ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

TRANSLATING INTUITIVE ASPECTS OF CONCEPTUAL MODELS INTO THE DIGITAL REALM

M.Sc. THESIS

Elif AKTAŞ

Department of Informatics

Architectural Design Computing Program

Thesis Advisor: Assoc. Prof. Dr. Mine ÖZKAR

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KAVRAMSAL MODELLERİN SEZGİSEL BOYUTUNUN DİJİTAL ORTAMA AKTARILMASI

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FOREWORD

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April 2014 Elif AKTAŞ
(Interior Architect)

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ABBREVIATIONS

CAD	**:**Computer-Aided Design
HCI	**:**Human Computer Interaction

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TRANSLATING INTUITIVE ASPECTS OF CONCEPTUAL MODELS INTO THE DIGITAL REALM

SUMMARY

In recent years, digital design tools have expanded the overall vision of design with uses such as digital manufacturing, modeling, animating, rendering, programming. Still, they are insufficient in assisting designers during the early phases of the design process. Conventional methods such as sketching and physical modeling are still the most effective and commonly used tools for conceptual design both in education and practice. It is mostly due to the challenges designers and tool developers face in attempts to digitally represent intuitive movements of the physical processes. The digital medium comes with its own technique, culture and way of thinking. Therefore, while working in the digital realm unconsciously or consciously, we operate within its limitations. What matters is to succeed in representing our thinking through the digital rather than letting the digital lead our thinking. Concerning that, this thesis addresses the problems that are revealed while trying to translate the dynamic and intuitive features of the physical conceptual models to the digital platform. Intuition plays an important role in the early phase of the design as the designer relays and develops his/her thoughts. Intuitively guided motions such as hand gestures, mimics and manipulations are mostly derived from intentions and experiences of the designer. During the model making process, the designer constructs a direct relationship between his/her thoughts and the modeled object. Quickly made draft models promote the instant decision-making process and help to link designer's thoughts with actions. As regards, the research is carried through conceptual draft models that are produced in the early phase of the design. With in the scope of this thesis conceptual draft model basically refers to quickly made physical models that represent the initial design ideas.

The experimental part of the study was carried out in two phases. In the first phase, a pilot study was realized in order to explore different aspects of conceptual model-making process that designers utilizes for developing their design ideas. The pilot study consists of design protocols that are conducted with three interior designers and observations of the protocols. In the second phase of the experimental inquiry, author analyzed her own design process. The exploration method is known as 'practice-led' design research or 'research through designing', which is fundamentally, involves capturing and analyzing researcher own design activity to achieve the stated research aims and objectives (Pedgley, 2007; Mäkelä, 2011). In order to identify the key features that are required to transfer to the digital media, both digital and physical model-making processes are explored through various experiments. The physical processes are investigated as dynamic representation where the modeled object is constantly evolving via conceptual draft models. The potential advantages and deficiencies of current digital tools that are used for representing these models are analyzed through digital experiments. As a digital medium Rhinoceros is selected since it allows for complex operations on the form.

The Main motivation of the research is to develop the knowledge that is acquired from the both digital and physical experiments. Consequently, the study aims to define a general framework that will assist to construct a methodology for the representation of conceptual draft models in digital medium.

KAVRAMSAL MODELLERİN SEZGİSEL BOYUTUNUN DİJİTAL ORTAMA AKTARILMASI

ÖZET

Tasarım süreci genel olarak ele alındığında; tasarımın tasarım fikrinin oluşup geliştiği kavramsal aşama ve bu fikrin detaylandırılıp son ürüne dönüştürüldüğü gelişim aşaması olmak üzere iki farklı aşamada evrildiği söylenebilir. Herbert Simon (1996) yapayın özelliklerini tariflerken *içsel* ve *dışsal* olmak üzere iki tür parametreden bahseder. Yapay, kendi öz yapısını ve organizasyonunu belirleyen içsel parametreler ve içinde bulunduğu çevrenin özelliklerine göre değişen dışsal parametreler tarafından şekillenir (Simon, 1996). Mimari bir yapı da benzer şekilde içsel ve dışsal parametrelerin etkisiyle biçimlenir. Mimari bir süreçte dışsal parametreler çevresel, kültürel ve sosyal veriler gibi ölçülebilir girdileri içerirken; içsel parametreler tasarımcının kendi bilişsel kapasitesi, deneyim ve bilgisi gibi ölçülemeyen değerlerden oluşur. Kavramsal aşama olarak da adlandırılan tasarımın erken dönemi çoğunlukla içsel parametrelerin kontrolünde gelişir ve ilerler. Tasarımcı kendi iç dünyasına ait soyut bilgileri dışsallaştırırken eskiz, diyagram, maket yapımı, fotoğraf gibi çeşitli araçlardan faydalanır. Bu araçlar tasarımcının düşüncelerini somutlaştıran yegâne aracılar olduklarından dolayı hem tasarımcının kendi tasarımıyla hem de tasarımda rol alacak diğer aktörlerle kurduğu iletişimin önemli bir parçasıdır. Her tasarımcı kavramsal tasarım aşamasında kendisini daha iyi ifade ettiğini düşündüğü araçlarla çalışır.

Gelişen dijital araçların yaygınlığına rağmen birçok tasarımcı tasarımın erken dönemlerinde eskiz, çizim ya da maket yapımı gibi geleneksel yöntemleri tercih etmektedir. Tasarımcılar arasında yürütülen araştırmalar, kayda değer sayıda projenin eskiz ve fiziksel model yapımıyla başladığını göstermektedir (Wiegers and Vergeest, 2001; Scali et al, 2002). Her ne kadar birçok tasarımcı hala tasarıma başlarken eskiz ve fiziksel maketlerden faydalanmaya devam etse de oldukça hızlı gelişen dijital araçlar ve bunun oluşturduğu rekabetçi ortam tasarımcıyı gün geçtikçe daha fazla dijitalde çalışmaya zorlamaktadır. Günümüzde yaygın olarak kullanılan dijital tasarım araçlarına bakıldığında çoğunun parametrik modelleme, sunum, benzetim ya da dijital üretim gibi son ürüne yönelik araçlardan oluştuğu gözlemlenmektedir. Buna karşılık kavramsal tasarım aşamasının dijitalde temsiline yönelik ciddi bir eksiklik olduğu görülmektedir. Kavramsal tasarımın sürecinin temsiline ilişkin eksikliğin en önemli sebepleri arasında tasarımcıların ve bu araçları geliştirenlerin fiziksel süreçteki sezgisel hareketleri dijital ortama aktarırken karşılaştığı zorluklar gösterilebilir. Mimikler, el kol hareketleri ve el ile işleme gibi sezgisel güdümlü hareketler çoğunlukla tasarımcının deneyimleri ve anlık niyetlerinin sonucu olarak ortaya çıkarlar. Özellikle uygulamaya dayalı disiplinlerde sezgisel düşünme biçimi problemi detaylı olarak incelemek yerine temel noktalarına odaklanır (Harbort, 1997). Tasarımın erken döneminde üretilen kavramsal maketler de benzer bir şekilde tasarımın temel problemlerine odaklanarak tasarımcının

tasarımıyla direk bir ilişki kurmasına olanak verirler. Bu bakış açısından yola çıkarak kavramsal tasarım sürecinin dijital ortamdaki temsili tasarımın erken aşamalarında üretilen, kolay ulaşılabilir malzemelerle yapılan ve tasarımcının fikirlerinin oluşup gelişmesine yardımcı olan fiziksel maketler üzerinden incelenmiştir. Temel maket malzemeleri ve maket teknikleriyle kolay ve hızlı bir şekilde ilk tasarım fikrinin temsiline ve geliştirilmesine yönelik üretildikleri için söz konusu fiziksel maketlere çalışma kapsamında “kavramsal eskiz maket” adı verilmiştir.

Sezgisel ve dinamik süreçleri yansıtmasının yanı sıra çalışma kapsamında kavramsal eskiz maketlerin kullanılmasının belli başlı nedenleri şu şekilde özetlenebilir. 1) Kavramsal eskiz maketler soyut düşünceleri basit ve hızlı şekilde ifade etmeye yönelik üretilirler. Bu sebeple üretilen maketler genelde birden fazla anlama gelebilecek muğlâk tasarım araçlarıdır ve yaratıcılığı tetiklerler. 2) Kavramsal eskiz maketler tasarımcıyla düşünceleri arasında somut bir köprü kurarak tasarımın ilerleyip gelişmesine yardımcı olurlar. Kavramsal eskiz maketler in kullanıcı ile kurduğu direk ilişki ani kararlar almaya ve onları uygulamaya olanak verir. 3) Kavramsal eskiz maketler iki boyutu temsillerden farklı olarak mekânsal ilişkilerin üçüncü boyutta kurulmasına olanak verir. Kavramsal eskiz maketler bu özelliklerinden dolayı tasarımının erken döneminde üretilen eskizlere ve diyagramlara benzerler. Farklı yorumlamalara açık olup, yaratıcılığı destekler. Özetle bu sebeplere dayanarak tezin uygulama kısmında yapılan deneyler kavramsal eskiz maketler üzerinden yürütülmüştür.

Tezin deneysel kısmı ikiye ayrılmaktadır. İlk kısım kavramsal eskiz maketlerin farklı özelliklerinin keşfedildiği bir ön çalışmadan oluşmaktadır. Ön çalışma kapsamında üç farklı tasarımcıyla gerçekleşen üç adet tasarım protokolü yer almaktadır. Protokollerde tasarımcılardan kavramsal eskiz maketler aracılığıyla verilen tasarım problemine çözüm üretmeleri istenmiştir. Tasarımcılar protokol süresince video kamerayla kayıt altına alınmıştır. Tasarım fikrinin nasıl geliştiğini ve evrildiğini daha iyi anlamak adına tasarımcılardan ayrıca protokoller süresince fikirlerini sözlü olarak dile getirmeleri istenmiştir. Ön çalışma tasarımın erken aşamasında üretilen kavramsal eskiz maketlerin tasarım sürecine olan farklı katkılarını ortaya koymaktadır. Ayrıca ön çalışma kapsamında kavramsal maket yapımının dinamik ve sezgisel özellikleri ele alınmıştır. Ancak şunu belirtmek gerekir ki ön çalışma belirli malzemelerle, kısıtlı sayıda katılımcıyla, kısıtlı bir sürede ve belirli bir konu üzerinden gerçekleşmiştir. Bu nedenle kavramsal maket yapımı üzerine bir genel bir çıkarım yapmak yerine çalışma kapsamında dijital ortama aktarılması gereken anahtar özellikleri belirlerken yardımcı olması amacıyla ana deneylerden önce kavramsal eskiz maket yapımını daha derinlemesine incelemeyi hedeflemektedir.

Deneysel kısmın ikinci aşamasında araştırmacının kendi sürecini belgelendirerek incelediği “tasarlayarak araştırma” ya da “uygulama öncülüğünde araştırma” olarak bilinen bir araştırma yöntemini tercih edilmiştir. Dijital ortama aktarılması gereken anahtar özellikler ve bu özellikleri aktarırken karşılaşılan problemler hem fiziksel hem de dijital ortamda gerçekleştirilen deneylerle incelenerek saptanmıştır. Ön çalışmaya benzer olarak fiziksel süreçlerin ani kararlar almayı sağlayan dinamik yapısı; kağıt, maket kartonu, asetat, iğne, tel gibi kolay ulaşılabilir malzemeler ile hızlı bir şekilde üretilen kavramsal eskiz maketler üzerinden incelenmiştir. Güncel dijital araçların kavramsal modelleri temsil etmedeki potansiyel avantajları ve eksikleri üç boyutlu tasarım ve modelleme programı olan *Rhinocores* kullanarak üretilen dijital modeller üzerinden analiz edilmiştir.

Deneysel kısmın ikinci aşamasında seçilen aynı tasarım problemi için araştırmacı tarafından üretilen, her biri farklı bir tasarım fikrini temsil eden dört adet kavramsal eskiz maket üretilmiştir. Fiziksel süreç ön çalışmadakine benzer olarak daha sonraki analizlerde kullanılmak üzere kamera ile kayıt altına alınmıştır. Her ne kadar kendi sürecini inceliyor olsa da araştırmacı belgelendirme amacıyla maket yapım süreci boyunca düşüncelerini ayrıca sesli aktarmıştır. Ayrıca deneyler tez kapsamında yazılı olarak rapor edilmiştir. Yöntem araştırmacının kendi sürecini analiz etmesine dayalı olduğundan, yapılan deneylerin kayıt altına alınması çalışmanın şeffaflığı açısından önem taşımaktadır. Üretilen fiziksel maketler daha sonra yine araştırmacı tarafından dijital ortamda benzer yaklaşım ve yöntemlerle yeniden oluşturulmaya çalışılmıştır. Fiziksel ortamdaki üzetilen maketler, üretim sürecinde izlenen yaklaşıma göre iki farklı grup altında incelenmiştir. İlk grup malzemenin bütünün deformasyona uğrayarak şekildendiği bütünden parçaya giden süreçleri içermektedir ve *tepeden-tabana* olarak adlandırılmıştır. İkinci grup malzemenin daha küçük bileşenlerle halinde biçimlenip bir araya geldiği parçadan bütüne bir modelleme yaklaşımını içermektedir ve *tabandan-tepeye* olarak adlandırılmıştır. Dijital modellerin fiziksel yapım sürecinde kullanılan yaklaşımlarla ve benzer fiziksel hareketlerle üretilmesine özen gösterilmiştir. Bu süreç boyunca karşılaşılan zorluklar ve bunun nedenleri yapılan araştırmalar ve deneyler sonucu elde edilen bilgiler ışığında tartışılmıştır.

Dijital ortamın kendine ait tekniği, kültürü ve düşünce yapısı vardır. Dijital ortamda çalışırken tasarımcı bilinçli ya da bilinçsiz şekilde programın izin verdiği olanaklar içinde kısıtlanmaktadır. Dijitalin elverdiği sınırların tasarımcının düşüncelerini yönlendirmesi gün geçtikçe dijitalleşen çağdaş tasarım pratiğinde önemli bir sorun teşkil etmektedir. Erken tasarım döneminin dijital ortamdaki temsilinin eksikliğinden yola çıkarak, bu çalışma kapsamında kavramsal düşünceyi dışsallaştıran erken tasarım araçlarından biri olan fiziksel maketler ve yapım süreci incelenmiştir. Çalışma, tasarımın erken aşamasında üretilen kavramsal maketlerin dijital ortamdaki temsiline yönelik bir araştırma içermektedir. Tez kapsamında kavramsal maket yapım sürecinin dinamik ve sezgisel özelliklerini dijitale aktarırken ortaya çıkan problemler ortaya koyulmaktadır. Yapılan araştırma ve deneylerden elde edilen bilgi ışığında, kavramsal eskiz maketlerin dijital ortamdaki temsili için bir yöntembilim oluşturulmasına öncülük edecek genel bir yapı önerilmiştir.

1. INTRODUCTION

When dealing with concrete problems in design, digital space might help us alter, simulate, integrate or connect data from the physical world in various ways, thus providing a more efficient environment for conceptualizing ideas. In *The Sciences of the Artificial* Simon (1996) defines artificial as an interface where “the inner environment of the substance and organization of the artifact itself” and the “outer environment, the surroundings in which artifact operates” intersect. “Whether a clock will in fact tell time depends on its internal construction and where it is placed” (Simon, 1996). Similarly, architecture is a superimposition of extrinsic and intrinsic parameters. The occurrence of an artifact depends on the environment where it is placed and who designs it. For architecture, extrinsic parameters are related to site, landscape, social and cultural data as long as these are calculable in some way. However, compared to extrinsic parameters, intrinsic parameters have incommensurable values such as designer’s own experiences, cognitive capacities and design skills. These parameters, incidentally, mostly shape the early design process. In the following passage, Peter Zumthor (2006) verbalizes how intrinsic parameters such as those coming from personal experience are related to architectural design ideas.

> When I think about architecture, images come into my mind. Many of these images are connected with my training and work as an architect. They contain the professional knowledge about architecture that I have gathered over the years. Some of other images have to do with my childhood. There was a time when I experienced architecture without thinking about it. Sometimes I can almost feel a particular door handle in my hand, a piece of metal shaped like the back of a spoon (Zumthor, 1988, p.9).

Any design process in architecture is lead by the architect with the help of several tools, which are composed of representational techniques such as drawing, painting, collage, photography, and modeling. Tools help the thinking process. These tools are significant because they are the media that externalize the designer’s intent, idea, and thought process. Each architect prefers to design with different tools, those that they are more comfortable with. However, highly developed digital technologies today push the designer to work more and more in the digital media, which is now a competitive factor. It is a fact that the digital media have brought many opportunities and possibilities to design theory and practice. Notwithstanding, they are still not very effective in the conceptual phase of the design process where the initial idea originates and gets developed.

Two-dimensional representations, especially architectural drawing and sketching, have conventionally been of great interest in the conceptual design development of early phases. There are several studies and tools that developed for the representation of sketching in digital realm. In contrast, even though “models have been used for over 500 years as an important method of communication in the understanding of architecture” (Dunn, 2010, p18), there is a minor focus on the architectural model making process for the same purposes. As Knoll and Hechinger state that “Just like a drawing, a model is an expression of the thought behind a design” (1992, p.8). Within the context of this study, architectural models are considered as a mode of thinking tool rather than as a representational medium that functions to represent a finalized design work.

Interests in architectural modeling have just recently been reinvigorated, especially with the rapidly emerging digital modeling tools. In recent years, digital design tools have expanded the overall vision of design with uses such as digital manufacturing, modeling, animating, rendering, programming etc. Still, they are insufficient in assisting designers during the early phases of the design process. Conventional methods such as sketching and physical modeling are still the most effective and commonly used tools for conceptual design. This insufficiency is mostly due to the challenges designers and tool developers face in attempts to digitally represent intuitive acts of the physical processes. There is a need for the early physical products such as sketches and physical models to be transferred or translated into the digital media to sustain the continuity of the process through the later phases and towards the final product.

In the early phase of the design working with models, promote the design process and assist designer in many aspects. Models afford a three-dimensional working space, thus in contrast to two-dimensional representations they enrich the spatial percipience. They also provide direct interaction with material and help to explore new possibilities and potentials of the material. Handling material evokes both visual and tactile senses and enriches the cognitive capacity of designer. While conceptualizing design ideas models link designer thoughts with actions and material. Quickly produced conceptual models provide a direct relationship between designer and his/her thought process. Therefore, in the early phase of the design process conceptual models can be considered as the representation of the architect's inner environment. Whereas conceptual models are already representations of the designer's imagination and transferring them into digital media requires another representation. It is believed that the design of such tools will not only save time in professional practice but also will decrease the evaporation of the knowledge during the transition from one representational form to another. With regards to this problem, this thesis addresses the problems in trying to translate the dynamic and intuitive features of the physical conceptual models to the digital platform. The ultimate goal is a general framework, which will lead to construct a methodology for the representation of conceptual draft models in the digital medium.

1.1 Background

In the early phases of the design process, conceptual models function as three-dimensional sketches. Porter and Neale (2000, p.21) describe conceptual models as an "embryonic sketch in three dimensions" which is used to examine "newly forming ideas directly in the space of the idea." Gürsoy (2010) investigates the model making process as a form of sketching and its contribution to the early design process. Dunn (2010) points out that experimentation with materials, especially at early stages in the design process helps developing design ideas. Studies that are conducted among practicing product and engineering designers reveal that a notable amount of projects start with sketches and physical models (Wiegers and Vergeest, 2001; Scali et al, 2002). Yet, today there is a strong shift towards digital modeling instead. Van Berkel and Bos (2006) criticize the rapid transformation in the digitalization due to the fact that digital tools are not adapted to design practice, as it ought to be.

> This is the Beaux Arts all over again; architecture has one again become restrictively academic…How this happen: the only reason for the lack of evolution of computational design techniques is that they are taught and exercised in a hermetic way that is impossible to sustain in actual practice. It simply is not possible to foresee and to register in your computer all of the parameters that you will be working with as you engage in the long and complex process of architecture (van Berkel and Bos, 2006, p.14).

Although van Berkel and Bos's critique focus on mostly parametric design and its techniques, same critique is also valid for the inadequacy of the digitalization of conceptual tools. The tools that are developed for different purposes afford different needs in the architectural process. Therefore there is a number of varying software that architects utilize for different purposes such as modeling, simulation and rendering. However, today there is no distinct digital modeling tool for conceptualizing design ideas. The representation of conceptual thinking in digital requires its own specific parameters and design. It is believed that there is a strong need in the field for the translation of conceptual process into the digital realm.

1.2 Purpose of Thesis

The aim of the research is to show the importance of architectural model making in the conceptual design phase and identify difficulties in the translation of intuitive aspects of model making. Essentially, intuition plays an important role in the early phase of the design as the designer relays and develops his/her thoughts. Intuitively guided motions such as hand gestures, mimics and manipulations are mostly derived from intentions and experiences of the designer (Boucouvalas, 1997). During the model making process, the designer constructs a direct relationship between his/her thoughts and the modeled object. Therefore, quickly made draft models promote the instant decision-making process and help to link designer's thoughts with actions.

Harbort (1997) asserts that in the practice-oriented disciplines, intuitive thinking focus on the general aspect of the problem and do not investigate the problem in a detailed manner. Similarly, in the conceptual phase of the design, designer focuses on the basic problems of the design. As regards, the research is carried through conceptual draft models, which is basically refers to quick hand made model that allow making instant decisions. Rather than proposing a fully functioning computational model, the study aims to define a general framework that will assist to construct a methodology for the representation of conceptual draft models in digital medium.

1.3 Methodological Approach

This study focuses on the intuitive aspects of model making in the early phase of any design process and reports on analyses of conducted experiments. Conceptual model making, as it represents the very initial idea of the design, is explored via both physical and digital experiments over a given design task. The experimental part of the study was carried out in two phases. In the first phase a pilot study was conducted with three interior designers in order to explore different aspects of conceptual model-making process. The pilot study consists of design protocols that are conducted with three interior designers and their observations. In total eight models are built in protocols. Each participant is developed the same idea in protocols through different models.

In the second phase the translation process of intuitive aspects of conceptual models into digital is explored via both physical and digital experiments, which were carried through the author's own design practice. The physical processes are investigated as a dynamic representation where the modeled object is constantly. Consequently, each conceptual model making process is regenerated in a digital environment in order to analyze potential advantages and deficiencies of current digital tools for representing conceptual ideas. As a digital medium Rhinoceros is selected since it allows for complex operations on the form. The method applied is Practice-Led research in literature (Pedgley, 2007). The aim was to collect data by analyzing dynamic and intuitive actions that occur based on the instant decisions that are made during the conceptual model-making process. As a base of source author documented and extracted reflection on her design process. Experiments are documented via audio-video recording. Later, the same process was tried to reproduce in digital environment in order to capture prime difficulties.

Both the pilot study and the physical process of author's own design experiments are explored via instant and quick handmade models, namely, conceptual draft models. Main motivation of the research is to develop the knowledge that is acquired from the both digital and physical experiments. The methodology is explained in detail in chapter 4.

1.4 The Structure of the Research

This thesis consists of two phases in respect of contextual and experimental knowledge. First phase highlights the theoretical background of the thesis within the scope of the study and comprise chapters 1-2. Chapter 1 provides an introduction to the study and clarifies research aim and objectives. Chapter 2 presents concept of models and model-making process both in architectural and scientific practice. It provides a classification example for the architectural models and presents a very specific type of model; conceptual draft models to set a ground for the experimental phase of the study. In addition, the study addresses the problems that reveal while representing physical model-making process in digital realm. Thus, chapter 2 provides also a background for the digital representation techniques in scientific practice with examples and demonstrates how they are related with the technological developments.

The second phase of the thesis is concerned with the experimental studies that are conducted both with participants and author herself and consists of chapters 3-5. Experiments that are realized by participants are held as a pilot study and presented in chapter 3. The pilot study includes three protocol studies, their discussion, advantages and limitations. The pilot study demonstrates the different aspects of conceptual model-making process. The main exploration method, which is carried out by author herself is also introduced in chapter 3 as a core method of the study named practice-led research. The author is realized several physical and digital experiments in order to investigate translation process of intuitive aspect of conceptual models into the digital realm. These experiments are presented and discussed in chapter 4. Lastly, the arguments of the thesis that are constructed from the experimental inquiries are discussed in chapter 5. Additionally, conclusions are drawn and projections for the future are given.

2. MODELS

> Three-dimensional models offer the possibility of unusually rich engagement and move routinely between the most private sites of the discovery and most public areas of display. (Chadarevian and Hopwood, 2004, p.12).

Models are intermediators that connect an audience to a material, apparati to understand the complexity, tools for design, or objects to exhibit. This chapter presents a survey of models that range from a general and interdisciplinary understanding of models to very specific contexts of modeling within the scope of the study. It is significant to understand the concept of "model" with references to other disciplines to make the connection with different types of models.

Subsequently, the survey will dwell on the early attempts for digital representation of physical models in a closer relation with the scope of the thesis. Similarly, architectural model making will be presented as a design tool in the design practice. There are various classifications for architectural models depending on their method, material, function, application or production technique etc. However, with regards to the context of this study, models will be explored concerning their contribution to early design processes excluding other subcategories. Based on Dunn's (2010) categorization of architectural models, the classification will be made according to stage of models during the design process to clarify role of design models .In addition to Dunn's (2010) classification the representational and intuitive aspect of conceptual models will be elaborated under the new category named conceptual draft models. With reference to their common characteristics with sketches and diagrams, conceptual draft models will be presented as mode of thinking and design tool in the early design process. Additionally, visual and tactile notions of the modeling process will be refined with reference to *learning by doing* in order to appreciate hands-on actions with deeper insight. Lastly, similar studies that attempt to engage the physical and digital world will be presented. Hence, it is important to grasp different aspect and requirements of transition process between physical and digital realm.

2.1 The Concept of Model

Models have always played an important role in scientific and technological practice throughout history. "From churches to watches, from coaches to tomb monuments, further to show the movement of the planets or the operation of water pump", models were used to represent all kinds of aspects of artifacts (Baker, 2004, p.23). In these diverse uses, models were not just built as an end product to demonstrate a result or communicate a plan, but also to understand the nature and complexity of the things in becoming. They are dynamic representations that reflect the discrete phases of various operations that occur between "transitions from two-dimensional form to three-dimensional one" through successive representations that "enrich the understanding of scientific practice" (Chadarevian and Hopwood, 2004, p.10).

Although, they were often built in different scales, with different methods and serving different purposes, they are mostly three-dimensional visual/spatial entities produced through various transformations of material. They afford tangible interaction between material and model maker. During the transformations of material, the model maker explores new possibilities and observes different aspects of the modeled object. James Griesemer, who is a biologist and also a philosophy professor, claims that models play an important role in "making knowledge" through "visual and tactile experiment" (2004). Similarly tangible and visual experience, which was propounded by philosopher and educator John Dewey (1916) as a pedagogical approach named "learning by doing" is encouraged in design education to produce knowledge (Dewey, 1944; Özkar, 2007). In this sense, models are not just a representative media but also arrangements of spatial elements that can be manipulated, constructed and designed in various ways.

According to Burnett (2008), the underlying strength of models is the ambiguity of the oscillation between "making analogies" and "ontological continuity". In his words: "The move from "as" to "is" can happen fast, can happen for only a moment, can subsequently be denied—it is in this instability, this indeterminacy, that models ultimately do their real work." Burnett explains that the modeling process starts with making analogies. But the generative role of models ends when the maker decides, "the thing you set out to model is nothing more or less than the thing you've just built as a model" (2008, p.46). Following this understanding, models within the scope of this thesis are referred to dynamic creations based on experiments where sometimes the results itself is less important than the process.

2.2 From Physical To Digital

Early attempts of digital representation of visual entities in scientific research go back to first interactive computer displays that are developed in early 1949s. In his speech at Siggraph '89 Panel Proceedings, Taylor (1989) indicated that interactive display systems were tested and developed simultaneously with *Whirlwind I,* which was the first digital computer with "man-machine interactive" system that operates real time functions. First primitive interactive display was a picture that consisted of 1024 points of lights, which were alterable by a *light gun*. Interactive display systems are significant within the context of the study since they were the first attempts for visual representations in digital media, which were evolved later towards the three-dimensional physical models with the development in computer science. Griesemer defines the position of interactive displays between "the static two dimensional displays of traditional graphics" and "dynamic interactivity of three-dimensional physical models" within the evolutionary process of representational mediums (2004). Besides understanding the historical progress of human computer interaction in cognitive and haptic sense and how they are evolved, it is important to draw the general framework of the proposed task. Taylor (1989, p.21) defines primitive interactive displays as "the first real tool that link people with computers."

Evolution of two-dimensional graphic displays continued with the first three-dimensional interactive graphic system that was developed by Levinthal who was a biologist at MIT. Due to the fact that building physical models of macromolecular structure was challenging since it requires possible various confirmations for hundreds and thousands of atoms with high accuracy (Francoeur, 2002), Levinthal was interested in modeling three-dimensional structure of macromolecules in the computer. In late 1963, Levinthal was introduced to the Kluge, the first computer display that capable of demonstrating three-dimensional objects on a "cathode-ray tube "through axonometric projection (Francoeur and Segal, 2004, p.406), by Robert Fano who was also the founder of Project MAC which was a further attempt to support "Machine Aided Cognition through the uses of multiple access computer" (Fano, 1989, p.34). In 1966, using the Kluge, Levinthal built the first system for the interactive display of molecular structures. The Kluge was influential from many aspects. Most importantly it was the first computer display that provide interactive screen with a light pen and *globe,* which could be considered as an initiator of today's mouse (Figure 2.1). Even it can be claimed that *globe* responds rotating action more intuitively than mouse roll since it can be grasped and controlled with both hands at the same time. Fano (1989) describes globe as "most outstanding thing of the display".

> That globe is a joystick, in effect, that was used to rotate the image on the screen. That is, a three-dimensional object was defined in memory and with the globe you could control the speed at which the object appeared to rotate. The goal was to provide a three-dimensional feeling for the object. And that worked very well. Now, that display was immediately very popular and a lot of very interesting work was done with it (Fano, 1988, p.35).

Figure 2.1 : Detail of interactive display and 'globe' (URL-1).

Beside globe and light pen the interaction between user and display was also provided by notably buttons (Francoeur, 2002). Figure 2.2 show the interactive display screen of Kluge and PDP-7 mini-computer. In front of the screen it can also be seen the physical space-filling model of the structure of the protein myoglobin. First graphical displays were aimed to construct an interactive relationship between human and computer and attempt to solve some specific problems of physical representation. Therefore the interface of the display and supplementary devices were developed specifically considering the interaction between human and computer. In addition to being pioneer of today's haptic and interactive system the first graphical displays were also mediated the digital representations that were developed to solve physical modeling problems.

Figure 2.2 : Showing Levinthal's molecular model building system: in the back, the PDP-7 mini-computer (URL-1).

The *Coons' Patch* is another important work in the field, which was implemented in the Kluge also (Fano, 1989). It was developed by Steve Coons, who was one of the early pioneer's of Computer-Aided Design. Coons (1967) investigated the mathematical structure of certain class of surfaces "from a designer's stand of point rather than analysis of geometric properties of surface." His motivation was creation of such surfaces in "natural and easy way" that will help to design process (Coons, 1967). He expressed his motivation for the mathematical description of "complex arbitrary surface" in his published work *Surfaces for Computer-Aided Design of Space Forms*, as in the following passage.

> The designer himself need not know or care about these internal mathematical details, anymore than he needs to know the specific composition of the pencils with which s/he writes or mechanics of splines with which he now draws curves. The mathematics is relatively simple, but it is nevertheless too complicated for hand calculation, and is designed for use on a computer (Coons, 1967, p.1-2).

Coons' motivation was directly related to translating intuitive aspect of hand drawing to computer. He deemed to save time designer since the hand drawings especially for the design of ships, automobiles and airplanes require complex calculations.

His work became the foundation for the surface descriptions that are commonly used today, such as B-spline surfaces and NURB surfaces. For the experimental part of this study also a NURB-based software is selected regarding its modeling capacity over the complex surfaces. It was not benefited from any other mathematical plugins; since it is believed that conceptual modeling environment should provide flexible manipulation over the form without requiring complex mathematical calculations.

To sum up, since the first graphical display Whirlwind I, interactive computer graphics have proceeded remarkably. With the developments of computing, that started in 1950's notion of representational medium shifted towards to real time simulation. Invention of the Sketchpad by Sutherland in 1963, foundation of Xerox Parc in 1970 and the introduction of first personal computer with graphic user interface, Macintosh, in 1984 are some of the noteworthy points in the field.[1]

Today with the latest technological development in the field, it is also possible to render real time physical actions via digital source with augmented graphical user interfaces. The smart interface that developed in 2013, named inFORM by the Tangible Media Group in MIT, interact with the physical world around it and captures the user's physical actions (Figure 2.3). The interface provides also tangible interaction through digital information (Figure 2.4).

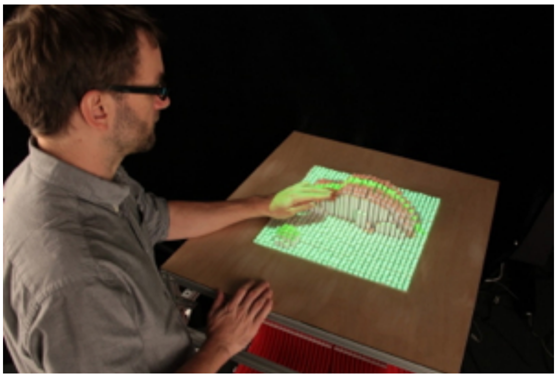


Figure 2.3 : Smart surfaces of inFORM. Manipulation by actual physical force (URL-2).

[1]URL-14

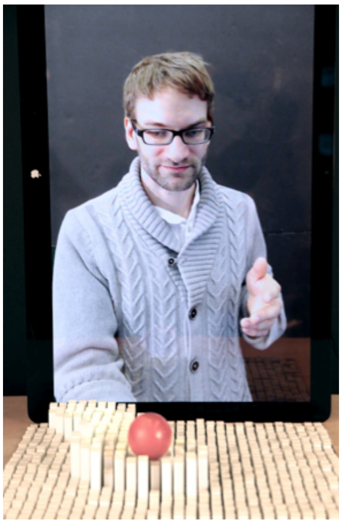


Figure 2.4 : Smart surfaces of inFORM. Manipulation by digital source (URL-2).

As also can be seen from examples, human computer interaction has developed in conjunction with technology. Current technology is granted wide opportunities in the field of human computer interaction. Beyond the keyboard and the mouse, with uses such as smart surfaces, touch screens, movement and gesture capturing cameras and so forth, the relationship between human and computer become more natural and intuitive over time. Yet developments in the field span a wide range of applications, they are still required to be adapted for the specific operations. The background for the human computer interaction and digital representational techniques are given to understand the progress and possibilities of human computer interaction. The adaptation of the technology is important within the scope of this thesis, because the proposed work in this study will also require high-level interaction between digital media and human designer.

2.3 Architectural Model Making As a Design Tool: An Overview

Architects have always benefited from models with different purposes throughout history. Even though the use of architectural models as a medium of representation dates back to ancient times, its use as a design tool is not that much old in the history. Architects' first interaction with models was highly different than the use of scale models in contemporary design practice. From ancient times till the Renaissance model was not a common tool in the architectural design practice as a thinking tool (Carpo 2001; Dunn 2010; Smith 2004). The main reasons of this can be interpreted within the frame of developments in information technologies. The representational techniques in architecture highlight the dominant movements in architecture also. Carpo (2001) who is an architectural historian investigates the transformation of representational media in architecture from antiquity to modern era in his book *Architecture in the Age of Printing*. According to him transmission of the architectural knowledge and the mode of architectural thinking are directly related to the representational media, which is used in that period. As regards, in this section a brief history of architectural model-making will be presented before analyzing modern use of architectural modeling.

In the ancient times, models were built to imitate certain elements of building in full-size prototypes (Dunn, 2010). Carpo (2001) indicates that medieval architects essentially used to build models to copy architectural elements. Most of the medieval architects were travellers and instead of visual representations such as drawings and models, they preferred to express their observations and abstract thoughts verbally. The verbal depiction was a common and powerful abstraction in that period for expressing visual perception rather than illustrations and drawings. Absence of printed media was one of the main reasons that verbal discourse was very common among medieval architects (Carpo, 2001). The verbal discourse was used to assist the imagination of visual existence of the artifact. However the transmission of architectural knowledge was week in verbal discourse. Moreover the subjectivity of verbal depiction was required to use more certain communication tools at the same time. The use of models as a more clear communication tool coincides to the early Renaissance. According to Dunn (2010) architectural scale models were emerged in the Renaissance as a design and communication tool rather than as physical prototypes or detailed replication of components. The models that were produced in the Renaissance were less ambiguous unlike the twentieth century design models and aimed to illustrate the artifacts in more explicit way. During Renaissance, models were mainly produced to communicate design ideas in architecture. Still, they were started to become a thinking mechanisms while illustrating details of the building with high hand workmanship. Figure 2.5 demonstrates Brunelleschi's wooden model for the dome of Florence Cathedral. It can be seen that how the proportions of the architectural elements are adjusted and details are elaborated over the wooden model rigorously.

Figure 2.5 : Brunelleschi’s wooden model for the dome of Florence Cathedral (URL-3).

Smith (2004) indicates that our current relationship with models was started to build in Renaissance together with philosophical shift which brought architects more freedom to express and interpret their designs. However, the major shift in the use of architectural models occurred in the beginning of the twentieth century with the use of design-development models for “the conception and refinement of countless built and unbuilt projects of the Modernist era” (Dunn, 2010, p.16). From the beginning of twentieth century, architectural models have started to use in more ambiguous and abstract manner to develop design ideas especially with quick made abstract design models. Owing to vast opportunities, they provide with material and form, despite the highly developed rendering machines and modeling programs in recent years, several architectural design studios are still working with the physical models to develop their ideas.

In previous sections, different examples from scientific practice were given to illustrate the general concept of the models as such. In this section, architectural models in current design practice are analyzed. As Killian asserts to be different than in science, in design “the model has to be generative, meaning that it has to be useful in producing novel opportunities for the designer” (2007, p.209). In this perspective, it is important to comprehend the role of the different architectural design models and their contribution to the design process. Architectural models are used in different phases of the design process according to their objectives. Based on Dunn’s (2010) classification of models according to their types and application, some specific selected models are grouped in the Figure 2.6. The contribution to Dunn’s classification here is that models are specified with regards to the stage of the design process they are utilized in. There is no definite boundary between design phases according to uses of models. Some types of models can be used in different stages of the design according to the designer's intent. For example, evaluative models are generally made after most of the design decisions are given. However, it is possible that the designer might need to produce an evaluative model before finalizing the design in order to test some specific. Indeed, it is also hard to make a keen distinction between the types of models since in some cases they may be built for similar purposes. For instance, a conceptual model may indicate a spatial relationship or an explorative model might seek for structural solutions at the same time.

As indicated before, in this study architectural models are explored according to their contribution to the early design process. Models are classified as in the Figure 2.6 in order to show which types of models enrich the early phase of the design process and how they are distinguished from other types of models. It is believed that before thoroughly explaining early design models, it is important to comprehend the role of other types of models in the design process since as seen in Figure 2.6, design is an integrated process, which is hard to divide with sharp boundaries.

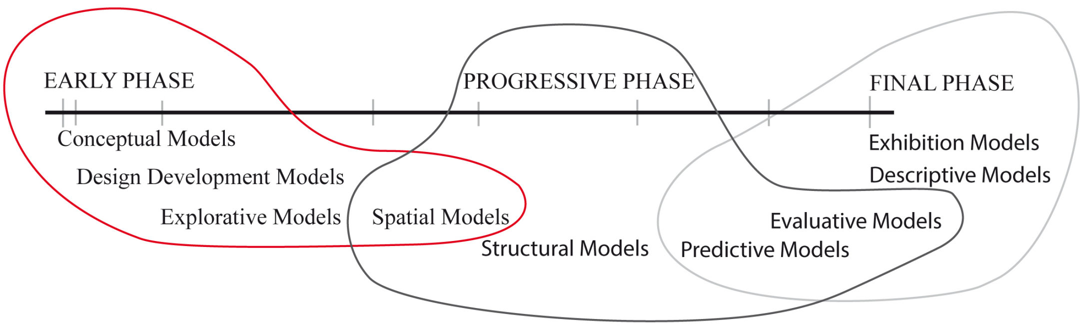


Figure 2.6 : Classification of the models with reference to the design phases.

In the following, models are explained in two groups; early and final phase of models regarding solely one main group they belong. Exceptionally, structural models are presented with explorative models due to their resemblance in use. Since the study focuses on early phase of models, each of them is presented individually. Exhibition, descriptive, evaluative and predictive models are complied as final phase of models and presented.

2.3.1 Conceptual models

Conceptual models are the most abstract type of representation in all models. They are among the initial acts of the design where the idea is embodied with material. These models are full of uncertainties. They convey the design idea generally at a metaphorical level. The message they convey can be interpreted in various ways. In addition conceptual models are visual entities that are composed of different materials of different texture and color. According to the method and material they are produced, they create different compositions each time and strongly impulse creativity. Designers can easily produce series of models and can explore the same model with different materials. As Dunn (2010, p.9) claims, "different visualization methods and techniques provoke different thinking and inspire greater insight during the design process". The selection of the material mostly relates to scale and abstraction degree. A strong abstraction and composition may influence designer's thought. Hence, several design studios work with conceptual models not only to facilitate their design process but also to elicit creativity instinct and share their initial design ideas. Figure 2.7 shows the conceptual model that is made of acrylic and paper by Vincent de Rijk for O.M.A. The contribution of conceptual models to the design process will be explain more specifically within the context of study thoroughly in the following section as conceptual draft models.

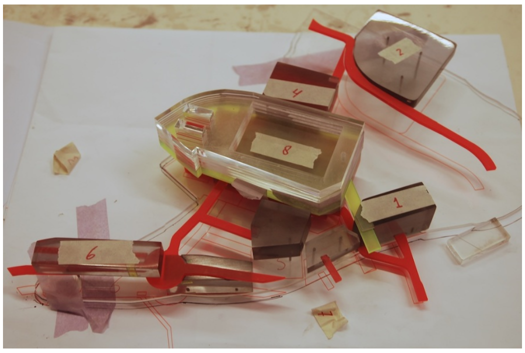


Figure 2.7 : Concept model that is made by Vincent de Rijk, Marloes Dans, Rob Gijsbers for O.M.A. (URL-4).

2.3.2 Design development models

Early phase design models mostly produce with easily accessible and manipulable materials to test and evaluate design ideas instantly concerning the spatial relationships, form and function. Especially design development models are quickly produced to search for possible solutions. Dunn (2010), states that 'design-development models illustrate the thought, effort and time committed to investigating design ideas." They usually do not consist of different type of material but one single material depends on the exploration method. Figure 2.8 shows the design development models of O.M.A for the project of Hyperbuilding in Bangkok in 1996. The model represents the building program by white block styrofams, which is easy to manipulate. The representation is notably abstract since most of the design decisions are not certain yet.

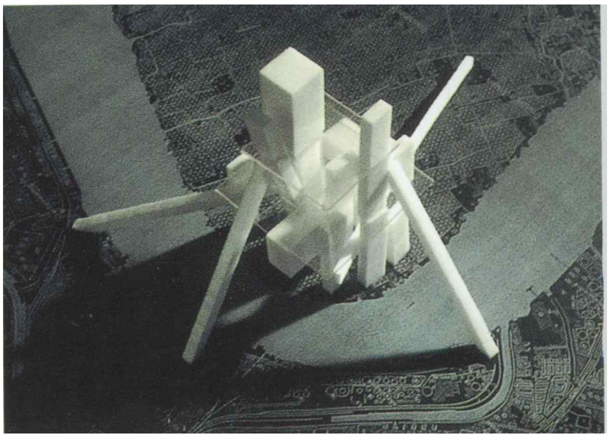


Figure 2.8 : Early development model of Hyberbuilding, Bangkok (El Croquis OMA [II], 1996-2007).

2.3.3 Explorative and structural models

Structural models are mostly built to test structural ideas of design. They may also contain utilization and jointing techniques but majority of them illustrates the construction technique (Knoll and Heichinger, 1992). In general, structural models are produced after the initial design decisions are made. Dunn (2010) points out structural models should be assisted with initial concept and spatial explorations during design process. However, in some cases, explorative models also seek for structural solutions in the early phase of process if the design concept is directly related to its structure. For example, Frei Otto used soap bubbles to discover minimal surface tension of a surface. The exploration lead to invention of lightweight structures in further researches and used as structural concept of different projects such as Olympic Stadium in Munich, Stuttgart Train Station etc. Explorative models not only produce to answer structural questions but also pursue the different combination of shape, geometry and material. Figure 2.9 demonstrates the UN

Studio working model that seeks for the right materialization for the twisted surface (Berkel, B. and Bos. C., 2006).

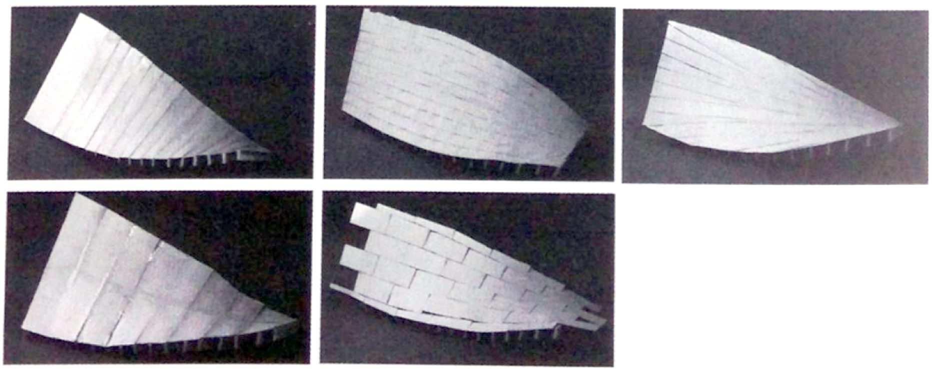


Figure 2.9 : Working model of Ben van Berkel and Caroline Bos. Constructed for the VilLA NM, Upstate New York. Exploring the materialization of ruled surface geometry (van Berkel, B. and Bos, C., 2006, p.78).

2.3.4 Spatial models

Spatial models mainly investigate the internal relationships according to building program. Smith (2004) states that models contribute to solution of spatial problems via visualization shape and design form in three-dimension. Figure 2.10 demonstrates the working model of Sou Fujimoto for Las Torres de Cotillas Auditorium International Competition. The model shows the possible internal circulation and its relationship with the landscape.

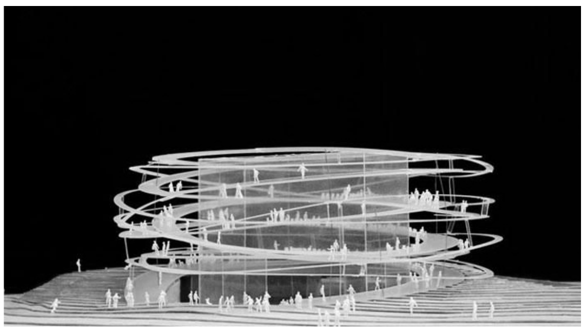


Figure 2.10 : Spatial model of Sou Fujimoto (URL-5).

Evaluative models are produced to observe qualitative aspects of nature. Predictive models are used to estimate future situations by producing qualitative data that can be measurable. Exhibition and descriptive models are produced to communicate with the audience after the design process. However they both convey different messages.

Descriptive models demonstrate the miniature of the finished building whereas exhibition models present different phases or components of the design according to message which designer deem to emphasize (Dunn, 2010). Figure 2.11 demonstrates the further model of the Hyperbuilding project of O.M.A. When comparing with Figure 2.8 it can be seen that two models represent the very different stages in the design. The representation is still abstract but gives the expression about the functions and materials of the actual building both to the audience and designer. The interior functions of building are readable from the transparent facade.

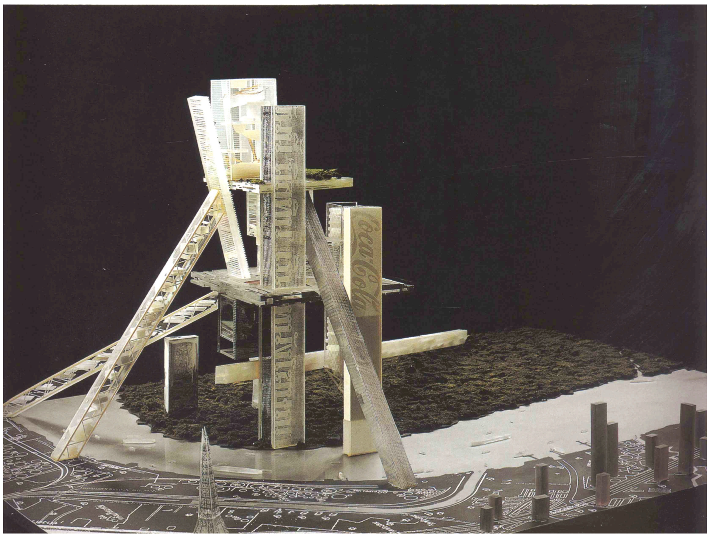


Figure 2.11 : Descriptive model of Hyberbuilding, Bangkok. Programmatic relationship both interior and exterior is readable. It reflects the impact of final building (El Croquis OMA [II], 1996-2007).

2.4 Conceptual Draft Models

The transformation from the design idea to design product itself consists of several stages. In the previous section particular types of models that are used at different stages of the design process are presented. In this section models that are produced in the conceptual phase of the design process will be elaborated specifically. Conceptual phase is the initial step of the design process where the design idea externalizes by abstract representations. Most of the fundamental design decisions are explored in the conceptual phase by various ambiguous media such as sketches, diagrams and physical models. Due to the fact that early outputs that are produced in the conceptual phase are ambiguous and open to diverse interpretations, conceptual design phase is also considered as the most creative phase of the design. During the process in order to develop his/her design ideas and explore new possibilities designer seeks for possible solutions constantly. As Schön (1992) states that there is a "reflective conversation" between designer and his/her representations based on seeing and moving activity. The designer produce knowledge by looking and evaluating his/her previous designs. Since the early phase of the design requires high level of productivity, representational medium is also required to be reflective. With respect to productive notions of conceptual design, in this section conceptual models are examined as dynamic representation within a specific context named conceptual draft models.

Essentially, within the scope of this thesis conceptual draft model refers to early abstract models that are made to embody and develop designer's initial ideas rapidly with easily accessible materials. It is a thinking technique, which allows for the instant decision-making. A conceptual draft model may represent any idea of design including structural, spatial or material concerns. It is considered as an immersive version of all types of models at a high level of abstraction. In this section two main aspects of the conceptual draft model will be investigated regarding their contribution to the design process. Firstly, their diagrammatic notion will be presented. Secondly, they will be examined as a form of three-dimensional sketches. In the following chapters, experimental part of the research will be presented through conceptual draft models.

2.4.1 Conceptual draft models as a diagrammatic representation

Model making is a work of abstraction. Dunn (2007) indicates, "Model is always an abstraction of reality since it could never possibly represent the complexity of reality". Abstract knowledge becomes tangible with the use of physical models. Dunn (2010) describes model as "a representation at spatial yet abstract level." As indicated previously, bottom line power of models is abstraction. The degree of abstraction changes regarding the stages of the design process. "The more abstract a model is, the more it conveys conceptual ideas" (Dunn, 2010, p.29). Conceptual phase of the design process is the most abstract phase where the design idea evolves.

The underlying strength of the conceptual models is that they are not the exact reproduction of the reality. They reduce complexity of design problem and manifest it in a novel way that leads creativity. Reducing here refers to taking out irrelevant components “that will not aid the understanding of the design being communicated” (Dunn, 2010). It does not mean scaling down expression or problem into one clear meaning. On the contrary, conceptual models promote diverse interpretations and enrich the designer’s imagination. Van Berkel and Bos (1988) define representational technique as a medium that helps to convey conceptual position to reality and construct structure “between idea and form and between content and structure”. In this context, the notion of conceptual models resembles to architectural diagrams. Conceptual models function in the similar way to van Berkel and Bos’s definition of diagrammatic practice; “a diagrammatic practice pursues a proliferating, generating and open intrumentalization in architecture” rather than reducing the expressions into one clear meaning which “excludes possibilities in architecture” (1988, p.23). When viewed from this aspect, conceptual models can be considered as three-dimensional diagrams.

In his interview with Crystal Talk (2009), van Berkel express how UN Studio benefits from several design models and diagrams to develop design idea. Figure 2.12 shows the Mobius strip, most re-used diagram by UN Studio several times to interpret in different ways and generate design ideas (van Berkel and Bos 2006). Additionally, Figure 2.13 and Figure 2.14 demonstrate the early the conceptual models of Mercedes- Benz Museum designed by UN Studio. Conceptual models were built to develop design idea based on continuous spatial relationship between the floors of the exhibition area, which is also inspired by fluid circulation of the Mobius strip. The first two conceptual models in Figure 2.13 and Figure 2.14 produced to construct diagrammatic relationship that functions.

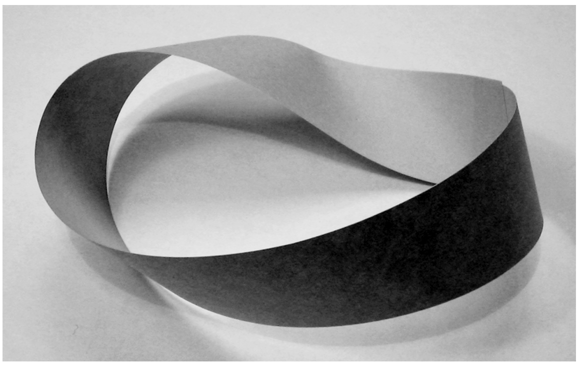


Figure 2.12 : Möbius strip. Mathematically infinite surface with only one side. One of the inspirational models of UN Studio. Remarked in the interview with Ben van Berkel (URL-6).

Figure 2.13 : Conceptual model: Ink on a ceramic plate retrieved from MOMA Architectural Design Collection (URL-7).

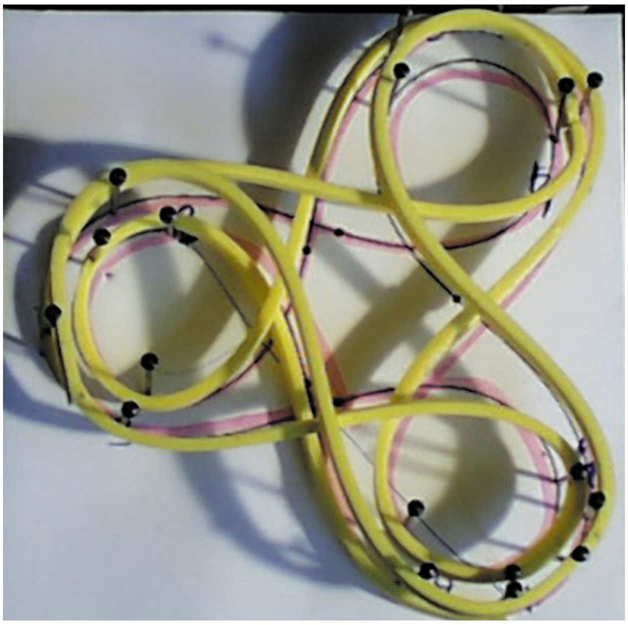


Figure 2.14 : Conceptual model made by plastic pipes. Showing spatial relationship between inside the building (URL-8).

2.4.2 Conceptual draft models as a mode of sketching

In addition to its diagrammatic function conceptual draft models serve as a three-dimensional sketches. Conceptual draft models have the main characteristics of the early design sketches that advance design process. Firstly, just as the free hand sketches conceptual draft models are ambiguous representations. They can be interpreted in various way each time and denote something different depending on the context. The uncertainty is one of the important natures of conceptual draft models that drive the creativity. Figure 2.15 show the early conceptual draft model that developed by Pyo Arquitectos. The folded surface over the plan drawings comprehendible in various ways. It conveys deeper implications for its maker than its observer.

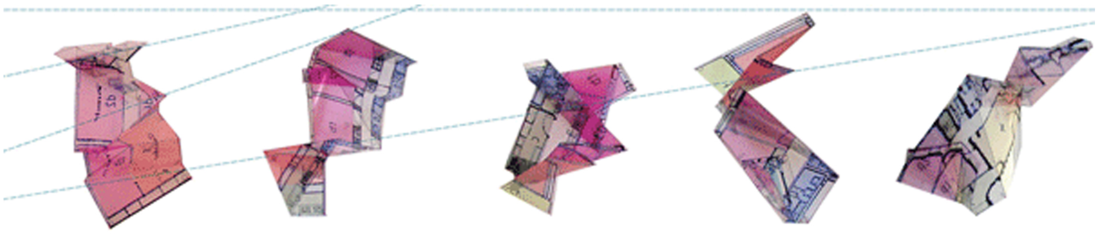


Figure 2.15 : Conceptual draft model by Pyo Arquitectos (URL-9).

Another common characteristic of conceptual draft models with sketches is that they employ a reflective conversation between the design and designer. Designer can build series of conceptual models very quickly with easily accessible materials in order to develop his/her design or explore different design solutions. Figure 2.16 shows the conceptual draft models that produced in the early design phase of Mercedes-Benz Museum project by O.M.A. It can bee seen that how design idea evolve using sequential paper draft models. Figure 2.17 also demonstrates the different design scenarios that are produced using quick made draft models for urban design project developed by Pyo Arquitectos.

Figure 2.16 : Quickly produced paper models that show the development of initial design idea (URL-7).

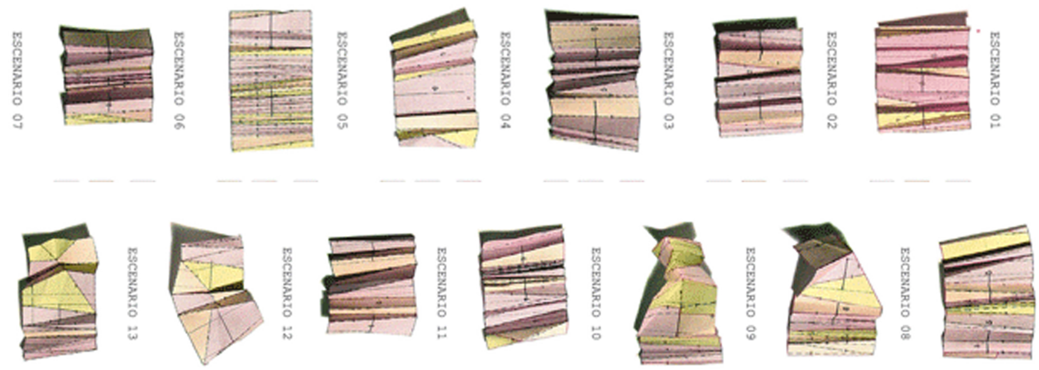


Figure 2.17 : Quickly made paper modes that produced to explore different design scenarios (URL-9).

The last common aspect is that deem to important is they both lead up to creative leaps. During the model making process, lateral transformation also occurs beside the vertical transformations. Lateral transformations refer to movement where the idea shifted towards a different one and vertical transformations indicates more detailed version of the same idea (Goel, 1996). According to Cross (2001, p.vii), “the ‘creative leap’, in which a novel concept emerges – perhaps quite suddenly – as a potential design solution, is widely regarded as a characteristic feature of creative design”. Both reflective and ambiguous characters of conceptual draft model promote the creativity and lateral transformations.

2.5 Making and Thinking

Chadarevian and Hopwood (2004) liken science without models to art without sculpture. They remark the importance of three-dimensional expression and mode of thinking in science. Similar analogy is also valid for architecture. As a matter of fact, there is more strong connection between making and thinking in architecture since hands on actions such as sketching, drawing and modeling have greater influence on the design process. Architecture is a practice that is directly related to the physical world. Therefore, for architects it is important to comprehend size, dimension, and geometry of the things, material properties and forces that are applied on materials. According to Otto (1979) despite the fact that form can be defined objectively by modern measurement techniques, form is a subjective matter understood differently by each individual. Zumthor (2006) also makes a strong connection between the subjective sense of material and architecture.

> The sense that I try to instill into materials is beyond all rules of composition, and their tangibility, smell and acoustic qualities are merely elements of language that we are obliged to use. Sense emerges when I succeed in bringing out the specific meanings of certain materials in my buildings, meanings that can only be perceived in just this way in this one building (1988, p.11).

Architects are not sculptors, but still they are builders who shape not only function but also form. “Builders’ thinking deals primarily with how to make; it mediates concept of form, method of science and practical way of dealing with materials” (Meinel, 2004, p.266). Hence, architects need actual connection with form and material. Since they do not directly work in real scale, different experiments in various scale is only source to make this connection.

This approach is not only circumscribed by architecture. Fröbel’s gifts set an example to understand how the actual relationship with the object is important to making knowledge. Fröbel drew his inspiration from the pedagogy of Johann Pestalozzi, who advocated hands-on active education. He initiated the *Kindergarten* movement with his invention Fröbel’s gifts (Meinl, 2004). Fröbel’s gifts basically an educational tool that consists of twenty specific object that help children to gain concept of space. The kits he created were influenced by his studies in architecture and also his work in the field of crystallography. Fröbel’s psychology of education is based on the belief that young children obtain the knowledge about external world by actively handling and manipulating it elements through experiments (Meinel, 2004). Including Buckminster Fuller and Frank Lloyd Wright several artist and designer have influenced by their experiments with Fröbel’s gifts. Buckminster Fuller recalled how Fröbel’s ‘Peas Work’ helped him to explore structures and construction principles, which will later lead him for the invention of Geodesic dome, by manipulating toothpicks and semi-dried peas with tactile senses otherwise he was not able to perceive structural lines because of his bed eyesight (*Buckminster Fuller: Thinking Out Loud*, 1996). Figure 2.18 shows the ‘Peas Work’ from Fröbel gifts that developed to build three-dimensional structures.

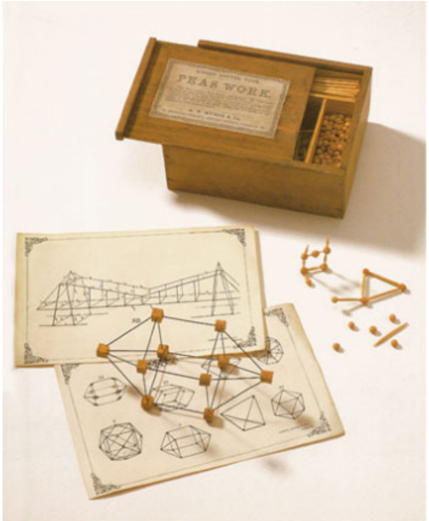


Figure 2.18 : ‘Peas Work’ from Fröbel gifts. Photos by Norman Brosterman (URL-10).

To sum up, as it has been indicated in previous chapters it is an undeniable fact that different field of science, art, history and even pedagogy have a considerable influence on each other. It is possible to make connections between the different use of models and its interpretation. The ambiguities inherent in models is one the strongest aspects of it. As Meinel assert, “Models mediate between the mind and the hand” and can be used to “conquer new spaces of possibility” (2004, p.270).

2.6 Intertwining Physical With Digital

In previous chapters, the significance of physical model making has been remarked from different aspects. In addition, the transition from the physical modeling to digital modeling in scientific practice and oscillation between both processes is noted by instances. On the other hand, translation from physical to digital model making has not been remarked within the context of conceptual model making in architecture, yet. Despite the wide range possibilities that computer enables, the role of the computer in the early phase of design process still being discussed since the computer aided design (CAD) is been introduced to architecture. Major point of discussion is that computer aided tools are weak to reflect the intuitive aspects of design process. Aldus Barnes (2007), structural engineer and member of Advanced Geometry Unit at Arup, has explains the importance of sketching in his work, especially when collaborating with architects. For Barners, "The computer is an enabler, but it is never the conceptual model…Sketches are the means of developing the conceptual model or diagram."[2] Similarly, Hechinger and Knoll (1992) claim that not either computer or sketchpad can be a substitute of the functions of conceptual modeling including, "actual material experience, the physical shape and spatial relationship”. Hence, as indicated previously many designers are still work with conceptual models and sketches when conceptualizing their ideas. Despite the general assumption that conceptual phase of the design process can not exactly perform digitally due to intuitive features, there are considerable studies that attempts to represent conceptual model making in digital environment.

Scali et al. (2002) remarks the need of a digital design tool for early phase of design process concerning the deficiencies of CAD software to reflect cognitive demands of the designer. In order to specify the appropriate digital platform, they explore the haptic and gestural aspects of physical model making through analyses of current design practice. Through their analyses they classify cognitive needs of designer, requirements of digital tool considering features of physical conceptual tools, requirements of industry and superimpose this requirements with the potential technical specification within the limit of technology. Their hypothesis is that integration of haptic devices such as data gloves, interactive screens, etc. with CAD system could be a solution for three-dimensional form conceptualization in digital. However the research does not present a method how and which degree haptic technology could implement to current digital tools in order to provide suitable design support for conceptual modeling.

Zaman et al. (2011) propose a more defined framework for adaptation of haptic features of model making to digital realm. Their aim is to translate haptic possibilities of model making process into digital media. In accordance with this purpose, they created “an abstract repertoire” by capturing hand movements during conceptual model making process. They observed through two different architects model making process via audio-video recording. Following the observations, they classified actions hand motions according to their main characteristics in order to use for recognition of actions in digital platform. The study shows that hand movements revealed during the model making process such as bending, tearing, folding, etc. are noticeably relevant to material properties and scale. According the observations and

[2]Aldus Barnes, interview by Yanni Alexander Loukissas 2007. Quoted in: “Co-Designers: Cultures of Computer Simulation in Architecture”. p.49.

classifications, the study is promising for the translation of the haptic features of model making into the digital realm via an algorithm that will recognize hand movements. However, it is limited with the certain hand movements and their interpretations.

The experiments in chapter 4, which are performed for this study does not only explore the physical process but also analyze the digital tools before promoting a proposal. The intuitive aspects of model-making process explores by author herself rather than being an observer. Additionally, the study not only investigates the haptic dimension of the model making but also concern for the translation of dynamic and intuitive features of model-making process in the early phase of the design process.

3. METHODOLOGY

The experimental part of the study was carried out in two phases. In the first phase, a pilot study was conducted with three participants in order to explore different aspects of conceptual model-making process that designers utilizes for developing their design ideas. The pilot study consists of design protocols that are conducted with three designers and their observations. Protocol studies use for the analysis of cognitive process in design as a physiological research method to gather data by verbal reports (Gursoy and Ozkar 2010). Within the scope of the pilot study design protocols are realized for the exploration of conceptual model-making process. Designers are asked to verbalize their thoughts during the protocols to capture their notions and intents. In the first section of this chapter, the design protocols will be presented including its background, advantages and limitations.

In the second phase of the experimental inquiry, author analyzed her own design process. The exploration method is known as 'practice-led' design research or 'research through designing', which is fundamentally, involves capturing and analyzing researcher own design activity to achieve the stated research aims and objectives (Pedgley, 2007; Mäkelä, 2011). In order to identify the key features that are required to transfer into digital media, both digital and physical model-making processes are explored through various experiments by the author. In the second section of this chapter, the method of the main research will be presented whereas both digital and physical experiments will be reported and discussed in chapter 4.

The pilot study and the physical process of author's own design experiments are explored via instant and quick handmade models, namely, conceptual draft models that are presented in section 2.4. The pilot study presents an empirical research about the different aspects of conceptual model making through conceptual draft models. In conjunction with, the main research explores the intuitive processes of conceptual model-making and their translation into digital realm.

3.1 The Pilot Study

Three protocols are performed by three interior designers, who study double major in the architecture as a pilot study. A short interview is made with participants in order to figure out their interest for the subject. These participants are chosen because they regularly use physical models as an effective design tool in their own projects. Each participant reported that they benefit from the different aspects of model-making. Participant 1 generally uses models to explore different materials and their compositions. Participant 2utilizes models in order to comprehend the design situation. According to Participant 2,working in three-dimensions eases the design process. Participant 3 assumes that model making helps her thinking process. Participant 3 also argued that comparing with two-dimensional representations such as sketching; model making is a more efficient tool for building spatial relationship and solving complex problems. All participants reported that they prefer physical models to free-hand sketches and digital modeling, especially in the early phase of the design.

Participants were given the same design task to develop conceptual design ideas. They are asked to design an exhibition unit for the entrance of the faculty of the architecture. The initial abstraction of the entrance, which was made by the Participant 1 is held as a constant base model and used by the other two participants. In order to observe changes between models each participant is asked to continue with different model when it is necessary to leap another idea or promote the same idea. Participant 2 and Participant 3 developed two different models while Participant 1 promoted three different models. Protocols were not time-limited specifically yet participants were asked to conceptualize their design ideas via conceptual draft models in maximum 30 minutes. The duration of protocols varies between 15 and 20 minutes.

Same materials are provided to all participants such as cardboard, colored papers, transparent papers, mesh materials, needles, glue, and rulers. Only planar materials are provided to participants to construct their models. The experiments are held in studio environment, where participants take their regular design courses. Experiments are recorded by a video camera and participants are asked to verbalize their thoughts while designing.

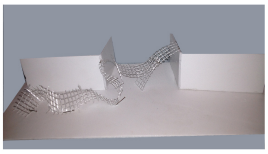
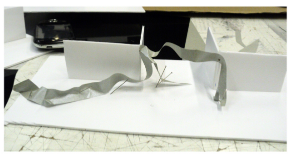
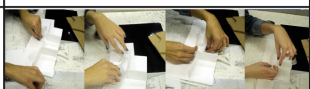
It should be noted that there are many limitations of the protocol analysis that inhibits to make a general inference for the conceptual model-making process. Firstly, experiments were conducted with limited number of participant within a limited period of time. In addition participants were restricted with certain environment and materials. If the experiment were performed by using different materials in a different environment, the result could be different. Lastly, protocol studies criticize for being unnatural due to the fact that participants are forced to design and verbalize their thoughts while they are filming (Gürsoy and Ozkar, 2010). It is observed that during the protocols occasionally participants were hesitated to explain each thought and action. Accordingly, being aware of its limitations the pilot study presents these protocol studies as an example of how designer benefits from conceptual draft models as an earl design tool for developing their design ideas.

3.1.1 The protocol studies

Each of three participants are developed a design idea for the same design task through conceptual draft models that are produced with similar materials. In total 8 models are built in protocols. Each participant developed the same idea in protocols through different models. Participants will be named respectively as D1, D2 and D3throughout the report of the protocols.

D1 produced three different models for the given task. Table 3.1 shows the design protocol of D1, which includes process, actions, duration and final design models that are produced during the protocols.

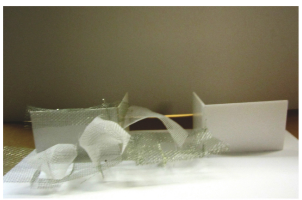
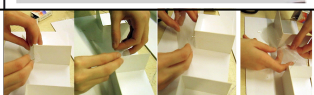
Table 3.1 : Design protocol of D1

	Design Protocols		
Designer	Model 1	Model 2	Model 3
D1			
Sections of process			
Duration	7 min	5 min.	3 min.
Actions	Bending - Twisting - Cutting Rotating - Pining - Pasting	Bending - Cutting - Rotating Pining	Bending - Folding - Cutting Rotating - Pining

D1 used three different materials in each model. They represent the same design idea with similar functions but in different forms. All models represent a continuous exhibition unit that starts with a high arc shaped entrance and slightly descends and turns into expo area. In the second and third models the surface of expo also partly transforms into sitting units in the lowest parts. Similar modeling techniques are used in all models. D1 preferred to work with straps and shaped them instinctively during the model-making process. In order to form straps besides cutting, rotating or pining; bending, twisting and folding actions are constantly applied to the material.

D2 produced two different models that represent similar design ideas in different level of detail. D2 express her first intention as "…this could be something attracts people from the entrance and take to exhibition area…When they enter people can walk under it at first." Accordingly D2 build a model of exhibition unit, which encounters visitors with high entrance and then transforms into an expo surface inside. In the second protocol D2 developed the first design idea. Initial design ideas are translated into second model in different forms. Using more structural mesh material, D2 created a semi self-structured entrance unit and three exhibition units that are identical to each other. Similar to first model's entrance the units provide exhibition experience by walking under and around them. Top of the last two units are also covered with bubble shaped mesh surfaces. Table 3.2 shows the design protocol of D2.

Table 3.2 : Design protocols of D2

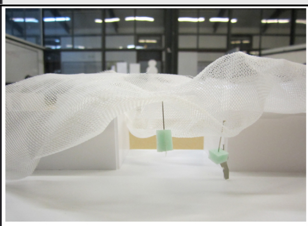
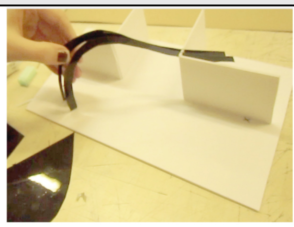
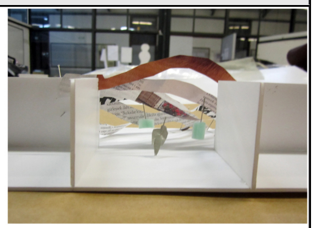
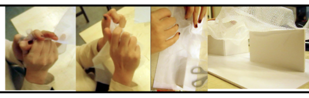
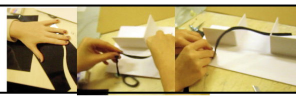
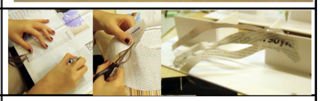
	Design Protocols		
D2			
Sections from the process			
Duration	5 min.	13 min.	
Actions	Bending - Twisting - Cutting Rotating - Pining - Pasting	Bending - Twisting- Folding Cutting -Rotating - Pining -Pasting	

D2 used different type of mesh material in two models. Comparing the second model, the first model was made with more elastic and soft mesh surface. D2 claimed that using more rigid mesh surface led her to design more structural units.

Similar to D1 beside cutting, rotating or pining; bending and twisting were main actions that are applied to mesh surfaces during the model-making process.

In the last protocol, D3 produced three different models including one unfinished model. While starting to build models D3 expressed her thoughts loudly as “ … I have something in my mind like a cloud. I imagine a big cloud that everything hang down from it and exhibit. Now, I will explore how I can built it with different materials.” Accordingly, D3 built the first model with the softest mesh to express the “cloud” idea. In the following models the idea was tested with different material to explore how it can be implemented to floor. D3 claimed, “I am not sure how the result will be. I will explore by doing.” In the following two models D3 cut non-uniform straps to construct a different version of the cloud. The second model was not finished due to the fact that the opaque acetate did not provide desired flexibility. In the third model D3 achieved more desired result using magazine paper and modeled the cloud idea with different understanding. Table 3.3 shows the design protocol of D3.

Table 3.3 : Design protocol of D3

	Design Protocols		
Designer	Model 1	Model 2	Model 3
D3			
Sections of process			
Duration	5 min	4 min.	10 min.
Actions	Cutting - Rotating- Squeezing Pining	Cutting - Rotating- Twisting Pining	Drawing - Cutting - Rotating- Twisting - Pining

In the third protocol actions that are applied during the model-making process were similar to D1 and D2 except for squeezing and drawing. D3 also replaced simple human-scale figures to each model to perceive the scale.

3.1.2 Observations an discussions of the pilot study

In the protocols, all participants are conceptualized their ideas via quickly produced early conceptual models, namely conceptual draft models that are presented in

Chapter 2. During the protocols the designers used conceptual draft models as a mode of thinking, design tool to construct, and develop their initial ideas. In the beginning, their design ideas were more ambiguous. After a while, they started to express their thoughts more clearly.

The protocols show that all the participants are benefited from the different aspect of the model making process. D1 produced three different models to explore different compositions and design alternatives for the same design idea. D2 produced two different models and detailed the initial design idea through them. D3 used models for expressing her design idea with different methods and material to explore how the design differentiates accordingly. D2 and D3 spent approximately twofold more time to built their second model than initial one. D1 spent less time for the following two models than the initial one. Table 3.4 shows the different aspects of model making that participants are utilized during the protocols.

Table 3.4 : The different aspects of model-making participants are utilized during the protocols.

Intended Purpose of Model-Making	D1	D2	D3
To embody the design idea	●	●	●
To develop the design idea	●	●	●
To communicate	●	●	●
To explore design alternatives	●		
To elaborate the design idea		●	
To explore different materials			●
To explore structural problems		●	●
To perceive the space and scale			●

Furthermore the pilot study shows that there is a dynamic relationship between models, which constantly evolves. For example the arc shaped form in the left side of three models represent an entrance for the visitors of exhibition. It can be observed that the form of entrance differentiates in each model while its function remains stable (Figure 3.1). This dynamic relationship between models also resembles the sketching process.

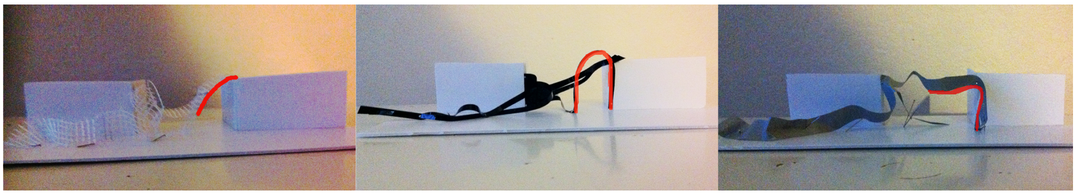


Figure 3.1 : Dynamic relationship between models. The red lines indicate the differentiation of the form of the entrance.

Conceptual draft models are abstract representations, which reduce the complexity of the problem. They do not imply one clear meaning. They are ambiguous and open to diverse interpretations. Being ambiguous is one of the strongest parts of conceptual draft models that led to creative process. Another strongest aspect of conceptual draft model is that they represent diverse ideas with simple forms and material. They generally convey multiple meaning with a simple representation just like diagrammatic representations. Therefore, they are open to different possibilities, which enrich the design process. Consequently, based on the observation of pilot study and previous researches, it can be claimed that in the early phase of the design conceptual draft models operates as an effective design tool, which assists designer.

3.2 Practice-Led Design Research

Cross addresses the problem that there should be a clear distinction between the method of science and design practice. He claims that in order to develop independent discipline of design rather than subcategorizing design under the example of science or art, the nature of the design activity, design behavior and design cognition must be well articulated (2001). Basically he suggests that intrinsic values of design to be as valid study subject. “These intrinsic values, I suggested, must derive from the deep, underlying patterns of how designers think and act, or the ‘designerly ways of knowing’ ” (Cross, 2001, p.v).

> Essentially, we can say that designerly ways of knowing rest on the manipulation of non-verbal codes in the material culture; these codes translate ‘messages’ either way between concrete objects and abstract requirements; they facilitate the constructive, solution-focused thinking of the designer, in the same way that other (e.g. verbal and numerical) codes facilitate analytic, problem-focused thinking; they are probably the most effective means of tackling the characteristically ill-defined problems of planning, d designing and inventing new things (Cross, 2001, p.vi).

This study investigates one of the intrinsic values of design through model-making process. In design practice process is in most cases important than the result. On the grounds that, in the practice of design the results do not need to be repeated or copied whereas the results must be approved in the science practice (Cross, 2001). Regarding these, author explored her own design practice and documented it. The exploration method is known as ‘practice-led’ design research or ‘research through designing’, which is fundamentally, involves capturing and analyzing researcher own design activity to achieve the stated research aims and objectives (Pedgley, 2007). Commonly, it is preferred in the design and art based studies where the new research culture is being developed (Pedgley, 2007). Mäkelä and Nimkulrat (2011) assert that exploration of knowledge through the documentation, interpretation and contextualization of process of making artifacts has brought a new dimension to design research. The main motivation of the practice-led research is acquiring new knowledge about the nature of the practice and search for the solution for improving it.

Generally in practice-led researches data collection were used to make by written design diaries but it is possible to collect data through sketches and video-recording (Pedgley, 2007). In this study, data collection was made by video-recordings and drawings. In order to capture intentions and intuitive action during the video recording the designer also explained her thoughts verbally. In addition the design process were reported in written. Since the method is based on a self-analyzing process the transparency of the documentation is significant. Mäkelä and Nimkulrat (2011) assert that the documentation itself can be considered as a research tool that “practioner-researcher” reflects clearly her/his own design process while analyzing it and “construct new design knowledge”.

4. EXPLORING THE TRANSLATION PROCESS

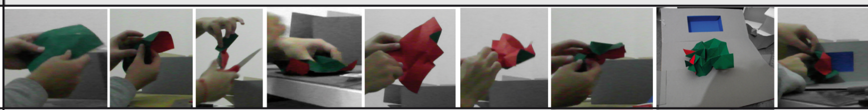
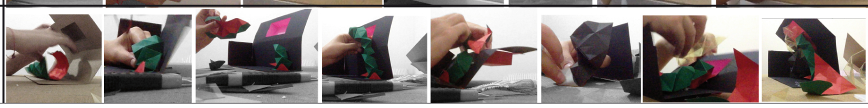
The translation process of intuitive aspects of conceptual models into digital is explored via both physical and digital experiments, which were carried through the author's own design practice. The research method is known as practice-led research or research through designing and was explained in the previous chapter. In this chapter, experiments will be analyzed and discussed. Physical processes are investigated as dynamic representations where the modeled object is constantly evolving via conceptual draft models that are presented in the previous chapters. In the experiments, four different physical models are produced for one design task. Consequently, each conceptual model-making process is tried to regenerate in a digital environment in order to analyze potential advantages and deficiencies of current digital tools for representing conceptual ideas. As a digital medium Rhinoceros is selected since it allows complex operations over the form. The author who conducts both the research and practice processes of the study, will be referred to as the designer throughout the report of the experimental inquiry.

4.1 Physical Experiments

The first phase of exploration was carried out through physical experiments. For a better understanding of the model making process, various physical conceptual draft models have been produced by the designer. Similar to the pilot study, they all were instant quick models that represent an initial design idea and made of easily accessible materials such as cupboards, papers, and needles, etc. prescribed for the study. The model-making processes were recorded in video and audio by a camera. For the documentation, the designer also explained her thoughts verbally while working. Similar to protocol studies the method is known as think-aloud, which helps to understand the underlying reasons behind the design idea and designers' thought process.

As a design task, a lightening installation for a gallery entrance was chosen. The designer produced four conceptual draft models for the given task. The duration of experiments varies between 12 and 40 minutes. Physical experiments are respectively named as pE1, pE2, pE3 and pE4 regarding the construction sequence. Table 4.1 demonstrates the duration of each experiment including particular sections from the design process.

Table 4.1 : Design process and duration of physical experiments.

Experiments	Process	Duration
pE1		12 min
pE2		30 min
pE3		20 min
pE4		40 min

The very first abstraction is started as the designer started to model the gallery entrance. The designer eliminated the unnecessary components that will not have an effect on her design and modeled only the components that were deemed important. A part of the ceiling, the empty volume, the floor and the adjacent walls of the gallery entrance were modeled. The designer modeled the installation site using similar materials for each model. Afterwards, four successive conceptual draft models were produced and their processes were recorded.

The study focuses on the model-making process rather than their result. Thus, the modeling approaches and main actions that are used during the model-making processes are considered in the following reports for the evaluation. Modeling approaches are examined under two groups named top-down and bottom-up modeling according to building method of the model. Top-down refers to processes that the design generates from whole to part. Top-down processes evolve with the manipulation of the whole surfaces or objects. Bottom-up refers to the exact opposite processes that the design generates from part to whole. Bottom-up processes establish with the composition of smaller design components. Each process will be explained in the following sections respecting their modeling approaches and main actions.

4.1.1 Physical experiment 1

Main action: Folding. **Modeling approach:** Top-down. **Model material:** Origami paper. **Base model material:** Paper

The first physical experiment is the initial expression of the design idea for the given task. It was made of colored origami paper and proceeded in 12 minutes. The folding in origami inspired the initial idea. The designer was intended to create continuous three-dimensional object from a planar paper. The intention is verbalized in the following passage, as “since the height of the entrance is quite high, I would like to design something hanging down the celling. Maybe not a surface but a volume hangs down continuously”.

After trying a couple of folding techniques to divide surface into triangles that can be foldable in x-y-z axe, the designer created the crease pattern in Figure 4.1. First, the paper was folded over the grid that parallel to one of its diagonal. Later, it was folded over the grid that parallel to its other diagonal over the inverse side of the paper. Finally, the paper was folded over the grid that parallel to edges.

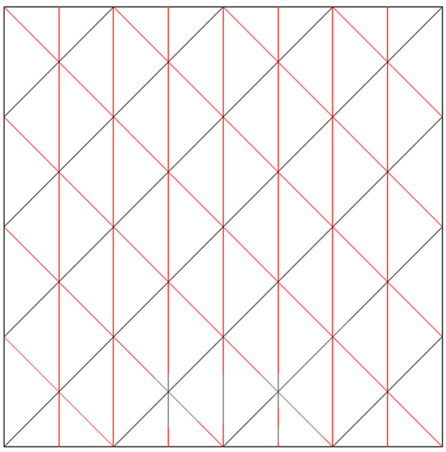


Figure 4.1 : Crease pattern. Red lines indicates the inverse side of paper

The planar surface was foldable in three-dimensions after the operations. The designer applied several forces with hands and finger movements to the surface. Including, reversing, cutting off, rotating, and folding several operations were performed in order to form the surface. The operations that are applied to front and back size of the surface are exposed in Figure 4.2 respectively.

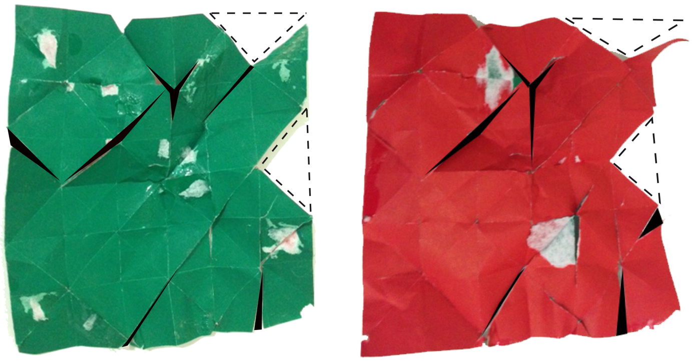


Figure 4.2 : Black lines indicates the slits and dashed lines indicates the subtracted parts

During the process, each action was triggered by a previous action. The surface became more complex in the further stages. Some particular stages of the model-making process are shown in the Figure 4.3**.** In order to decide the next step and position of the designed object in the space; frequently the model is replaced into celling model during the operations. Finally, a continuous three-dimensional pattern that consists of triangle surfaces is formed as the initial idea for the given design task. Figure 4.4 shows the model of pE1, which is transformed from a planar paper into a continuous three-dimensional object.

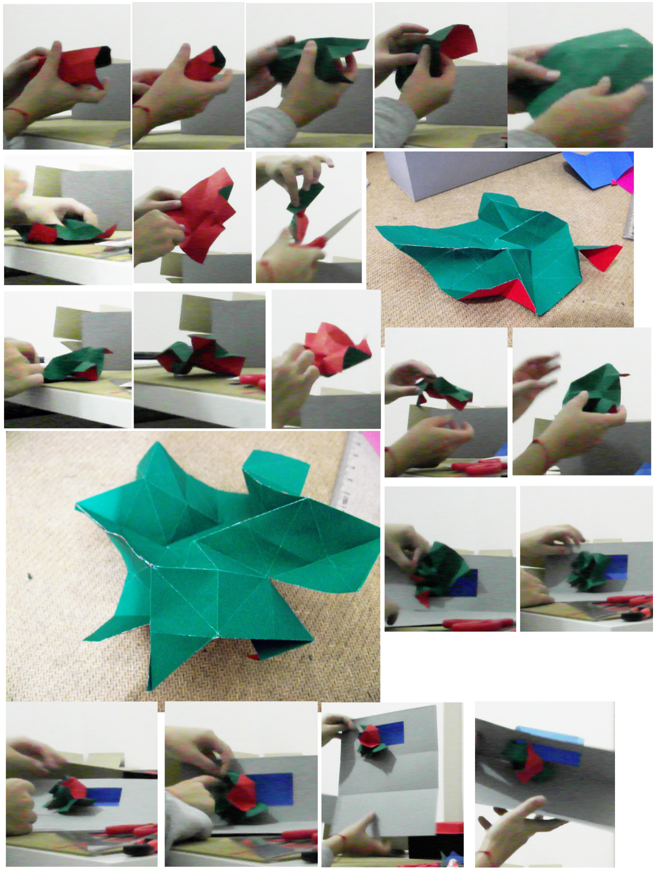


Figure 4.3 : Design phases of pE1

Figure 4.4 : Final model of pE1

4.1.2 Physical experiment 2

Main action: Folding. **Modeling approach:** Bottom up. **Model material:** Cardboard, acetate. **Base model material:** Cardboard

In the second experiment, the designer was intended to create more fragmented and transparent form than the previous experiment. The experiment took 20 minutes in total. The folding capability of the material was tested with more rigid material, cardboard and acetate, instead of origami paper. The designer stated “This time I would like to repeat the same idea with different material and method. I prefer to work with cardboard to create a more rigid form. This model will not be massy as previous one.” Two different crease patterns were generated from 15cmx15cm cardboard and acetate. Different than the previous experiment, designer cut the pattern into smaller parts instead of folding the whole pattern. The working process is explained as in the following passage.

> … I created similar surfaces that consist of folded triangles. I subdivided these surfaces into parts, because this time I would like to explore how this triangles could join each other, how could they become more porous and transparent. I want to control all of these.

The subdivision was provided more control designer over the form. Figure 4.5 shows the parts that are subtracted from the cardboard crease pattern while Figure 4.6 demonstrates the subtracted parts from the acetate. In total, eight different components were produced by folding technique. Even though all the parts were created with the same rule, regarding the number of the triangle segments, crease pattern and their assembly angles none of the components were identical. In addition, each component positioned differently over the celling model. The arrangements of the components were decided over the model by trying different angles and positions. The designer stated that working with components provided more flexibility over the geometry of the designed object.

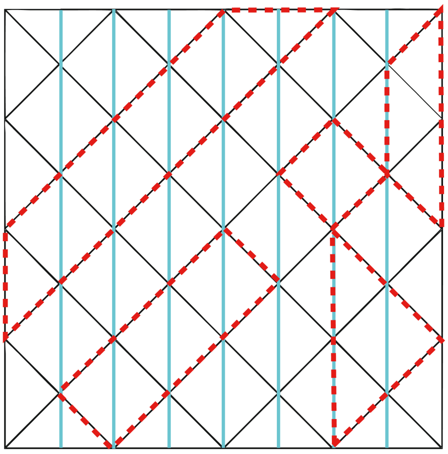


Figure 4.5 : Crease pattern that shows the subtraction of cardboard. Red dashes indicate the subtracted components. Cyan lines indicate the inverse side of paper.

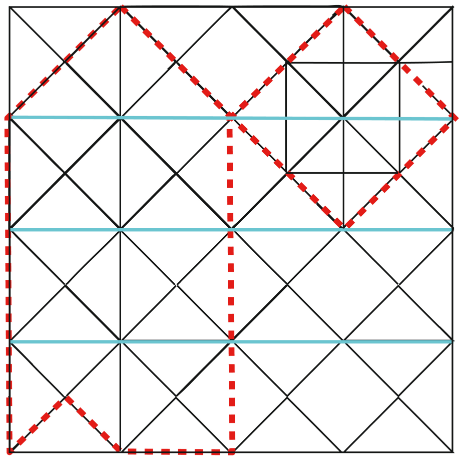


Figure 4.6 : Crease pattern that shows the subtraction of acetate. Red dashes indicate the subtracted components. Cyan lines indicate the inverse side of paper.

During the model-making process the designer manipulated the components both with hand and finger movements. Design phases of model-making process are shown in Figure 4.7. Concerning the technique and material properties of the model such as rigidness and transparency, it can be said that the level of abstraction of pE2 was lower than the pE1. Accordingly, different than pE1, the designer thought up some ideas about later phase of the design process with some specific comments such as "…the mobility of the modules give me the idea that maybe in further steps some of the modules could design as an actual moveable panels." Additionally, different materials that were created different compositions lead designer to different ideas in the following models. Figure 4.8 demonstrates the final model of pE2.

Figure 4.7 : Certain design phases of pE2.

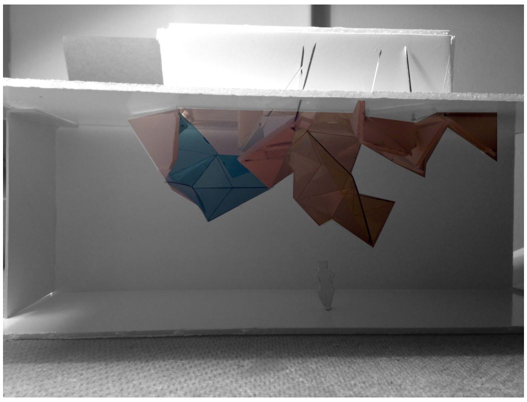


Figure 4.8 : Final model of pE2

4.1.3 Physical experiment 3

Main Action: Bending-Twisting. **Modeling approach:** Top-Down
Model material: Metal mesh, acetate. **Base model material:** Cardboard

In the third experiment, the designer was inspired by the previous two experiments from different aspects. As in pE1 model was constructed from top to down. Triangular components, which were produced in pE2 used in the third experiment, were also used in pE3. The duration of the experiment was 20 minutes. In order to explore different structure rather than triangular surfaces, different materials were used in pE3. The intention of the designer is indicated as in the following passage.

> I want to explore something different in this model. Maybe the structure does not consist of triangular surfaces. The triangular surfaces might be separate units on the floor or ceiling. I want to explore main structure with different material. It can be a continuous surface as in the first experiment.

As it was stated, the designer tried to create a three-dimensional form by applying external forces to the planar surface similar to pE1. The third model was made of mesh metal sheet and colored acetates. The material selection was also affected the physical actions that are applied. The elasticity of the mesh material provided the designer a flexible surface. Thus, different than the previous two experiments main actions in pE3 were bending and twisting actions. During the model-making process the designer bent and twisted the surface on x, y, z axis simultaneously (Figure 4.9). Figure 4.10 presents a sample crease patter for the mesh surface. The surface was shaped as a continuous curled form from celling to floor inside the base model. During the process in addition to bending activity, the designer applied several operations to mesh material including cutting, rotating and reversing (Figure 4.11). Figure 4.12 shows the final model of pE3.

Figure 4.9 : Bending action over the metal mesh surface

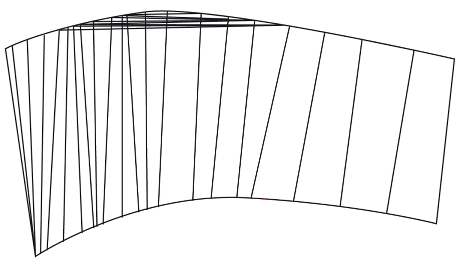


Figure 4.10 : Sample crease pattern for pE3. The black lines indicate degree of bending. The dense parts are more curved parts.

Figure 4.11 : Design phases of pE3

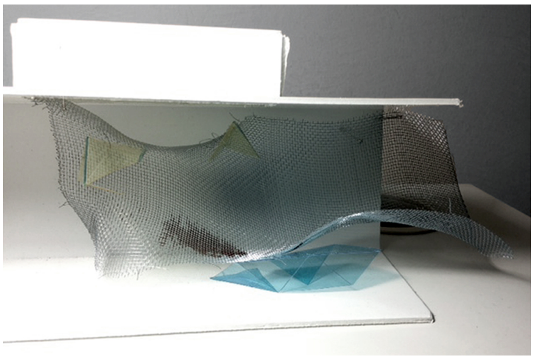


Figure 4.12 : Final model of pE3

4.1.4 Physical experiment 4

Main Action: Folding-Bending. **Modeling approach:** Top-Down, Bottom-Up
Model material: Origami paper, acetate **Base model material:** Cardboard

The fourth experiment is shaped as an interpretation of the previous three experiments and took 40 minutes. Origami papers and acetate were used to express the design idea. The designer explicit that "I have returned the triangular surfaces in the first two experiments because I decided they express what I want better… However I want to design something that extends from ceiling to floor as in the previous experiment". Accordingly, the designer reinterpreted the triangular form that was experienced in pE1 and pE2. Nonetheless, the form was neither integrated to each other as in pE1, nor separated as in pE2. With regards to multifunctional purposes that the designer attributed; the model was constructed between the ceiling and floor continuously similar to pE3. Different than all the experiments, in pE4, bending and folding actions applied to the same surface together. Besides, both5modelling approaches were used. The components were created with the top-down approach and composed in the site model from bottom to up. Firstly, the designer folded the paper over the grid that is parallel to both diagonals of the square. Later on, the inverse side of the paper was folded over the grid parallel to edge (Figure 4.13). The material gained multidirectional folding capacity in virtue of the superimposition of two different grids. Eventually, a natural curvature was emerged by bending paper around itself through the same direction of diagonals. Consequently, a structural three-dimensional form that consists of foldable triangles was formed.

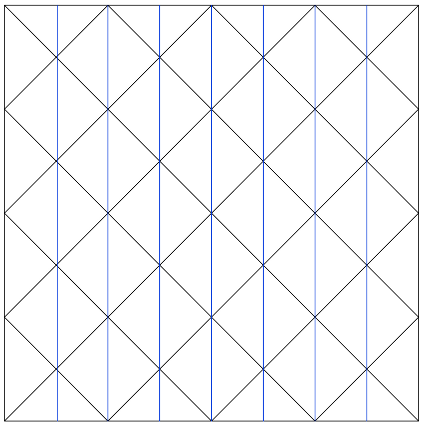


Figure 4.13 : Basic X form, made by dividing the paper horizontally and diagonally. Blue lines indicate the inverse side of folding.

Including a transparent one, which was made with acetate, the designer created four similar components. Afterwards, regarding their relationships and positions, the designer attached the components over the base model by bending them. Each component was bent and positioned in different angle in the site model. Certain stages of the process are shown in Figure 4.14 and final phase is demonstrated in Figure 4.15.

Figure 4.14 : Design phases of pE4

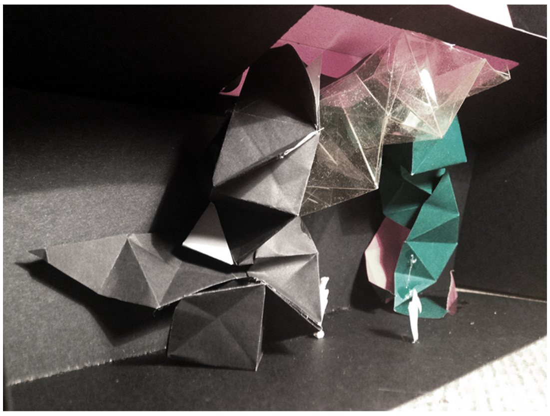


Figure 4.15 : Final model of pE4

4.1.5 Discussions and observations of the physical experiments

The designer produced four physical models successively as reproductions of an evolving design idea for the given task. The experiments were ended when the result was fulfilling for the designer. Accordingly, the duration of experiments varies between 12 and 40 minutes. When looking at separately the models might be observed irrelevant to each other but indeed althea processes were affected by each other in formal, conceptual and diagrammatic sense. In the Table 4.2 common physical, conceptual and diagrammatic features of the experiments can be seen.

Table 4.2 : Physical, conceptual and diagrammatic features of the physical experiments

	PHYSICAL FEATURES				CONCEPTUAL FEATURES					DIAGRAMMATIC FEATURES	
	Material		Form		Function related			Abstract concepts		Pattern	
Experiments	Solid	Transparent	Smooth	Sharp	Lightening	Sitting	Exhibiting	Integrity	Continuity	Fold	Bend
pE1	•			•	•				•	•	
pE2	•	•	•		•			•		•	
pE3		•		•	•	•	•		•		•
pE4	•	•		•	•		•	•		•	•

As it has been stated before there are many factors that drives the conceptual model-making process. In these physical experiments besides the designer's skills and experiments the processes were affected basically from the physical, conceptual and diagrammatic aspects that are given in Table 4.2.

The designer used four different materials in each experiment among the provided materials. In the very beginning, the material selection was based on intrinsic properties of the material such as rigidness, permeability, elasticity and so forth. When the idea began to get develop extrinsic features of the material for instance color, texture and transparency were involved to process also. Each material provided different opportunities to the designer and led to different design ideas. For example, mesh material was easier to shape comparing to paper and cardboard in terms of elasticity. Working with mesh material was promoted different actions such as bending and twisting. Accordingly, the form of designed object in pE3 was more organic when comparing with the other models.

The initial two conceptual draft models were developed with the purpose of lightening installation. However, in the following two experiments the designer attributed different functions to design also. Besides a lightening unit the third model was representing a multi-functional unit that consists of sitting and exhibition surfaces. Similarly the fourth model was an expression of both an exhibition and a lightening design. Conceptual ideas such as continuity and integrity effected both formal and functional characteristic features of the models. For instance the multi-functional model in pE3 was influenced by the continuity of the origami model in pE1. Furthermore, all the previous models with regards to formal, functional, conceptual and diagrammatic characteristics influenced the fourth model. The folding crease pattern in each model changed and developed parallel to designer's interaction degree with the material. Accordingly, more developed crease pattern was generated in the fourth experiments.

The designer applied similar actions during the all experiments. Actions that are constantly applied to materials during the modeling process examined into three groups regarding the dominant action in each process. Folding, bending and twisting actions, which lead the experiments, are grouped as main actions. Actions such as cutting, rotating and pasting that are used in all experiments are considered as general actions. Besides, in each experiment the designer used different modeling approaches. Modeling approaches are examined under two groups named top-down and bottom-up modeling according to building method of the model. Top-down refers to processes that the design generates from whole to part. Top-down processes evolve with the manipulation of the whole surfaces or objects. For example Figure 4.4 shows the model of pE1, which is transformed from a planar paper into a continuous three-dimensional object. Bottom-up refers to the exact opposite processes that the design generates from part to whole. Bottom-up processes evolve with the composition of smaller design components. Figure 4.8 shows the model of pE2, which is created with bottom-up modeling approach. The physical experiments will be analyzed based on their modeling approach and main actions that are used during the model making process. Table 4.3 demonstrates the modeling approaches and main actions that are used in each experiment.

For instance, top-down bending refers to shaping whole modeling surface by bending action while bottom-up bending refers to bending certain part of the surface. Main motivation of modeling approach is the generation processes. During the translation process of physical experiments to digital, the modeling approaches and the actions will be respected.

Table 4.3 : Modeling approaches and main actions of physical experiments.

		Main Actions	pE1	pE2	pE3	pE4
Modeling Approach	Top Down	Folding	●			●
		Bending			●	●
		Twisting			●	
	Bottom Up	Folding		●	●	
		Bending				●
		Twisting				

4.2 Digital Experiments

Digital experiments are consists of re-modeling process of the physical experiments. The physical experiments were tried to regenerate in digital media in order to observe main differences between the digital and physical modeling process. As a digital medium, Rhino was chosen regarding its modeling capability over non-linear forms. In Rhino there are certain ways to create a model based on the intended use. Rhino is able to create models that can include surfaces, polysurfaces and solids. In the digital experiments, the designer worked with NURBS (Non-Uniform Rational B-Splines) curves and surfaces to build digital models. NURBS can be basically defined as a mathematical description of geometric forms, which eases the drawing and modeling process of non-linear complex forms (Piegl and Tiller, 1997).Besides modeling, Rhino serves different operations such as analyzing, rendering and digital fabrication. Accordingly, it has an extensive interface, which includes several command tools. During the digital experiments most optimal commands were tried to use considering the physical processes. Digital experiments are named as dE1, dE2, dE3 and dE4. The experiments are respectively re-modeling attempts of the physical conceptual draft models in the digital. It should be noted that, the designer was not limited with her knowledge about the software and seek for the different solutions to regenerate physical models in the digital. Therefore, the experiments were realized certain amount of time but were not time-limited since they are revised during the research.

Since the main focus of the study is the process of model making, the digital models were tried to regenerate regarding the modeling approaches and actions that were practiced in the physical experiments. Therefore, as stated before conducting the digital experiments physical experiments are divided into groups with regards to main actions of modeling process; folding, bending, twisting, and design approaches; bottom-up, top-down. Therefore, each experiment is evaluated with respect to given properties in Table 4.3.

4.2.1 Digital experiment 1

In the first digital experiment, it is aimed to simulate modeling process of pE1. The designer utilized from the Rhinoceros environment for the process. The modeling process consists of two steps. The first step was folding the whole surface and controlling the folding process. The second step includes replacing the folded surface into base model. The designer tried two different methods to simulate folding action. In the first step the surface was created with mesh parallelograms with respect to crease pattern in pE1. Each parallelogram was created individually and manipulated from its control points to fold the surface (Figure 4.16). The process was not easy to control while working with a whole square surface. Therefore, the surface was divided into two parts. However, due to the fact that the edges of the surfaces and control points are not attached to each other with certain parameters, the boundaries of the surface calculated manually. Besides the manipulation done by mouse click for each control point. Therefore, it was time-consuming process and did not give the desired result. As a result, the method was able to fold the surface but ineffective in simulating the folding action with regards to physical actions in pE1.

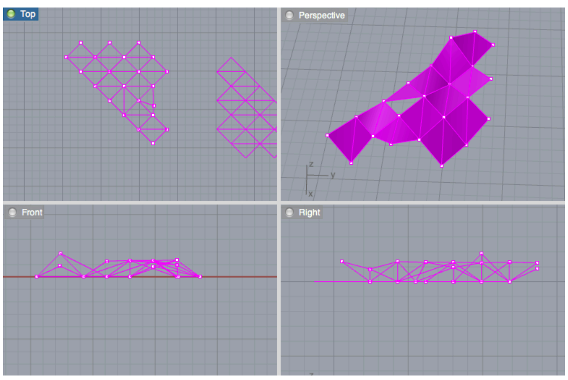


Figure 4.16 : Folding action with control points

In the second method, designer directly benefit from the *foldface* command in Rhino. The command basically rotates selected polysurface face around an axis line. It includes three steps: selecting the face to be fold, defining the folding axis and angle. It is possible to fold a surface with the given direction and angle using this command (Figure 4.17). However, after each folding action, the folded surface is defined as a new surface mathematically by the program. Accordingly, the surface loses its whole and the program does not allow the folding of the initial whole surface again on a different axis. Therefore, the folding action in the physical was simulated digitally at a certain degree.

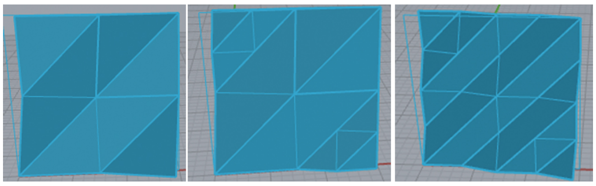


Figure 4.17 : Folding action with *foldface* command

Consequently, folding the surface with top-down modeling approach in digital was challenging in several aspects. Firstly the crease pattern could not created by folding action. Secondly the surface could not be manipulated designedly without dividing into smaller components in both methods. Besides folding, cutting, pasting and rotating actions were used during the process. All the physical actions that were used in pE1 and their digital equivalences are listed in Table 4.4.

Table 4.4 : Digital equivalences of physical actions in Rhino for dE1 and dE2

Physical Actions	Digital Equivalences
Cut	Split/Extract Surface
Paste	Move/Join
Rotate	Rotate
Fold	Control Points/Foldface

Each action has a digital corresponding as indicated in the table. However, the actions in physical do not always correspond directly the same/similar actions in digital. For example, the cutting action in physical model making have more than one representation in digital according to result after the cutting action. Particularly, dividing a surface into pieces requires different command than taking out a part from the surface. Nevertheless basic modeling actions like cutting, pasting or rotating were easier to control when comparing with the folding action in digital.

4.2.2 Digital experiment 2

The purpose of the dE2 is to simulate modeling process of pE2 in the digital environment. Similar to pE1 the main action in pE2 was folding but the modeling approach was completely different. In pE2, the model was constructed from smaller components, which was called as bottom-up modeling approach. Respecting the physical process, first the crease pattern was created with mesh parallelograms. The same parts were subtracted from the whole pattern as in pE2. Then the parts were folded by manipulating control points (Figure 4.18). Since the size of the surface was decreased, the numbers of the triangular surface were fewer and accordingly control of the folding action was easier comparing to dE1. After creating the components they were attached each other and the celling model by moving and rotating actions as in the physical model.

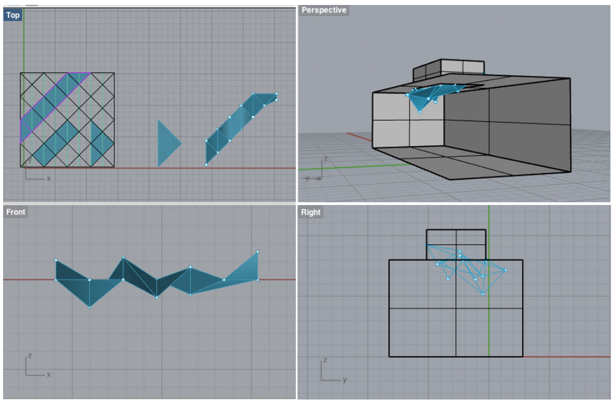


Figure 4.18 : Folding process with control points

As an extension of the conceptual model in pE1, dE2 also includes same actions with dE1 that are shown in Table 4.4. Due to the fact that digital modeling programs are more suitable for working with components, the simulation of the pE2 process in digital was more successful than pE1. However, there were many limitations. For example, even though the digital model enables to work in a three-dimensional space, the action of the designer was still limited within the two dimensional flat screen. The mouse click and scroll was the only connection between designer and the model. The interaction with the modeled object was lower than the physical experiments. Accordingly digital experiments were weak to reflect instant decisions and intentions of the designer comparing with physical experiments.

4.2.3 Digital experiment 3

The third digital experiment is the re-modeling attempt of the conceptual model-making process in pE3. With regards to modeling approach, modeling process of pE1 was similar to pE3. Commonly in both modeling processes, final form is reached through various transformations of a single piece of sheet material. Correspondingly, in the digital process similar curvatures in the physical model were tried to create by applying external forces to the whole surface. The main actions that are applied during the physical process were considered during the digital process also. Different than pE1 and pE2 main actions were bending and twisting in pE3. Accordingly dE3 includes different steps and commands in contrast to dE1 and dE2. The table of action used in the pE3 and their equivalences in digital are given in the Table 4.5.

Table 4.5 : Digital corresponding's of physical actions in Rhino for dE3

Physical Actions	Digital Equivalences
Cut	Split/Extract Surface
Paste	Move/Join
Rotate	Rotate
Bending	Bend
Twisting	Twist

In order to shape for surface as in pE3, the designer tried two different methods in digital. In the first method a rectangular mesh surface was created in Rhino and tried to reshape by manipulating the control points. The control points deforms surface with sharp edges rather than continuous smooth edges. Therefore, the manipulation of control points was not successfully simulated physical bending action (Figure 4.19).

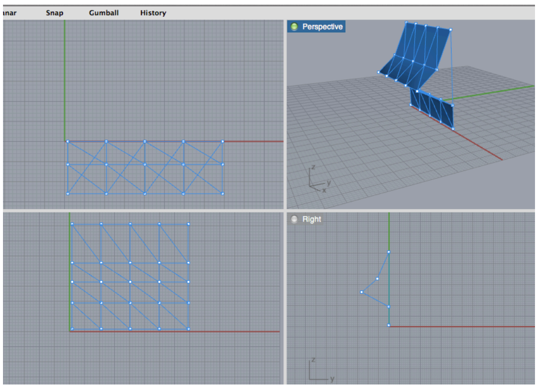


Figure 4.19 : Bending try by manipulating control points

As a second method the bend command in Rhino was applied to the surface. It was provided more similar result to pE3. The command allows bending the surface towards the chosen direction, around the given axis. The bending axis and the its direction is defined by the user. The boundaries geometrically redefine over a circle according to bending degree (Figure 4.20). The command simulates the physical bending under two circumstances. The first one is that bending direction should be given within the surface boundaries. The ortho command, which restricts the marker movement to points at multiples of a specified angle, should be on also. Otherwise, the shape looses its initial size and deforms unrestrictedly. Figure 4.20 is drawn to show the working principle of the command in the given circumstance above.

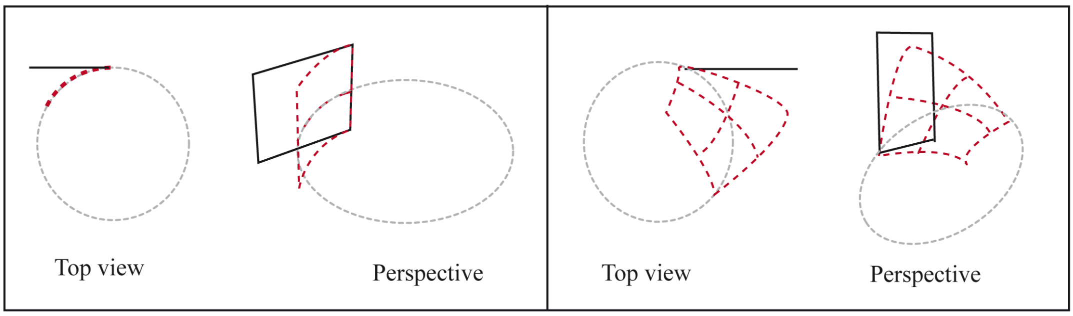


Figure 4.20 : Drawings are created to show bending rule in Rhino. Black line indicates the surface before bend, red dashes indicates the surface after bend and grey dashes shows the boundaries of the circle that bending curve occurs over.

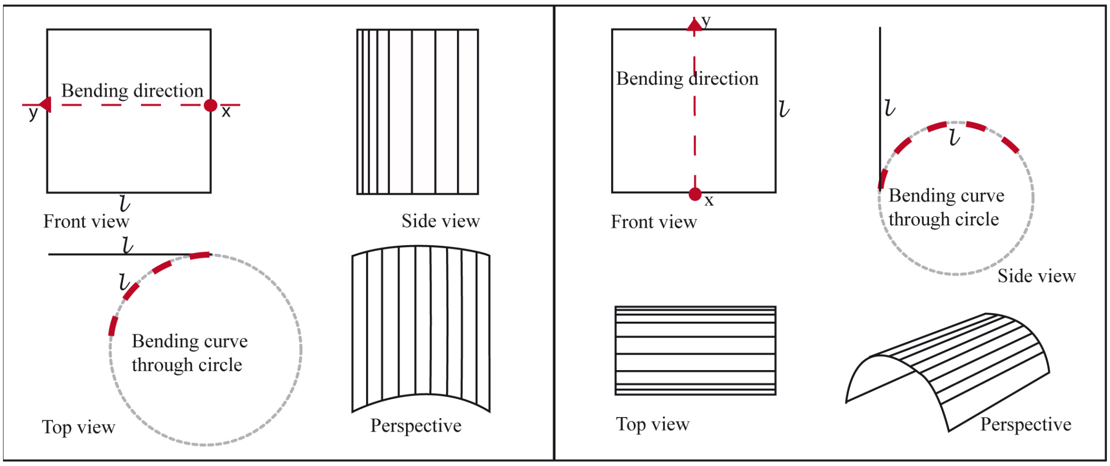


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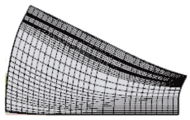
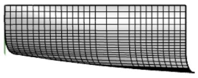
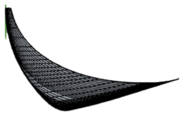
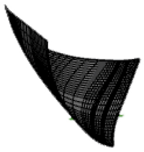
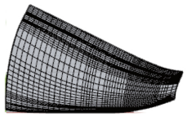
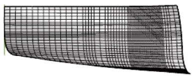
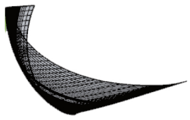
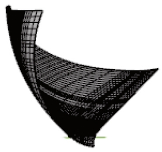
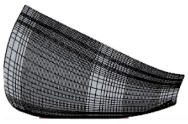
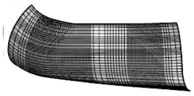
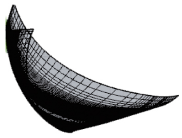
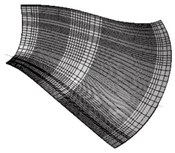
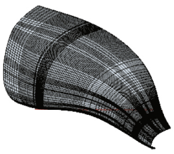
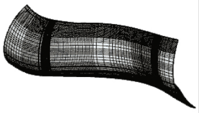
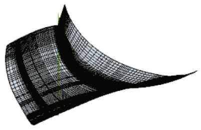
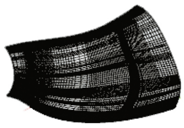
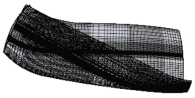
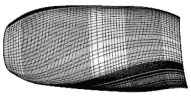
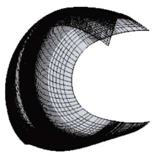
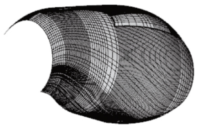
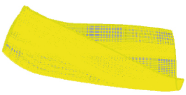
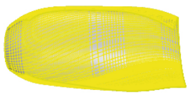
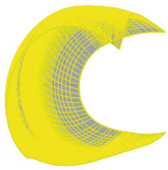
Figure 4.21 : Drawings are created to show bending behavior in Rhino. Respectively it demonstrates bending behavior of the surface in horizontal and vertical directions. Black line indicates the surface before bend, red dashes indicates the surface after bend and grey dashes shows the circle.

Since the bend command is easy to control within the limitation of given descriptions, the model-making process of pE3 regenerated at a particular degree by the designer via bend command. As it is seen from the physical process, the surface was deformed gradually. Similarly Table 4.6 demonstrates the bending process of the surface in Rhino. Even though the bending process was successful within the scope of bend simulation, the command was not able to create continuous curvature with centered two different circles. The bend command was applied until creating the curvatures in the same directions. In order to model curvatures in different directions, twist command was applied to the surface in the next step.

When we look at twist command, this command deforms objects by rotating them around the given axis. The axis and rotation angle are assigned by the user. The rotation axis is defined between two selected points. According to draw order the shape deforms differently. The parts closest the first selected point is fully twisted while the part farthest from it keeps its original orientation (Figure 4.22). Therefore, the command is more flexible to create continuous deformation through different directions. As an extension of bending process, Table 4.7 shows the deformation of the surface respectively after each twist command.

Table 4.6 : Bending process in Rhino

Bending steps	Top View	Front View	Side View	Perspective
1st				
2nd				
3rd				
4th				
5th				
6th				

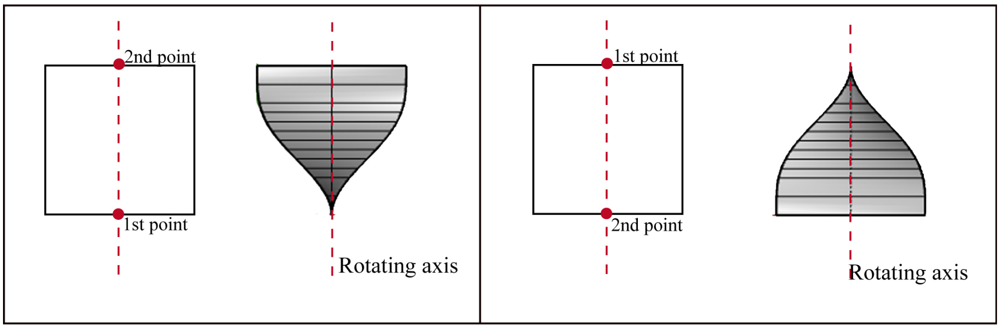
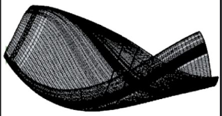
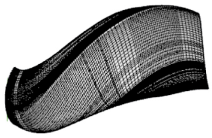
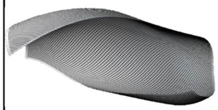
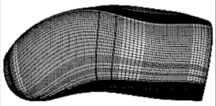
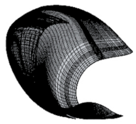
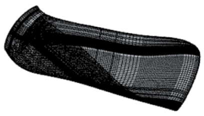
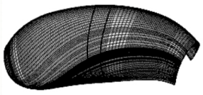
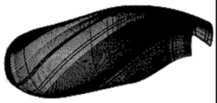
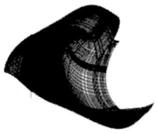
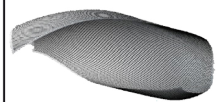
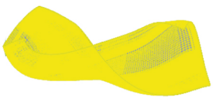
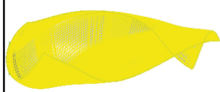
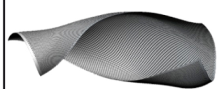


Figure 4.22 : Drawings are created to show bending rule in Rhino.

Table 4.7 : Table showing the twisting process in Rhino.

Twisting steps	Top View	Front View	Side View	Perspective
1st				
2nd				
3rd				
4th				
5th				

Consequently, the result was not the same with but similar to the physical processes. Despite the fact that a very similar result is achieved, the physical process could not be represented exactly due to several reasons. Firstly, even if the rules are well defined, it was still hard to control the bending and twisting direction and angle over the specific part of the surface. Unlike the foldface command, bend and twist commands identify the surface as a whole after each manipulation. It was a positive aspect of the commands in terms of similarity to the physical characteristics. On the other hand the both commands deforms to whole surface at a certain degree even though the bending and rotating axis defines the area that will be affected. Therefore, some specific curvatures could not model. In the physical modeling process, the bending process of the surface was controlled by hand movements more effectively when comparing with the digital process. For example, while bending some part of the mesh with one hand, it is possible to keep another part fixed with the other hand or to bend towards another direction. The physical process gives the opportunity to create curvatures with one simple move in different directions with different angles.

Another aspect of pE3 that dE3 remain incapable of reflecting is interaction process with the modeled object. The coordination between the commands and mouse click was not entirely easy to control. For instance, in the bending process while the bending curve decreases the radius of the circle, which determines the bending degree increases, and after a certain point it does not fit to screen. Even the user zooms out and repeats the process again; it does not provide proper view to the user to observe the changes over the form. That restriction leads user to make another try with more curved axis. At that points like this, user start to be excluded from the process and restricted with the capability of the program. The more the user encounters that type of restrictions during process, the decision-maker role of the him/her shifts to decision-made-r. The control of the twist command was even more problematic since its effect was more dynamic. Therefore, the interaction of the medium with the user is important as much as its capability of applying commands.

Lastly, the digital process was inadequate to reflect the material properties. In Rhino, in the further step of the process due to the deformation, the lengths of the boundaries were distorted. Unlike the physical process the deformation was not convertible to the initial shape. Moreover, in the physical modeling process, bending action was directly related with the material properties of the mesh metal. Since the material was elastic, the deformation over the surface was reversible. If the same experiment had been tried with different material such as modeling clay, the result would not be the same. However, in Rhino material properties were irrelevant to bending and twisting processes.

4.2.4 Digital experiment 4

The last digital experiment includes the modeling process of pE4 in Rhino. As an extension of the previous experiments, pE4 is a combination of pE1 and pE3 in terms of modeling actions, whereas regarding the modeling approach it has the characteristic of both pE1 and pE2. Therefore, the designer faced with the similar difficulties in the previous experiments during dE4. Since pE4 is an interpretation of the previous experiments in terms of modeling approach and actions, the digital process of it includes similar steps and commands with the previous experiments. The table of action used in the pE4 and their digital equivalences are given in the Table 4.8.

Table 4.8 : Digital corresponding's of physical actions in Rhino for dE4

Physical Actions	Digital Equivalences
Cut	Extract Surface
Paste	Move/Join
Rotate	Rotate
Fold	by Control Points
Bending	Bend
Squeezing by fingers	none

In this experiment both, the folding and bending actions were applied to the same surface. As it has been shown in the figures of pE4 the structural form was created from a planar sheet. The superimposition of two folded grids on the same surface created a three-dimensional structural form after bending the surface. However, when modeling in the same process in digital, it was not possible to create crease pattern that can be foldable later with a simple move as in the physical model. Instead the crease pattern was modeled, as it ought to be before bending action. As in dE1 and dE2 the surface was created with mesh parallelograms and folded by manipulating its control points. When modeling this action in digital, the designer considered the relationship between bending and folding actions. After positioned the control points of the parallelograms manually considering how they are positioned in the hand model (Figure 4.23), the designer applied the bend command. In order to ease the manipulation of control points, the designer modeled surface partially and unified them after (Figure 4.24). Figure 4.25 shows the bend command in action.

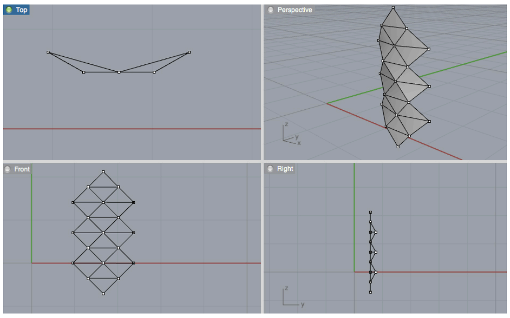


Figure 4.23 : Surface component that formed based on the physical model position before bending action.

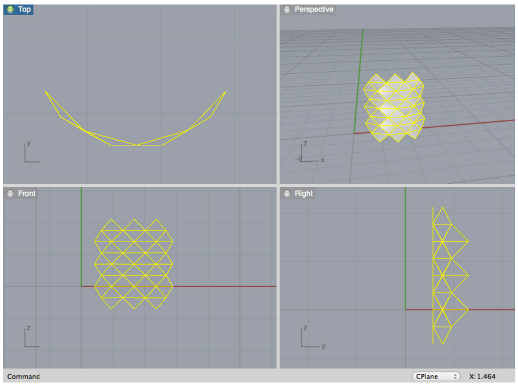


Figure 4.24 : Unified components before bending.

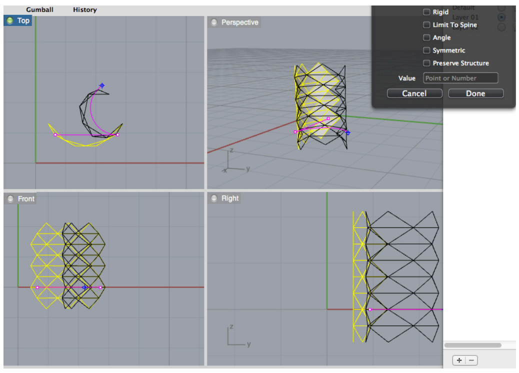


Figure 4.25 : Bend command in action.

Consequently, the basic components that used in the pE4 we remodeled. Although the process was not exactly simulated as in the physical modeling process, the result was the same (Figure 4.26).

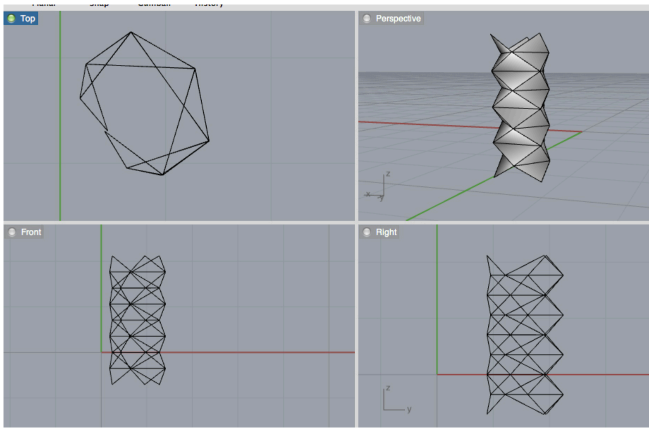


Figure 4.26 : After bending command in Rhino.

However, after creation of the components, manipulations of them as in the hand model, was not successfully performed in Rhino. In pE4, the designer used her hands and fingers effectively to shape the components and attach them in the site model by bending the components in different angles. The final design was shaped simultaneously with the bending capability of the components with instant decisions in pE4. Each component was positioned regarding the previous one. Nonetheless, the dynamism of the physical process was hard to transfer to the digital model. One of the reasons is that Rhino interface does not provide a real three-dimensional experiment with the modeled object since it is limited with the two-dimensional computer screen. Another reason is that the process was highly dynamic but the digital model was very stable. The model created with certain parameters that only provide limited interaction as it has been shown in the figures. It is possible to create more interactive model with the help of an algorithmic-based program such as Grasshopper. However, this research seeks for a simpler and intuitive interface rather than an algorithmic-based software for the conceptual part of the design process. Consequently as in the previous three digital experiments, the physical processes are simulated at a certain degree in dE4.

4.3 Discussion and Observation of the Translation Process

Four different digital experiments were conducted in order to explore difficulties that reveals while translating intuitive and dynamic aspect of conceptual model-making process. As regards the physical experiments were tried to remodel in the digital environment with respect to their modeling approaches and modeling actions. Some of the actions could not model with the same approach as in the physical experiments. For example folding crease patterns of pE1 and pE3 were not created from the whole surface instead it was composed of smaller mesh surfaces. Table 4.9 shows the digital modeling approach and actions with comparison of physical ones.

Table 4.9 : Matching modeling approaches and main actions of physical experiments with digitals'.

		Main Actions	pE1	pE2	pE3	pE4	dE1	dE2	dE3	dE4
Modeling Approach	Top Down	Folding	•			•				
		Bending			•	•			•	•
		Twisting			•				•	
	Bottom Up	Folding		•	•		•	•	•	•
		Bending				•				•
		Twisting								

Almost all the physical actions have one or more digital corresponding that gives same or similar result as it in the physical experiments. The digital equivalences of physical action were given in the Table 4.10. There is more than one equal vent command in digital for each physical action. E.g. subtract, split, extract all refers to basically cutting action in physical.

Despite the fact that very similar results were achieved in the digital experiments, the physical process could not be represented exactly due to several reasons. As conclusion of the experiments, four different challenges are identified. The difficulties that occur during the translation process of physical model making into digital platform will be explained under the following these three topics; modeling approach, shape definition, materiality and tangibility.

Table 4.10 : Matching modeling approaches and main actions of physical experiments with digitals.

	Physical Experiments				Digital Experiments				
Physical Actions	pE1	pE2	pE3	pE4	dE1	dE2	dE3	dE4	Digital Actions
Fold	•	•		•	•	•			Foldface
					•	•		•	Manipulating Control Points
Rotate	•	•	•	•	•	•	•	•	Rotate
Paste	•	•	•	•	•	•	•	•	Move/Join
Cut	•	•	•	•		•	•	•	Extract Surface
					•				Split Face/Surface
Bending			•	•			•	•	Bend
Twisting			•				•		Twist
Squeezing				•					None

4.3.1 Modeling approach

One of the most distinct differences between digital and physical modeling is their modeling approach. Generally in the contemporary design practice digital modeling process begins after the design idea is originated. The digital media serve various tools to the user to model their design ideas that are already developed at a certain degree. Accordingly most computer programs, including Rhino open with an empty screen and notably buttons. However, in the beginning of the design process, the designer seeks for alternative solutions and design ideas for the given problem. The digital interface affects directly the modeling approach of the designer. In this thesis modeling approach are examined as part to whole and whole to part processes, which are respectively bottom-up and top-down approaches. In the physical processes the designer preferred to work with both approach depending on the intention. However the representation of the whole to part process were more challenging during the digital experiments. The digital interface intrinsically impulses to model from part to whole. As it can be seen in Table 4.9 the top-down folding actions in the physical are realized with bottom-up approach in the digital. In addition, as it has been indicated in this thesis both visual and haptic senses enrich the cognitive processes and promote the different ideas. On the contrary, the empty screen of the computer does not give any inspiration to the user unlike the physical existence.

Consequently, the digital environment effects the modeling approach and accordingly the design process. When we look at pE1 and pE2, they both were modeled with the same actions but with the different approach. It can bee seen that how their process are distinctive despite the fact that they are modeled using both folding technique. With regards, instead of using same interfaces with current digital tools, the digital conceptual model requires its own specific environment.

4.3.2 Shape definition

One of the main reasons of the difficulties that were occurred during the translation process was based upon the shape definitions in the digital. The definition of the shape in the computer is based on the geometric or mathematical descriptions. However real definition of the shape in physical world is different than the geometrical description of it. For instance a physical shape is never infinite in the space like the digital representation of it. The accurate definition is crucial in order the represent physical actions and deformation of the shapes in digital platform. Since the working principle of the Rhino is mostly based on the three-dimensional production process, the shapes are needed to define precisely in the program.

Definition is related to the surface properties and accordingly its manipulation. In order to represent the physical actions and their results, the shape definition is significant. For example, in pE1 and pE2 the folding action is simulated with foldface command in Rhino. After each folding action using that command, the folded surface is defined as a new surface mathematically by the program. Accordingly once the surface was folded towards a given direction, the command was not applicable to the same whole surface in the different direction.

Furthermore the definition is also related with the ease of use of the software. To given an example, there is more than one definition to generate a surface in Rhino such as mesh, polygon or planar surface. However, high-level geometrical definitions for the shapes are inconsiderable for the conceptual models when compare to other types of model.

As a consequence conceptual representation requires its own definition rather than a parametric or geometrical definition. The definition comprises the ease of use, the shape deformation and surface properties. Further, reflection of the surface properties such as texture, color, transparency and so forth will be discussed in the following section.

4.3.3 Materiality

Material properties of the digital representations are actually directly related to the shape definitions. Even though most of them are made very basic material such as cardboard, acetate and styrofoam, material properties have an essential role in the conceptual model-making process. In the physical model making process, the modeler also explores the way of creating model, so that every choice has an effect over the process. For example, if the designer had chosen different material such as modeling clay instead of metal mesh in the pE3, the result would be completely different. However digital processes are not affected by the material properties. Material properties generally attribute for the visual presentations after the modeling process is done.

Both the physical experiments and the pilot study show that material properties remarkably affect the design process. For example, in the pilot study D2 asserted that working with more rigid mesh material led her to design a more structural exhibition unit that carries itself. Similarly, the author is benefited from the folding capacity of origami paper in the physical experiments. If the material was more rigid or plastic the folding technique could not be applied. As regards, certain intrinsic properties such as elasticity, hardness and smoothness are required to be represented in the digital modeling process.

Furthermore material properties are not only essential for the exploration of form but also important since it provides different compositions that trigger creativity. Therefore representation of extrinsic properties such as color, texture, transparency and so forth are important as well as intrinsic properties. For example, the colorful acetates that the author used in pE2 was used also in the following three experiments in different form since their effect with light create a desired atmosphere. Similarly in the first protocol D1 created similar forms with using different material in order to explore different compositions.

Consequently, both certain intrinsic and extrinsic properties of the material affect the design process during the physical process. However, the material properties were irrelevant from the process during all the digital experiments. For a decent representation of the intuitive processes certain aspect of the material properties need to be reflected in the digital platforms. These properties are basic features of the material, which are referred as intrinsic and extrinsic properties such as hardness, smoothness, transparency and color.

4.3.4 Tangibility

Tangibility might be the most significant advantage of the physical model-making over the digital model-making and most challenging feature of the intuitive processes that need to be translated. The importance of the actual tangibility in making knowledge was remarked in the chapter 2. Handling material connects designer with actual world and augments the visual perception. Although digital models enable three-dimensional working space, they are literally bounded in two dimensional flat computer screens. Current digital modelling media in use provide only indirect relation with the modelled object via mouse or touchscreen. Accordingly, the reflection of the action is very low in contrast to the physical experiments. Even the simplest actions rotating, changing the position of components recurrently takes notably time.

Furthermore, actual tangibility provides more control to the designer over the form. For instance, in dE3 while the bending the surface to create less curved surface the designer need to draw a wide scale surface for definition. At some points the circle does not fit to screen. Even the user zooms out and repeats the process again; it does not provide proper view to user to observe the changes over the form. That restriction leads user to make a bit more curved surface as intended at the beginning. At that points like this, user start to be excluded from the process and restricted with the capability of the program. The more the user encounters that type of restrictions during process, the decision-maker role of him/her shifts to decision-made-r. The designer uses both hands effectively during the physical modeling process. Therefore, physical models are manipulated easier than the digital models in the experiments.

Consequently, the more designer interacts with the modeled object, the more process gets developed. Therefore, the interface that connects the user and model is important for the conceptual modeling process. In this sense, implementation of more developed interactive systems such as touch screens, tangible smart surfaces, motion and capturing cameras to digital modeling tools is significant to bridge the gap between physical and digital existence.

5. CONCLUSIONS

The digital medium comes with its own technique, culture and way of thinking. Therefore, while working in the digital realm unconsciously or consciously, we operate within its limitations. It is an undeniable fact that there is rapid shift towards to digitalization in every aspect of live. When dealing with concrete problems, digital mediums provide wide range possibilities for the solution. Still, they are insufficient to solve the problems that have more than one solutions, in the words of Rowe (1987) *wicked* problems. Therefore, in the some specific field such as art and architectural physical mediums are still in use especially for conceptualizing design ideas. Most of the architectural design studios continue to work with sketches and physical models. However extensive usage of digital tools are detracted architects from the traditional tools. It is believed that this rapidly increasing tendency towards digital, especially affects the conceptual thinking in the architecture due to the fact that digital tools are still have not adopted to architecture as an efficient design tool that reflects the dynamic and intuitive aspects of the early traditional design tools.

There are considerable studies that search for the cognitive aspect of sketching and their digital representation. However, it has gained acceptance by several studies that conceptual models function as three-dimensional sketches during the process of creation and development of the design idea in the early phase of the design process. It is also approved in many pedagogical and educational studies that interaction with actual object play important role in the knowledge of making. Designers construct a direct relationship between his/her thoughts and the modeled object during the model making process. Therefore, quickly made draft models allow for the instant decision-making and helps to link designer’s thoughts with actions. Concerning the importance of the conceptual models in the design process and rapid shift into digitalization in the field of architecture, this study denotes the dearth of such a digital design tool and seeks for the solution. With this motivation both physical and digital processes are explored in order to address the problems while transferring intuitive aspects of the model-making process into digital. First a pilot study was conducted with three interior designers in order to explore different aspects of conceptual model-making process. Later the author was explored her own design process through physical and digital experiments. The exploration was aimed to address the problems that reveals while translating dynamic and intuitive aspect of model making process. In the physical experiments four different conceptual draft models were produced with cardboard, acetate, origami paper, metal mesh and other supplemental modeling materials. Digital experiments were practiced in NURB-based digital modeling program, Rhino. Exploration and documentation method, which is carried by author herself, is known as Practice-Led in the literature and mostly prefer in the researches where the process itself is more important than the result.

As conclusion of the experiments four different challenges is identified. First challenge is the modeling approach of the digital medium. First challenge is the modeling approach of the digital medium. Physical processes are always started with the existence of material. It is up to designer to decide whether constructing models from bottom up or top down approach. In the physical experiments, the designer preferred to work with both modeling approaches depending on the intention. However, digital medium imposes modeling with components. Instead opening with empty screen conceptual digital model should propose alternative modeling space to user. The interface of the medium needs to be designed in a specific way, which helps to promote different ideas.

Second challenge is related to description of the shape. Since the Rhino is designed for parametric design and digital manufacturing purposes, the shape definitions are made accordingly. The definition of shape is based on the geometric or mathematical descriptions. However real definition of shape in physical world is different than the geometrical description of itself. For example, a physical shape is never infinite in the space unlike the digital representation of it. Conceptual digital model needs its own definition for the shape. The definition should be based on basic properties of shape such as size, material, texture, color, and surrounding environment. The manipulation should be allowed only within the limitation of physical rules. A decent shape definition is crucial in order the represent physical actions and deformation of the shapes in the digital platform.

Third challenge is the representation of material properties in the digital platform. Even though most of them are made very basic material such as cardboard, acetate, and Styrofoam, material properties have an essential role in the conceptual model-making process. For example, if the designer had chosen different material such as modeling clay instead of metal mesh in the pE3, the result would be completely different. However, digital processes are not affected by the material properties. As it is observed from both protocol studies and author's own experiences, intrinsic properties such as elasticity, hardness and smoothness affect the design process while working with models. Besides, according to the material they are produced, conceptual models create different compositions each time and strongly impulse the creativity. Rather than representing the actual properties of the material a digital conceptual model is expected to reflect certain material properties. These properties are basic features of the material that are referred as intrinsic and extrinsic properties such as hardness, smoothness, transparency and color. It should be not that conceptual modeling is an abstraction of reality; therefore it does not have to represent all the aspect of the material.

The last and most challenging aspect of the physical modeling that need to transfer into digital platform is actual tangibility. As stated previous chapter, actual tangibility enriches the model-making project at many points. Handling material connect designer with actual world and augments the visual perception. Beside it provide more control over the form, so the designer act more freely when forming the material. The digital experiments showed that the interaction with the modeled object very low in digital in contrast to physical process. Furthermore existing interfaces are inadequate to build this interactive relationship. In the digital experiments, the only connection between model and the designer were provided by mouse and its coordination between commands not entirely was sustained harmonically all the time. Therefore, implementation of more developed interactive systems such as touch screens, tangible smart surfaces, motion and capturing cameras to digital modeling tools is significant to bridge the gap between physical and digital existence.

In addition to interaction, tangibility is directly related to thinking and learning. The technological developments in the augmented graphical interface, smart objects and similar research that are related ought to be analyzed thoroughly for implementing intuitive processes of physical process into the digital realm. The only way of to solve the problem of tangible interaction is the adaptation of the technology with computer-aided design. For example, the previous examples in the field of human-computer interaction that are given in the chapter 2 are inspirational for the adaptation. Even the adaptation of *globe* with mouse as a new device could solve the same basic problems of the screen control such as rotating and zooming.

To sum up, an integrated approach with technology and design cognition can solve the problematic of intuitive aspects of digital representation with well-defined set of constraints. In future work the experiment also can be made with different participants to specify the constraints for the definition of shape. It is possible to test the interactive interface that is proposed in the context of design approach by a participatory workshop. The technological developments in the augmented graphical interface, smart objects and similar research that are related to the subject ought to be analysed thoroughly for the adaptation of technology to current digital tools within the scope of conceptual model making.

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