gestural models' size generated in the space. It was decided that size of the whole objects should have a certain measure and proportion. The smallest measurement tool is finger for the people and modeling tool is hand, so if there is a modeled object, the smallest unit of it should be constituted according to these proportions. Consequently, the smallest unit of the physical models were agreed on 3 cm, next all of the edges, surfaces and components produced as multiples of 3.

The first pilot study was performed before formulating research questions detailedly. Participants were instructed about describing given 3D physical models with their gestural representations in this pilot study. Speech was not prohibited in this study because it was thought that speech can contribute to the modeling process. But, it was observed that although there were some associations and overlapping between the information conveyed by gestures and speech, gestures and speech generally conveyed different type of information. So, it was decided that there should be different phases speech included and speech excluded as gesture-only and gesture-plus-speech in the next study. It was wondered that how would architects behave if they were not allowed to speak during the gestural modeling process.

Findings of this study helped to form a more well-constructed approach for the next pilot study and the main empirical study. As a result of this pilot study, various different 3D primitives and alternative compositions of them were generated. So, new 35 3D physical models were designed. They were arranged to explore the modeling behavior behind them to see where gesture can be representative for modeling act and how.

Section 2 – The Second Pilot Study:

The second pilot study was designed with the objectives of searching participants' modeling behaviors with and without speech, and also exploring the information conveyed by gesture and speech. Different from the first pilot study, two different phases were implemented in this second pilot study as gesture-only phase and gesture-plus-speech phase. Participants were allowed to speak, also encouraged about talking in gesture-plus-speech phase. But, alike in the first pilot study they were requested for giving the maximum information with their hands in the gesture-only phase. Furthermore, speech was prohibited in the gesture-only phase, in this phase they were directed to give the modeling information just by using their hand motions.

Two different non-architect participants took place in the second pilot study -as modeler participants- who have different background knowledge. Also there was an architect participant -as sketcher participant- in this pilot study who watched the gestural modeling videos of two participants and tried to sketch the real-models according to their statements.

These two phases were performed in different turns for two participants. Therefore, it was aimed to compare the gestural modeling behavior with and without speech through these different phases. Besides, it was searched that how to turn of the gesture-only and gesture-plus-speech phases effected the understandability of the gestural models for a third sketcher participant. Another reason of the different turn application was to search which medium was better in conveying the thought and generating the gestural models throughout this study. In the first phase of the first participant, he was asked for modeling objects with only his gestures and in his second phase he was asked for modeling with hand motions and speech. On the other hand, in the first phase of the second participant, she was asked for modeling the objects with hand motions and speech and the second phase of her, she asked for modeling just with hands.

The whole modeling process was recorded via two camcorders, one positioned opposite of the participants, the other one was on the top of the participants' head. Every participant executed the study alone and they were asked to explain the given 3D physical configurations via hands motions.

Second pilot study was conducted with a different set of models designed by taking some of the observations in the first pilot study into consideration. During the second pilot study, the new revised 3D physical models were given to the participants (**Figure 3.2**). The participants' whole gesture-only and gesture-plus-speech processes were performed with these 3D physical models. Different from the first pilot study, there were a (3x3) cm. reference grid on the table during the process.

Figure 3.2 : Configurations of the Second Pilot Study.

In this second pilot study, an architect sketcher participant was involved in the study for a different task. He was asked for watching two participants' certain gestural modeling videos and then he was asked to sketch about the real models from their gestural statements. One purpose of this task was to search the understandability of the gestural models which were produced with only gesture and gesture-plus-speech. The other purpose was to test reliability of the experimenter's observations. He watched some videos that include gestural models and he sketched about these models to represent the real 3D physical models again with paper and pencil. In this sketching process, the participants' videos were watched to the architecture participant in two phases. First of all, videotapes of the 3D physical models divided into two groups according to their morphological similarity. In the first phase, first group videos of the modeler participants were watched to the sketcher participant as only gestural, then he was asked for sketching them. In the second phase, second group videos of the modeler participants were watched to the sketcher participant as gestural+verbal, then he was asked for sketching them.

Implications of the second pilot study:

First of all, it can be said that when the study began, participants were do not have any experimental knowledge about such a study and in the first few models they tried to get used to the modeling act. After several models, they became familiar with the process and the study, so they started to model more efficiently, explicitly and relaxedly. Therefore, participants learned the modeling process and they mostly modeled the next shapes faster. Also, when they finished the first phase, they learned the shapes and they modeled better in their second phase. With this implication about learning effect, phases of the main study were organized differently.

During this second pilot study, there were more holistic, well-produced and proportioned 3D physical models and some configurations of them, for this reason it was observed that participants generally perceived these materials in a similar way, thus the perception differences and misunderstandings were prevented arising from the different material features and textures.

Participants behaved differently during the gesture-only and gesture-plus-speech phases. The first gesture-only phase, first modeler participant examined the physical models for a long time and his gestural models also took a long period of time. He tried to give all of the information via hands in the first gesture-only phase and it was an unfamiliar study for him. But, in the second gesture-plus-speech phase he relaxed, he learned how to overcome the process of the modeling via hand motions and also he learned the 3D physical models better. Because of the first application's acquisitions, he modelled these objects in a short time. Second modeler participant first modeled with her hands and speech, it was easier to explain the models via hands and speech for her, because it can be asserted that the speech helped her. Furthermore, she had the opportunity for giving the information with two modalities in this first conversancy process with the objects. It was observed that she modelled faster in the second phase, although she first modelled with hands and speech. Second participant's gesture-plus-speech phase (first turn) was faster than the first participant's gesture-only phase (first turn) as time taken. Also second participant's gesture-only phase (second turn) was faster than her own gesture-plus-speech phase (first turn) in its own right. Hereat, it can be noted that whether speech comes with gesture or not, they modelled in the second phases faster and more rationally, so there was a learning effect in their modeling process. Because, they modeled the same 35 3D physical models two times seperately. Therefore, a selective combination was built for eliminating this learning effect in the main study. Four architect participants modeled different 3D physical model sets for once with different orders and phases in the main empirical study.

In architect participant's sketching task, several observations were carried out. It can be noted that it was important in terms of comprehensibility of the real 3D physical models, participants' gestural modelings should be clear, holistic, well-defined. In addition, these models should give the whole information about shape completely. For instance, if the modeler participant did not define the true coordinate plane, thickness, and accurate geometrical words, the sketcher was misdirected. If the modeler repeated the motion again and again in the modeling process, the sketcher confused with the model and he could not sketch the real model accurately. However, mostly in the gesture-only phases, the participants' gestural models were more holistic. They did not speak in these phases, so they could not use the wrong words about the shapes. Hence, sketcher participant was not misdirected, he could understand better the real models in the gesture-only phases. For this reason, it was decided that the gesture-only phase should take place again in the main empirical study.

3.2 Main Empirical Study

The main empirical study was conducted with a total four expert architecture participants who are graduate students from different universities such as Yıldız Technical University, Selçuk University, Erciyes University. These four modeler participants were labeled as P1, P2, P3 and P4. In addition to them, there was an external reviewer included in the study, who sketched about the possible physical models of the real 3D physical models according to the modeler participants' gestural modeling videos. They have been practicing for among 3-7 years. P1 has been running his own architectural office and P3 is a senior-designer in a well-known architectural firm. P2, P4 and the external reviewer are employees in three different public organizations. In the selection of the architecture participants, the decisive factor was that participants should get having a Bachelor of Architecture degree.

Here, 3D physical models were divided into two sets as Set A and Set B for eliminating the learning effect (**Figure 3.3**). All participants modelled one shape for once. Every model sets contain 16 3D physical models which have similar morphological features, contextual complexities and scales across the groups. For example, there were linear configurations, flat surfaces, single and double curved surfaces, primitive shapes for both model groups. There were totally 32 physical models, thus three of the 35 3D physical models were ignored as it was seen that participants had difficulty to model them in the second pilot study.

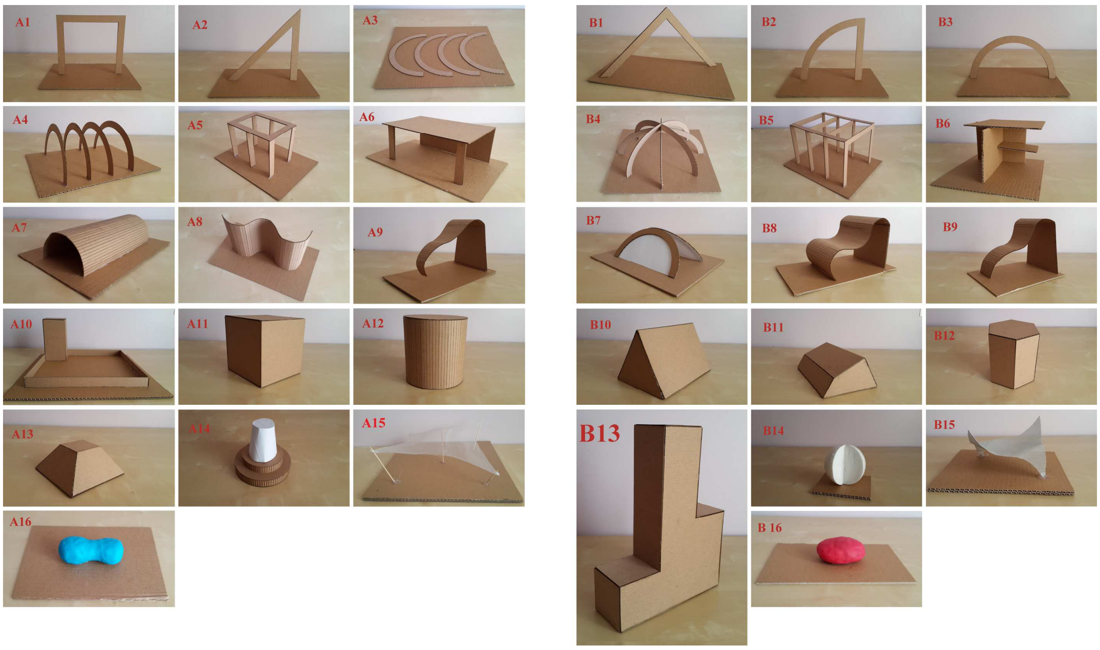

Figure 3.3 : 3D physical models - Set A 3D physical models – Set B

Two different study phases were performed as ‘gesture-only phase’ and ‘gesture-plus-speech phase’ in the main empirical study. These phases were conducted according to a specific selective combination logic as explained below (**Table 3.1**). Here, speech was allowed in the gesture-plus-speech phases, but it was prohibited in gesture-only phases. The purpose of this approach was to investigate what kind of information would be conveyed by gestures and speech during these modeling processes. In addition, it was aimed to compare these conveyed informations with each other for searching similarity and parallelism. For both phases, the gestural statements were the first priority medium. Participants were informed about that they should give the maximum information about shapes with their hands. Because, participants were instructed to generate gestures in their statements.

Table 3.1 : Table of the participants' selective combination.

Participant	Set A Models	Set B Models
P1	1. Order – Gesture-Plus-Speech Phase	2. Order – Gesture-Only Phase
P2	1. Order – Gesture-Only Phase	2. Order – Gesture-Plus-Speech Phase
P3	2. Order – Gesture-Only Phase	1. Order – Gesture-Plus-Speech Phase
P4	2. Order – Gesture-Plus-Speech Phase	1. Order – Gesture-Only Phase

- First of all, P1 (Participant 1) studied A set models in the first turn as gesture-plus-speech circumstance. Second, he studied B set models in the second turn as gesture-only circumstance.
- P2 (Participant 2) studied A set models in the first turn as gesture-only circumstance, then she studied B set models in the second turn as gesture-plus-speech circumstance.
- P3 (Participant 3) studied B set models in the first turn as gesture-plus-speech circumstance, then she studied A set models in the second turn as gesture-only circumstance.
- P4 (Participant 4) studied B set models in the first turn as gesture-only circumstance, then she studied A set models in the second turn as gesture-plus-speech circumstance. Thus, with these circumstances the learning effect could be eliminated.
- Lastly, the external reviewer watched 32 -chosen- gestural shape modeling videos as gesture-plus-speech and gesture-only phases and she sketched about these gestural modeling videos for the purpose of generating the real model with sketches.

The object described to the participants was to generate the best and the most accurate gestural model of the configurations that were given to them with the aim of a different participant would watch these videos and try to re-model the real configuration from their gestural statement. One of the major purpose of this experiment was to assess whether participants were familiar with gestural modeling techniques and behaviors. Participants were not instructed about any modeling type, start point or shape description style with the purpose of finding out whether the participant had a specialized modeling behavior and for examining is there any similar gestural behavioral pattern between the architecture participants.

The whole modeling process was recorded via two camcorders, one positioned opposite of the participants and the other one was on the top of the participants' head. Every participant executed the study alone and they were asked for explaining given 3D physical model configurations via hand motions. There was no time limit and they were not allowed to taking notes and doing sketches while examining the real 3D physical models. It was expected from them to give the maximum information with their hands in modeling process. Their task, modeling circumstances and turn of the phases were explained them clearly.

The procedure of the main empirical study can be summarized as follows:

- The experimenter gave the written design brief to the participant. There were several questions about the participants' background and individual data. The participant viewed and filled in the form this document.
- The experimenter explained the brief to the participant. The experimenter provided a feedback about whether the participant understood the study.
- The participant was instructed that (s)he was required to model several physical models with the help of hand motions in the 3D space.
- The participant was informed about (s)he can examine in detail the given physical models and can see them during the whole modeling process as so the models could not stay in camera angle.
- All these studies were conducted with one participant at a certain time in two consecutive phases as defined above that were scheduled based on the participant‘s available times.
- Every physical models were given to the participants' hands one by one. First, the physical model was given to the participant's hand, then (s)he examined the shape carefully and lastly, generated the gestural model of the

real object with hands. P1, P2, P3 and P4 modeled the whole A and B set physical models via their hands as explained circumstances above.

- Participants' gestural modeling videos were cut in Camtasia Studio 8 –a video processing program- as only modeling process can be seen in the screen. Then, 32 gestural modeling videos, which executed as gesture-only and gesture-plus-speech were selected as mix. Videos were arranged as including the whole four participants' statements and both gesture-only and gesture-plus-speech phases for elimination of learning effect.
- Then, in the last session the external reviewer studied on these 32 videos. She watched these gestural shape modeling videos and sketched about them.

3.3 Analysis

The gestural models of the participants were examined for finding answer of three main research questions as followed; (1) How the shapes were modeled by gestures under each of the circumstances? (2) To what extent architects can represent a shape/form via gestures under each of the circumstances? (3) What shape/form information was conveyed via gesture under the gesture-only circumstance, and via gesture and/or speech under the gesture-plus-speech circumstance?

For the purpose of developing an understanding for the first research question, every gestural modeling videotape -generated for every 3D physical model- was watched once and again session by session. In totally, every participants' protocols contain description of sixteen models via gestures and sixteen models via gesture-plus-speech. Therefore, for each participant, the modeling of thirty-two physical models were examined. That is to say, there were totally one hundred-twenty-eight modeling videotapes for four participants. First, all of the videotapes were watched by a clear and naked eye for examining the question of how participants modeled shapes with their gestures. All of the participants modeling processes were observed by taking notes and producing sketches by the experimenter-observer. Architects' 3D gestural shape modeling protocols were investigated according to their similarities and differences. 3D physical shape knowledge, which was gained before by the experimenter, was ignored. The experimenter tried to comprehend and sketch the real 3D physical models according to the participants' gestural modelings.

Then, with the aim of providing an understanding for the second research question, all of the videotapes were watched again carefully. All the gesture-only phases were compared each other and the gesture-plus-speech phases were compared in its own right, based on the real 3D physical model and the gestural model. Then the synchronized audio and video data were segmented in the way of gestural descriptions. The verbal data of the gesture-plus-speech phases was transcribed and these transcriptions were attached as text to the related gestural modeling video frame. These text data was also compared with the gestural modeling data by taking into consideration conveyed information with them. Several comparative analyzes were presented as tables in the way of verbal and gestural transcriptions and conveyed shape information via them. Then, all of the videos were watched again and several hand sketches were produced according to the gathered information from them.

Lastly, for providing reliability for the study, an external reviewer was included in the study. Twenty-two gestural modeling protocols of the participants were chosen from all of the four participants protocols as containing the models generated in both gesture-only and gesture-plus-speech phases. Then, the external reviewer watched these 32 videos and she tried to sketch about what she comprehended about these gestural models concerning the real 3D physical models. The time elapsed while examining the real 3D physical models and gestural modeling act were noted for each participants and for each 3D physical models.

In this part, the audio and video data collected from the participants' modeling tasks were segmented according to every meaningfull hand moves -gesture occurrences-. There were some other body movements, eye movements and eye fixations during the participants' explanations, but these occurrences were generally ignored as focus of this study was hand movements. Participants' gestural modeling behaviors were examined by paying careful attention to the way they modeled different shapes. These segmentations were executed as indicated below:

- First every gestural model produced by the participants was watched and examined according to the modeling characteristics and they were compared each other.

- In gesture-plus-speech phases, verbal descriptions of the participants were transcribed and they were attached as texts to the related video intervals. In addition, gestural descriptions of the 3D physical models were transcribed and compared each other for every participant and for every modeling phase.

- Every participant's modeling manner was compared each other and searched for looking whether there would be any characteristic similarities between their protocols also their gestural models for the same 3D physical models.

- In all gesture-only and gesture-plus-speech phases, the protocols were segmented with regard to the modeling actions. While watching them, the experimenter tried to sketch the entities described by the participants based on the information (s)he could glean from the gestures.

- An external reviewer was requested to review video segments of the participants' gestural modeling videos in order to seek reliability. She was asked for producing sketches based on the information gathered from the gestural models of the participants, the entities they were trying to model were represented via sketches by the external reviewer.

- Then, experimenter's (observer's) and the external reviewer's sketches were compared with each other for providing reliability to the study.

- In addition to above aspects, some further features were looked at in the protocols of the participants, one of them was time. In all gesture-only and gesture-plus-speech phases, time taken by the participants for modeling the real 3D physical models were segmented and compared with each other.

- The participants' verbal and gestural descriptions were analyzed for seeking what shape information was conveyed through them in the gesture-plus-speech phases. With the same approach, gestural descriptions were analyzed for looking at the information conveyed by gestures in the gesture-only phases.

4. ANALYSES AND RESULTS

The first section of this chapter provides an insight into gestural modeling behavior of the architects during the shape modeling process. The second section discusses the similarities and differences observed in the gestural modeling processes of participants while modeling the various shapes/configurations. The third section presents the outcomes of the analysis of the shape information conveyed by gestures in the gesture-only modeling circumstance and by the gestures and speech in the gesture-plus-speech circumstance.

4.1 Gestural Modeling Behavior of the Architects

As outlined in the previous section, participants were first provided as much as time as they required to examine the physical models of the shapes one at a time. In review of this examination process, participants were seen to be explaning the shape, either in the form of whispering or as if describing to a listener for instance a participant whispered “hmm, here some space occurrences have been increased” while examining B6 shape. Another participant spoke aloud ‘I am learning now in this way, actually, I am memorizing’ while studying A8 shape. One of the participants generally touched objects’ surface with fingers and experienced the object via their tour around the object. Besides, participants used different hand movements while examining planar, waved, edged and curved objects that have different characteristics.

In this examining process, participants were seen to notice the (3x3) grid system which was not told to them and used this grid for measurement of 3D physical models by turning them over and over again on the grid system. After this examining process, participants generally stayed silent for a while in both of the modeling circumstances i.e. the gesture-only and gesture-plus-speech circumstances, as understood from the comments they made after the study, the reason for this silence was preparing themselves for the description phase.

Figure 4.1 : Participants are measuring 3D physical models.

In examination of participants modeling behavior while modeling various shapes, some commonalities were found that almost all participants modelled in the way all or most of the participants modelled each shape/configuration and shapes or the configurations with shapes that have similar physical characteristics such as configurations with linear elements, configurations with surfaces and etc.

Based on the commonalities in their modeling, it was possible to categorize shapes into six major groups, which are hereafter referred to as Group 1, B, C, D, E and F respectively. The rest of this section outlines the observations made in participants' modeling of the shapes in each of these groups.

4.1.1 Group 1

3D physical models of this group can be seen in (**Figure 4.2**). This group consisted of compositions with linear elements i.e. elements whose one dimension is much larger than the other two directions, and some more complex configurations of them. There were two types of sub-groups as 1.a and 1.b. Sub-group 1.a was 'one-piece configurations' i.e. configurations which, if were to be drawn or modeled by hand can be drawn/modeled by a continuous movement (A1, A2, B1, B2, B3). Sub-group 1.b can be described as 'multi-piece configurations' which involves a number of one-piece configurations (A4, B4, A5, B5).

While modeling the one-piece configurations, participants mostly behaved like chalking up on a blackboard with their thumbs and index fingers under both circumstances (gesture-only and gesture-plus speech). They generally used their right or left index fingers or both of them for modeling these type of geometries. Generally, in the first step, one index finger touched the base plane and defined a start point in the x plane, movement started with this touch. In the second step, this starter finger began to move in z plane. Then whatever form the model has, the finger followed this path in the gesture space. Lastly, this finger finished the model by touching the base plane like defining an endpoint, similar with the start point. To give an example, P1’s gestural modeling for A1 can be seen in (**Figure 4.3**).

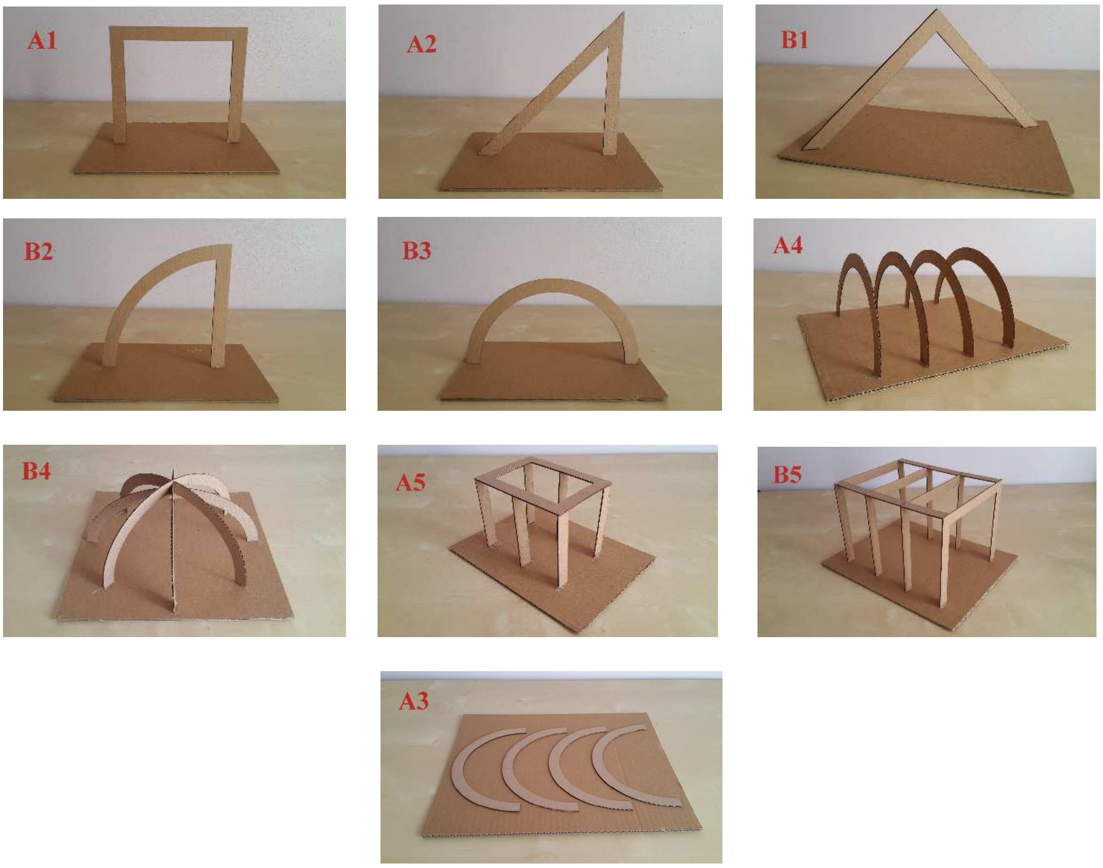

Figure 4.2 : Group 1 Models

While modeling shapes, participants were seen to often make an effort to capture the real proportions of the 3D physical models with their hands, also they tried to express these proportions in a correct and relational way for their descriptions. For this reason, they measured the real physical models with their eyes, hands and with the reference grid that took place on the table. It can be said that this (3x3) cm. grid had an important role in building of the spatial proportions and relations of the gestural models also, in measurement of the real physical models. Participants frequently took this grid as a reference for positioning their gestural models in the space.

While they were describing wall thickness of the linear objects, most of the participants generally used their thumb and index fingers. These fingers looked each other, came closer and they took a form like keeping a thin object. They defined a space or gap as a measurement style for describing wall thickness of the objects. Throughout the gestural modeling process, if (s)he gave a measure with thumb and index finger in the beginning of the modeling process, (s)he kept fingers as this form and followed the whole modeling path with this gap. Mostly, they behaved like chalking up on a blackboard in modeling of these type linear configurations.

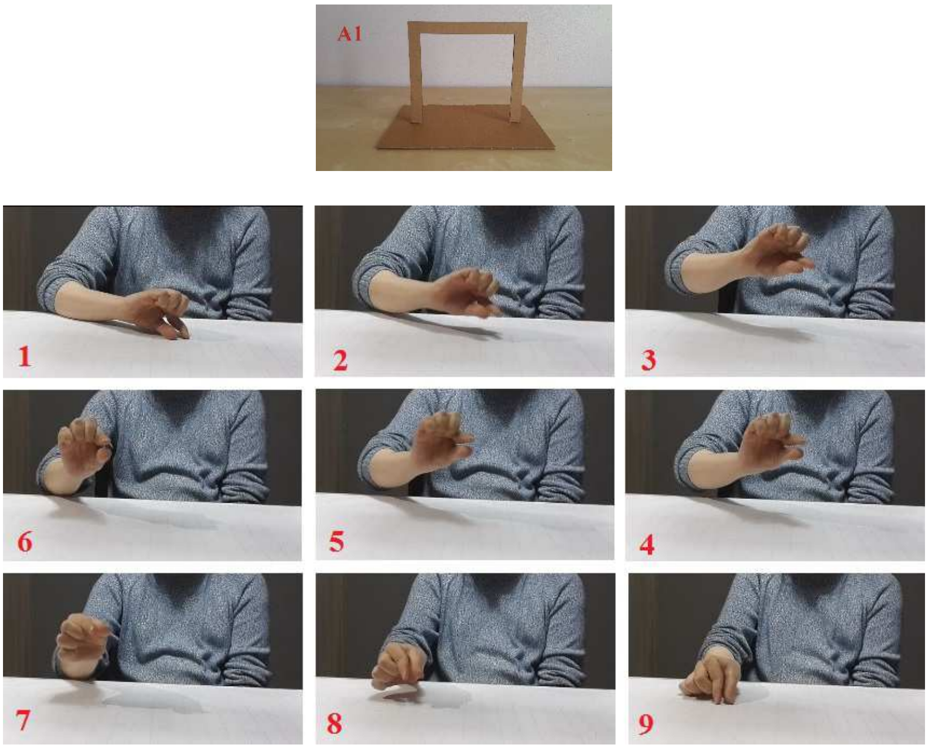

Figure 4.3 : P1 was modeling A1.

1- Here, P1 was mainly depicting the start point of the model and he gave the thickness of the object.
2- He moved his starter fingers (thumb and index finger of right hand) upward through z plane.
3- His hand slowed down while he was getting close to the corner.
4- His hand paused for a little time and he rotated her hand in the first corner of the object.
5- He continued to the model as parallel to x plane.
6- His hand paused for a little time.
7- He rotated his hand in the second corner of the object.
8- He moved his hand downward in z plane.
9- Lastly, he arrived the finish point and he touched his fingers to the base plane.

Participants generally behaved similarly while describing the multi-piece configurations under both circumstances (gesture-only and gesture-plus speech). When the configuration became complicated, they struggled for decomposing the configuration to the small pieces and later they tried to represent every small component one by one in a certain reason. First, they segmented these type of multi-piece configurations to the smaller components and they started with description of the first component. Next, they modeled the second one. Then they constructed the whole model by positioning the other components to the configuration relatively.

In addition to the modeling similarities, there were some differences resulting from the configurations. For instance, in modeling of the horizontal A3 model, different from the vertical ones, they positioned the object in x plane like in the real view. They also started with an initial point and their index finger followed the objects' path in x plane by touching on the table and they finished the model with an end point (as seen in **Figure 4.4**).

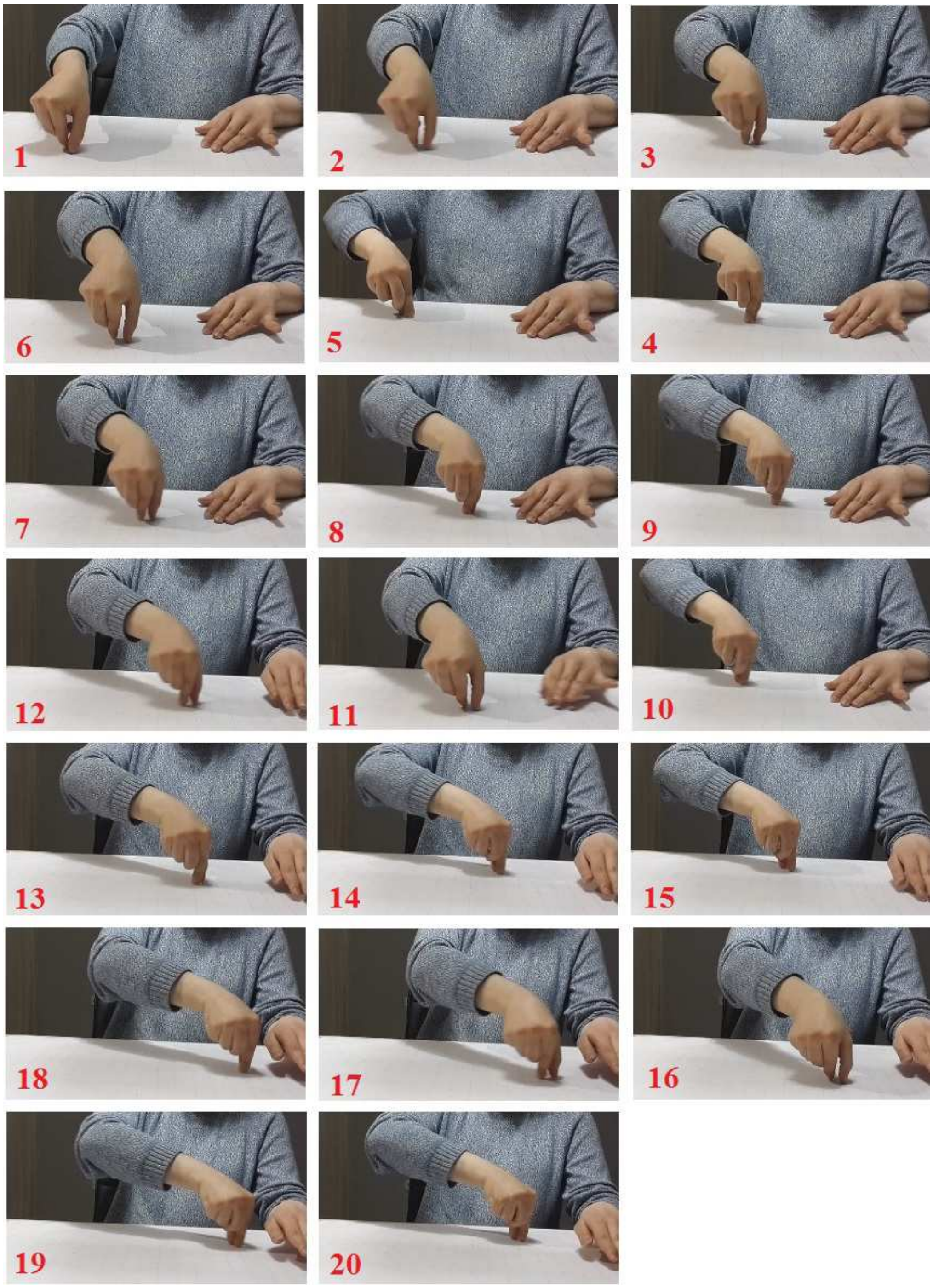

Figure 4.4 : P1 was modeling A3.

Participants tried to give the correct spatial relations of the components by measuring with hand or eye. They kept eyes on the 3D physical model during the gestural modeling, took references from the model and mostly they generated their model by one-to-one tracking. All participants modelled B4 in a similar way except P2. They behaved like there was an invisible central point in the middle of the object. They positioned four arcs as turning on this center with 45 degree angle. They first modelled one arc in the gesture space. Then they positioned the second arc in configuration by considering the central point, later they added a third one and the last one with the index finger. However, P2 modelled B4 differently from the others by using two hands (**Figure 4.5**). First of all, she perceived whole configuration as a dome and she described a dome in the gesture space with her two curved hands again and again. She began to model the first arc by starting with the peak point and then going to the two points, that arc touched on the plane. Later, she modelled other three arcs with the same approach and she positioned all of them by considering the real 3D physical model. P2's detailed B4 modeling process and gesture transcriptions can be seen below.

Model A5 and B5 are similar but they have different production methods. In A5, six small piece of materials bear a piece of rectangular frame. B5 is an object that consists of four rectangular frames which one edge was cut. Moreover, B5 has six small piece of materials between these four cut rectangular frames. The objective of generating these models with different production methods was to explore how participants would model these objects. In addition, it was searched that whether such production method diversities could cause any possible differences in the gestural modeling approach of participants. As expected, participants were aware of these production differences and they behaved according to them. However, it can be added that in the second pilot study, non-architect participants could not notice these details, this two participants modeled two shapes similarly. So, architect participants paid more attention to such details about the objects more than the non-architect participants.

Participants drew some vertical columns via their thumb and index fingers from the base plane through the gesture space in the z plane during the modeling process of the model A5. Then, they drew the rectangular frame element on the top of them as the columns were still there in the air. In modeling of B5, they firstly generated vertical rectangular frames with the same approach from x to z plane, then again through x plane like chalking up on a blackboard. Later, they positioned the second vertical frame according to the real distance between the first and the second ones. They tried to position all these vertical components with the correct relations and proportions. Later, they described the horizontal material pieces that took place between the top sides of the each rectangular frames. They closed these horizontal gaps by drawing linear elements with their index fingers.

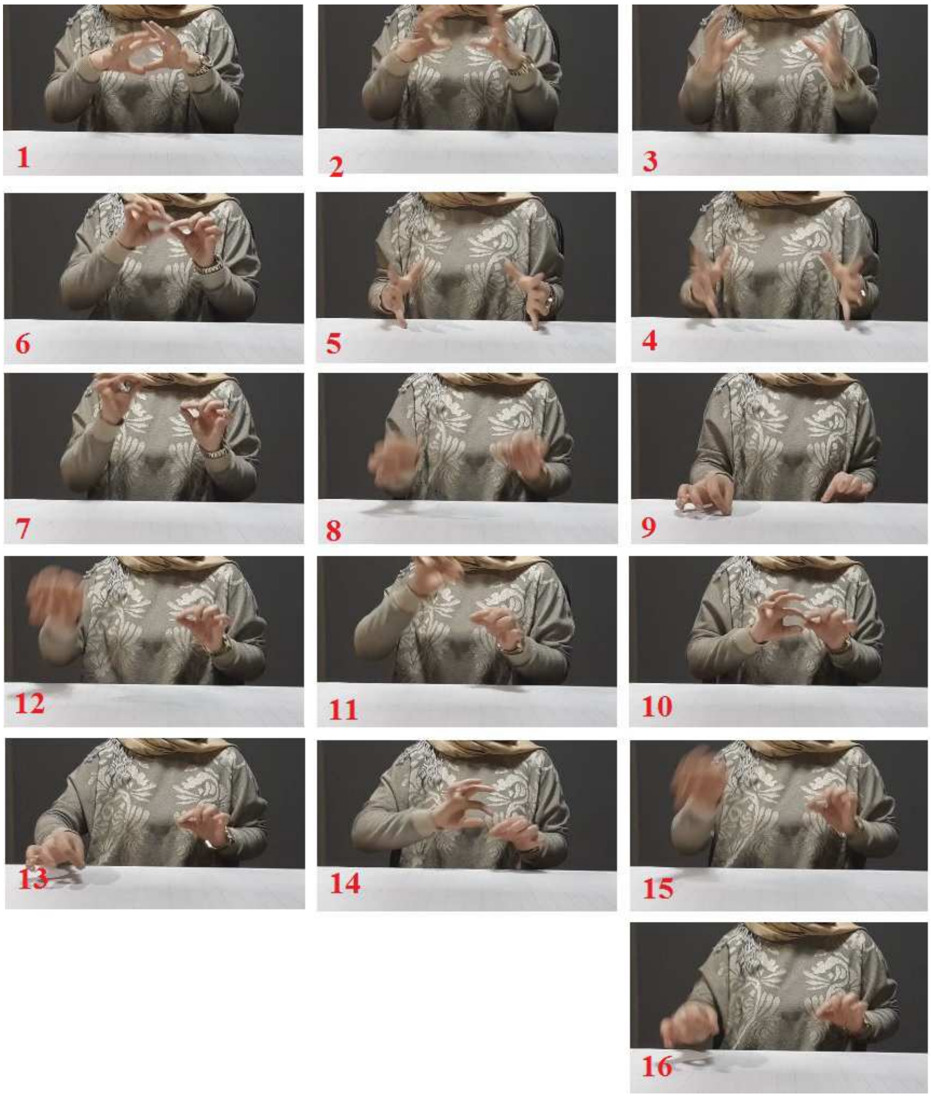

Figure 4.5 : P2 was modeling B4.

1- Here, P2 first defining a dome with her two curved hands.
2, 3, 4, 5- P2 depicted the dome form again and again.
6- She started to model the object from the peak point through downward where the arc was going towards x plane.
7, 8, 9- She combined her thumb and index finger for each hands separately and follow the path of dome. She arrived to x plane, the finish point of the arcs.
10, 11, 12, 13, 14, 15, 16- She repeated this motion for every arc of the dome.

4.1.2 Group 2

3D physical models of this group can be seen in (**Figure 4.6**). This group consisted of the configurations including simple linear elements and flat surfaces. Participants experienced a different type of geometry in this group, because lines turned into planes by laying together and participants faced with surfaces in this model group. As expected, hands of participants exhibited some different behaviors while modeling these type of physical models.

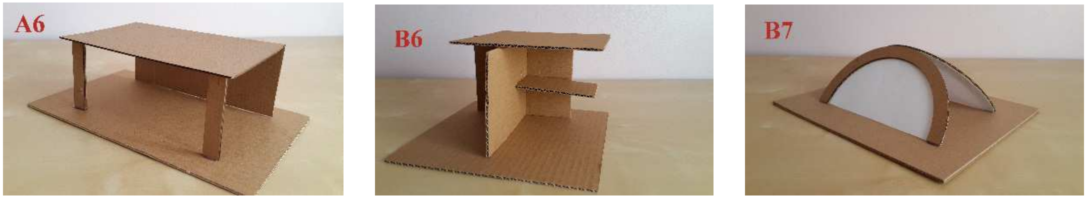

Figure 4.6 : Group 2 Models

Most of the participants' fingers exhibited a similar behavior during the flat surface modeling processes under both circumstances (gesture-only and gesture-plus speech). All of the fingers came closer to each other and constituted a contiguous-finger surface while investigating and describing these geometries. When participants handled the given models at once, they started to lead around the object by contiguous-finger surface. It can be said that when the surfaces and proportions of the closed parts were increased, they started to use whole hand than the singular fingers. Also the participants' hands tried to behave like objects' surface.

In modeling of A6, they frequently positioned the first vertical wall plane via hands, secondly they turned the hand's surface by generating an overhead plane top of the object, then the fingers got on the stage again for generating the small vertical columns. They drew these small pieces by using index finger from top of the object through the base plane. The architect participants commented about the space occurrences of these planar physical models.

In modeling of B6, they reported that this model was more challenging according to the previous models. They found it difficult because there were more complex spatial locations also there were different proportional material pieces even though all of them have a relational proportion. Moreover, they had to measure the horizontal and vertical gaps and needed to organize the whole object according to these spaces.

Besides, they had difficulty in keeping the proportions and locations of the pieces in their mind.

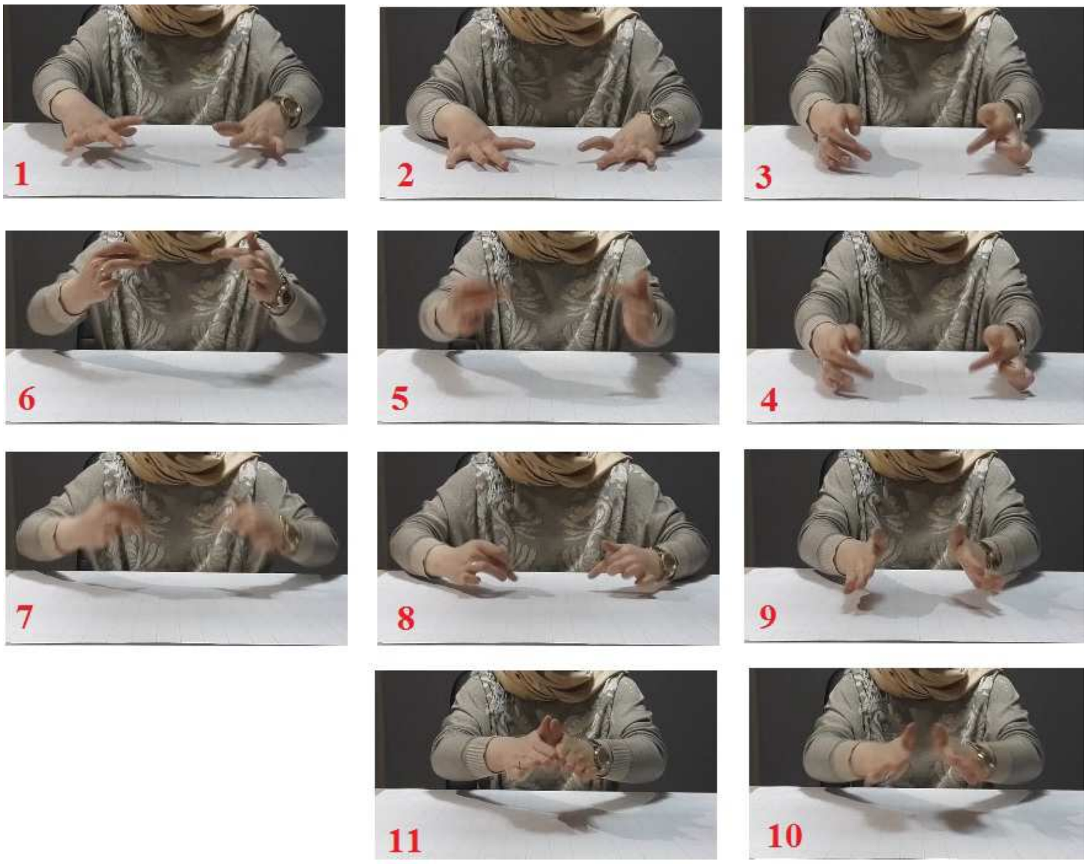

Figure 4.7 : P2 was modeling B7.

In modeling of B7, they also used hands' surfaces, but firstly they started the modeling act with index finger or fingers. First of all the fingers started to draw the circumference of the hemicycle in gesture space with converging each other prominently. Same as before, the action started from x plane, later moved through z plane and turned back to x plane for stopping the motion. After fingers' action, participants described white surfaces via their whole hand. It can be noted that they were aware of this white-color surfaces and they commented about them.

For example, P2 can be seen above as modeling B7 (**Figure 4.7**). She first defined the diameter of the hemicycle on the table. Then, she drew two hemicycles in gesture space with her index fingers. Later, she describe the surface of the hemicycles with her two hands and adjoined fingers. Her two hands behaved like touching on surface of the object and they defined the oblique position of these hemicycles. So her hands became closer and turned 45 degree and her thumbs touched each other.

4.1.3 Group 3

3D physical models of this group can be seen in (**Figure 4.8**). This group consisted of the configurations including the single and double-curved surfaces.

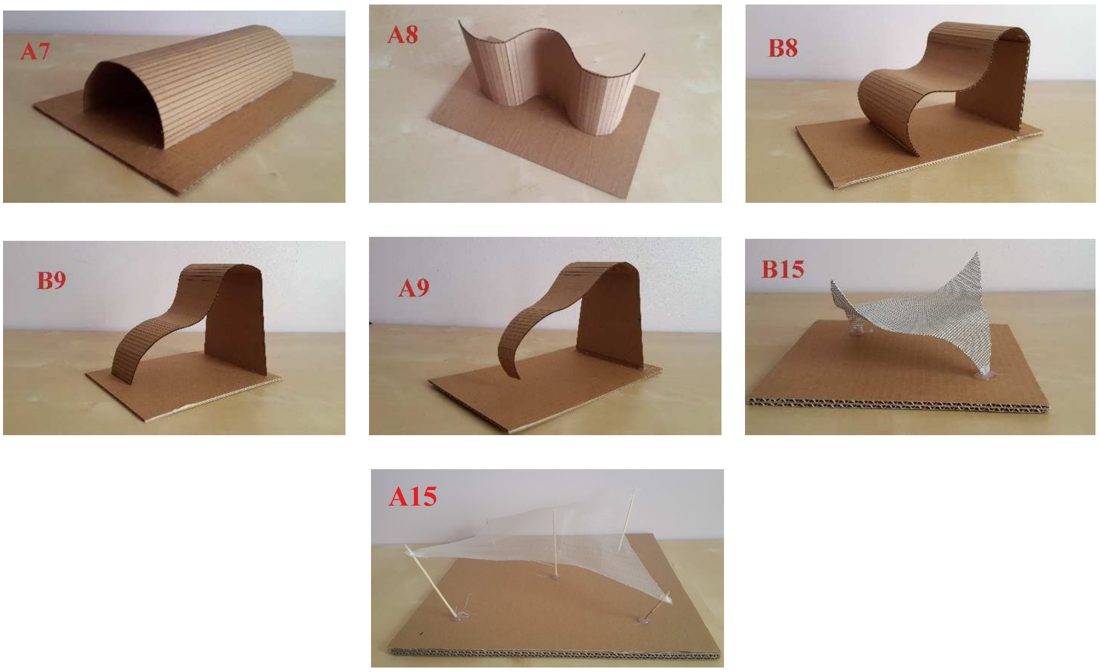

Figure 4.8 : Group 3 Models

In modeling A7, P1 and P4 behaved partly similar, they swept surface of the object with the hand like touching on the surface of it. At first, hand was vertical to the base plane and the little finger touched this plane, then hand started to move through z plane, turned, defined the cylindrical surface, then turned again and stopped the movement with thumbs’ touch to the plane. Although there have been some similarities in participants’ A7 modeling, there were certain differences, participants comparative A7 modeling can be seen in Appendix B.

P3 used her two hands in modeling A7 and these hands had a different position and action (**Figure 4.9**). The palm of the hands looked to the x plane, the fingers were curved and adjoined. Two hands were articulated back to back. All of them defined the length of the object via two hands in the end. Two hands were vertical to the plane, the little fingers touched the plane and they showed a distance about length of the object. Her hands moved on the base plane like sliding and described the curved surface.

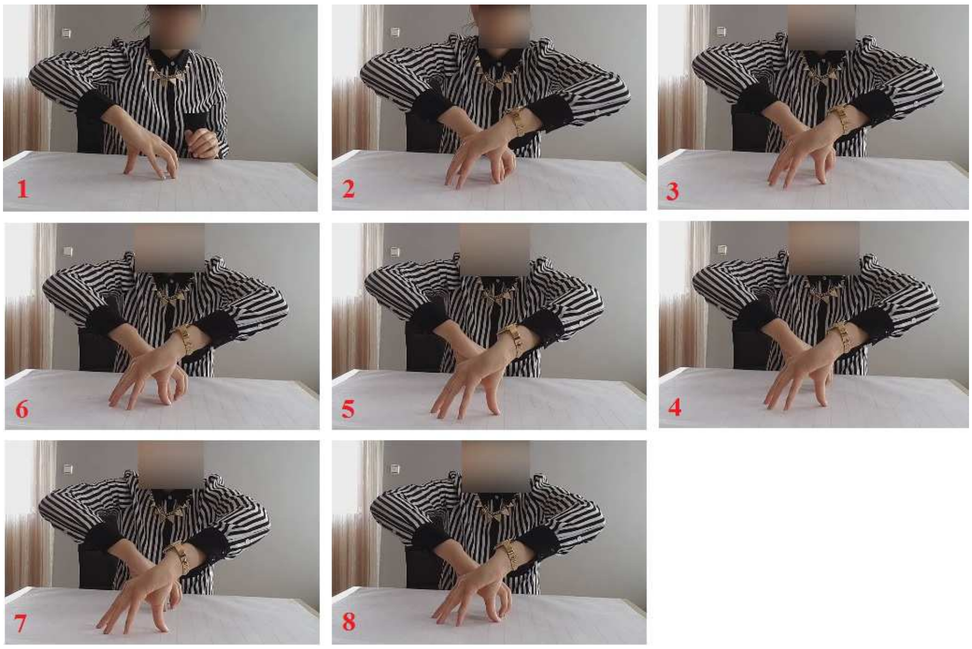

Figure 4.9 : P3 was modeling A7.

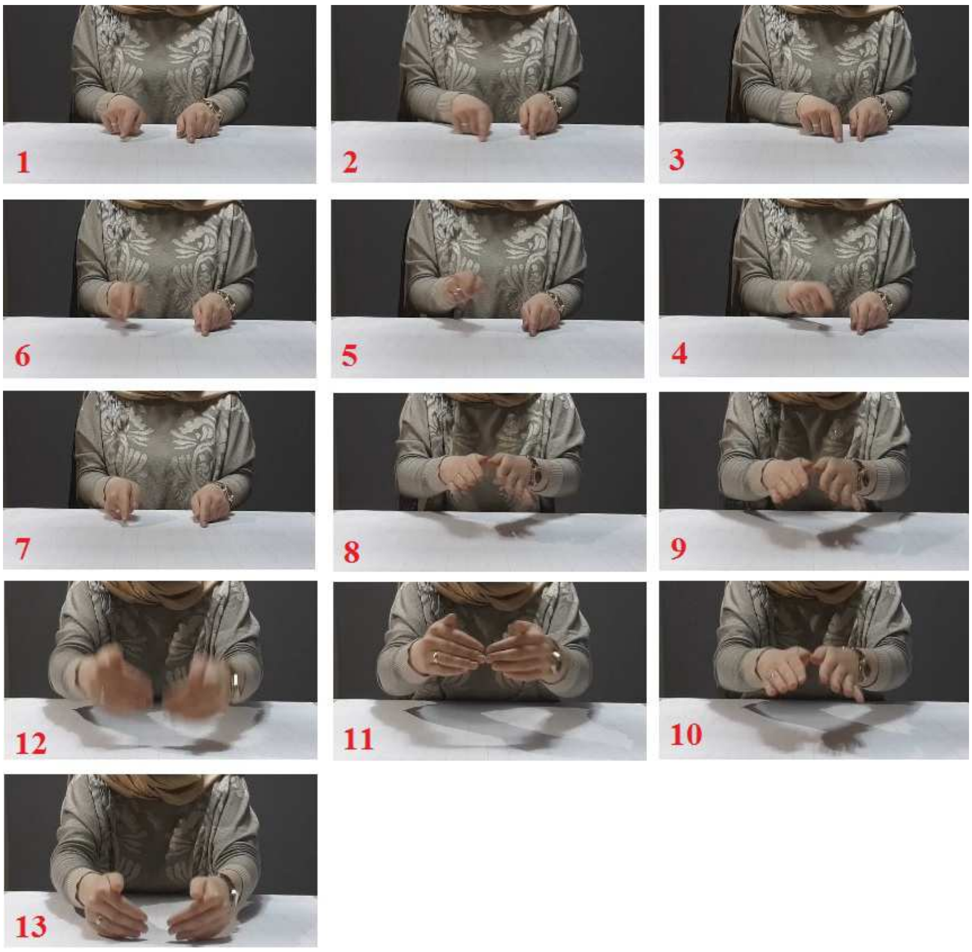

Figure 4.10 : P2 was modeling A7.

P2 behaved differently in the modeling of A7 (**Figure 4.10**). She started to model with drawing a hemicycle in z plane with right index finger. Then her two hands' fingers took the form of an adjoined and straight surface. Beginning with the first hemicycle, she moved her hands forwardly as the little finger touched the plane horizontally, in other words slid her hands through the length of the cylindrical surface. Lastly she defined the length of the surface with putting her adjoint hand to the endpoint of the object as the little finger touched the plane horizontally also she hit the plane a bit drastically.

A8, B8, A9, B9 have a similar production method with A7, but these models have more complicated forms and needed several different stages in the modeling process. In modeling of A8, different approaches were observed. Two of the participants behaved similarly, the fingers were adjoined and they positioned them as four fingertips were touching on the plane vertically, then the hand began to move slowly through the curved path. Different from them, P3 used her right hand while she was modeling A8, the fingers were adjoined and hand positioned as the little finger touching the base plane horizontally (**Figure 4.11**). Then she curved her hand along the curved surfaces' path in the base plane by weaving horizontally.

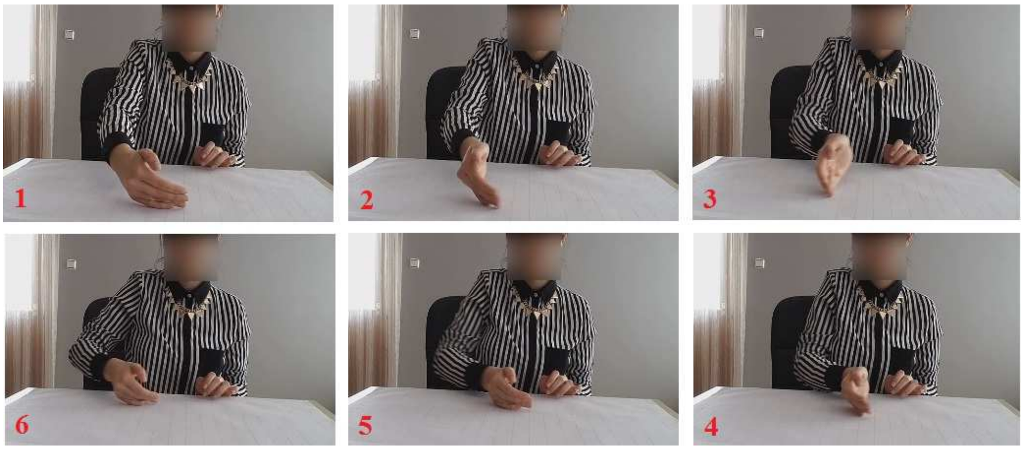

Figure 4.11 : P3 was modeling A8.

P2 also behaved different (**Figure 4.12**). Firstly, she drew the curved path in the base plane with the right index finger. Then the fingers were adjoined for both of the hands separately. Later her hands curved, the little fingers touched the plane horizontally. Then one of the hands stated to one after another by ones' fingertips touching the others' wrist line. Participants' comparative A8 modeling can be seen in Appendix B.

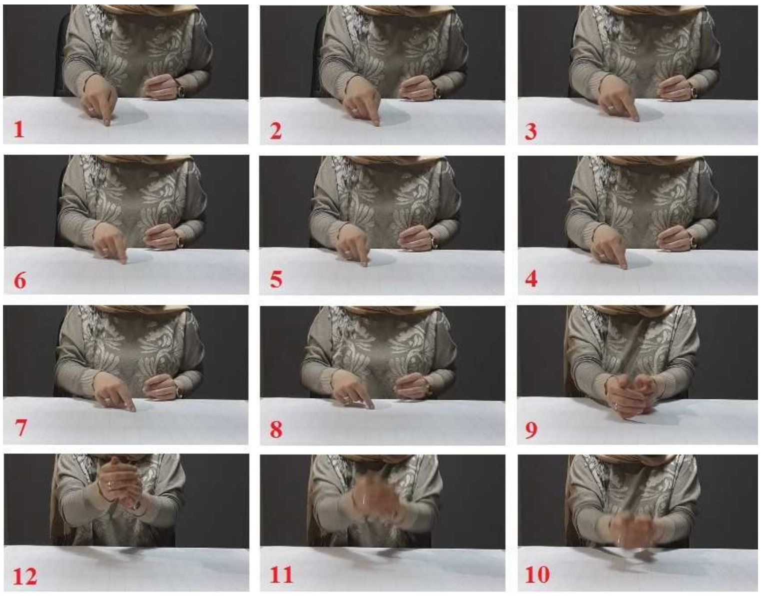

Figure 4.12 : P2 was modeling A8.

In modeling of B8, B9, A9 two of the participants used their one hand, the other two participants used their two hands. P1 and P2 stated their left hand as the little finger touching on the table horizontally also the hand was vertical. Then their right hand came closer to it and became to wave horizontally as parallel to the base plane. They gave the angle of constriction of B9 and A9 by hands (**Figure 4.13**).

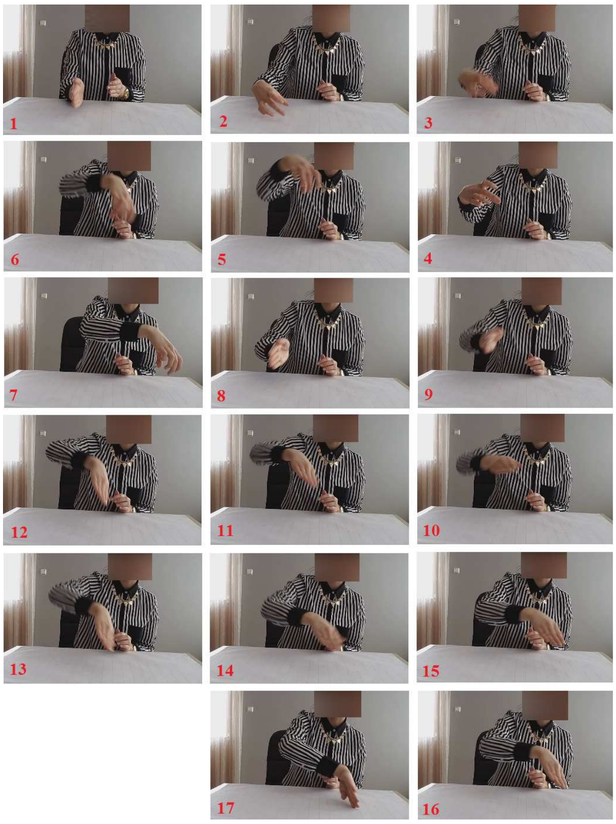

Figure 4.13 : P3 was modeling B8.

A15 and B15 have an upward curvature in one direction and a downward curvature in the perpendicular direction. It was difficult for participants to address and attach two surfaces that behave differently by hands. In modeling of B15, they first usually drew the curvature surface in x plane, as it was straight. Then they held it with hands and put in the air. Then they put two diagonal vertexes and stretched them to upward, later held the other two diagonal vertexes and stretched to the downward of the surface. P4 emphasized the different action of two vertexes with her fingers in modeling of B15 and she stretched the two diagonal vertexes upward and the other diagonal two vertexes to downward (**Figure 4.14**).

In modeling of A15, they drew the curvature form in x plane, as it was straight. Then they followed the same approach with the modeling of B15, but in the end, they emphasized the beams that supported the curvature surface. They modelled these beams via their index fingers, from x plane through the z plane. P4 especially underlined stretched sharp edges of A15 and she slid her hand on the curvature surface of the object like it was there on the air by touching it in the end of modeling. She tried to give the accurate curvature dimensions by sliding her hand on the invisible modelled objects' surface.

Figure 4.14 : P4 was modeling B15.

4.1.4 Group 4

3D physical models of this group can be seen in (**Figure 4.15**). This group consisted of the configurations including the primary solid geometries. It was aimed at here to look at how participants would model these type of closed geometries, how they would give the closeness information also height information of the objects.

Participants were faced with closed solid geometries in this group. They generally tried to give the height value and the organization of the surfaces by their hands and adjoined fingers.

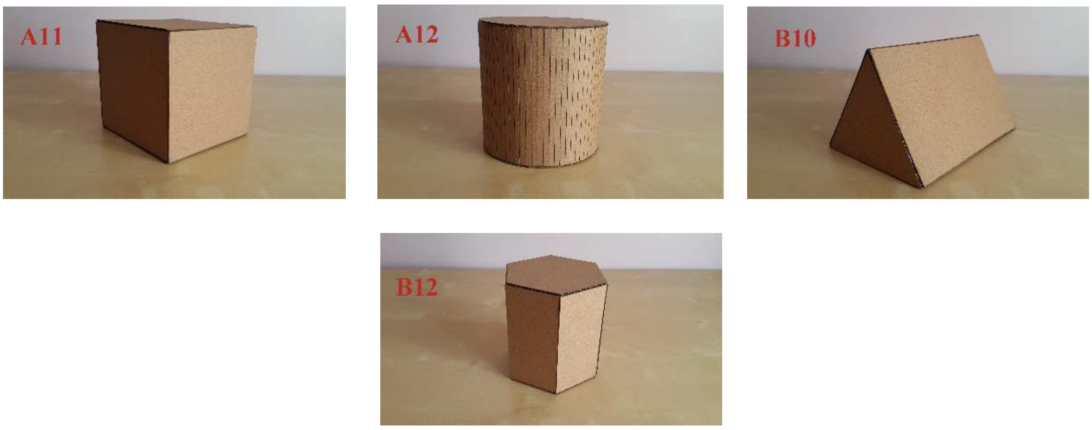

Figure 4.15 : Group 4 Models

In modeling of A11, firstly all of the participants mostly drew a square as the basic component of the cube on the base plane. After definition of the bottom peripheral, they held this region with hands from the edges or vertexes and stretched via motion of the hand in z plane (see also, **Figure 4.16, Figure 4.17**). The finish of the objects frequently were given by motion of the hands like cutting something in the air by moving from one side to another. Furthermore, hands occasionally behaved like that in depiction of the objects' end, they were parallel to the base plane and came from above and restricted the objects' length.

Sometimes, it was observed that the fingers were adjoined and the hands took a straight form. Thereafter the hands defined the surfaces of these geometries like touching on the surfaces that hung in the air. P4 modeled A11 by directly defining the surface geometries with her hands (**Figure 4.17**). She modeled all of the closed surfaces by hands and in the end, she closed the form with her hands' finish motion on the top side of the object.

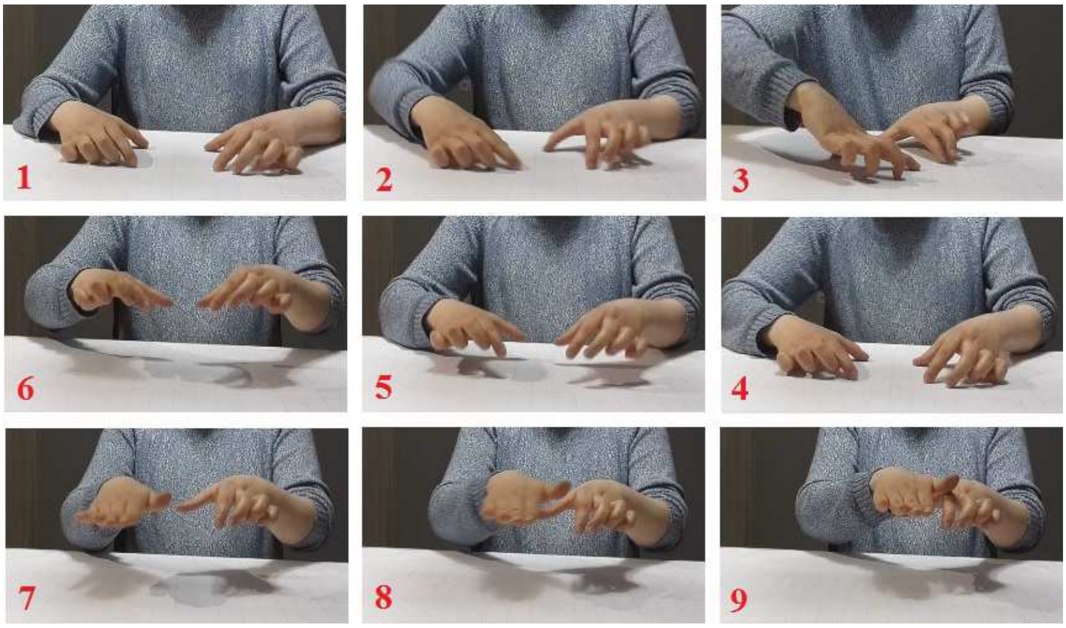

Figure 4.16 : P1 was modeling A11.

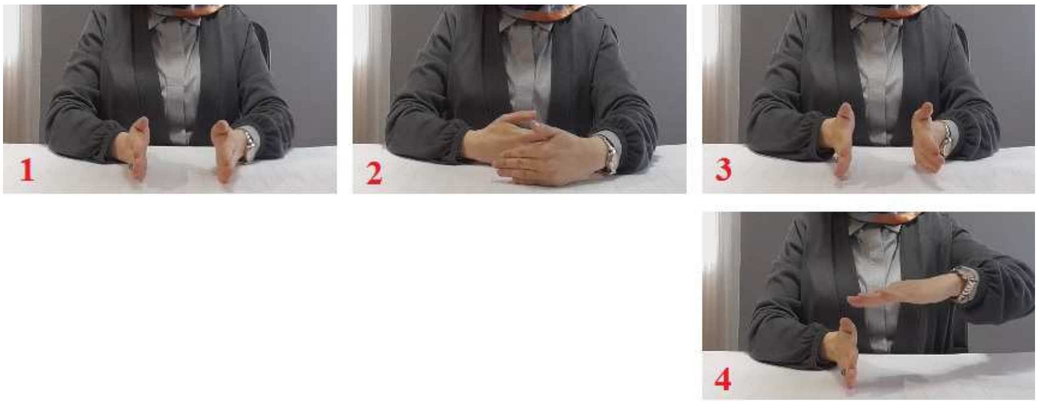

Figure 4.17 : P4 was modeling A11.

If the model has a volume that can be created by stretching a shape in a certain coordinate plane, most of the participants specified the contour of the shape and height information separately for instance first they drew the silhouette or shape then stretched it in a certain coordinate plane. They were successful at this type of modeling. There were several primitives in the participants' minds and words like cylinder, prism, cone, polyhedra or pyramid, because our physical models contain these type of ruled geometries. According to this observation, it can be said that if the configurations have regular geometries, they were easily understood and modelled maybe it resulted from the geometrical education background. On the other hand, maybe mind can easily give the meaning to the geometries if there was a visible regular logic.

4.1.5 Group 5

3D physical models of this group can be seen in (**Figure 4.18**). This group consisted of the configurations including the forms generated with several subtraction and union operations. In modeling of A10, participants started with short square object, later they stated the model rectangular solid in the corner of the first short square. The finish of the solid object defined with the end motion of the hands once again.

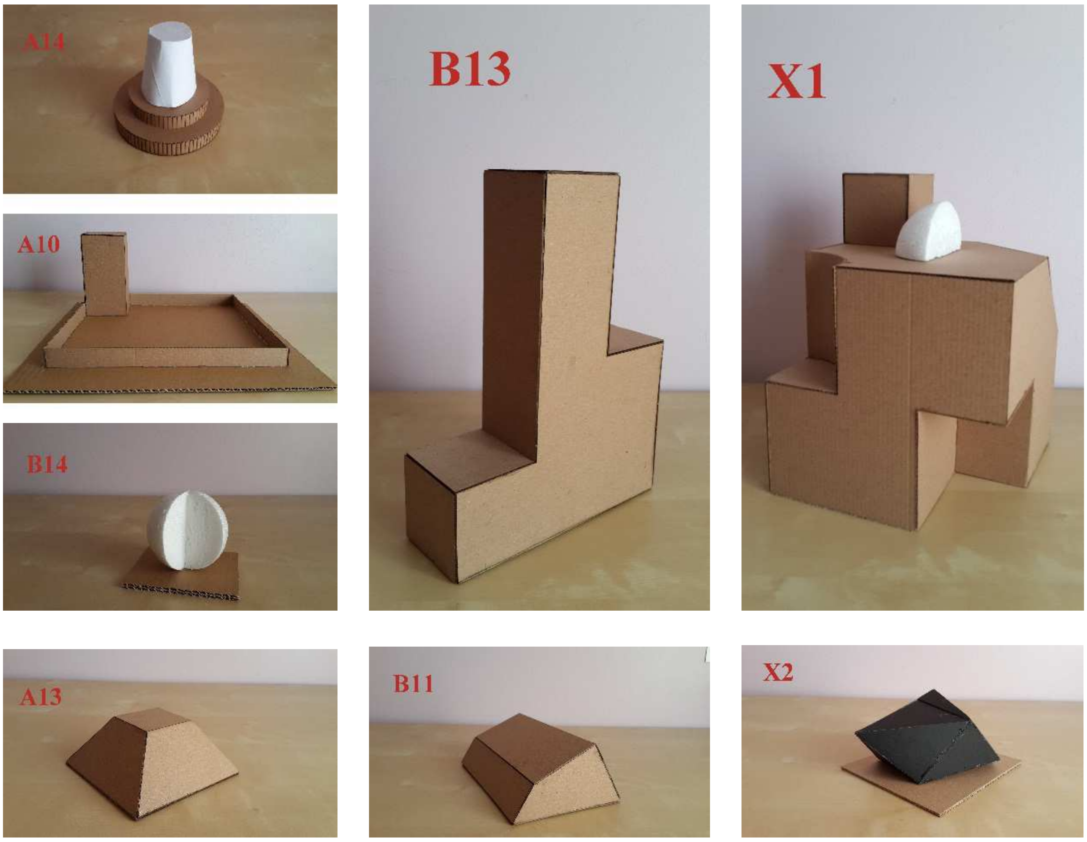

Figure 4.18 : Group 5 Models

In modeling of B13, all of the participnats followed a new path as union of three different objects. They modelled B13 step–by-step. P1 firstly modelled the small piece as (2x2) unit, next he modelled the piece took place in the middle as (2x8) unit, then the last one as (4x4) unit by sweeping all the surfaces by hand. Lastly, he described the thickness of the object by his two hands. He joint his fingers, he gave a vertical position to his hands and defined the thickness of the object by their distance. P2 first gave the thickness information of the shape by left thumb and index finger then she modelled this object by drawing the silhouette in z plane (**Figure 4.20**). P4 situated the model more verbally, she mentioned that there was a significant visible proportion, second piece (4x4) is double of the small one (2x2) and the biggest one is double of the middle one (4x4). P3 modelled B13 differently by subtraction operations. She first modelled a whole object as a rectangular prism. Then she drew the pieces -which will be subtracted- on it as it was still there in the gesture space and then she subtracted the right and left pieces from it (**Figure 4.19**).

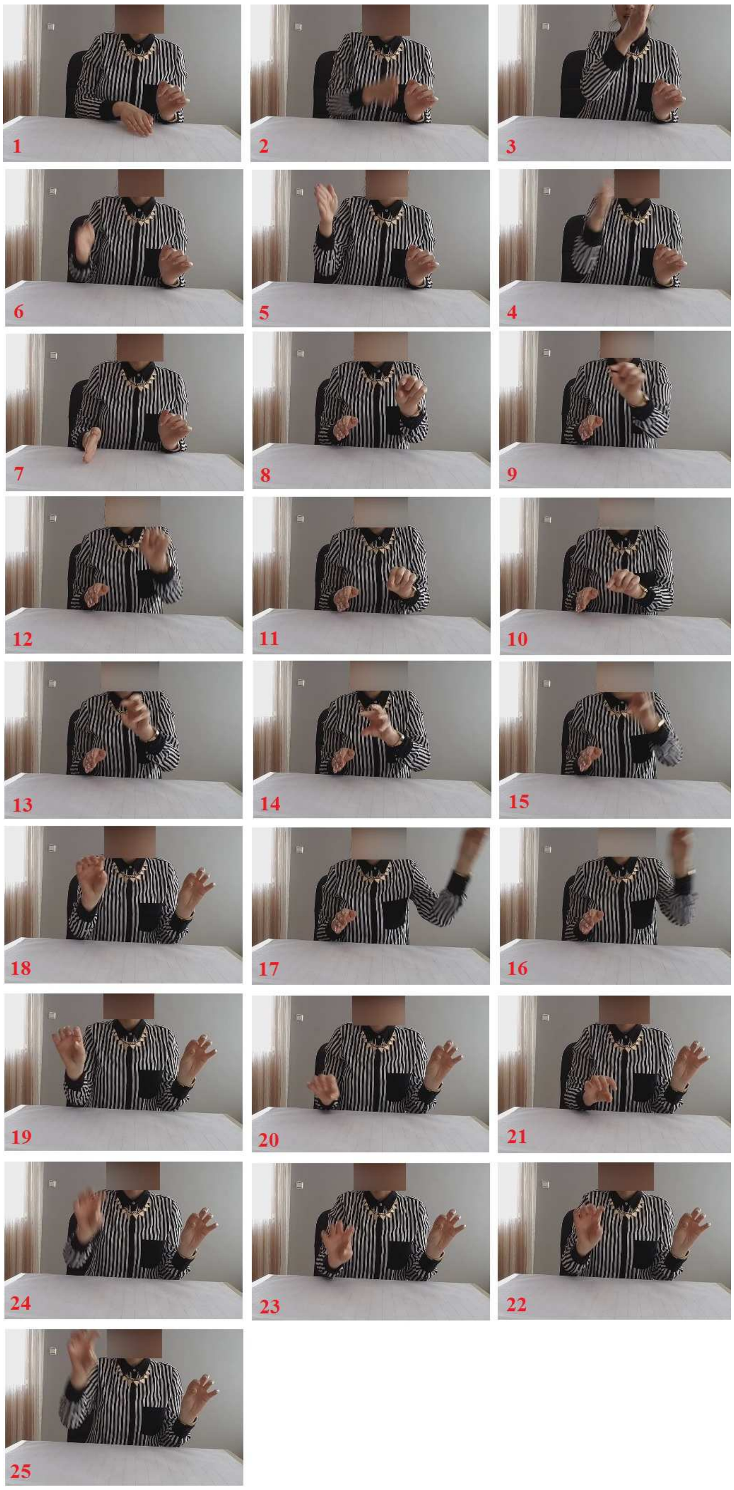

Figure 4.19 : P3 was modeling B13.

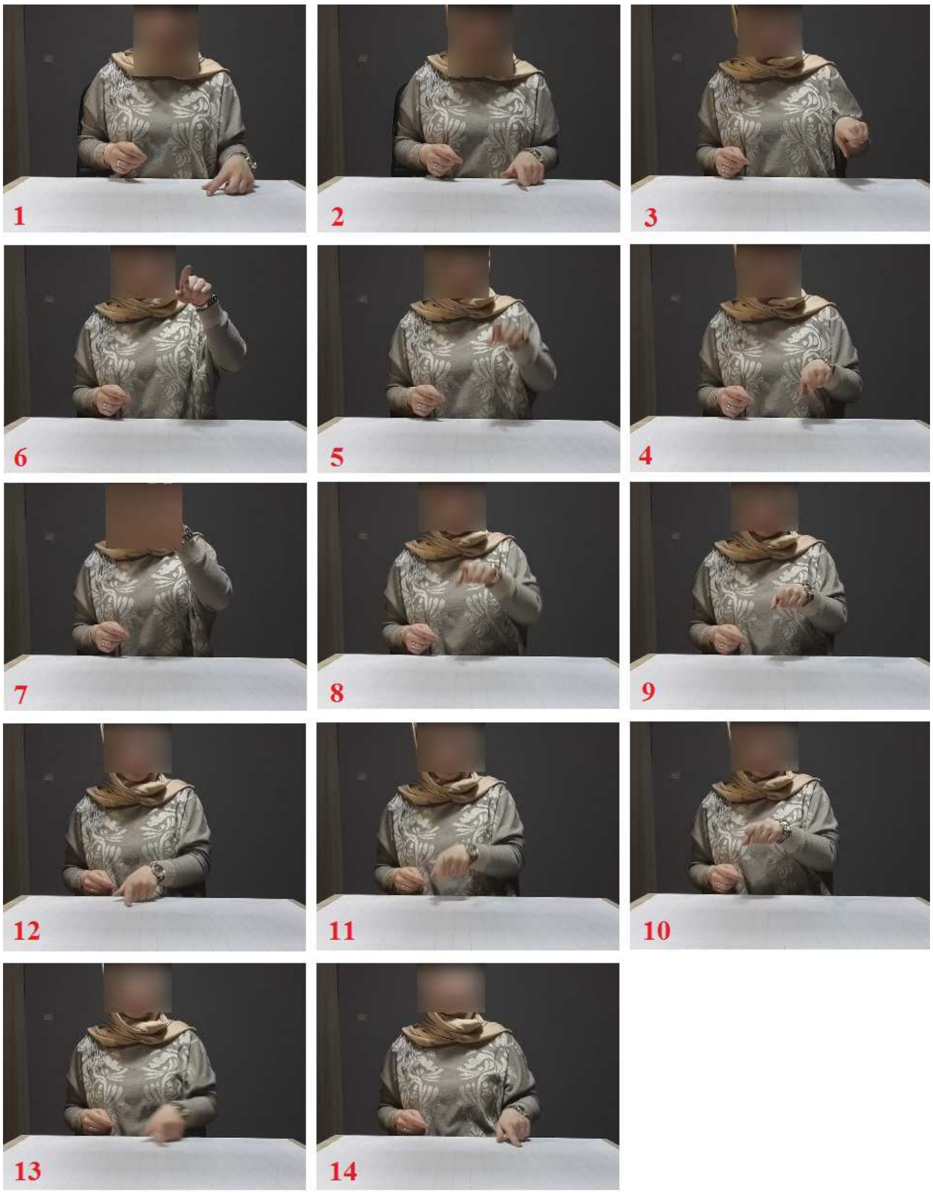

Figure 4.20 : P2 was modeling B13.

In modeling of cut objects as A13 and B11, the main solid geometry was generated at first, next the cut-piece was thrown away. Apart from that it was hard to model B11 for some participants, in this case they firstly rendered the silhouette of the object in 3D space vertically then stretched this region by hands. If the geometry have oblique surfaces like A13 and B11, participants began to move their hands as this form while defining the related surface. In these oblique surface geometries, they generally swept the oblique surfaces with their hands successfully but they could not define the 3D geometry of the surfaces. For instance, in modeling of A13 they could not draw the oblique surfaces with their hands in any plane, they did not even try. The reason can be that definition of these geometries requires secondary, tertiary supportive lateral planes. In the first pilot study, just one of the participants -he was not an architect- he was a lawyer surprisingly tried a different way for modeling B11, by rolling out it in x plane. However, in the second pilot study the architect participant who watched his modeling video, he could not understand this gestural model from opened-position of the shape.

Figure 4.21 : P3 was modeling A13.

Modeling of X1 was challenging for all participants, because it has multi-operations and a more complicated surface geometry. Participants modeled X1 in both circumstances; gesture-only and gesture-plus-speech. Their modeling behavior was observed according to their performance. They commented about the difficulty of this physical model, they sometimes missed the spatial relations of the subtracted and added parts, but mostly they positioned these parts accurately. When they missed the relations, they needed to organize the model again. They first modelled the whole cube then they tried to describe all operations edge by edge. While describing these subtraction and union operations they behaved like the whole cube that they modelled before were still there on their gestural working space. With reference to this cube they organized their hand motions and executed the operations step by step. They emphasized the need about visibility of the physical model-X1 throughout the modeling continuum and they always tracked the visible object by their eyes.

In modeling of B14, they firstly modelled the whole sphere. After modeling of the sphere, P1 drew a vertical cut with two hands' index fingers by constituting a 90 degree angle and took this sphere segment. P2 and P4 drew a curved cut on the surface of the sphere as the sphere was still there, hung in the air, next they took the cut segment. P3 did not draw a cut, she directly held the sphere segment with right hand and took it from the sphere in the air.

In modeling of A14, participants divided the object to three parts and segmented the modeling process too. In the first segment, they positioned the first and the biggest cylinder bottom. Next, they positioned the second cylinder on it and the last truncated-cone was placed to top of them. While generating the forms they firstly drew the circumferences in x plane then stretched the form through z plane and stopped with cut movement.

X2 was a challenging model for participants, because it has an irregular form. Two of the participants studied this object and it was so hard them to organize different surfaces of the object. This was an expected situation because this 3D physical model has a duty about measuring the challenging of the task. It was aimed at with this model to see, how the participants would model such a shape which have no regular geometry? Where challenging became visible in the gestural modeling of the objects? This model has irregular and disproportional oblique surfaces and participants had a difficulty to describe them. Also one reason of having difficulty to explain X2 was that there was no regularity as dimensional and orientational plane for this object. So, they needed different coordinate planes for describing this object's oblique surfaces. Differently, one of the participants tried to model this object with several subtraction operations. She first modelled an approximate complete object then she began to cut this complete object with oblique hand movements and she cut various pieces and threw away from the object. But there was not a holistic and continuous surface relation in her model. Another participant tried to model the mesh of the shape, but she did not positioned accurately the vertexes and they were not continuous. Expectedly, these gestural models could not represent the real 3D object as containing the whole shape information. When participants saw this shape, their first reaction was like that 'Mmm, oh my god! What's that?' P4 wanted to pass this model and she said that she could not comment about this object.

4.1.6 Group 6

3D physical models of this group can be seen in (**Figure 4.22**). This group consisted of the elements including the ellipsoid forms.

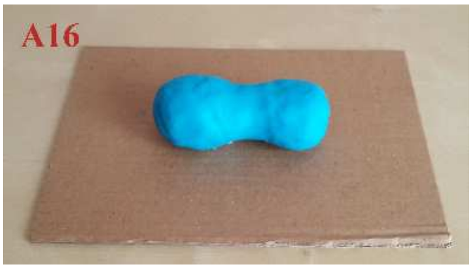

Figure 4.22 : Group 6 Models

In modeling of B16 and A16, participants had similar approaches. They mostly put their fist on the table and defined the objects by analogy. While they were using one fist in modeling B16, they used two fists during the modeling of A16. These forms have dimensional transformations. Participants generally emphasized the transformed shape of these ellipsoid forms and tried to show the joint of the two nods by hands in A16.

4.2 Comparative Gestural Shape Modeling Results of the Participants

With analyses of the individual shape modeling protocols for every shape and every participant, significant similarities were observed in the modeling behavior of the architects under both circumstances (gesture-only and gesture-plus speech). Some hand movement resemblances were resulted from the certain characteristics of the shapes. Also when compared with second pilot study which was conducted with two non-architect participants, specific 'architectural' statements could be seen.

There were some modeling similarities and differences between the architects. They can be listed as:

- When a 3D physical model was given to the participants' hand, first of all they tried to understand it. They tried to measure the objects' several parts.
- If the 3D physical model was a simple linear configuration, they behaved like chalking up on a blackboard with their thumbs and index fingers in gesture space.
- While the participants were describing the wall thickness of the linear objects, they generally used their thumb and index finger.
- If the 3D physical model was a multi-piece configuration, they first segmented the object to the small components and started with description of

the first component. Then they constructed the whole object by addition of the other components to the configuration relatively.

- If the shape became a surface, they started to use their whole hands' surface, they adjoint their fingers and they behaved as touching on surface of the object while modeling it.
- Their second hand supported the other one for giving the height information or positioning a different piece of object. Sometimes one hand was primary and preferred.
- If the configuration was a complex form, they first tried to decompose it and they described the small components one by one.
- If the shape has a ruled geometry such as cube, cylinder, prism, cone etc. they spontaneously made a mention of the special name of it.
- If the shape has not a ruled geometry, participants had difficulty to model it. When complexity of the shape increased, challenging became visible and participants mentioned about this difficulty.
- If shape has various different proportions and more complex spatial relations as horizontal and vertical, participants had some difficulty in modeling it.
- If shape has two surfaces that behave in different dimensions, participants had difficulty in overlapping and organizing these different dimensional relations, for instance in hyperbolic parabolic shapes.
- If 3D physical model is a form, which was generated by stretching a certain geometrical shape in a certain coordinate plane as square to cube, circle to cylinder, triangle to triangular prism, rectangle to rectangular prism, participants first drew the basic shape (square, circle, triangle, rectangle), next they stretched the source shape to 3D form. They mostly exhibited a finish motion with their hands in this stretching motion, so they restricted height of the objects by hands' horizontally sliding motion.
- If 3D physical model is a shape generated with some subtraction and union operations, participants firstly modeled the main source object with their hands then they implemented the related subtraction and union operations to

this object. They threw away several cut-pieces from the source object or they added some pieces on it.

- Participants behaved different in gesture-only and gesture-plus-speech phases. There were controversial comments about speech usage in the modeling process. Some of them argued that speech facilitated the modeling process while giving the quantitative explanations, describing some un-ruled geometrical forms and reflecting the special name of the several ruled geometries. Other Group 1rgued that they had difficulty in using speech with gesture. They confused about organizing these different modalities. They tried to make a meaningful sentence on one hand, on the other hand they tried to organize hands for giving the maximum information about shape. So, there were controversial comments about speech usage. But if we compare all of the participants' verbal descriptions and information conveyed by them, we can said that speech conveys quantitative information (distance, size and measure) about the objects and reflects special name of the ruled geometries such as cube, cylinder, pyramid, prism etc. Despite this, several gesture-speech mismatches were observed in participants' protocols. This issue will be explained in detail below.
- When speech got involved in the modeling process, they started to use speech for defining several features of the objects via it. Although the speech gave some important information like size, name of the object and the proportion quickly, some gestural expressions became lost. Sometimes, the participants' hands hung in the air, they hesitated about the next word and the next hand motion. There were a visible gesture-speech asynchrony.
- Although speech has numerous contributions and association with gesture, there were various mismatches between the participants' gestural modeling protocols and speech. For example, the modeler participant sometimes mispronounced name of the geometrical objects. He used the word 'cylinder' for the 'rectangular prism' and he modeled a rectangular prism with hands or he used 'circle' for 'sphere' and modeled a sphere with hands or 'circle' for 'circular region' and drew a circular region with hands in gesture space.

- They were also some individual differences in modeling protocols, but these differences were generally ignored and holistic observations were carried out.
- Participants behaved differently in some vertically curved surface descriptions. While one of them curved his/her hand horizontally as little finger touching on the table, the other one first defined a curved path with index fingers on the table and then swept the path with adjoint fingers vertically. On the other hand, the other participant curved two hands and put them on the table like positioning on the curved path as little fingers touching on the table.
- When compared with non-architect participants of the second pilot study, the architect participants paid more attention to the details, they were more aware of spatial proportions and relations, and also (3x3) grid plane. Non-architect participants realized the grid plane in tenth and fifteenth gestural modeling. The architect participants thought over more about the real size of the objects' width, length, height and they tried to give the correct value of them by hands and speech. The architect participants tried to model the objects in the current coordinate plane that object positioned, but non-architect participants' gestural models were mostly generated in the air regardless of the coordinate planes. But when non-architect participants realized the grid plane they paid attention more to model the objects in current coordinate plane and they became to measure the real 3D physical objects via this grid plane.

Body is one of the mediums that people interact with and perceive the world via it. In this study, when a 3D physical model was given to the participants' hand, they first touched it, they learned and saw it by their "hand's' eye" (Hostetter et al., 2007). Later, their first ruler was their fingers; they tried to gain the size information with their fingers at first. They interacted with the object by way of movements of their hands. So "gesture may be a 'hand's eye' that is not only helpful for others, but one that is also helpful for ourselves" (Hostetter et al., 2007). There was a significant point that gestures benefited to both the modelers and the sketchers (the observer and the external reviewer of the main empirical study) in different ways and types. In other words while one type of gestures helped the modeler participants more, the other type of gestures helped to the sketchers more. Some gestures that the modeler participants produced before the modeling process helped them for positioning their mental gestural models on the gesture space. They generated some meaningless gestures while trying to produce spatial relations. These gestures were meaningless for the observer and the external reviewer, but they facilitated to the modeler participants for thinking and constructing the spatial domains. On the other hand, the visible, clear and meaningful gestures helped to the observer for comprehending the real objects.

Besides, several important observations can be add on that the external reviewer could respond the gestural models more quickly if the modeler participant used true descriptions about size of the shapes, spatial relations and proportions. In this case, in addition to the external reviewer, the observer generally understood the real physical models easier, too. But, when the object became more complex and the modeler participant could not describe the model step by step completely and (s)he could not give the right information about the shapes, the external reviewer could not understand the object and she could not sketch about it correctly. So, complexity level of the models was a challenging point for the modeling process.

In this section, participants' comparative gestural modeling video frames were presented. Especially, strictly visible similarities and differences were illustrated in this chapter. In spite of the overt several differences and diversity, there were a considerable amount of modeling similarities between the gestural modeling behavior of the architects. For instance, giving the height information, requirement for drawing the shapes, hand waving during the curved object modeling and endeavoring to stretch the forms that has a volume etc. Also, using two hands when the number of the surfaces increased and using supportive second hand while describing extra information can be given as examples of the modeling similarities. Here, several remarkable examples were exhibited and the other important video frames were added in Appendices. In these video frame segmentations, it was observed that some similarities were resulted from the characteristics of the forms and objects such as production method, surface geometry. Otherwise, most of the participants' gestural descriptions have similar features.

In participants A1 modeling, they generally behaved similar, three of them used one hand except P4. The singular linear geometries were modeled like drawing an invisible line in the gesture space (**Figure 4.23**).

Figure 4.23 : Participants' comparative A1 modeling.

While watching the participants' gestural modeling protocols, several hand sketches were produced as observer, according to the gathered information. An external reviewer was requested to review video segments of the participants' gestural modeling videos in order to seek reliability. She was asked for producing sketches based on the information gathered from the gestural models of participants, the entities they were trying to model were represented via sketches by the external reviewer. Observer's sketches were compared with the external reviewer's sketches. There were totally thirty-two gestural modeling protocols for all participants as gesture-only and gesture-plus-speech. Observer and the external reviewer watched 32 -chosen- gestural shape modeling videos as gesture-plus-speech and gesture-only phases. These 32 videos were arranged as containing the modeling protocols chosen from all of the four-modeler participants. Observer and the external reviewer sketched about these gestural modeling videos for generating the real model with sketches. Results of their sketches showed that twenty-six out of thirty-two sketches for the external reviewer reflected the real physical models. Twenty-seven out of thirty-two sketches for the observer reflected the real physical models. So, there was approximately a ratio of sixty percent for all of the thirty-two shapes in the way of modeled correctly.

Besides, it can be emphasized that there were more successful sketches with regard to containing the quantitative information about distance, size, measure and name of the shapes in videos of the gesture-plus-speech phases. Because, it was an important point for all the protocols that speech mostly gave the quantitative information (distance, size and measure) about shapes and reflected special name of the ruled geometries such as cube, cylinder, pyramid, prism etc. At this point, while observer and the external reviewer were sketching about the videos of the modeler participants, these extra informations provided a better understanding to them. Thus, the observer and the external reviewer were seen to sketch about the gesture-plus-speech phases'videos much easier when compared with the gesture-only phases' videos. These comparative sketches can be seen in Appendix C.

4.3 Usage of Speech with Gestures

In this section, architects' video statements were watched repeatedly and their verbal descriptions and gestural modelings were transcribed to the texts. The videos were analyzed in three parts as looked for gestural descriptions, second verbal descriptions and in third one these two data were overlapped and compared each other. Also these gesture-speech analyses were compared with the only gestural models in terms of the information conveyed via them.

The answer of several questions were wondered as noted below:

- Where the language was complemented in the modeling process?

- Which information was conveyed with gesture, speech, gesture-plus-speech?

- Were there any redundant information during the usage of verbal descriptions?

- Where there any gesture-speech mismatches during the gesture-plus-speech circumstance?

Gesture offers a more direct way than speech on conveying and acquiring the action information. Besides, speech enables people to describing some quantitative information about the shapes such as distance, size and measure. When speech got involved in the process, they started to use language for defining several features of the objects with it. Although the speech gave various spatial and qualitative information like size, form and proportion very quickly, some gestural expressions became lost, sometimes their hands hung in the air and the hands waited for short time intervals while they were defining something with the words. Besides, participants sometimes hesitated about the next words and the next motions of the hands because they tried to find the correct word or they tried to form a meaningful sentence. As a consequence of these observations, it can be said that the modeling and narration were interrupted for small time intervals in the gesture-plus-speech phase and the speech was dysfluent. The gesture-only phases were more fluent and compact.

Table 4.1 : Table of the participants' comparative gesture and speech analysis (A7).

Model Sets	P1 (gesture+speech phase modeling-1st. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **A7**	He defined the length and width information by touching with his two thumbs and index fingers on the table. He held the width by left hand and his right hand slid on the table while defining the length information. Then, his adjoined right hand started to move as his little finger was parallel to the table then his hand modeled a curved surface, possible a vault surface in the gestural space. The hand continued to move till her left thumb touched to surface of the table.	"A rectangle form with 18-cm-long and 9-cm- (no!) 12-cm-wide was bent and created a hollow circular (mismatch) form."	curvature of the surface, width and length of the source flat surface, height and width of the curved surface, possible a surface form, locational and proportional information about the shape	height and width information, operation performed (bend) to the surface, hollow surface information, circular form of the surface
	P4 (gesture+speech phase modeling-2nd. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **A7**	First, her two hands with adjoined fingers restricted the length of the shape by -parallel to table- position of the two little fingers. Later, she emphasized the length information by movement of her right index finger. Then, her adjoined right hand fingers modeled a vault in the gesture space.	"I can say completely a semi cylinder for this shape. Like this (she started to model on the table) positioned in the space, such… (she gestured) sizes are the same…"	length of the surface, curvature of the surface, possible a surface form, locational and proportional information about the shape	name of the surface (cylinder), location of the shape in the space

Table 4.2 : Table of the participants' comparative gesture and speech analysis (A6).

Model Sets	P1 (gesture+speech phase modeling-1st. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **A6**	First, he positioned his right hand vertically on the table. His fingers were adjoined and the little finger was touching on the table horizontally. Then, he moved his vertical hand through z plane and when came to the corner, his hand rotated 90 angle and moved horizontally. Thus, he defined two surface of the shape. And lastly, he defined the small columns with his two hands thumbs and index fingers like holding a small object.	"A rectangle folded plate with 9-cm-height and 18-cm-width which the top width is 9-cm. and it has two load-bearing small column with 9-cm height in front of it."	possible a surface form, locational and proportional information about the vertical and horizontal surfaces and also their spatial relations with each other, spatial position of the vertical small pieces (columns)	vertical and horizontal position of two surfaces, height and length of the vertical surface, width of the horizontal surface, two vertical columns and their height information, spatial information of the vertical columns (in front of), a folded plate information
	P4 (gesture+speech phase modeling-2nd. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **A6**	First, she defined the length of the small pieces by using thumb and index fingers. Later, she moved hands by holding distance information through behind closed surface. She defined vertical surface by sliding hands (thumb and index fingers). Then she adjoint her fingers and define two surfaces. In the end she again defined the contour of the object by her thumbs and index fingers.	"Here, shape became to have different space units. (She has a dysfluent speech, she stuttered while trying to start the modeling.) There are two small pieces …parallel to me… hmm… in x plane yes x plane (mismatch). There is a plane behind which has equal proportions with two small pieces. Again, these pieces are associated for performing special spaces on the top side."	vertical and horizontal (possible) surfaces and their spatial relations with each other, vertical small pieces' spatial locations and their relations with the surfaces	existence of different space units, two small pieces, plane (surface) information, spatial locations of the pieces (parallel, on the top side etc.)

To illustrate, in P1 and P4's some modeling statements can be seen above (**Table 4.1 and Table 4.2**). It was observed in these modeling examples that they gave more information about horizontality, verticality, adjacency, position, direction, parallelism, surface information and contour of the objects by their -iconic- gestures. When defining these features they produced representational gestures -mostly iconic ones-. The information was conveyed by gestures did not usually take place in their speech. They generally described the production rational of the shape or numerical value about the components of the shape by their speech. They depicted their hands motion by choosing the words such as, like this, such, in this way etc. While they were using these -deictic words- they synchronously started to model the object by their hands. Different from this, sometimes they thought a little time first, then they positioned their hand on the table and later they started to speak and model. P1 generally first thought about his utterance and modeling after examining shape. Then, he started to model or speak, thus his models were more clear. On the contrary, P4 generally started to model and speak together quickly, probably based on this approach, her hands hung in the air, and she hesitated about the next movement of the hands and her words. So, her speech was dysfluent. It can be said that if the shape has a ruled geometry and a special name like cylinder, cube etc. they generally define the special name of the objects in their speech. However, sometimes for instance P3 mispronounced the name of object. For example, as seen in the table below while she was defining a prism she used the word 'pyramid' instead of the word 'prism'. In other words, sometimes the participants' speech has some mismatches. Therefore, while I am watching and analyzing the participants' videos, if there is a mismatch between the speech and the model or the speech and the hands, I am confused, I hesitated and generally despite the fact that I know the real shape (I ignored this shape knowledge), I could not understand and sketched the real shape. I observed similar situations in the second pilot study. If there were gesture-speech mismatches, it was difficult to comprehend and sketch the real models for the external reviewer. Also, when participants commented about their modeling process after the studies, they generally emphasized that when they use speech directly with their hands in a concurrent fashion, they tried to organize their speech and gestural modeling. Because of this compound operation, both their gestural models and speech were not fluent.

Table 4.3 : Table of the participants' comparative gesture and speech analysis (B10).

Model Sets	P2 (gesture+speech phase modeling-2nd. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **B10**	She first drew the triangle on the table with her two index fingers. Later she defined the surfaces as holding them with two curved hands. Then she stretched the triangle with her curved hands along the surface of the prism. Lastly, she restricted the height of the object by her hands' finish/close motion.	"An equilateral triangle which one edge is 4 unit and a prism which height is 6 unit."	the source object by drawing on the table, stretched operation with curved hands, defining the height of the object with finish/close motion.	name of the object, numerical value information of the edges, height information, geometrical definition of the object (triangle).
	P3 (gesture+speech phase modeling-1st. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **B10**	She first drew the triangle on the table with her right index finger. Later she pointed with her right index finger the height information while saying "height is 6 unit". Then she adjoint her fingers and behaved like touching with them to the surface of the prism. Lastly, she restricted the height of the object by her hands' finish/close motion.	"An equilateral triangle which one edge is 4 unit. Height is 6 unit. (here she defined 1 unit according to the grid (3x3 cm). An triangular pyramid have been generated. (mismatch)."	the source object by drawing on the table, stretching operation with adjoint fingers, defining the height of the object with finish/close motion.	name of the object, numerical value information of the edges, height information, geometrical definition of the object (triangle).

Table 4.4 : Table of the participants' comparative gesture and speech analysis (B14).

Model Sets	P2 (gesture+speech phase modeling-2nd. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **B14**	First, her two hands curved as holding surface of a sphere and they defined a few times sphere form in the gesture space. Later, she drew a straight quarter cut with her two index fingers, then she drew a curved cut on the surface of the sphere as the sphere was hung in the air. Lastly, she extracted a piece of object from the sphere as holding it with her left hand's thumb and index finger.	"A sphere which diameter is 3 unit. And quarter of it is extracted like a slice of water melon."	form of the object, cut piece information, cutting motion and throwing away motion.	name of the object, numerical value of the diameter, proportion of the cut piece object.
	P3 (gesture+speech phase modeling-1st. order statement)			
	gesture transcription	**speech transcription**	**information conveyed by gesture**	**information conveyed by speech**
 **B14**	First, her right hand defined a sphere surface, later she drew a ring as defining 2 unit in the gesture space. Then she behaved like holding a piece of object and lastly, she extracted a piece of object from the sphere as holding it with her right hands thumb and adjoined four fingers.	"A piece of quarter sphere have been taken from a sphere which diameter is 2 unit. (mismatch)"	describing diameter of the object, throwing away motion.	name of the object, numerical value of the diameter, proportion of the cut piece object.

In modeling B10 as using gesture and speech, two participants first drew the fundamental geometric form on the table (**Table 4.3 and Table 4.4**). A similar approach was observed mostly in the shapes have a ruled geometrical form. In other words, if object have a form, which can be generated by stretching a basic ruled geometry in a certain coordinate plane, participants generally first drew this source geometry on the table or the gesture space. Later, they performed the stretching operation to this ruled source geometry. While modeling B10 and B14, there were some mismatches in the speech of P3. For instance, in modeling B10, she used the word 'pyramid' while modeling a prism with her hands. She was not aware about this mismatch. Also, while describing B14, she did not give the length of diameter information, she said '2 unit' instead of '3 unit' length while her hands defining a relatively accurate size. So if I did not watch only listen the verbal descriptions, I would comprehend the real size as 2 unit. P1 and P3 sometimes highlighted height in their speech but width in their gesture (Similar with, Church & Goldin-Meadow, 1986). Church & Goldin-Meadow (1986) define match as "concordance" which means that if gesture expresses the same information with speech about related task. They define mismatch as "discordance" which means that if gesture contains different information from speech about related task. In this research study, it can be noted that there were different type of mismatches. For instance, some mismatches -about knowledge- which stem from giving wrong information about shape's size, height, length, width etc. Here, they frequently give the right information with their hands but they failed in speech. Besides, some mismatches -about attention- which stem from the participants' instant lack of attention, here they know right utterance but they generally miss out it. Also there were some mismatches –about modeling strategy and followed path- which can be observed while trying to determine the shape modeling path. Here, participants tried to decide their first movement or word, so their speech presented a modeling strategy and their hands exhibited the other strategy which was not conveyed by the speech (Similar with Garber & Goldin-Meadow, 2002). Besides, it was also observed that sometimes when participants produced gesture-speech mismatches and realized them, they tried to model the shape again with a different modeling strategy, similar with "a second problem-solving strategy" of Goldin-Meadows' study (Goldin-Meadow et al. 1993).

5. DISCUSSIONS AND CONCLUSIONS

This thesis presented an empirical study, which was conducted with four architects on the purpose of exploring the gestural modeling behavior of them while modeling shapes via gestures under two different circumstances; with or without speech and to adress these research questions; (1) how shapes were modeled by gestures under each of the circumstances? (2) to what extent architects can represent a shape/form via gestures under each of the circumstances? (3.1) what shape/form information was conveyed via gestures under the gesture-only circumstance and (3.2) what shape/form information was conveyed via gesture and/or speech under the gesture-plus-speech circumstance?

In the analyses of the modellling process of the participants, some similar behaviors were observed in the gestural modeling behavior of the architects under both circumstances (gesture-only and gesture-plus speech). For instance, they gave distance information of the shape (height, width, length and wall thickness) by measuring with their fingers. Most of the participants modeled simple linear configurations as chalking up on a blackboard with their thumbs and index fingers in gesture space. Most of the participants described flat and curved surfaces as touching on them. They mostly started to use their whole hands' surface and their adjoined fingers for describing surface of the configurations. They represented spatial locations and relations by co-operation of their two hands. They rendered contour or silhouette of the shapes by drawing them in space. They expressed stretching operation by moving the shape from vertexes or edges with their hands. Most of them modeled subtraction operation by throwing away the cut piece object with their hands and also modeled addition operation by adding the related pieces on object by their hands. They mostly tried to decompose complex configurations to the small pieces, then they tried to model it part by part. Most of the participants had difficulties in modeling shapes which has not a regular geometry. Similarly, when the configuration has numerous different spatial locations and relations, most of the participants struggled for constructing these relations properly. That is to say, when complexity of the shape increased, challenging became visible and participants mentioned about this difficulty with their hands or speech.

From the results of the detailed comparative analyses, conclusion reached with regard to the question, to what extent architects can represent a shape/form via gestures, is that architects could effectively represent shapes with their gestures to a certain extent under both circumstances (gesture-only and gesture-plus speech). Indeed, most of the participants were seen to model easily some basic primitive forms, and the shapes, which have certain ruled geometries such as cube, cylinder, prism, cone etc. In addition, they could describe these shapes verbally with their names. However, when the shape became more complex like containing different spatial proportions and relations or different characteristics of shapes, most of the participants had some difficulties in modeling them with their hands. It was problematic to model the shapes, which have numerous different surfaces, some upward and downward curvatures, various subtraction and addition operations, or irregular geometries. That is to say, complexity level of the shapes was a challenging point for modeling shapes with gestures. At this point, what we have learned from these observations with regard to gesture usage for representing shapes is that architects can model shapes with their hands to some extent depending on the complexity level of the shapes.

Another conclusion drawn with regard to the question, what shape/form information can be expressed via gesture, is that gestures mostly could convey the information about several physical entities of the shapes under both circumstances (gesture-only and gesture-plus speech). Thereby there can be summarized certain types of information conveyed via gestures as follows;

- distance information - height, width, length, diameter and wall thickness,
- possible surface information - flat and curved surfaces,
- spatial locations and relations - top, bottom, near, front, back, across, through,
- proportional information,
- contour or silhouette of the - shapes circle, square, rectangle, triangle etc.,
- stretching operation,
- moving operation,

- subtraction and addition operations etc.

Although complexity level is a limitation for gestural modeling, gestures help to describe substantially too many physical characteristics about shapes. Clearly, architects can use several gestural models for providing shape information to the computer or for describing shapes to other architects. However, if shape has a complex geometry, understandability of the gestural models decreases as seen in quantitative observations of the analyses and also in the external reviewer's protocols.

On the other hand, information conveyed via speech under gesture-plus-speech circumstance can be specified as;

- distance information - numerical value about height, width, length, diameter and wall thickness of the objects,
- certain action and position information - while modeling the shape with hands such as 'it was curved like that…; a piece of object put here…; this piece cut from the object..; it was positioned near… ; it was moved in x plane…; it was stretched in z planı… etc.,
- name or geometrical definition of the objects (cube, cylinder, pyramid, prism, cone etc.)

Although speech has a significant role in conveying information stated above, participants indicated different feedbacks about the gesture-only and gesture-plus-speech modeling phases. Three of the participants reported that they were more relaxed in the gesture-only phase. Because, they said that they tried to give the correct information with speech and to find the words from the working memory in the gesture-plus-speech phase. Therefore, during this rehearsal and inference-making process, their hands hung in the air and they hesitated about the next hand motion. They also suggested that while they were trying to explain the shape with speech, they forgot the hands and their hands could not reflect the same information with speech. So several gesture-speech mismatches were observed. In addition, they commented about that they were more focused in the gesture-only phase. It can be stated that they tried to overcome three different mediums in the gesture-plus-speech phases, the first one is learning and visualizing the object, second finding the correct words and the last one is that modeling the shapes via hand motions. These different action sessions were compelling for them. Different from them one of the participants commented that, speech was an effective medium for her conveyance of the size, thickness and height information of the objects. Therefore, if speech was dysfluent, gesture was interrupted as well in the gesture-plus-speech phases. However, in the gesture-only phase, a great majority of the participants' gestural models were more holistic, complete and fluent. That is to say, speech is an effective medium for conveying several distance, size, measure information, and names of the shapes; however usage of speech was a challenging point for most of the participants. So, it can be interpreted that speech can be used to some extent for representing certain shape information, but it cannot be ignored that most of the gestural models of the participants produced in the gesture-only phases were more fluent and holistic according to the ones produced in the gesture-plus-speech phases. Possibly, speech can be proposed for providing some quantitative information (distance, size and measure) and geometrical names to the computer, but we need hand motions-gestures for describing spatial locations and relations of the shapes. At this point gesture-speech mismatches should be minimized by instructing the participants studiously for conveying true information about shapes with their gestures and speech.

While investigating sketches which were produced by the observer and the external reviewer, it was seen that there were more successful sketches with regard to containing information about distance, size and measure of the shapes in videos of the gesture-plus-speech phases. Because, it was an important point for all the protocols that speech mostly gave the quantitative (distance, size and measure) information about shapes and reflected special name of the ruled geometries such as cube, cylinder, pyramid, prism etc. In addition, when the observer’s and the external reviewer’s sketches were compared each other, results of their sketches showed that twenty-six out of thirty-two sketches for the external reviewer reflected the real physical models. Also, Twenty-seven out of thirty-two sketches for the observer reflected the real physical models. So there was approximately a ratio of sixty percent for all of the thirty-two shapes in the way of modeled correctly.

Some of the participants generated gestural models as containing all of the shape information holistically. During the analyses, it can be noted that if shape was not modelled as giving all the data about its’ characteristic features, it would be difficult to understand the whole shape accurately as observer and the external reviewer. Therefore, it can be interpreted that conveying the true, clear and complete information about shape has an importance about the comprehensibility of the related shape by an external observer.

Although there can be several individual differences as observed in this study, it can be noted that if shapes -given to the participants for the purpose of modeling them via hand motions- have well-defined forms and regular geometries, most of the shapes could be modeled by the architects cognizably. It was observed that architects mostly exhibited similar behaviors during the modeling of similar forms. There were significant modeling similarities for all the architect participants as emphasized in section 4.2. That is to say, there were extensive amount of similar modeling patterns between these architects.

This thesis was conducted from two different viewpoints; ‘gesture researches in HCI’ and ‘use of gestures in design communication’. That is to say, the potential of gesture and speech as representational mediums for architects in defining shapes/configurations to a computer system as well as describing them to others in the context of collaborative design meetings, presentations etc. In consequence of all these investigations and analyses, it can be suggested that with the technological developments, gestural models -produced by the participants for representing shape information- can provide an input data to the computer in the near future, in the way of conveying several quantitative information. On the other hand, gestural modeling via hand motions can be a representative and communicative medium between architects for architectural education and practice with regard to the expressing some basic shape information. However, it should be specified for these two viewpoints, complexity level is a limitation for representing shapes with and without speech via gestures.

The present study provided a contribution to the issue of shape modeling with hand motions and speech from a different viewpoint among architects. Several studies in the literature have been conducted with the use of predefined and preconditioned gestures and transferring this gesture data to the computer. In this study, we focused on natural and spontaneous hand motions-gestures; speech usage with gesture; and information conveyed by gesture and speech for architects. We did not work on transferring the gesture data to the computer and recognition algorithms. We just aimed to develop an understanding about the questions; (1) What can we model and represent with our natural hand motions about shape? (2) What kind of information can be conveyed with gesture and speech for representing shape? (3) Can spontaneous gestures and speech provide a shape modeling data to the computer as a design representation medium? (4) Can gesture and speech have a role as communicational mediums in representing shape information between architects? In sum, analyses and results of this study could contribute to these topics in point of architectural design and communication.

In future work, this experimental study can be conducted with different groups, which contain a greater number of architect participants to specify the constraints for describing shapes with gestures. Furthermore, this experimental study can be executed in a collaborative design meeting, which enables architects for communicating directly. Modeling process can be tested with an architectural problem definition task in this collaborative design meeting. On the other hand, with the technological developments, this study can be performed by interacting with a natural-user-interface. Moreover, technological developments in the natural user interfaces, space that hand renders can be made visible and captured and digitally modelled in a real-time fashion.

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APPENDICES

APPENDIX A: Examples of the Participants' Gestural Modeling

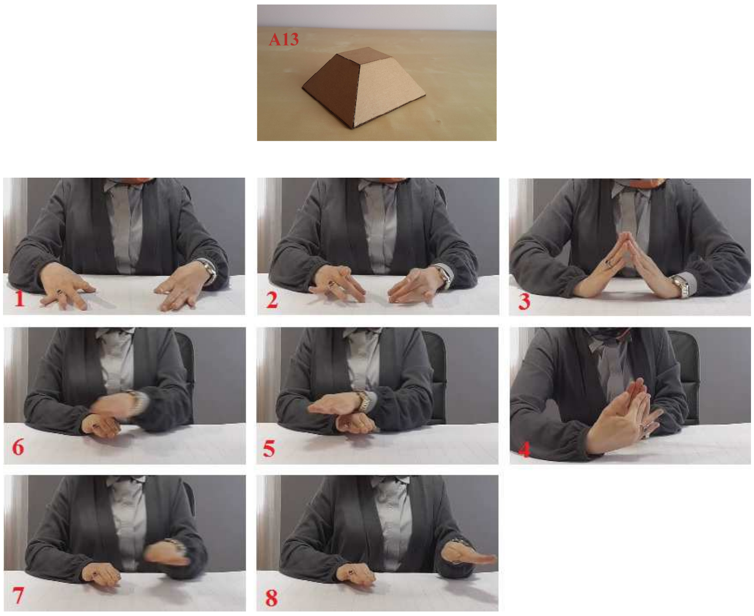

Figure A.1 : P4 was modeling A13.

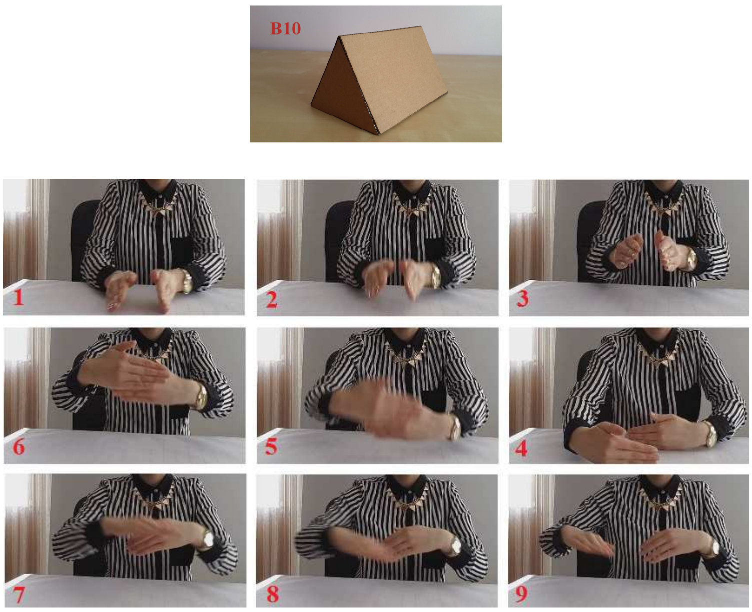

Figure A.2 : P3 was modeling B10.

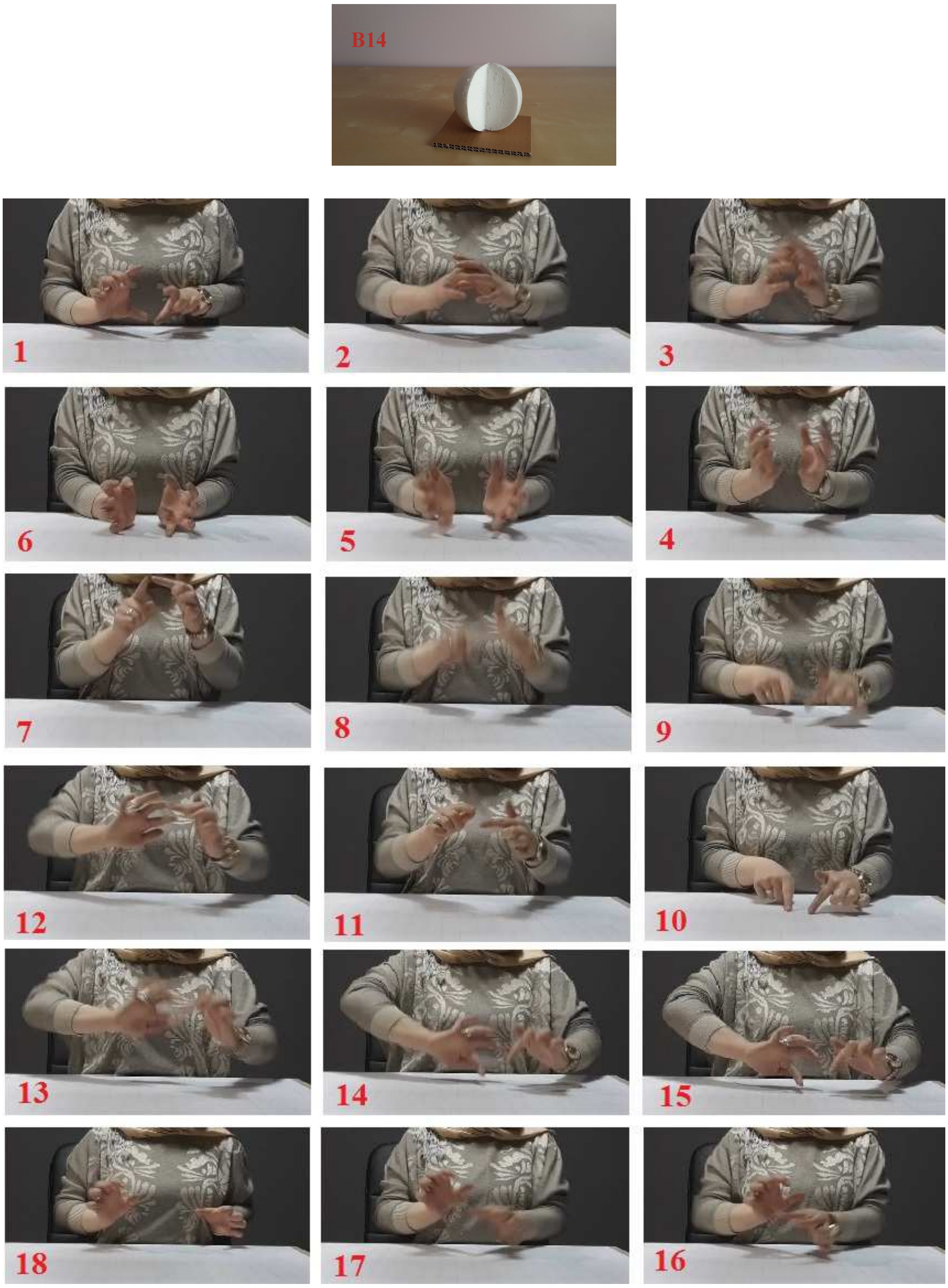

Figure A.3 : P2 was modeling B14.

APPENDIX B: Examples of the Participants' Comparative Gestural Modeling

Figure B.1 : Participants' Comparative A6 Modeling.

Figure B.2 : Participants' Comparative A7 Modeling.

Figure B.3 : Participants' Comparative A8 Modeling.

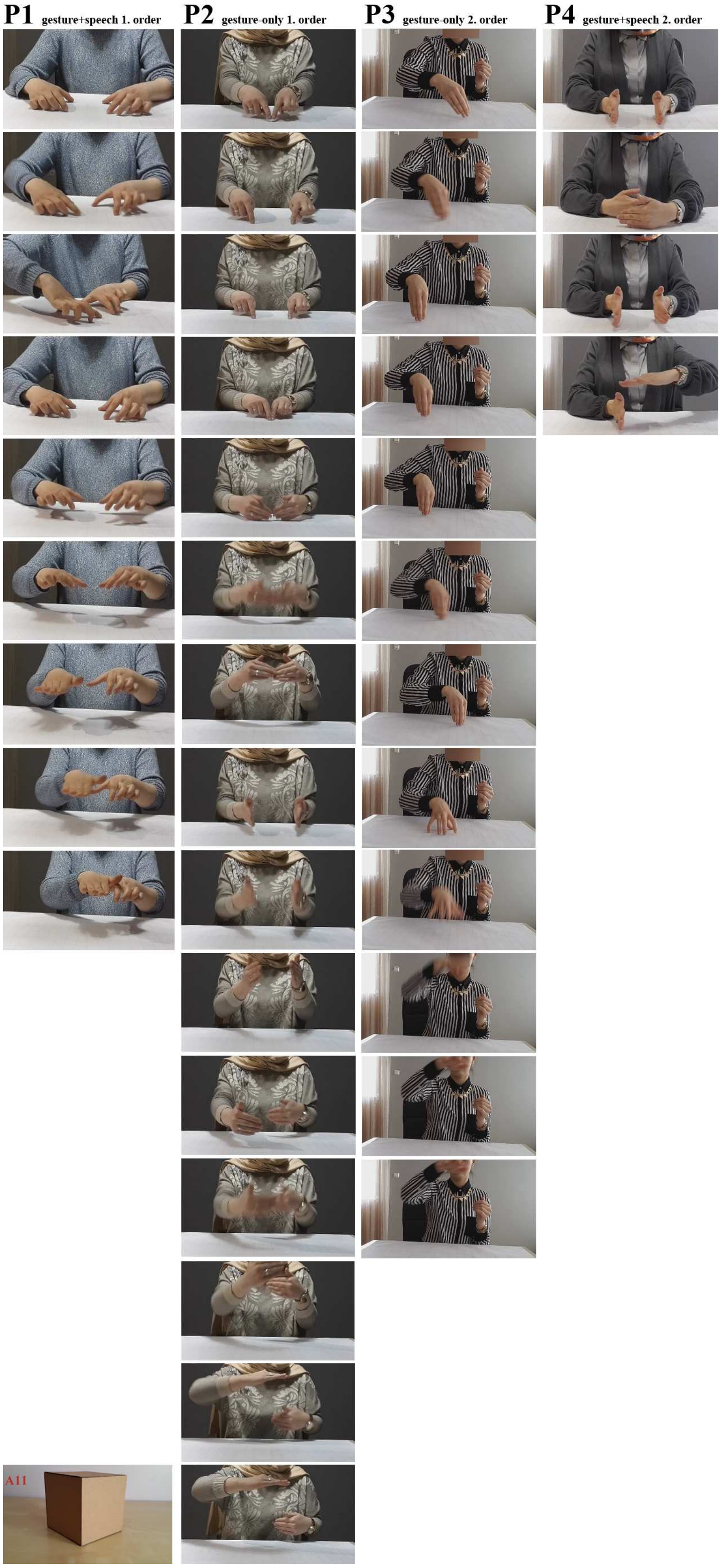

Figure B.4 : Participants' Comparative A11 Modeling.

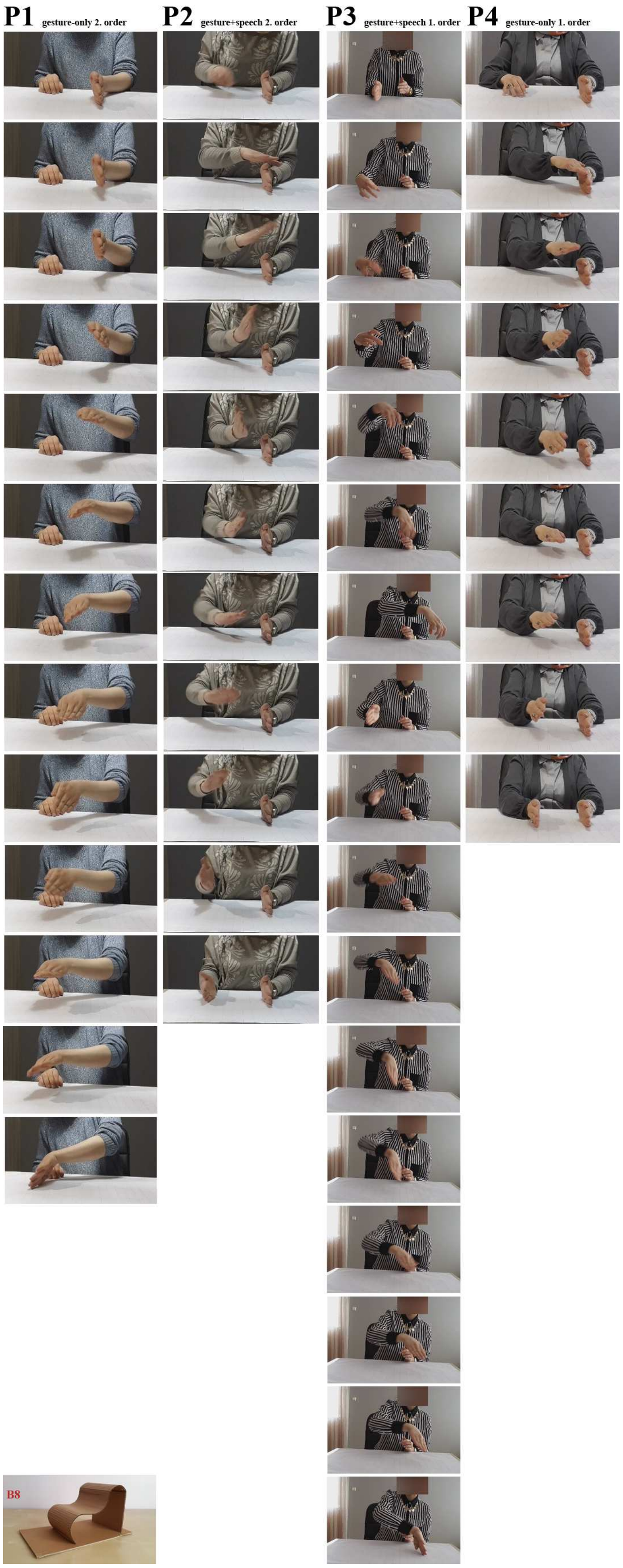

Figure B.5 : Participants’ Comparative B8 Modeling.

APPENDIX C: Sketches of the Observer and the External Reviewer.

3D Physical Model **Observer** **External Reviewer**

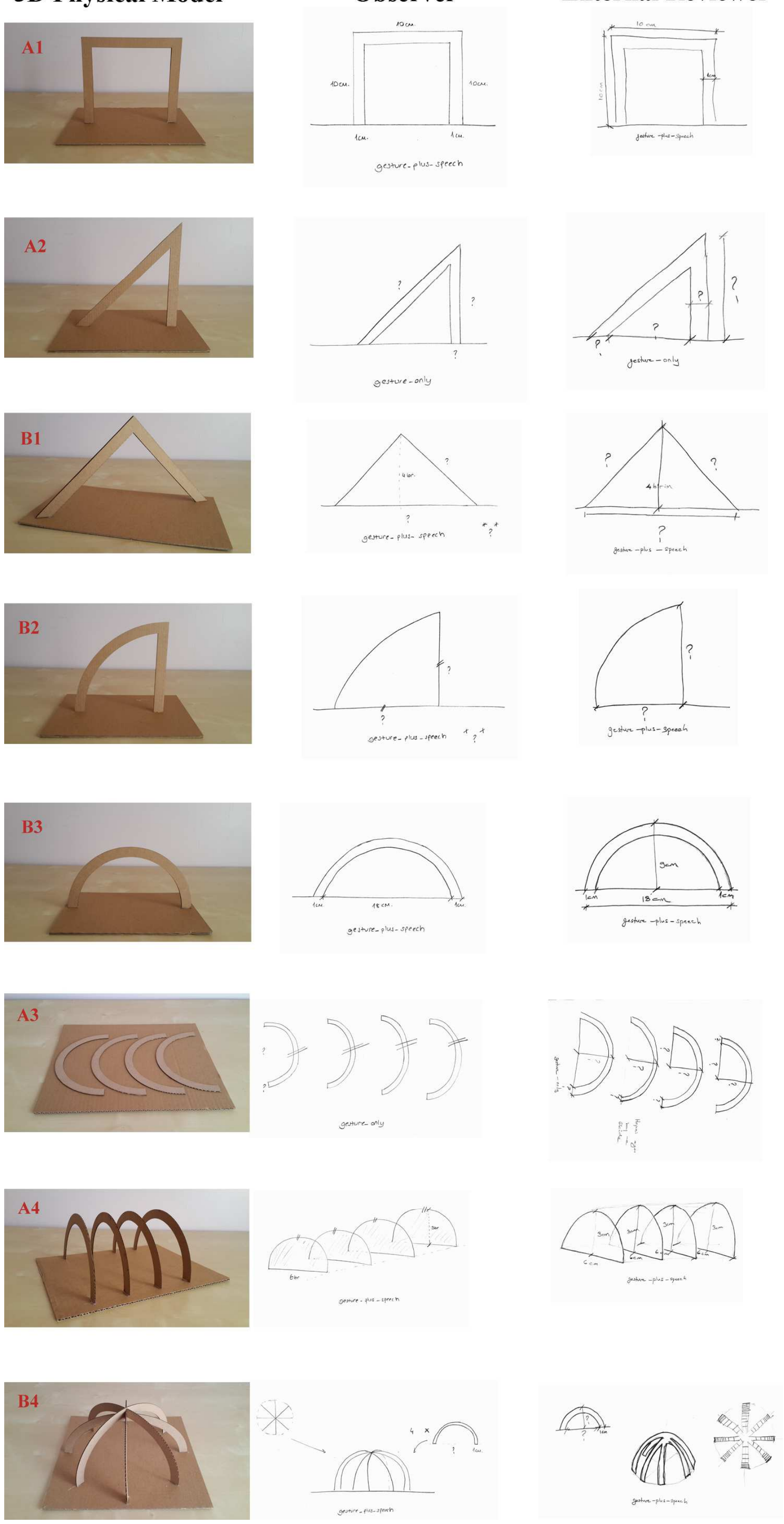

Figure C.1 : Sketches of the Observer and the External Reviewer.

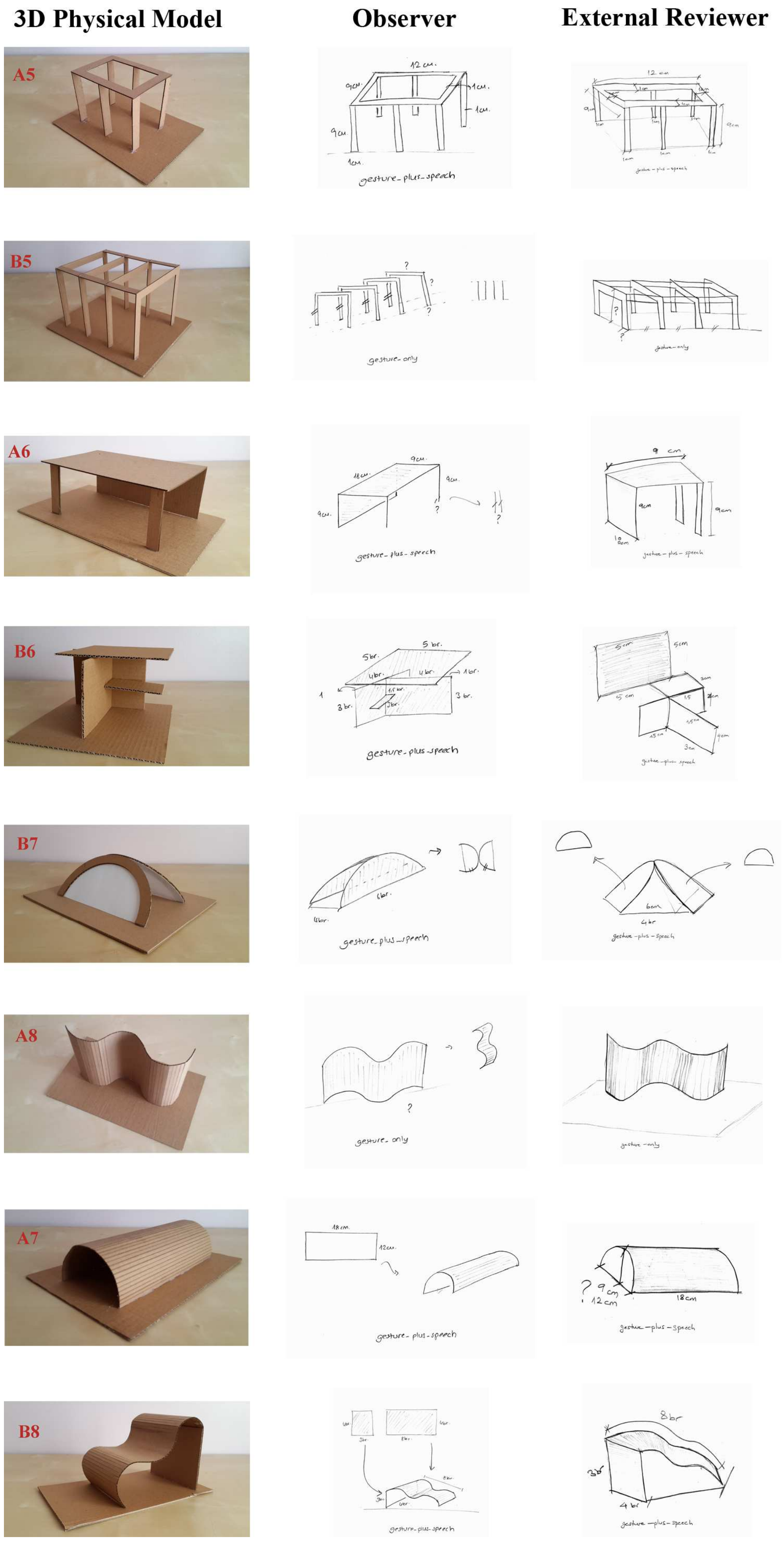

Figure C.2 : Sketches of the Observer and the External Reviewer.

3D Physical Model	Observer	External Reviewer

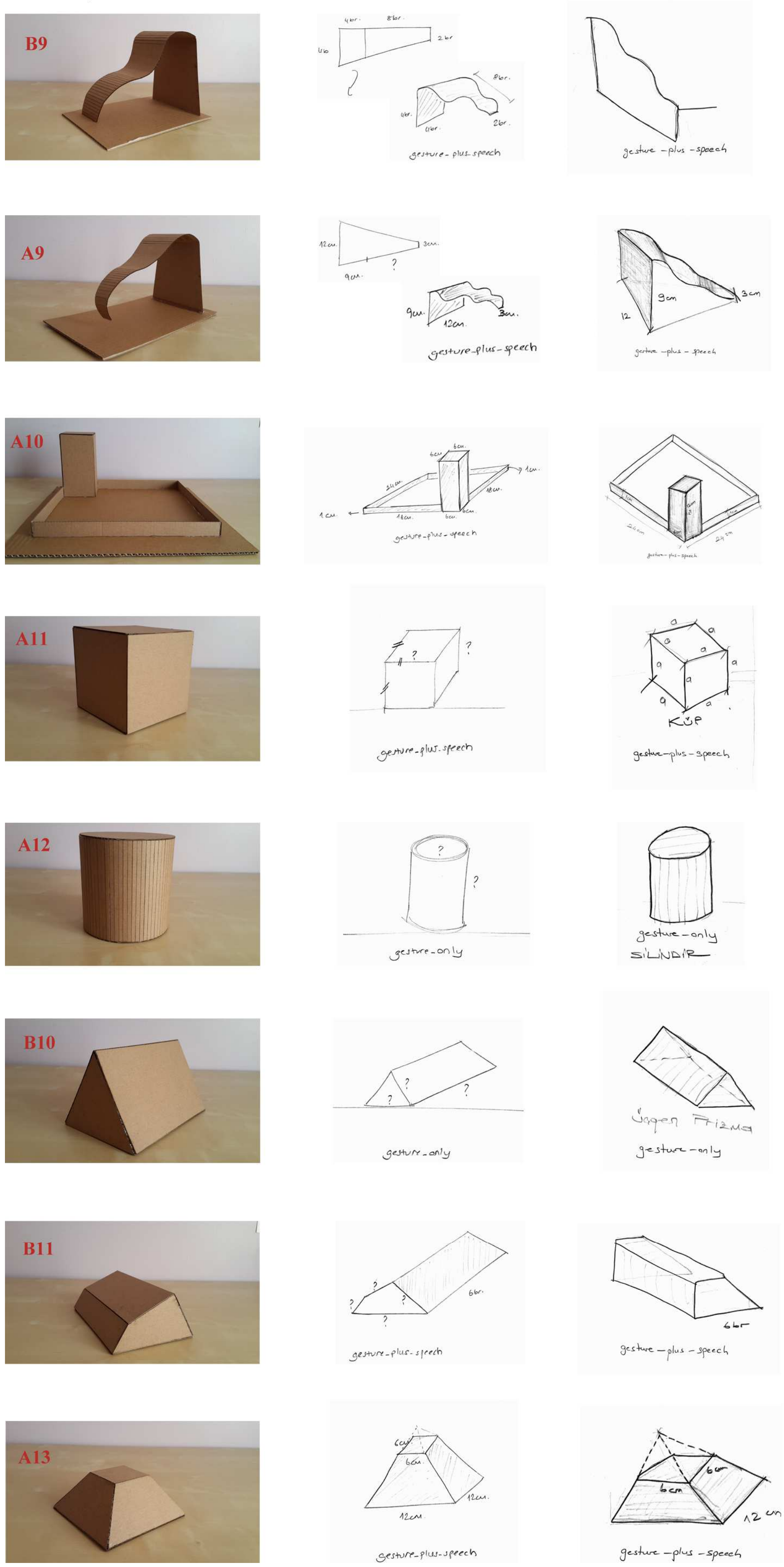

Figure C.3 : Sketches of the Observer and the External Reviewer.

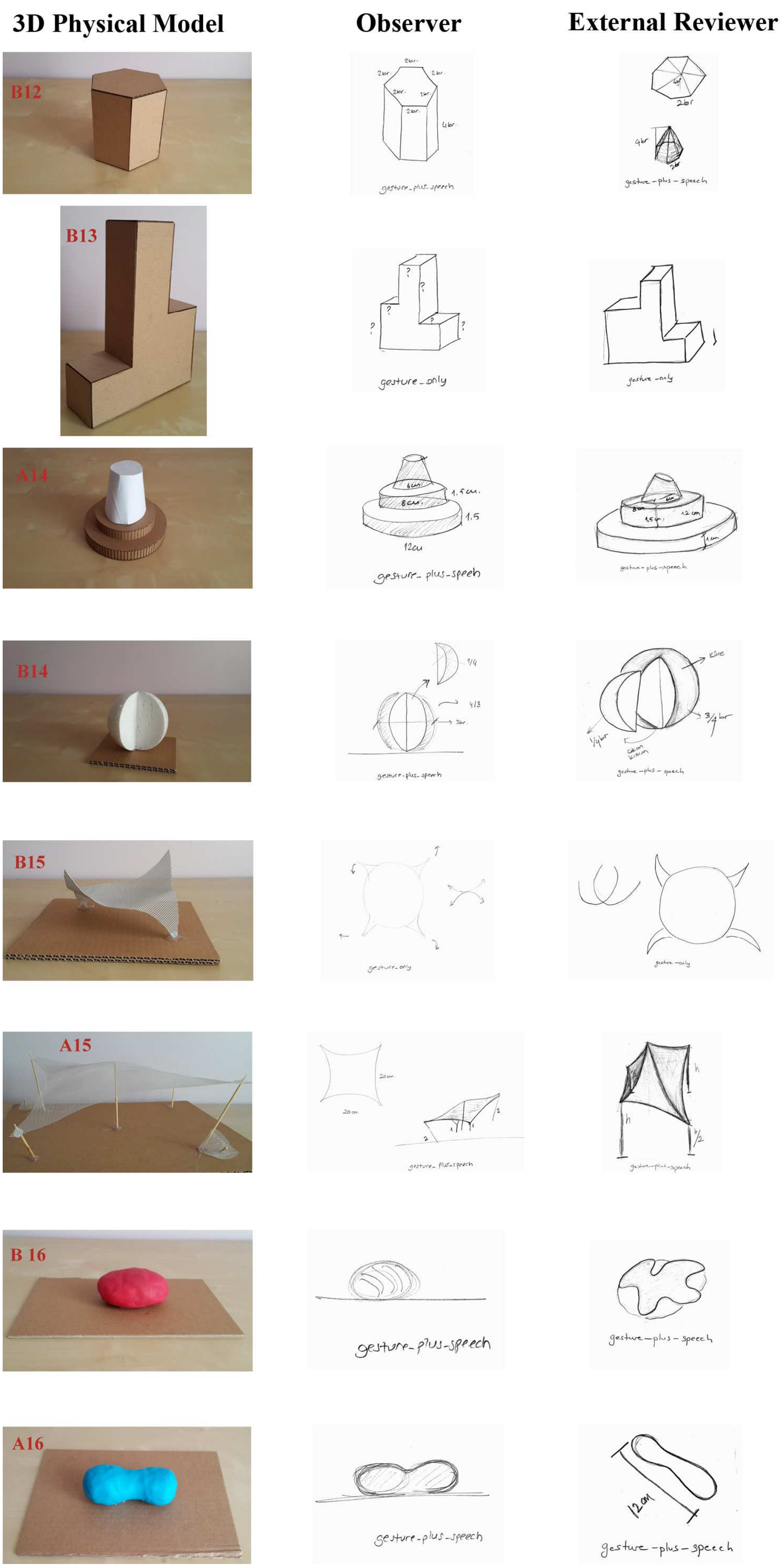

Figure C.4 : Sketches of the Observer and the External Reviewer.

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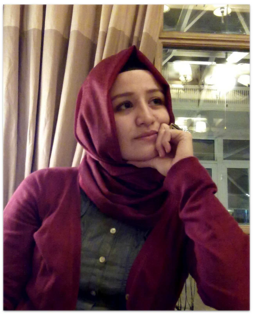

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