THE COGNITIVE ASPECTS OF MODEL-MAKING IN ARCHITECTURAL DESIGN

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ABSTRACT

THE COGNITIVE ASPECTS OF MODEL-MAKING IN ARCHITECTURAL DESIGN

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Considerable research has been done by various scholars to assess the significance of sketching in the early stages of the design process. However, sketching in design studies usually corresponds to drawing and the extensive research on the cognitive aspects of sketching does not always include three-dimensional sketching through physical and digital models produced in the early phases of design process. The aim of the presented research is to identify some characteristics of model-making that make it effective in the design process and design cognition as a form of sketching. Departing from key research on sketching which articulates its uncertain nature as a positive drive in early design phases, this thesis looks at whether physical and digital models can also be counted among ambiguous design tools. The inquiry is supported by empirical data from the protocol studies realized with three graduate students of architecture.

Keywords: Design; Design Protocols; Sketching; Model-Making; Reflective Practices; Cognition; Computer-Aided Design; Linkography; Ambiguity.

ÖZ

MİMARİ TASARIMDA MAKET VE MODEL YAPIMININ BİLİŞSEL YÖNLERİ

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Tasarım sürecinin erken dönemlerinde eskiz yapımının önemini ortaya koymak için, çeşitli bilim adamları tarafından çok sayıda çalışma yürütülmüştür. Ancak, tasarım çalışmalarında, eskiz, genellikle çizimle ilişkilendirilmekte ve eskiz yapımının bilişsel yönlerine ilişkin araştırmalar, tasarımın erken dönemlerinde, maket ve bilgisayar modeli kullanılarak yapılan üç-boyutlu eskizleri kapsamamaktadır. Bu araştırmanın amacı, maket ve model yapımını, bir eskiz yapma yöntemi olarak, tasarım sürecinde ve bilişsel tasarımda etkili kılan yönlerini ortaya koymaktır. Eskiz yapımının muğlak ve belirsiz olma durumunun tasarım sürecinin erken dönemlerindeki önemini vurgulayan eskiz üzerine yapılmış temel araştırmalardan yola çıkarak, bu tez, maket ve modelin de muğlak tasarım araçları arasında sayılıp sayılamayacağına bakmaktadır. Bu sorgulama süreci, mimarlık bölümü yüksek lisans öğrencisi olan üç öğrenciyle yapılmış protokol analizlerinden çıkan ampirik bulgularla desteklenmektedir.

Anahtar Kelimeler: Tasarım; Tasarım Protokolleri; Eskiz Yapımı; Maket ve Model Yapımı; Biliş; Bilgisayar Destekli Tasarım; Linkografi; Muğlaklık.

To My Grandparents

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CHAPTER 1

INTRODUCTION

This thesis is about the place of model-making in architectural design conversation and for the purpose of this context a model can be defined as:

> A representation of reality, where representation is the expression of certain relevant characteristics of the observed reality and where the reality consists of the objects or systems that exist, have existed, or may exist. (Echenique, 1970, p.25)

According to this definition, a model is considered as a representation tool and therefore can be noted important for communicating information within many disciplines. The use of models in design is different than its use in other disciplines. In scientific research, a model is considered useful if it is reproducible under controlled circumstances, independent of the individual researcher but in design, since it deals with the new and non-existing, models can be used as the basis of conceptualizing, communicating, assessing, and realizing design intentions (Cannaerts, 2009). Models make complex realities comprehensible, operational and workable and enable a reality to be interpreted and represented by selectively reducing complexity, focusing on certain aspects, altering scale, adding coloration etc. Models can also act as exploratory devices by working as self-communication tools and allowing new questions to be raised, alternative solutions to be explored, hypotheses to be formulated. This thesis aims to reveal this aspect of models that makes model-making a self-communication process in architectural design. This chapter, therefore, provides an introduction to the background and main concerns of study, presents an overview of methodological considerations and explains the structure of the thesis.

The aim of the study is to contribute to the understanding of model-making in the early stages of the architectural design process with the main concern being the *architectural learning environment*. The objectives of the study are as follows: to make use of a methodology to formalize descriptions of the relationship between the designer (the architect) and models during the early conception of ideas in the

design process, and then to use these descriptions as a means of explaining how and why model-making can be effective.

Within the context of this study, model-making refers to both physical and digital model-making unless a clear distinction is made. However the departing idea and the main concern is to inquire the role of physical model-making and the uses of the physical models in the conceptual design process. The scope is later expanded to also include digital model-making in order to keep the discussion alive since the use of digital models is getting more frequent in architecture with new developing technologies. Introduction of new manufacturing techniques and technologies which allow the virtual to become real and concrete, started to obscure the boundaries between physical and digital models. Digitally designed objects, through developing CAM technologies, are produced with very few effort. These developments in technology are very useful, therefore, for the later phases of the design process. However, the significance of using CAD software, and digital model-making mediums as a self-communication tool in the early phases of the design, still remain blurry. This thesis, by including digital model-making along with physical model-making aims to highlight this situation.

The study aims to address to the architectural learning environment rather than of practice. This is an important distinction since the conception of model-making in practice is often very different. Models used in practice are generally made as verisimilitudes of the final scheme to describe and sell an idea after a design has reached a stage at which it will only be developed in detail and will go under negligible change (Dunn, 2007). Furthermore, in practice, in most of the architectural design firms, models in the conceptual design phases are not done by the senior architect but are created by interns or novice architects (Burry, Ostwald, Downton, & Mina, 2007). This obstructs the self-communication process during the design that this thesis aims to focus upon. On the other hand, in architectural education, the making of a model is to assist the student in their learning and understanding of architecture and to develop their skills of design communication (Dunn, 2007). The students develop their own models for their projects and get in a conversation with their models that Schön and Wiggins call "a reflective conversation with the situation" (Schön & Wiggins, 1992). So, this study can be useful for architectural pedagogy in pointing out the aspects of model-making which enable such a conversation.

The idea of questioning the use of model-making in the early phases of the architectural design process emerged after a literature review into existing attitudes concerning sketching. Sketching is one of the most explored activities in design

cognition studies and considerable research has been done to assess its significance in the early stages of design process. However, through the literature survey, it is noticed that sketching in design studies usually corresponds to drawing and the extensive research on the cognitive aspects of sketching does not always include three-dimensional sketching through physical and digital models produced in the early phases of design process. Despite the general tendency in literature to underline the importance of model-making in the design process, its effects on the cognitive process are not sufficiently articulated. So, the initial motivation of the study was to enable a discussion of model-making within the sketching research and inquire the cognitive aspects of model-making in architectural design.

The apparent dearth of research into the role of model-making in the cognitive process led to a search of methodology in order to formalize a description of the reflective relationship between the architect and models. Previous research and analysis methods in design cognition studies are reviewed with the aim of developing an empirical approach that would allow a more rigorous examination of the significance of model-making in the design process and design cognition. Therefore, protocol studies are realized with three graduate students of architecture using three different mediums: freehand sketching, physical model-making and digital model-making. The protocols are held as think-aloud protocols which are recorded using cam-corders. The qualitative and quantitative data of the recordings are analyzed and the Linkography method is used as the analysis method (Goldschmidt,1992). A new approach is introduced, with this study, to interpret the Linkographs in terms of the sequence of ideas during model-making and free-hand sketching processes. This new approach, related different terms and notions specific to design cognition and opened way to new debates. The development of this new methodology became one of the primary objectives of this study and its contributions to design cognition is can be more important than the possible contributions of the discussion on model-making in architecture.

In order to assist the reader's understanding of the scope of this work it may be useful to conceive this thesis as two parts. The first part of the thesis is concerned with the contextual information behind the generation of the empirical research and comprises the chapters 1-3. The second part of the thesis considers the protocol studies realized and includes the chapters 4-6. The present chapter provides an introduction to the study as a whole and prepares the ground for the chapters that are to follow.

Chapter two clarifies the basic vocabulary of this study. It focuses first on the definition of model and model-making, and establishes their different

properties. It provides examples of different classification systems for models and underlines upon which type of model and which type of model-making process this thesis constructs its arguments. Then, it sets out a review to the cognitive studies in design mainly focusing on sketching and indicates the approach of this thesis to design cognition. Properties of sketching is explored and the key literature on sketching is reviewed to build the links from sketching to model-making. Key literature on sketching articulates the ambiguous and uncertain nature of sketching as a positive drive in generating new ideas and making novel discoveries in the early phases of the design process. This study questions whether physical and digital models in the early phases of the design process are also ambiguous and enable creative shifts to new alternatives, therefore whether physical and digital model-making can be considered as a form of sketching. This set of questions are followed with another set of questions inquiring in which ways physical and digital models and model-making processes can be ambiguous.

Chapter three presents the methodology through specific terms, methods, notation and analysis systems used. First protocol analysis which constitutes the core analysis method of design cognition studies, is elaborated. Both its limitations and advantages are discussed and its use within design cognition is explored. Think-aloud method is widely used within protocol studies to capture the thought process of the subjects through their verbal acts. Its place within design cognition studies is examined through the limitations and possibilities it evokes. Consequently, Linkography which is an analysis technique to study designers' cognitive activities, is presented. The criticism against Linkography in design cognition literature is elaborated. Finally, the reasons why these particular methods are chosen among other empirical methods is clarified.

In chapter four, the experiments are presented in detail. Background information about the experiment participants and the settings of the experiment environments are given. The experimental procedure is cited and limitations concerning the proposed experimental research are indicated. At the end, the Linkographs of the protocol studies are provided.

Chapter five offers a synopsis of the study and provides a synthesis of the protocol studies and discusses the results. Divided into two parts, first part, discusses through quantitative date obtained from the Linkographs, whether physical and digital model-making in the early design phases can be considered as a form of sketching. In the second part, the use of models in each design session are examined and snapshots from cam recordings are provided to support the arguments concerning the aspects which make models and model-making

processes ambiguous.

Chapter six draws some conclusions and makes suggestions for further research. It also provides further evaluation of the methodology used in the experimental research through an appraisal.

CHAPTER 2

BASIC CONCEPTS IN APPROACHING MODEL-MAKING

This chapter provides a general explanation concerning the basic concepts of the thesis. It starts with establishing different properties of a model and through examples of different taxonomies for models. It clarifies to which type of model and to which type of model-making process this thesis mainly refers to. Further on, it sets out a review of the cognitive studies in design and exemplifies the studies in this field focusing on designers' sketching activities. In light of these studies, it explores properties of sketching and builds the links between the current study and previous studies on sketching. It then concludes with the main research questions of this work.

2.1 Clarifying what *model* and *model-making* refers to within this work

A model, as defined by Echenique (1970) is a representation of reality where "representation is the expression of certain relevant characteristics of the observed reality and where the reality consists of the objects or systems that exist, have existed, or may exist". In this definition, a model is described with conditions of simplifying assumptions. Dunn (2007) similarly argues that a model is always "an abstraction of reality since it could never possibly represent the complexity of reality" and that "by its very definition it should not aspire to since the entire purpose of a model is to focus on a particular area of inquiry" for different purposes. Therefore, a model is always a simplification and is designed for a certain purpose. This purpose varies in different contexts and even in the context of *architectural learning environment,* models are employed for a variety of reasons altering between evaluative, descriptive, predictive, explorative and cognitive purposes (Dunn, 2007). These reasons influence the architectural models produced in terms of scale, simplification, accuracy, material etc. and serve as classification clues for models.

Before discussing different classifications of models made by various scholars, it is important to remind that the word model in this thesis refers both to physical and digital models unless a distinction is made. However it should be clarified that the main focus of the study is "architectural model-making" rather than

"architectural model", with physical model-making process having a particular priority. Therefore, this thesis chooses to adopt a taxonomy for models that is done regarding the operational values of models which are mostly related to the process of model-making rather than representational values which are mostly related to the end product. In order to provide a wider understanding about models and model-making, different classifications will be presented first as a background information and within each categorization, which type of model and which type of model-making process this study refers to will be highlighted.

Architectural physical models can be classified according to their function under five main categories: models for town-planning research, building models, construction and detail models, interior models and special models (Janke, 1968). However this classification is done regarding the representational values of the models, discarding the design process and it is not helpful for this study.

Porter and Neale (2000) expand the categories determined by Janke and provide a more comprehensive list of architectural physical model types: conceptual models, site models, design development models, block models, space models, structural models, interior architecture models, lighting models, wind tunnel models, presentation models, exhibition models and full-sized prototypes. Regrettably, Porter and Neale do not indicate their rationale behind this classification system. They do not cite regarding which aspects of these model types they differentiate the models. It is not clear whether the classification is done regarding the purpose for which a model is made, or the scale, accuracy, construction technique of a model, etc. It is not easy to figure this out either. However, according to the definitions they provide under each title, the model type and the model-making process that are closer to the scope of this thesis is examined under the conceptual model title. Conceptual models are defined as three-dimensional diagrams fabricated when an idea is still fragile. They are usually constructed quickly and inventively using found materials or mixed media. Conceptual models, when used as an initial working design tool by many designers who prefer to test newly forming ideas "directly in the space of the idea", represents "an intimate and embryonic sketch in three dimensions". The ability of conceptual models to be quickly changed make these "embryonic design models" a flexible medium.

Architectural physical models can be classified depending upon how they are made, regarding the purpose that they are made for and regarding the stages of the design process (Knoll & Hechinger, 2000). The latter classification method is more related with the scope of this study and it distinguishes models as

conceptual models, work models and exhibition models. Conceptual models, in this classification, correspond to models that are constructed with easily and quickly obtainable materials which are also easily shaped and worked. These models should accommodate modifications easily with the essential features being spontaneity and flexibility when a change is needed.

The classifications presented up to now consider architectural physical models only and do not sufficiently answer to the needs of clarifying what model and model-making refers to within the context of this study. Dunn (2007), at this point, develops the taxonomy proposed by Echenique (1970) and applies it to architecture. He classifies models under four main categories: descriptive model, evaluative model, predictive model and explorative model. This classification can be used for both physical and digital models since it is not related with the physical appearance of the models but with the operational values they acquire during the design process. The explorative model, within Dunn's taxonomy, fits into the research area of this thesis:

> Explorative models, along with drawings of the building, can be used as method of refining judgements, decision-making or conveying information i.e. factors that are at the very core of architectural design. (Dunn, 2007, p. 76)

Explorative models, as their title indicates, are used to try out and test ideas "at different degrees of scrutiny" and consequently they are used at various stages during the design process. However, they are typically used throughout the early stages of design development when the designer's ideas are at their most novel and then subsequently developed. They are quickly produced and may appear unfinished since they function as three-dimensional sketches to help develop the design.

Therefore in the light of these different categorizations, the model that this thesis builds its arguments upon is the model that is constructed in the early phases of the design process when the designer's ideas are not crystallized and are open to further exploration. They are mostly quickly assembled and are open to changes to test further ideas. Porter and Neale (2000) and Knoll and Hechinger (2000) call this type of model conceptual models, Dunn (2007) calls explorative models. However this thesis chooses to adopt the terminology from a simpler yet meaningful distinction: *models of* architecture and *models for* architecture (Cannaerts, 2009). *Models of* architecture can be qualified as interpretative and be corresponded with the presentation model made after designing. *Models for*

architecture could be seen as explorative and correspond to the working model, the sketch model, or the conceptual model, made while designing. They are made "with no other purpose then testing a certain design issue" and "whether digital or physical, they are made during the early stages of a design process and they are part of this iterative process of representation and interpretation" (ibid,p.782). This thesis is concerned with the *models for* architecture rather than *models of* architecture. It inquires their use in the *architectural learning environment* and questions to what extent and how can physical and digital model-making processes be described within *models for* architecture.

2.2 Cognitive studies in design: a brief overview

Thus far, what the terms model and model-making signify within this study is clarified. Now, the intention behind the cognitive studies in design and what do they seek to reveal will be elaborated in order to be able to convey the approach of this study to design cognition. Hence, an initial discussion on design research and design thinking will be presented before specializing on cognitive studies in design.

An historical review of the 20th century significantly points World War II as a turning point concerning research in design that Herbert Simon (1970) calls "the sciences of the artificial". Most design research studies are made in architecture because of the requirements of the societies after World War II (Bayazit, 2004). Regarding this historical overview, it is assumed that design thinking enables the development of new ways to approach to and solve the problems. The problems mentioned here are not concerned only with architecture or design but are of interest to a general situation in the society. Therefore, the scope of design thinking is not solely limited with design. Today as well, design thinking penetrates to different fields other than design. A recent example to this situation is the acquisition of design thinking paradigm within management which means approaching managing problems as designers approach design problems. Roger Martin is the leading figure of this synthesis. He interprets design thinking as an intersection of analytical thinking and intuitive thinking and proposes that it is absolutely critical to having organizations overcome the problems they face (Dunne & Martin, 2006). Hence, in order to be able to understand design thinking, first, how designers approach to design problems has to be enlightened and this is basically the aim of the cognitive studies in design. Cognitive studies in design aim to reveal how designers design, what kind of knowledge they have, how they approach to the problems, also what design is, and what kind of thinking it requires.

Design cognition is a sub-field of design research. Today, the rise of the design research can be related to the world-wide spread of the understanding that design thinking boosts the value of every-day objects. This understanding consequently moves design research "from being an arcane field closer to centre stage" (Gero, 2006). The other sources of the design research apart from design cognition are design computing and advanced technology. These sources are interrelated nourishing one another: design computing could not be developed without design cognition and design cognition would not be as purposeful as it is today without design computing. This is one of the reasons why this study also includes digital model-making as an area of interest along with physical model-making. Although, it is located within design cognition field, considering the questions that it seeks to answer, the methodology it acquires and the literature it benefits from, the conclusions of the study can influence the design computing field as well. Therefore, first, what cognitive studies in design aim to reveal, what kind of a methodology is developed with and for design cognition studies and how these studies contribute to the design research pool should be clarified.

Design cognition is founded on concepts from cognitive science and uses language and concepts from cognitive science studies of problem solving behaviour. The concepts from cognitive science are first applied to AI. Studies on AI researchers, then effected the studies on designers and certain analysis methods and techniques (i.e. think-aloud technique, protocol analysis) are adopted, to be noted later. Thus, within the core of design cognition, these empirical research methods lie for the study and analysis of the design activity and the primary aim of design cognition studies is to understand the act of designing itself and the behaviours of designers (Bayazit, 2004).

There can be various reasons behind the aim of understanding the act of design and how designers design. As pointed previously, for example, this knowledge is even useful for management field. Roger Martin requires this knowledge to be able to adopt design thinking paradigm within management field. In order to generate this kind of knowledge, present it in a scientific way and make it available to be used by other fields than design, cognitive studies in design are realized.

One other point of view concerning the necessity of design cognition studies is to enhance design computing studies and open way to further developments in AI. Nigel Cross (2006), for instance, relates the studies in design cognition to the studies in design computation and AI. He claims that the knowledge of the human designer's cognitive behaviour is of fundamental importance in the development of

interactive systems that support designers and enable them to use these systems in ways that are cognitively comfortable. Moreover, he cites that understanding human designers' cognitive behaviour is critical for AI research in design as it is the results of human behaviour that set the standards for performance against which to assess the progress of the computational machines. This is an example of how design cognition and design computing fields are interrelated and depend to each other. Besides the goals of developing interactive design systems or autonomous design machines, there are still other goals of this research field.

The act of designing has been examined previously for the sake of proposing systematic models of the design process, and suggestions for methodologies or structured approaches that should lead designers efficiently towards a good solution (Cross, 2006). Although the necessity of these kind of systematic approaches are still questioned, cognitive studies in design can be useful in generating these methodologies by revealing how good designers' cognitive activities progress over the design process. They can also be useful in testing the effectiveness of these methodologies and in improving them.

Understanding how designers design can also be helpful in revealing the efficiency of experience and education over the designing ability. Therefore there are various cognitive studies in design held with this departing point to compare novice and expert designers. Results generally accentuate that novice and expert designers do present different cognitive processes under different empirical circumstances. The implications of these studies can be seen in architectural design pedagogy. By revealing what can be thought, what cannot be taught, what is a talent and what is learnt, the architectural design curricula can be shaped anew. Designers' and engineers' problem solving activities are also comparatively studied within design cognition studies to reveal the distinctions and similarities that exist. These latter studies can be helpful in understanding how design and engineering educations shape the novice student. Understanding this can again enable improving the education systems into a desired state.

On the other hand, cognitive studies in design can be realized just with the simple aim of trying to demystify design. For many years, before the emergence of design research studies, design was not a questionable era. The designer's head was a "black box" and the design process was related solely to intuition (Tekeli, 1978). To make this black box transparent, enables also the ground to discuss other notions such as creativity which are also deemed to be unexplainable. Thus, cognitive studies in design define new areas of research by simply asking questions that has not been asked before.

One other purpose of studying the cognitive aspects of designing is to understand how designers make use of different design tools and different design mediums as aids to their design processes. The cognitive studies on designers' free-hand sketching activities can be exemplified under this purpose and they occupy a considerable space within design cognition studies. Many researchers investigated the ways in which free-hand sketching helps to promote creativity in design thinking (Goel, 1995; Goldschmidt,1991; Goldschmidt,2003; Purcell & Gero, 1998; Suwa & Tversky,1997). The results from these studies revealed why for many years designers required pen and pencil to generate their ideas in the early phases of the design process. By revealing the aspects about free-hand sketching that helps designers to generate, foretell, speculate and test their ideas, development of new design tools and mediums, evaluation of the existing ones can be possible. This study approaches to the design cognition studies through a similar aim. In the light of previous research on free-hand sketching, it defines what sketching is and questions which aspects of physical and digital model-making make physical and digital models effective tools in the architectural design process as *models for* architecture. Therefore, first, a review to the free-hand sketching studies in design cognition must be provided to build the links between free-hand sketching and model-making.

2.3. Sketching in cognitive studies in design and what it contributes to the design process

Sketching is one of the most explored activities in design cognition studies and considerable research has been done to assess its significance in the early stages of design process. Analytical studies conducted by various scholars include research focusing both on freehand sketching with conventional methods and sketching in contemporary media using computer-aided sketching tools. These research claim that sketching is more than an external memory aid and that it promotes the kinds of thinking that are relevant to design cognition. According to Goel (1992), sketching enables the creative shift to new alternatives that he calls “lateral transformations” in the solution space. It helps the designer to find the unintended consequences that keep the designer exploring in what Schön and Wiggins (1992) call “the reflective conversation with the situation” that is characteristic of design thinking. Goldschmidt (1991) calls it the "dialectics of sketching": a dialogue between "seeing that" and "seeing as", where "seeing that" is reflective criticism and "seeing as" is the analogical reasoning and reinterpretation of sketch that provokes creativity. Goldschmidt (2003) also names

sketches as “self- generated displays” and argues that sketching allows one to review the entire history of design moves in a given session concurrently. Suwa and Tversky (1997) similarly argue that sketching enables designers to see unanticipated relations and features that suggest ways to refine and revise ideas and they called this process as “having a conversation with one’s self”. In the quest of outlining how designers think, Bryan Lawson (2006) asserts that sketches represent a sort of hypothesis or “what if” tool. These arguments driven from diverse empirical research situate sketching in design process as an indispensable tool to foretell, generate, evaluate, communicate, and restore ideas.

It is necessary to clarify what sketching refers to within the context of the studies cited above to be able to draw an understanding of its position within this study. Sketches that are attributed the mentioned properties consist a special category of drawings which architects and designers have the habit of making in the early stages of the handling of a task. They are "often scribbled on lightweight, transparent tracing paper, are usually made very fast and are sometimes so idiosyncratic that they are only comprehensible to their maker" (Goldschmidt, 1991). Compared to drawings that are made in the subsequent phases of the design process i.e. orthographic drawings, sketches remain fuzzy and imprecise, an aspect that makes them essential in the idea generation process, to be discussed further in detail in the current study. Therefore as the design moves from the preliminary stage through refinement to detailed design, there is a marked increase in the level of detail and explicitness of the drawn material that is produced, that is the drawing moves from unstructured representations to more precise and explicit drawn materials (Gero,1998). However, sketching in design cognition studies usually correspond to drawing and the extensive research on cognitive aspects of sketching does not always include three-dimensional sketching through physical and digital models produced in the early phases of design process. Although within the classifications provided concerning the types of models, it is pointed out that there are models that do bear sketch properties and serve to foretell, generate, evaluate, communicate, and restore ideas as do free-hand sketches. Porter and Neale (2000) names them conceptual models, Dunn (2007) exploratory models, and Cannaerts (2009) *models for* architecture. It was this remark concerning the dearth of research in design cognition field about model-making as a sketching method, while free-hand sketching is elaborately explored by numerous researchers, that initiated and motivated this research.

Later, it is discovered that there were other researchers aware of the fact that “whilst the use of graphic representation and visual design thinking are well

documented areas of research, [for example, Goldschmidt, Lawson and Loke,] the role of the model is not" (Dunn, 2007, p.14). Cannaerts (2009) similarly claims that "in the field of design research, model-making did not receive as much attention as sketching and drawing, and was considered of peripheral importance at best". This common lack of interest for models is pointed out also from a perspective of architectural history field:

> Interestingly, compared to the subject of architectural drawings, little specific research has been done about the meaning of architectural models. When one considers the important position the scale models have maintained in the architectural process for centuries, this seems quite strange. (Smith, 2004)

Consequently, this study aims to contribute to the understanding of model-making as a sketching method in the early stages of the architectural design process. Therefore it is first necessary to cite which aspects of sketching, as understood within the context of previous research on design cognition field, makes it an indispensible tool in the design process. The properties of sketching that allow unintended discoveries and/or creative shift to new alternatives and the aspects or features of sketches that allow a reflective conversation are previously inquired by other researchers through empirical studies and their research will be taken as a basis to initiate the research on model-making.

2.4. How *free-hand* sketching contributes to the design process: correlations of ambiguity

As mentioned previously, compared to drawings that are made in the subsequent phases of the design process where the ideas are refined, sketches remain fuzzy, imprecise and uncertain. They are often only comprehensible by their makers. As the design moves from this early phase through refinement to detailed design, the level of detail and explicitness of the drawn material increases, so the drawing moves from unstructured representations to more precise and explicit drawn materials (Gero,1998).

Key research on sketching articulates this uncertain nature of sketches as a positive drive in early design phases. Goel (1992) presents evidence, based on protocols of design sessions, relating to both the overall design process and to the specific role of sketching within that process. He compares the effects of different drawing techniques on the cognitive design process and accentuates the importance of using ill-structured representations for ill-structured problems which

are corresponding to using "fuzzy" (ambiguous, ill-defined) drawings instead of "hard-line" (well-defined) drawings during the early design process. Goel claims that because free-hand sketches in the early design process are "dense" and "ambiguous", they work well for exploring design ideas. He, then identifies two types of transformations in the drawings. There are lateral transformations where the movement is from one idea to a different idea and vertical transformations where one idea is transformed to a more detailed version of the same idea. Goel associates lateral transformations with unstructured, ambiguous sketches and claims that they occur in the preliminary design phases while vertical transformations occur during the refinement and detailed design phases and are associated with more detailed, precise and unambiguous drawings. Goel then performs a second experiment designed to assess why lateral transformations and sketching are characteristic of the initial phase of the design process. He argues that sketching constitutes a specific symbol system which is characterized by syntactic and semantic denseness and ambiguity, and that it is these aspects of sketching which allow lateral transformations to occur, that are deemed to be an essential aspect of the initial phases of the design process. He examines this hypothesis by comparing protocols of design sessions where expert graphic designers either solved a problem using free-hand sketching or using a computer based drawing system. He claims that, compared to free-hand sketching, the computer based drawing system is non-dense and unambiguous and should consequently make lateral transformations difficult. The comparisons between the free-hand sketching sessions and computer based drawing sessions reveals that significantly higher numbers of variations and reinterpretations are made within the free-hand sketching sessions which is associated with a higher value of lateral transformations. Therefore, according to Goel's study, ambiguous media, which is free-hand sketching in this case, enable lateral transformations, and lateral transformations enable the widening of the problem space and development of kernel ideas.

Therefore, what is meant by ambiguity and by an ambiguous drawing must be clarified in order to draw an analogy between sketching and model-making. Goel (1992) adopts the notion ambiguity from Goodman (1976) and defines unambiguity as a situation where "every symbol type has the same referent in each and every context in which it appears". Accordingly, ambiguity corresponds to a situation where "symbol types do not have the same referent in each and every context in which they appear". Goel measures the ambiguity in terms of reinterpretations of drawings which occurred whenever during the design protocols,

subjects returned to earlier drawings and gave them a different interpretation. Therefore, with reference to Goel's conclusion, the ability to enable attribution of different interpretations and meanings to something is a proof of ambiguity.

Taking for granted that free-hand sketches are ambiguous drawings, their common formal properties can be cited to clarify what an ambiguous drawing refers to. An ambiguous drawing may have a lots of lines and markings in it as opposed to *e.g.* orthographic drawings which are sharp-cut and where every line has a specific indication. There may be lines and markings which have occurred unintentionally, and consequently there may be eraser traces to eliminate these *mistakes*. Some lines or markings can be drawn thicker/darker than the others or some may be over-traced many times in order to establish a hierarchy of importance.

Up to this point, what free-hand sketches contribute to the design process is discussed. It is shown that free-hand sketches, besides their function as representations for external memory aids, enable the designers to engage with a reflective conversation with the situation, to discover unexpected clues about their designs, and to generate creative shifts to new alternatives. Further, what sketching refers to within these studies is clarified and which aspects of sketching allow these cognitive processes is discussed. Through Goel's (1992) study, it is shown that it is the uncertain, ambiguous character of free-hand sketching that opens ways to new discoveries and creative shifts to new alternatives that he calls lateral transformations. Accordingly, what ambiguity refers to is cited and which formal characteristics makes a drawing ambiguous is pointed out. Now, how do architects interact with these ambiguous drawings, namely free-hand sketches, will be discussed.

2.5. How do architects interact with free-hand sketches?

Sketches are relatively unconstrained and ambiguous, and consequently allow for new ways of interpreting the sketch of an image to emerge. These new ways of seeing a sketch then result in a new sketch or "in accessing different material from long-term memory which then produces a new sketch" (Purcell & Gero, 1998). Schön and Wiggins (1992), based on the analysis of a number of design protocols, suggest that sketching presents a visual display which can be perceived in different ways, that is the sketch can be reinterpreted. The general formal characteristics of a free-hand sketch is previously cited as having lots of lines and markings on it, with some of them appearing accidentally or being over-traced many times, etc. Therefore, what is it in these ambiguous representations

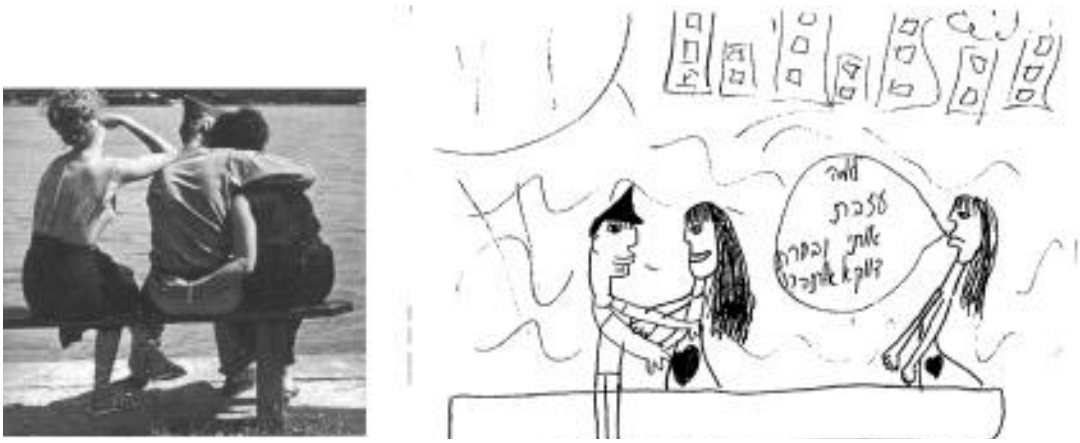


Figure 1 The photograph presented to Naomi and the drawing Naomi drew as a reaction to that photograph. (Goldschmidt,2003)

that allow designers and architects to deduct new interpretations from them?

Goldschmidt (2003) examined the sketching activity of a nine year old toddler Naomi. Naomi likes to draw and is said to be interested in playing with building blocks to build 'models' when she was younger. Goldschmidt showed Naomi a photograph (source) and asked her to react to it by making a drawing (target), while talking out loud (Figure 1). When the source and the target representations are compared, along with Naomi's commentary on her drawing, it is depicted that she *invented* features that are not traceable on the source photograph. One feature among these is interesting as it reveals how the ambiguity of sketches enable discoveries of new ideas. Naomi, while making the drawing of the woman from the source photograph, draws her wearing a dress. Unintentionally, the dress she draws appears rather "swollen" to her, so she decides that it would make sense to attribute the swelling to a pregnancy, while in the source photograph there is no reference to that women's pregnancy. Therefore, this reveals the fact that she decided on the pregnancy interpretation because the dress was accidentally drawn too large. In Goldschmidt's words, "this is not a premeditated notion, but one resulted from Naomi's reading of what Schön called the drawing's 'backtalk'". This kind of *mistakes* are also common in the early stages of architectural design while free-hand sketching. As does Naomi, architects also attribute novel meanings to (accidentally) drawn material, a move which can change the whole design process.

A pilot study is held as a protocol with free-hand sketching medium, before initiating the experimental research presented in this paper, to test the

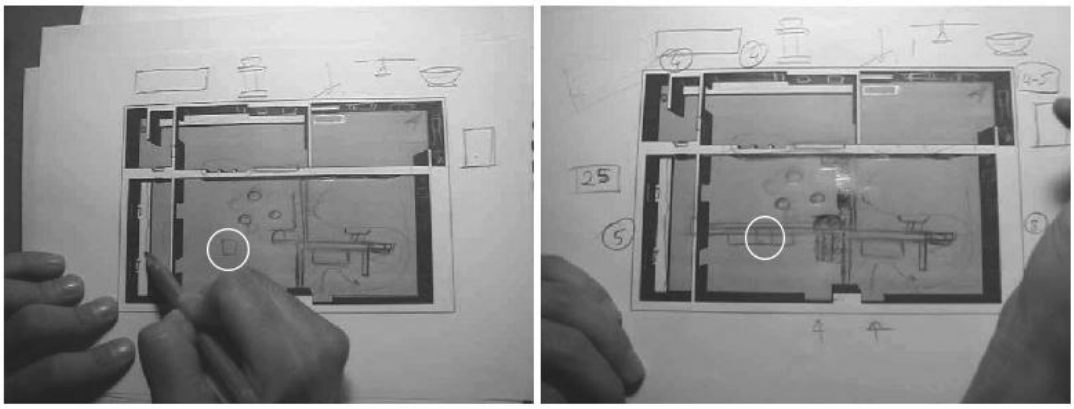


Figure 2 Snapshots from pilot study: the accidentally drawn rectangular cocktail table which then becomes a sofa

methodology and to get acquainted with protocol studies. It also helped to test the facts about free-hand sketching cited in many design cognition studies. Details of this study can be found in Appendix. In this pilot study, the subject was asked to make the arrangements of twenty-two paintings and three ceramic vases, an information desk and three cocktail tables in an art gallery which the plans, sections and isometric views are provided. During the protocol, as Naomi did with the dress, the subject mistakenly drew a rectangular cocktail table larger than it normally should be and did not erase it. Later, after having worked on other parts of the task, he noticed the rectangular cocktail table once again and claimed that it could make a good sofa for the visitors of the exhibition (Figure 2). Therefore, as Naomi did, the subject deducted from his mistake a new idea, an idea that may not have emerged if it was not drawn mistakenly or if it was erased.

Since sketching in the initial phases of the design process is fast, designers often do not make use of erasers. Sometimes, even if they do erase, traces of their mistakes remain. This creates an overlapping of lines, of ideas in fact, which can be a cause of ambiguity. As the design progresses, designers very often forget about the previous purposes of the lines they drew and attribute them new meanings, another example of how ambiguity of free-hand sketches allow lateral transformations in Goel's (1992) sense.

Free-hand sketches can sometimes be idiosyncratic, meaning that they are only comprehensible to their maker (Goldschmidt,1991). Drawings generated in the subsequent phases of the design process, which are more precise and unambiguous, on the other hand, are more comprehensible by others since they use known symbols and notation systems. Therefore, during the initial phase of a collaborative design session, members of the group may not clearly understand

each other's ideas behind the individual free-hand sketches. This causes misinterpretation/reinterpretation of others' ideas which is a reason for ambiguity. While ambiguity in the initial phases of the design is a preferred characteristic for the fruitfulness of the design session, it is not an aspect much preferred in the sequential phases of the design process where design communication is the primary concern in the representations being made (Stacey & Eckert, 2000).

Architects, hence, interact in many different ways with the ambiguous drawings they generate in the early stages of the design process. The path that this study followed to comprehend how architects interact with the free-hand sketches is therefore:

- pointing out what previous cognitive studies on free-hand sketches revealed about their contribution to the initial conceptual design phase
- discussing which aspects of free-hand sketches enable the cited contributions to the design process
- defining ambiguity and citing the ambiguous aspects of free-hand sketches
- inquiring the interactions between ambiguous drawn materials (free-hand sketches) and architects which result in generation of new ideas.

In light of these findings on free-hand sketching, this thesis tries to build the links between sketching and model-making, questioning whether model-making in the early phases of the design process is a form of sketching. The cognitive aspects of model-making in architectural design will be inquired to identify the interactions between architects and *models for* architecture.

2.6 Sketching vs. model-making

Model-making has significant advantages that are appreciated by a vast majority of designers. First of all, models are important communication tools. They are potentially much richer sources of information since they represent the design data in three dimensions:

> [M]odels can help the creative process of visualizing 3D space directly in the round. Also, by functioning to help understanding complex visual relationships, a model typically outperforms drawings. (Dunn, 2007)

The information contained within a model is denser since models provide the possibility to perceive the design as a whole by presenting relations between different parts and different properties (*i.e.* size, form, materials, color, and texture) of the design at once without any verbal aid. As Dunn points out concerning the architectural ones in particular, models inherit the formal and spatial problems of a building in an analogous way. He cites that this cannot be said of drawings since they may deceive the eye and create a pseudo-reality.

Unlike models, drawings control the observer in the angle or focus of attention, directing these to significant elements (Kvan & Thilakaratne, 2003). The viewer has to be trained to comprehend certain drawings (i.e. standard geometric projections of plan, section and elevation) while models do not necessitate a specific training to communicate.

Besides the incomparable role of model-making in design communication, making models may also establish "the reflective conversation with the situation", a significant role on cognitive design process that this thesis aims to reveal. Batterton and Whiting (1974) speculate on the role of model-making in discovering hidden features during a design process that, if graphic techniques are the sole method employed in design, alternative solutions that might exist beyond their capacity could remain hidden or even ignored. As quoted by Rolf Janke (1968), Helmut Borcherdt from Saarinen's office writes about the TWA building for Kennedy Airport:

> It would have been impossible to carry out such a project without a model. The representation of buildings on paper is simply a way of communicating information, but it says nothing about spatial qualities. A building's formal vocabulary will certainly be influenced by the medium in which the project is realized. A building designed by elevations and floor plans will inevitably have a different character from one designed with the help of a three-dimensional model.

By easing the three-dimensional thinking, model-making may enhance the creativity of the designers as well. As cited by Kokotovich (2000), Anderson and Helstrup have conducted an experiment to investigate whether or not drawing can influence creativity aspects of the designing task. They argued that developing an object by performing this task mentally might involve a high cognitive load and that drawing while thinking and developing a solution may lighten the cognitive load on the subject by externalizing the form being worked with. In order to test the importance of drawing in creative mental synthesis they conducted an experiment.

In the procedure, subjects while developing their forms, were sometimes encouraged to draw to develop their forms, and other times they were instructed to develop the forms only mentally. Although the results of their experiment showed no difference between using only internal visual imagery and using external visual imagery as support for generating ideas and no difference in the number of creative patterns generated, Kokotovich asserts that the results might be misleading because of a number of reasons. First, because the participants in the design experiment were randomly chosen university students who may not know how to draw in a way that assist mental synthesis and creativity. Second, because they were instructed to draw while they carried the task and that it could be that drawing is only of use at particular points in the process, for example when the drawing activity follows mental synthesis. So, he proposes further research on the relation between drawing and creativity. Assuming therefore that sketching during the design process lightens the cognitive load on the subject and enables creative discoveries, model-making by easing the three-dimensional thinking might enhance the creative aspects of the designs produced.

Working with physical and/or digital models might enable the designers to review the entire history of their design moves concurrently and with comparison to each other. Putting the models aside might give way to the generation of new ideas by combining the aspects from different models. Since they are the concrete forms of mental images, they might also function as external memory aids.

A vast majority of designers and researchers talk about the benefits of model-making in shaping their design ideas. During interviews they attribute an essential role to model-making as a design tool (Burry, Ostwald, Downton and Mina, 2007). These are for sure important references for the significance of model-making. However, they remain anecdotal and are not considered significant in the field of design research.

Therefore, this study develops an empirical approach that would allow a more rigorous examination of the significance of model-making in the early phases of the design process. Although, above, a comparison is made between free-hand sketching and model-making, this study does not intent to declare that model-making should be regarded as a foolproof method of producing good designs, or to state that models are better design tools than drawings.

2.7. Inquiring ambiguity of model-making and of *models for* architecture

As previously cited, *models for* architecture correspond to explorative models made while designing with no other purpose then testing a certain design

issue. Key research on free-hand sketching in design cognition studies articulates the ambiguity of free-hand sketches as a positive drive in early design phases to enable lateral transformations. From this argument, the following relations can be drawn:

sketching--> ambiguous media
ambiguity-->lateral transformations

Taking this relation as a basis, this thesis tries to find answers, first, to the question

- Can model-making be considered as sketching in the early phases of the design process? and its sub-questions:
- Do model-making stimulate creativity?
- Do *models for* architecture enable lateral transformations?
- Are *models for* architecture ambiguous and can be considered as three-dimensional sketches?

The features that make free-hand sketching ambiguous and the interactions between the architect and free-hand sketches which result with lateral transformations are previously cited. Accordingly, as a second phase of inquiry, this thesis seeks answers to the following questions to define the cognitive aspects of model-making in architectural design:

- In which ways *models for* architecture can be ambiguous?
- In which ways *model-making* process can be ambiguous?
- Which design moves do architects generate using *models for* architecture that result with lateral transformations?
- Are there any technical constraints that model-making impose that inevitably structure the cognitive design process?

In order to find the answers to these questions, protocol studies are conducted with graduate students of architecture where they were asked to think-aloud as they performed the tasks. Interviews are held with the participants before and after the protocols. The protocols are analyzed, first, using Linkography technique (Goldschmidt, 1992) and Linkographs are generated. Further, a method is developed to interpret Linkographs in terms of determining lateral and vertical transformations. Development of this method which interrelates transformations and Linkography was one of the primary objectives of this study, besides inquiring

the cognitive aspects of model-making in architectural design. The results from this analysis constructed the answers to the first set of questions. To find the answers to the second set of questions, cam-recordings are reviewed along with the Linkographs where lateral transformations are indicated. Snapshots of design moves generated by the participants are provided along with their corresponding verbalizations to put forward the ways architects interact with *models for* architecture that enable lateral transformations.

Before explaining in detail the design of the protocol studies, the methodology used will be presented in chapter three. The limitations of this methodology will be discussed and why this particular methodology is chosen among other empirical methods used in design cognition studies will be clarified.

CHAPTER 3

METHODOLOGY

There are certain methods developed to acquire information and analyze empirical data in design cognition studies. To prepare the ground for the protocol studies realized, this chapter presents the methodology through specific notation and analysis systems used. First protocol analysis which constitutes the core analysis method of design cognition studies, is elaborated. Both its limitations and advantages are discussed and its use within design cognition is explored. Think-aloud method is widely used within protocol studies to capture the thought process of the subjects. Its place within design cognition studies is examined through the limitations and possibilities it evokes. Consequently, Linkography which is an analysis technique to study designers' cognitive activities, is presented. The criticism against Linkography in design cognition literature is elaborated. Finally, the reasons why these particular methods are chosen among other empirical methods is clarified.

3.1 Protocol analysis

Of all the empirical research methods for the study and analysis of cognitive processes in design, protocol analysis is the one that has received the most use and attention. As a psychological research method, it elicits verbal reports of thought sequences as a valid source of data on thinking. American psychologist John Watson's (1878-1958) argument that thinking is "largely a verbal process" and that the term "'thinking' cover generally all implicit language activity and other activity substitutable of language activity" constructs the basis of protocol analyses (Hayes, 1986). Departing from this argument, Herbert Simon and Anders Ericsson (1993) developed protocol analysis method and it became widely spread with their collaborative work "Protocol Analysis: Verbal Reports as Data". The central assumption of this method is that "it is possible to instruct subjects to verbalize their thoughts in a manner that doesn't alter the sequence of thoughts mediating the completion of a task, and can therefore be accepted as valid data on thinking" (Protocol analysis and Verbal Reports on Thinking, 2002).

The verbal reports of protocols can be gathered in two ways. In the first

one, subjects are forced to verbalize their thoughts while designing, and their verbalizations and actions are recorded with cam-corders to enable further analysis. This type of protocols are called *think-aloud protocols*. In the second type, subjects are not forced to verbalize their thoughts during the protocols in order not to obstruct the design process. The verbal reports are gathered after the protocols while they comment on what they did through watching their cam-recordings. This second type of protocols are named *retrospective protocols*.

Also protocol analysis methods can be divided into two categories in terms of what they seek to observe: the process-oriented approach and the content-oriented approach. The former approach focuses on describing design processes in terms of a general taxonomy of problem-solving, i.e. problem-states, operators, plans, goals, strategies, etc. The latter approach aims to reveal the content of what designers see, attend to, think of and retrieve from memory while designing (Dorst & Dijkhuis, 1995). This study uses both of these approaches. While trying to depict the lateral transformations in the search of ambiguity, this study presents a process-oriented approach and while inquiring how architects cognitively interact with their own models, it presents a content-oriented approach.

Although being the most commonly used empirical research method for the study and analysis of cognitive processes in design, protocol analysis method is criticized with having some severe limitations as a research method for investigating design activity. A principal reference when seeking to capture design activity using protocol analysis is a timeframe. Because of the need to make research practicable, protocols are centered on time-restricted periods. This type of analysis is called *microscopic analysis* of the design activity. They are criticized with creating an unnatural design process by forcing the designers to solve a design problem within a limited time while they are constantly filmed. Furthermore, protocol analysis method is claimed to be extremely weak in capturing non-verbal thought processes, which are important in design work (Lloyd, Lawson, & Scott, 1996). The method is also criticized with providing a very valuable but highly specific research technique, capturing a few aspects of design thinking in detail, but failing to encompass some other broader realities of design in context (Cross, 2006). Being aware of the limitations of protocol analysis method, this study makes use of think-aloud protocols.

3.2 Think-Aloud method

Think-aloud protocols allow researchers to understand the thought processes of subjects where as the subjects attempt to complete a defined task,

are forced to verbalize their thoughts. Ideally, researchers observe and only speak to remind the subjects to keep talking if they lapse into silence. What the subjects say are recorded and used as data for analysis of the design process. It is considered as “a very direct method to gain insight in the knowledge and methods of human problem solving” (Someren, Barnard,and Sandberg, 1994). Think-aloud protocols give information about designers' reasoning that could not be obtained by simply looking at the resulting design. It gives data about strategies and the knowledge that designers use to construct a design, also data about lines of reasoning that were abandoned at some point.

Thinking aloud during problem-solving means that the subjects keep on talking, speaking out loud whatever thoughts come to their mind, while performing the task at hand. During the protocols, they just have to concentrate on the task and verbalize whatever comes to their mind without any interpretation. This can in fact be harder than it seems and think-aloud method is mostly criticized for obstructing the design process by forcing the subjects to do something (thinking out loud) that they are not generally accustomed to do. During one of the think-aloud protocols realized for this study, the subject reported that because of having to talk about each move she makes, she had to be conscious about the things she did and this obstructed her habitual design process where she makes discoveries through random moves. This specific problem is elaborated further in chapter five.

On the other hand, it is claimed that for most people speaking out loud their thoughts becomes a routine in a few minutes and talking out loud does not interfere with the task performance (Ericsson & Simon, 1993). In this study, except the mentioned protocol where the subject reported having problems with talking aloud, there are no other complaints about the think-aloud method.

3.3 Linkography

Linkography is a technique developed by Gabriela Goldschmidt and used in protocol analysis to study designers' cognitive activities. It is "a representation system that uses links as input and displays structural design reasoning patterns as output" and it is claimed to be "a simple graphic notation in which the sequence of moves is shown on a straight line and the links are nodes at the intersections of diagonal network lines connecting to related moves"(Goldschmidt, 1992). Figure 3 shows a Linkograph example provided by Goldschmidt.

In this technique the design process is decomposed by parsing the recorded design protocol into small units of design moves. A design move is defined as: “a step, an act, an operation, which transforms the design situation

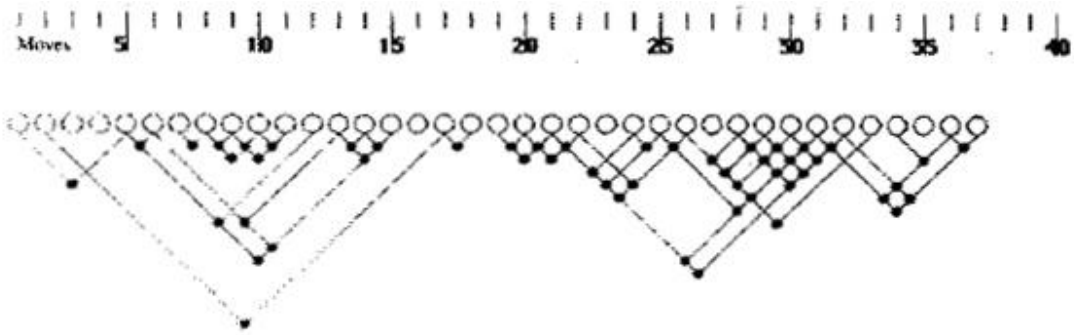


Figure 3 Linkograph example provided by Goldschmidt (1992).

relative to the state in which it was prior to that move" or "an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed". A Linkograph is then constructed by discerning the relationships among the moves to form links. It can be seen as a graphical representation of a design session that traces the associations of every design move.

The links have different characters: Goldschmidt identifies two types of links as backlinks and forelinks. Backlinks are links of moves that connect to previous moves and forelinks are links of moves that connect to subsequent moves. She claims that conceptually they are very different: "backlinks record the path that led to a move's generation, while forelinks bear evidence to its contribution to the production of further moves".

The design process can be looked at in terms of the patterns of the Linkograph which displays the structural design reasoning. Goldschmidt identifies three patterns: *chunk*, *web*, and *sawtooth track*.

1. A chunk is a "block of links among successive moves which form links almost exclusively among themselves and are barely or not at all interconnected with other moves". In Figure 3, two chunks can be discerned, comprising moves 2-17 and 21-32. In the geometry of the Linkograph, chunks take the form of a triangle enclosed by the move line and link lines of the first and the last moves of the chunk.
2. A web is formed when a "large number of links is formed among a relatively small number of moves". Compared to chunks, webs are smaller however the density of links in webs are very high. Within the geometry of the Linkograph, as in the case of chunks, webs also take the form of an enclosed triangle. The Linkograph in Figure 3 has a web between moves 26 and 32.
3. A sawtooth track is present when a sequence of moves link each to the one preceding it. When a designer "builds one proposition upon

other in a sequential order, he or she is said to be tracking and the resulting track is called a sawtooth track". In Figure 3, tracks can be seen in the following strings of moves: 7-11, 19-22, and 28-32.

Linkography technique is often used to assess design productivity. Goldschmidt relates design productivity to link index value, which is the ratio between the number of links and the number of moves. According to Goldschmidt, Linkographs of the more productive processes display higher link index values, more chunks and more webs. In a productive process, therefore, design propositions are made neither at random nor as a non-differentiated continuous progression. Moves in this kind of processes should have a high potential for connectivity to other moves where as in less productive processes, designers make more random trials which end up with moves which do not interlink much with other moves. As Goldschmidt interprets, the thinking in less productive cases is "less structured and issues are not systematically investigated before the designer goes on to look at other issues". No strong concepts which require the "backing of interconnected arguments" are present. This study takes this description of design productivity as a basis to discuss the productivity of the design protocols realized. A more elaborate discussion on design productivity and its correlations with sketching activity can be found in chapter five.

Different types of relations among design moves can indicate different levels of productivity. Kan and Gero (2008) exemplify and interpret four Linkographs consisting of five moves:

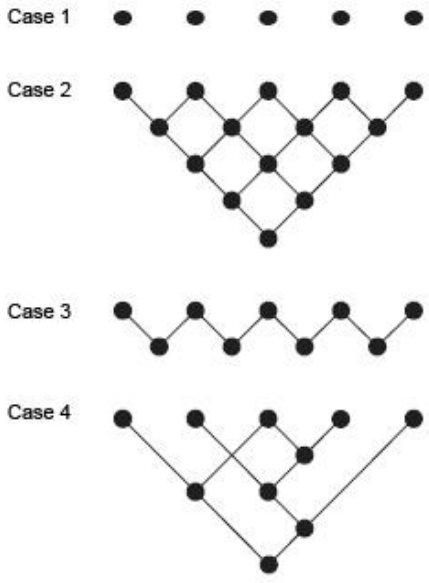


Figure 4 Some possible Linkographs of five design moves (Kan & Gero, 2008)

In the first case, all the moves are totally unrelated, indicating no converging ideas, hence very low opportunity for idea development. On the other hand, in the second case, all moves are interconnected. Kan and Gero claim that this inter-connectedness shows that this is a totally integrated process with no diversification, hinting that a pre-mature crystallization or fixation of one idea may have occurred, therefore there is a very low opportunity for novel idea. In the third case, moves form a sawtooth track and are related only to directly preceding moves. This, according to Kan and Gero is an indication that the process is progressing but not developing, therefore some opportunities for idea development. The final case presents a Linkograph where moves are inter-related but not totally connected. This is the indication that there are lots of opportunities for good ideas to develop. This study makes use of these interpretations while commenting on the Linkographs of the realized protocols.

Although it seems as an objective analysis method, Linkography is criticized mostly for lacking objectivity. Therefore, there are different levels of subjectivity: determining the moves (segmentation process), judging the links among moves (coding process) and interpreting the meaning of the resulting Linkograph (analysis process). In order to overcome the subjectivity within the segmentation and coding processes, inter-coder arbitration is advised (Mc Neill, Gero, & Warren, 1998). In this method, there are more than one analysts -coders- and each coder after making a first past of the protocol transcript for segmenting and coding, gives a break about ten days to return to study the protocol. He or she makes a second pass to segment and code the protocols without any reference to the first one. After a further ten day break, the coder compares the two coding results and performs a process of "self-arbitration". If the two protocol codings match, the result is copied to a third protocol. In circumstances where there are discrepancies between the two protocol codings, the coder revises the problematic segments. When the arbitration is completed for each coder, the coders combine their results in a joint arbitration process, similar to self-arbitration and discuss the results. Finally, an arbitrated result is achieved by a consensus approach. This method should provide less subjective Linkographs however is definitely much more time-consuming. Therefore, this study did not adopt this approach to segment and code the Linkographs (For segmentation and coding examples in this study, see Appendix).

In this study, in order to discuss ambiguity of models and model-making processes, lateral and vertical transformations done during the design protocols

are sought using Linkography technique. For this purpose, a method which interprets Linkography in a way to indicate the transformations made is developed.

Linkographs present different link patterns among moves. Goldschmidt (1992) identified three patterns: chunk, web and sawtooth track. What differentiates these patterns is the density of the links which constitute the patterns and their relation with other moves within the Linkograph. While seeking a way to detect the transformations done during the design process, the idea to use Linkography and to associate link patterns with transformations emerged. Through Linkographs, Goel's (1992) typology which distinguishes between lateral and vertical transformations could easily be read. Further evidence is later found concerning the argument that Linkographs can easily indicate what types of transformations are being made by displaying link patterns: dense clusters of links correspond to vertical transformations while scattered links denote lateral transformations (Goldschmidt & Tatsa, 2005). Correspondingly, vertical transformations generally would form chunks and webs, while lateral transformations remain as non-interlinked moves or form sawtooth tracks. Departing from this idea, in this study, a method which interprets Linkography in a way to explore transformations done, is developed. Figure 5 shows how this exploration is done through the Linkograph of one of the subjects' design protocol.

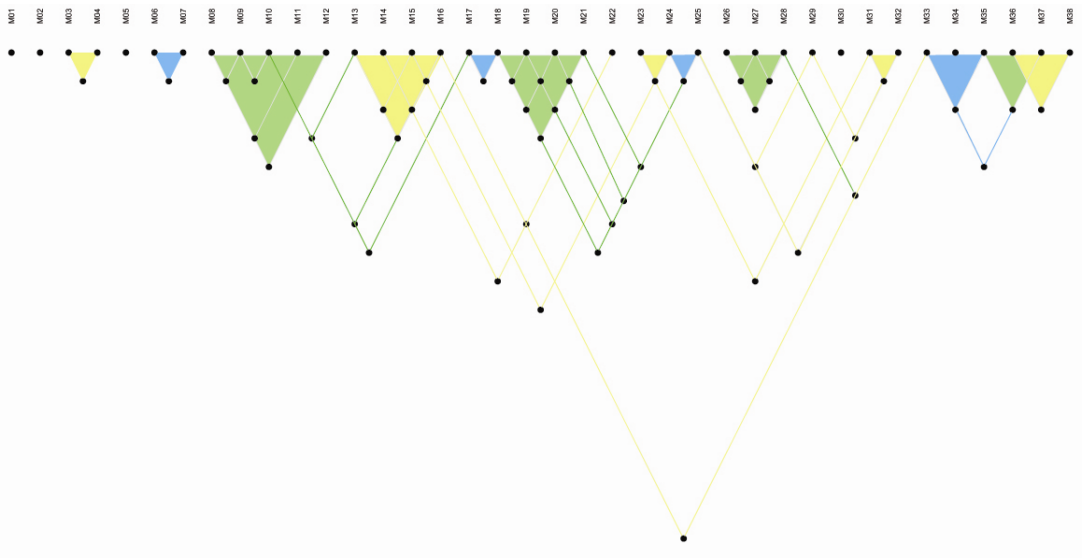


Figure 5 Example of Lateral Transformation Determination on Linkographs

On the given Linkograph, first the links forming chunks and webs are identified as triangular areas and those triangular areas are colored to be easily perceived. Later the links that exist only between two sequential moves are explored and the triangular area between two moves are colored. The total number of triangular

areas that are formed on the Linkograph are counted. Moves that are totally unlinked with other moves are also considered as lateral transformations since they are sudden changes in the design process. The sum of these unlinked moves are added to the number of the colored triangular areas. The final value gives the total number of lateral transformations that appeared during the design session. Links that are not within a chunk or a web, but are back-links to previous ideas are also indicated on the graph. However since they are not new ideas the triangular areas formed with these back-links are not colored and are not counted as lateral transformations.

Vertical transformations are not easily identified as the lateral ones. Kan and Gero (2008) have developed a method where they consider the linking nodes as points in Cartesian coordinate system and find the mean value of X, which is the average location of the nodes in the X-axis and the mean value of Y, which is the average location of the nodes in the Y-axis. The mean value of X is calculated to find whether more nodes appear through the beginning or through the end of the design session. The mean value of Y, is calculated to find out how deep the ideas process, therefore to find out the lengths of the links. In this study, Kan and Gero's method is used to calculate the mean value of Y of the Linkographs and those values are interpreted to compare the design sessions in terms of vertical transformations. Figure 6 shows how nodes in the Linkographs are transformed to points in the Cartesian coordinate system to calculate the mean values through the same Linkograph of Figure 5.

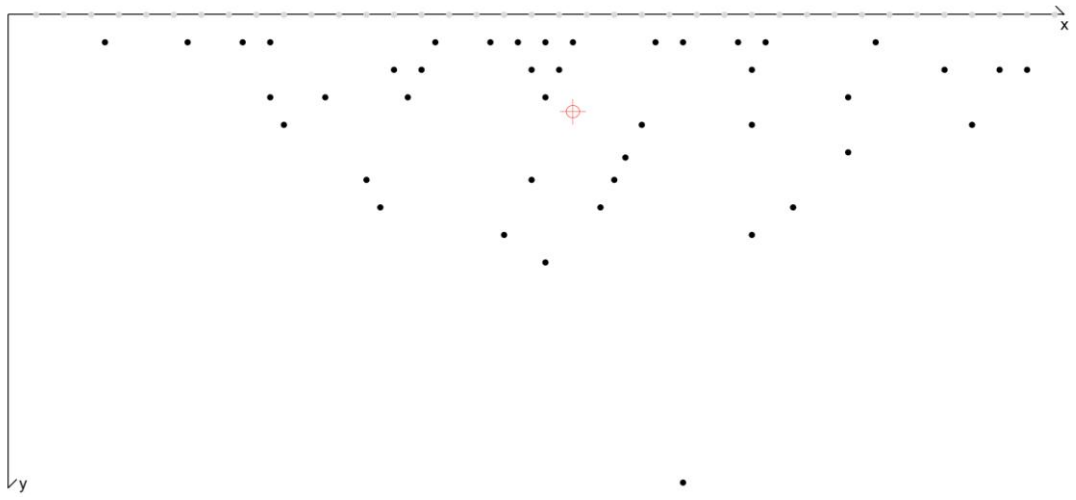


Figure 6 Transformation of the nodes on Linkographs to points in Cartesian coordinate system to calculate the mean values X and Y. Mean value Y is than interpreted as the vertical transformation value

The application of these methods to Linkographs and the results are

discussed further in chapter five. Linkography is proven to be also useful in detecting the transformations in Goel's (1992) sense.

3.4 Related work and discussion

3.4.1 Microscopic and macroscopic analyses

Microscopic analyses of design activity are time-restricted and therefore are mostly associated with short-term goals. *Macroscopic analyses*, on the other hand, are associated with long-term goals and the design activity is not captured solely with individual episodes where there are definite, short timeframes. Microscopic analysis methods are mostly criticized with creating unnatural settings. It has been argued that a comprehensive understanding of design decision making cannot be formed from time-restricted studies and un-naturalistic interactions that they involve (Pedgley, 2007). However, this study makes use of microscopic analysis to capture the initial phases of the design process where the subjects are asked to develop their conceptual ideas. Therefore, the time given to the subjects to solve the design problems corresponds more or less to the time they would normally spend to solve the problems. Also since more than one subject is involved with more than one protocol, carrying out a macroscopic analysis for each subject would demand an unnecessary effort and time. Instead of carrying out macroscopic analyses, concerning this study, it would be better to carry out more microscopic studies which could lead to a more reliable data through comparative discussion.

3.4.2 Think-Aloud protocols vs. retrospective protocols

Think-aloud method is criticized with obstructing the design process by interfering with subjects' perception. In order not to disrupt the process, some researchers prefer gathering verbal reports through retrospective protocols. However, in retrospective protocols, another undesirable effect, selective recall, is inevitable. Subjects may tend to selectively report what they think is relevant to the tasks and neglect other thoughts which might occur during the design session (Suwa & Tversky, 1997). This study analyzes the protocols with Linkography method to detect lateral and vertical transformations. In order to be able to make this analysis, subjects' spontaneous verbal reactions are necessary and that is why think-aloud protocols are preferred to retrospective protocols.

3.4.3 Why Linkography

With an understanding of the construction of a Linkograph, one is able to comment on the design behaviour without studying the whole design protocol (Kan & Gero,2005) since the Linkographs present the relations among design moves within a unified graphic representation. Although Linkography method is criticized for its subjectivity, it provides a more objective ground than sole observation of design protocols does, when discussing issues such as design productivity. This study, while making use of Linkographs to determine lateral and vertical transformations done during the design protocols, benefitted from the wholistic nature of Linkographs in representing the design sessions. Representing the design process graphically, thus, eases the perception of relations among design moves and enables easy determination of the transformations.

Now that the context of the study and research questions are clarified, and methodology is discussed, the protocol studies realized can be presented. Therefore, chapter four provides information concerning the subjects, the design tasks given to the subjects, the setting of the study, the procedure, and the outcomes. The results of the study and observations are discussed and analyses are made further in chapter five.

CHAPTER 4

EXECUTING THE PROTOCOL STUDIES

In order to inquire whether model-making can be considered as sketching in the early phases of the design process and in which aspects models and model-making can be ambiguous, nine protocol studies are conducted with three graduate students of architecture where each is involved in three protocols. This chapter presents these protocol studies. First, it provides information concerning the subjects, i.e., why they are chosen, their educational background, their acquaintance with model-making, and their knowledge about design cognition studies, etc.. Further the design tasks given to the subjects are presented and information is given concerning the settings and the procedure of the study. The procedure of analysis is provided and the quantitative outcomes of the analyses are presented. The results of the study and observations are discussed and analyzed further in chapter five.

Before presenting the protocol studies, it is of crucial importance to cite that these protocols are not conducted to end up with concrete facts concerning models and model-making in architecture. There are many limitations in this study which prevent the generation of a universal argument on model-making and models. The results could be totally different if the subjects, the design tasks, the settings of the study, the procedure of the study, the materials and software provided to the subjects, the time given for each task, the order of the design tasks were different. As cited in the previous chapter, the methodology used to gather information and to analyze that information has also severe limitations. Therefore, this study, instead of ending up with a *de facto* argument, presents these protocol studies as an example of how ambiguity of model-making can be sought within design cognition studies and discusses the results only with reference to these specific protocols.

4.1. Background information about the subjects of the study

The current study is conducted as protocol analyses with three graduate students of architecture. Interviews are held with the participants before the protocols to reveal their acquaintance with model-making and their knowledge

about design cognition studies. The subjects are graduated from different universities in Turkey and were successful students during their undergraduate studies, having good grades in architectural design studio courses. They are currently studying in different universities to obtain master's degrees.

The first subject, namely D1, is 25 years old. She is graduated from Middle East Technical University. After graduation, she attended Universitat Internacional de Catalunya for a master's degree in Biodigital Architecture. She is currently a graduate student of architecture in Middle East Technical University and expects to graduate in 2011 with M.Arch degree. In the interview, she claimed that she generally starts to design using free-hand sketches and that she makes use of models to test the ideas generated through free-hand sketches. She compared the use of free-hand sketching, physical and digital model-making in the initial phases of the design process. She argued that using solely free-hand sketches in the design process is not practical since free-hand sketches do not allow the perception of the design as a whole. She cited that with the use of physical models, this perception is facilitated, however, by using only physical models, some features concerning the plan decision can be left immature. She argued that designing only with digital models also causes difficulties since there are many constraints of digital medium. D1 can practically use the three-dimensional Nurbs modeling software Rhinoceros but she claimed that she is not sure what the outcomes will be when she uses Rhinoceros to develop conceptual design ideas without any other medium. She has previous knowledge about cognitive studies in design and especially protocol analysis method, however she did not participate to any empirical design study.

The second subject, D2, is 24 years old. He is graduated from Kocaeli University. After graduation, he worked for nine months in Emre Arolat Architects, one of the biggest architectural firms of Turkey, where he worked in the conceptual design team. The tasks he was responsible for in this firm included development of conceptual design ideas, drafting, physical and digital model-making, conceptualizing animations, and preparing the presentations. He is currently a graduate student of architecture in ETH and expects to graduate in 2011 with M.Arch degree. During the interview, he cited that in the initial conceptual design phases, he makes equal use of freehand sketches and models. He further clarified that he prefers to work with two-dimensional drawings (i.e. plans and sections) to working with three-dimensional drawings (i.e. perspectives and axonometric drawings) and that he prefers to make three-dimensional explorations through physical and digital models. As the reason for this, he claimed that he thinks he is

able to mentally construct the three-dimensional images depicted on drawings but through models, he discovers certain aspects he cannot imagine. He mentioned that during his undergraduate study, he made frequent use of physical models and that there were times when this frequency exceeded the frequency of designing with free-hand sketches. Concerning the use of digital models, he argued that he can comfortably use the modeling software Autodesk 3ds Max. He cited that, during his undergraduate study, he used digital models for presentation purposes only, after a certain level is achieved in the design process. However, he argued that in his professional experience, digital models penetrated to each stage of the design process. He commented that he thinks digital models are very useful especially in collaborative design works because they facilitate extremely the design communication within the group. D2 does not have any previous knowledge about design cognition studies and it is the first time he participates to a cognitive study in design.

The third subject, D3, is 23 years old. She is graduated from Istanbul Technical University. She is currently working in Maltepe University as a research assistant and she is a graduate student in Istanbul Technical University, expecting to graduate in 2011. During the interview, she claimed that she always starts the design process with physical models and makes very rare use of free-hand sketches. She argued that the ability of physical model-making to interact with haptic senses and to represent the design idea in three-dimensions are the reasons for which she prefers physical models over free-hand sketches and also over digital models. D3 said that she is familiar with the interface of digital modeling software Autodesk 3ds Max but that she only made use of it for presentation purposes and not as a design tool in the design process. She does not have any previous knowledge about cognitive studies in design and did not participate to a design experience before.

These subjects are chosen for this study since all the three were successful students during their undergraduate study. They all claimed using physical models occasionally in the design process and all have the required skills of working with different digital modeling software. There were other people who were asked whether they would participate to a design research, but none of them were as keen as these subjects. Therefore, the protocol studies are conducted with these subjects.

4.2 The design tasks

The participants are given three architectural design tasks which are similar in terms of contextual, functional and programmatic complexity, and scale. They are asked to solve the given design problems by using three different mediums: free-hand sketches, physical models, and digital models. In order to neutralize the effect of the individuals, each participant is involved in all the design mediums mentioned. So at total, nine experimental sessions are realized. Table 1 shows the distribution of design tasks among designers and the design mediums used for each design task.

Table 1 Distribution of design tasks and design mediums among designers of the experiment

	Design Task # 1			Design Task # 2			Design Task # 3		
	Physical Model	Freehand Sketch	Digital Model	Physical Model	Freehand Sketch	Digital Model	Physical Model	Freehand Sketch	Digital Model
D1	●				●				●
D2		●				●	●		
D3			●	●				●	

The design tasks consist of formal explorations for mixed-use buildings in urban plots in Paris. They are located at the same environment and have common specific topographic qualities such as being sloped, being next to a bridge and on the waterfront, having different levels, etc. that expectedly calls for three dimensional inquiries. The numbers on the satellite view from Figure 7 correspond to the design tasks presented in Table 1.

For design task no:1, the participants are asked to design a mixed-use building consisting of housing units and a cinema / a theatre. For design task no:2, they are asked to design a mixed-use building comprising housing units and an exhibition gallery. Design task no:3 is again to design a mixed-use building with a dormitory and a café. Tasks are designed to be similar in terms of complexity but with programmatic differences. The reason why slight changes on the program exist is to prevent the transfer of experience from one task to another. No specific data are given about the total area of each program unit. However a simple site analysis is provided to the designers prior to the experimental sessions and the participants are allowed to ask further questions.

Figure 7 Satellite view of the design task sites of the experiment

All the participants are asked to start the experiment first with physical model condition. They continue with freehand sketch and finalize with digital model conditions. For the physical model condition, they are provided a cardboard site model of 1/200 scale. On the model, buildings, pedestrian roads, vehicular roads, canal, and the bridge are clearly indicated. The participants are given cardboard, colored papers of different thicknesses, transparent papers, needles, glues, a ruler, and colored pens as materials. They are not allowed to sketch by making drawings to generate ideas. Cardboard and paper are chosen as the primary modeling materials since they correspond to the most commonly used modeling materials in architecture (Burry, Ostwald, Downton and Mina, 2007). If the experiment could be realized by using other modeling materials (i.e. modeling clay, styrofoam) , the results could be different.

For the freehand sketch condition, the participants are given 1/200 scale site plans and site sections of the design tasks, sketching papers, colored pens and pencils, erasers, and a ruler. The site section from Figure 8 is the site section provided for design task no:1.

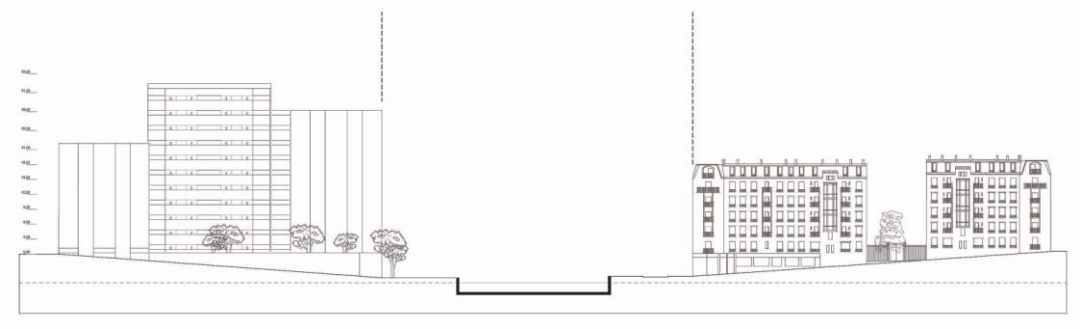


Figure 8 Site section provided for design task no:1

For the digital model condition, the designers are provided Sketch-Up, Rhinoceros, and 3ds Max models of the site comprising the same area as the physical model. Participants are free to chose among these digital modeling soft-wares. D1 chooses Rhinoceros; D2 and D3 choose 3ds Max. The site model image from Figure 9 is the Sketch Up model.

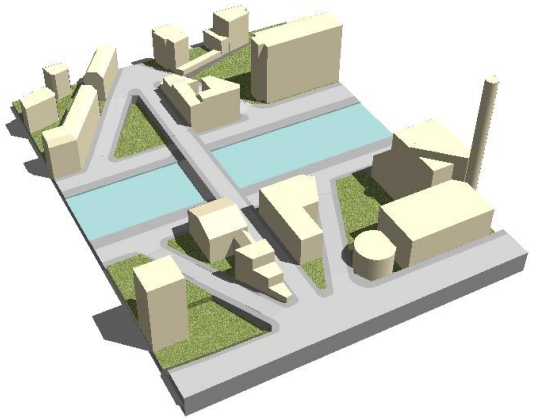


Figure 9 Sketch Up site model provided to the participants of the experiments

4.2 The settings of the protocol studies

All of the design sessions are recorded using cam-corders. Cam recordings during free-hand sketching sessions, focused both on the gestures of the subjects and their free-hand sketches. Similarly, in physical model-making sessions, both the movements the subjects made and the physical models are recorded. For the digital model-making sessions, a software which records the onscreen activity, Camtasia Studio, is used to record the movements done in the digital model-making medium along with the verbalizations of the subjects.

The design protocols are held in environments where the subjects would feel comfortable and where there is no risk of interruption. The subjects are asked to think-aloud during the design protocols in their native language, which is Turkish for all the participants.

4.3 The procedure of the protocol studies

The protocol studies of each participant followed this procedure:

1. Presentation of the study
2. Presentation of the site analysis
3. A pre-interview with the participant about the experiment. He/she is asked to talk about his/her expectations about the experiment, whether he/she thinks he/she will be successful in the experiment with the given medium or he/she would be more comfortable with another medium and the reasons.
4. Presentation of the design briefs
5. Initial conceptual design phase. At this primary session, the participants are asked to generate conceptual design ideas. For the physical model condition, they are asked to make a match-box physical model of their idea that they will

develop in scale further on. The physical model do not have to be in scale but has to clearly explain their ideas. For the freehand sketch condition, participants are asked to make a conceptual diagram of their design ideas. For the digital model condition, they are supposed to make a digital model representing their conceptual design idea. The duration of this initial phase is limited in terms of the duration of the conception of their design ideas. It varies between 8 minutes to 21 minutes.

6. Development of the conceptual design idea. At this second stage of the protocol, the participants are asked to develop their design ideas. This time, they are asked to work in 1/200 scale for physical model and freehand sketch mediums and to fit into the given site model for the digital model medium. The sessions end when the participants declare that they are satisfied with the result. However in cases when they exceed 60 minutes, they are reminded to straighten up their designs.

7. A post-experiment interview. The participants are asked whether they were right in their expectations about the design session, what were the difficulties they faced and whether they could be more successful using another design medium.

4.4 The procedure of the analyses

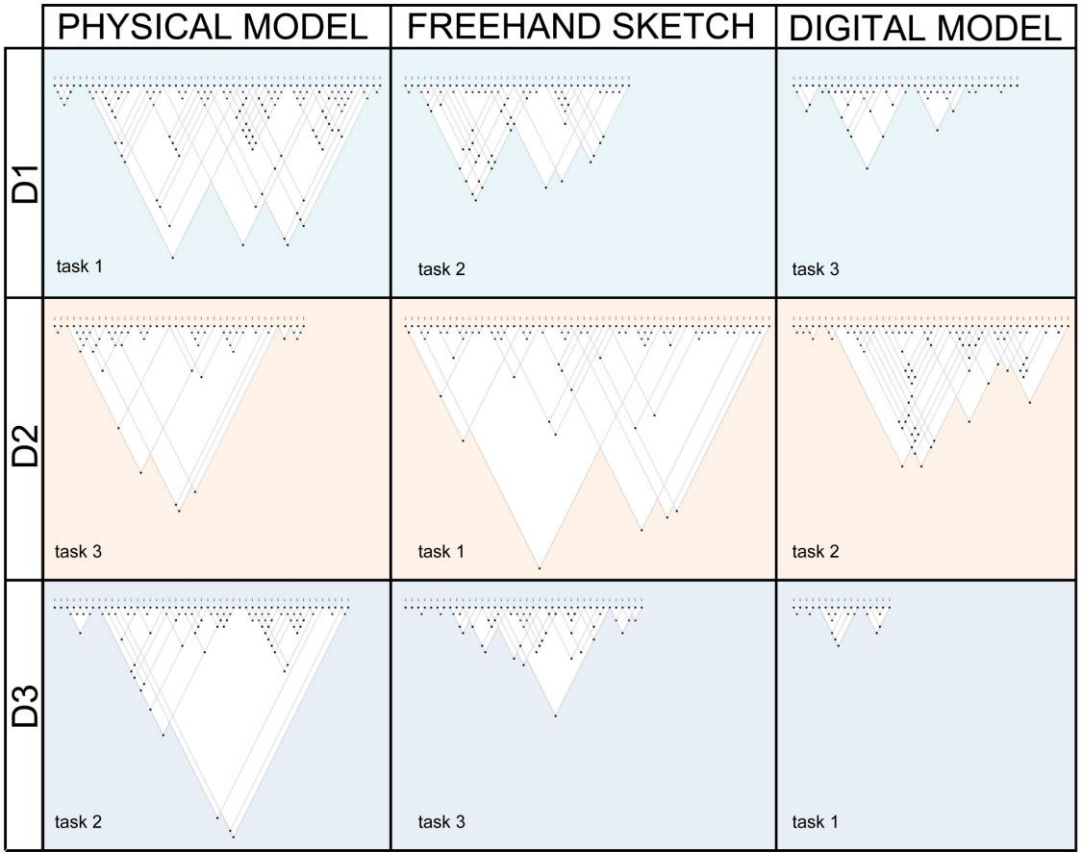
In order to analyze the protocols, first the transcripts of the protocols are written. While writing the protocol transcripts, both the verbalizations from the think-aloud sessions and the physical movements the participants made are noted together with the exact movement time. Later, the protocol transcripts are segmented to the design moves. According to Goldschmidt (1995), a design move is "an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" or "an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed". This definition is taken as reference while segmenting the protocols to its design moves.

Linkography technique is used for the analyses of the protocol studies. For this study, the Linkographs are generated only for the initial conceptual design phases since otherwise the Linkographs would be too long to manage. So, it is very important to underline that the following discussion concerns the initial conceptual design phase of a design process and not the detailing phase of a conceptual idea.(see Appendices for protocol transcripts and Linkographs)

With an understanding of the construction of a Linkograph, one is able to comment on the design behaviour without studying the design protocol (Kan & Gero,2005). For each designer, three Linkographs are created. These Linkographs

are shown on Table 2. The difference in length in horizontal direction is due to the number of moves generated to complete the design task. Time spent to complete the tasks is not presented on this table as a variable. Therefore lengths of the Linkographs do not differ because of the duration of the protocols but because of the number of design moves generated. The interpretation and comparison of these Linkographs is made in chapter five.

Table 2 Linkographs of the protocol studies



Once the Linkographs are obtained, first the link index values are calculated. These values enable a comparative discussion concerning the productivity of the design sessions. Then, the methods to count the lateral transformations made, that are described in chapter three are applied and the vertical transformation values are calculated. These results are presented and discussed in chapter five. They constitute the research done to find an answer to the first set of questions with the main question being whether model-making can be considered as sketching in the early phases of the design process. To find the answers to the second set of questions inquiring in which ways models and model-

making processes can be ambiguous, the cam recordings are reviewed along with the Linkographs depicting the lateral transformations. The snapshots of the related instances are provided and discussed in the subsequent chapter.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter offers a synopsis of the study and provides a synthesis of the protocol studies and discusses the results. First the Linkographs presented in chapter four are interpreted and compared. The link index values are calculated to compare the design protocols in terms of design productivity which is considered as an indication of creativity. Through the method mentioned in chapter three, the number of lateral transformations made are counted and the vertical transformation values are calculated. These results are presented to discuss whether model-making can be considered as sketching in the early phases of the design process and constitute the first part of this chapter. In the second part, the use of models in each design session are examined and snapshots from cam recordings are provided to support the arguments concerning the aspects which make models and model-making processes ambiguous.

5.1. Is model-making sketching in design?

This study makes use of quantitative data for questioning whether model-making is a form of sketching in the early phases of the design process. Link index and the vertical transformation values, and the number of lateral transformations made constitute the quantitative data on which the arguments are based. However, as previously cited these results do not present concrete facts concerning models and model-making in architecture since there are many limitations in this study which prevent the generation of a universal argument on model-making and models. The results presented here and the discussion made comprise only these specific protocol studies.

5.1.1 Link index value, design productivity, creativity and their correlation with sketching activity

Link index is the ratio between the number of links and the number of moves that generate them in a given design cycle (Goldschmidt,1992). Goldschmidt introduces this value to assess productivity of the design processes: a higher link index value corresponds to a higher link density and is one of the

indicators of a productive process. In this study, the link index values of the design protocols are calculated to enable a discussion on whether model-making can be considered as sketching. Therefore, it is first necessary to discuss what a productive design process indicates for this study and how it relates to sketching activity.

Departing from the description provided by Goldschmidt, by making use of Linkography and link index values, a design process can be measured in terms of productivity without the necessity to look at the end product. But what a productive design process leads to is not clear. Whether it leads to better design ideas, thus what makes a design idea better than the others, or to generation of numerous ideas should be clarified in order to indicate how this study approaches to design productivity.

A further research is done to reveal the correlations between the links among moves generated during the design protocols and the *creativity* of the end products (Goldschmidt & Tatsa, 2005). Goldschmidt and Tatsa, with this study, inquire which ideas qualify as good ideas, how they are developed and how do they lead to a good product. They start by associating creativity with ideas, with good ideas mostly and claim "not every idea or every good idea qualifies as creative, but every creative outcome can be traced back to good ideas that started it off ". In inquiring how good ideas lead to a good product, they make use of Linkography method and justify the use of Linkography departing from Gruber's (1980) argument that "Interesting creative processes almost never result from single steps, but rather from concatenations and articulation of a complex set of interrelated moves". Departing from this argument, they build their hypothesis and claim that intensive interlinking among design ideas, design decisions or design moves, is the hallmark of good and creative design. Consequently, they analyze the design activity of second year architectural students during a semester-long exercise. They conclude with the fact that good ideas can be identified, counted and characterized by looking at the links they generate on Linkographs and that the ideas are as good as suggested by the network of links they create among themselves. If the density of links is considered as an indication for the quality of ideas, then with this research, Goldschmidt and Tatsa claim that the most productive processes (which have the highest link index values and densest links) are the most creative ones. Although, this correlation between design productivity and creativity still needs further research to be accepted as true, this study discusses the creativity of the design protocols through their productivity. It is important to underline that it is not the creativity of the product that is in concern,

but the creativity of the process. Therefore, why discussing creativity and productivity of design protocols to reveal whether model-making can be considered as sketching in the early phases of the design process? How is creativity related to sketching activity?

In chapter two, while what sketching refers to within the context of this study is clarified, it is mentioned that *free-hand sketching* enables creative shift to new alternatives (Goel, 1992), and that it constructs a dialogue between "seeing that" and "seeing as", where "seeing that" is reflective criticism and "seeing as" is the analogical reasoning and reinterpretation of free-hand sketch that provokes creativity (Goldschmidt, 1991). Therefore, free-hand sketching in the early phases of the design process is considered as an activity which stimulates creativity. This paper, while inquiring whether model-making can be considered as sketching in the initial phases of the design process, questions whether it also stimulates creativity as free-hand sketching does. The answers to this question is sought through the link index values of the protocol studies. As cited, link index values reveal the productivity of the design sessions which can be considered as an indication for creativity.

5.1.2 Link index values of the protocol studies and related discussion

Table 3 shows link index values of each participant's design sessions with three design mediums. Time they have spent to finalize the initial conceptual design phase is also indicated and the moves and links they have generated per minute is calculated.

Table 3 Total number of moves and links, link index values and duration of the protocols

Designer	Design Medium	Total # of moves	Total # of links	Link index	Time elapsed	Moves / min	Links / min
D1	Physical model	52	111	2,13	10' 50"	4,8	10,2
	Freehand sketch	36	59	1,63	8' 30"	4,2	6,9
	Digital model	36	36	1	20' 55"	1,7	1,7
D2	Physical model	40	47	1,17	15' 55"	2,5	2,9
	Freehand sketch	58	62	1,06	19' 30"	2,9	3,2
	Digital model	44	77	1,75	9' 25"	4,7	8,1
D3	Physical model	47	70	1,48	21' 50"	2,1	3,2
	Freehand sketch	38	43	1,13	9' 25"	4	4,6
	Digital model	16	14	0,87	9' 30"	1,7	1,5

According to this table, the link index value is higher for D1 in physical model condition (2,13) compared to freehand sketching (1,63) and digital model (1,0) conditions. Time spent to complete the initial conceptual design phases

however is more in digital model condition (20'55'') than the physical model (10'50'') and freehand sketch (8'30'') conditions. These values indicate that the design session using physical model is the most productive and the design session using digital model is the least productive process for D1.

For D2, the link index value is higher in digital model condition (1,72) compared to physical model (1,17) and freehand sketch (1,06) conditions which have closer values. D2 spent very less time to complete the initial conceptual design phase in digital model condition (9'25'') when compared to physical model (15'55'') and freehand sketch (19'30'') conditions. According to these values, the design session using digital model is the most productive and the design session using freehand sketch is the least productive process for D2.

For D3, the link index value is higher in physical model condition (1,48) compared to freehand sketch (1,13) and digital model (0,87) conditions. However, the time spent during the physical model condition (21'50'') for the conceptual design generation is comparatively very high than the freehand sketch (9'25'') and the digital model (9'30'') conditions. For D3, the design session using physical model is the most productive and the design session using digital model is the least productive process. So for D1 and D3, physical model condition result with the highest link index value and digital model condition, end with the lowest link index value. On the other hand, D2 has the highest link index value with digital model condition and lowest with freehand sketch condition.

In all the three cases link index values of physical model-making conditions are higher than the link index values of free-hand sketching conditions. If the assumption that there is a correlation between the productivity and the creativity of a process is true, and it is taken for granted that free-hand sketching promotes creativity, then, we can deduct regarding the values presented in Table 3 that physical model-making stimulates creativity. Therefore, physical model-making satisfies one criterion of sketching: to provoke creativity.

Link index values of the sessions with digital model-making are in two of the cases lower than link index values with free-hand sketching conditions. Therefore, again through an inductive reasoning process, it can be said that digital model-making do not stimulate creativity, hence do not satisfy this criterion of sketching. The example where link index value of digital model-making condition is the highest link index value, is discussed further in detail in this chapter, pointing out the possible reasons behind this extremity.

Link index numbers might be useful in discerning productivity of the design sessions (Goldschmidt,1992) however are not sufficient to analyze the protocols. It

is previously shown that Linkographs can generate different linking patterns which enable different interpretations of the design process. For instance, designers who start the design process with exploring different options and then select one to develop will produce a very different Linkograph compared to designers using a holistic approach without exploring different options, although the link index values are similar(Kan & Gero, 2005). Therefore analysis of these linking patterns are also necessary along with link index values while commenting on design processes.

5.1.3. Lateral transformations and vertical transformation values of the protocol studies and related discussion

Goel's (1992) study shows evidence that the uncertain and ambiguous character of free-hand sketches opens ways to new discoveries and creative shifts to new alternatives that he calls lateral transformations. Therefore, another criterion of sketching activity is to enable lateral transformations. In questioning whether model-making is a form of sketching in the early phases of the design process, this criterion is taken as a reference point to compare free-hand sketching and model-making. Linkographs can easily indicate what types of transformations are being made by displaying link patterns: dense clusters of links correspond to vertical transformations while scattered links denote lateral transformations (Goldschmidt & Tatsa, 2005). A method which interprets Linkography in a way to explore the lateral and vertical transformations is developed in this study. This method is previously explained in chapter three. The outcomes of this method are quantitative data constituting of the number of lateral transformations and the values of vertical transformations. Table 4 shows these values along with the link index numbers.

Table 4 Lateral transformations and vertical transformation values of protocols

	Design Medium	Total # of Lateral Transformations	Vertical Transformation Value (Mean Value Y)	Link index
D1	Physical model	15	5,85	2,13
	Freehand sketch	18	6,05	1,63
	Digital model	25	2,66	1
D2	Physical model	16	4,53	1,17
	Freehand sketch	29	5,16	1,06
	Digital model	16	5,98	1,72
D3	Physical model	21	4,88	1,48
	Freehand sketch	17	3,42	1,13
	Digital model	6	2,28	0,87

According to this table, D1 made quite a lot of lateral transformations during the design session with digital model (25) compared to design sessions with freehand sketch (18) and physical model (15). However, the vertical transformation value is very low for the digital model condition (2,66) compared to freehand sketch (6,05) and physical model (5,85) conditions. These values, together with the link patterns of the Linkographs presented in Table 2, in chapter four, indicate that D1, during the protocol with physical model and freehand sketch, generated ideas that she also could develop. Her protocols with these mediums displays dense clusters of links. Moves are generally inter-related but not totally connected indicating that there are a lots of opportunities for good ideas with development. During the digital model session, on the other hand, she jumped from one design move to another but her moves are random trials that do not have a contribution to the design concept. Her protocol with digital model therefore displays many totally unrelated moves or moves only related to directly preceding ones. This indicates that either there are no converging ideas, so low opportunity for idea development, or that the process is progressing but not developing. Link index values of these sessions also correspond to this interpretation with the highest value for physical model condition and the lowest value for digital model condition.

During the design session with freehand sketch, D2 made much more lateral transformations (29) than his design sessions with physical model (16) and digital model (16). The session with digital model has the highest vertical transformation value (5,98) and the session with physical model has the lowest vertical transformation value (4,53).Therefore, D2's protocol with digital model displays dense clusters of links compared especially to his protocol with physical model. In his protocol with physical model, there are quite a number of moves but the chunks are not deep. This indicates that either D2, with physical model, could not deepen his ideas, or that he had an already crystallized idea that he did not need to deepen.

D3 has the biggest number of lateral transformations (21) and highest value of vertical transformation (4,88) from the design session with physical model and the smallest number of lateral transformations (6) and the lowest value of vertical transformation (2,28) from the design session with digital model. Similarly, her protocol with physical model displays dense clusters of links forming chunks and webs when compared to her two other protocols. Her protocol with digital model is radically poor in moves and links. The very few number of design moves indicates that either she could not make use of the design medium to generate ideas, or she had an early crystallized design idea. Eventually, links that are very

few in number could not form webs or chunks, indicating that she could not deepen her ideas with digital model medium.

From these results, it is not possible to end up with a clear cut conclusion, since in each case the medium with the highest lateral transformation value is different. However, the study revealed two important issues. First, it showed that there is an important distinction to be made concerning ambiguity and lateral transformations. Lateral transformations can due to two types of ambiguity: ambiguity of the medium and ambiguity of the process which effect the outcomes in totally different ways. Adapting this argument to the current study, it is necessary to clarify whether it is the ambiguity of models or the ambiguity of the model-making process that led to generation of lateral transformations. Second, it revealed that the number of lateral transformations do not have any significance in assessing sketching activity unless they are accompanied with vertical transformation values. This implies that a design medium is useful in the conceptual design process as a sketching tool as long as it enables emergence of new ideas together with the possibility of maturing those ideas into a satisfying design proposal. Therefore, Goel's (1992) argument to associate the initial design processes with lateral transformations and the subsequent processes with vertical transformations is misleading. The initial design phases should also comprise vertical transformations so that the lateral transformations gain significance.

5.1.4 Observations and remarks about the protocol studies and comparison with the quantitative data

Data deducted from the Linkographs concerning the design protocols might be sufficient to analyze the protocols. However personal observations and remarks of the author must also be taken into consideration.

According to the Linkographic data, D1 and D3 had the highest link index value with the physical model-making condition, while D2 had a comparatively low value. The Linkographs of the physical model-making condition of D1 and D3 displayed dense clusters of links while in D2's Linkograph links did not deepen. This difference however is probably not due to the physical model medium but due to the physical model-making processes. D1 and D3 did not have an early crystallized design idea during the protocols. They explored the problem space with different options and progressively developed their design. D2, on the other hand, had a holistic approach. He came up with a very early idea about the form of the building, and during the protocol, he did not search for other alternatives. This

approach continued at the second phase of the experiment as well, where the designers are asked to develop their initial conceptual ideas with a 1/200 scale model. D1 and D3, while developing their ideas through physical models, made unexpected discoveries, but comparatively D2 had very few discoveries of that sort. Figure 10 shows the 1/200 scale models of each designer at the end of the design processes.

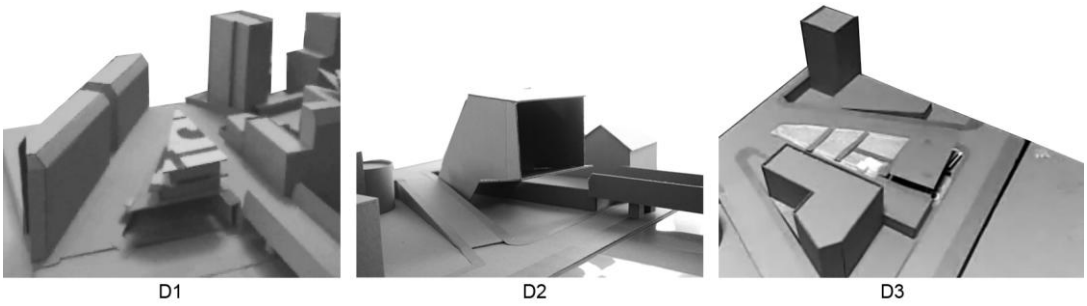


Figure 10 1/200 scale physical models D1, D2 and D3 presented at the end of the physical model-making sessions

D3, at the pre-experiment interview stated that she is used to conceptualize her ideas through physical models and she thought she would be more comfortable designing with physical model. Although she had the highest link index value with the physical model medium, she spent more than twice the time she spent with freehand sketch and digital model to generate the conceptual design idea. She later claimed in the post-experiment interview that being supposed to think-aloud was confusing her ideas and that she could not focus on her design. She said that while she is on her own, she makes random moves without knowing the consequences and that these moves ends with surprising discoveries. However, she argued that since she is asked to verbalize each move, she could not benefit from that discovery process.

Another very important observation to highlight is concerning D2's design session with digital model medium where he ended with the highest link index value. He might have the highest link index value with the digital model medium, but most of the moves presented on the Linkograph are moves conceived because of his verbal acts and are not totally related with a search through digital modeling media. So, it can be said that at least during the initial conceptual design phase of the experiment with digital model, he made intensive use of the mental imagery instead of searching alternatives through digital modeling media. Linkographs however do not reveal this fact. Figure 11 presents the digital model D2 generated at the end of the initial conceptual design phase.

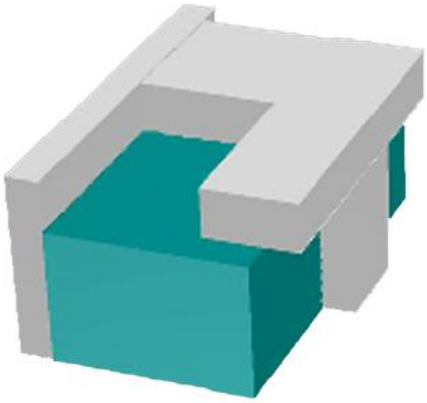


Figure 11 Digital model of D2, generated at the end of the initial conceptual design phase.

The reasons why D1 and D3 had the lowest link index values with the digital design medium in the early conceptual design phase are different. D1 had control over the CAD software, she knew the commands and she could do what she wanted to do. However, she did not have control over the design process as much as she had with physical model condition and freehand sketch condition. She could not develop her ideas and she made random trials which are not connected with each other. What is interesting is that she also had the highest number of lateral transformations with the digital model-making process. Therefore, it can be deducted that what led to lateral transformation is not the ambiguity of the digital model medium but the ambiguity of the digital model-making process which are two different notions. D3, on the other hand, had a different problem. She did not have control over the CAD software. She spent a lot of time searching for the right commands and ended up by generating her design through very few of them. She claimed that this caused too much discomfort during the design session and that probably while searching ways to control the interface of the software, she lost the sequence of the design process and missed good ideas. Accordingly, her lateral transformation number with digital model-making process is extremely low. In her case, this can be attributed to the unambiguity of the medium, of the digital models. The second part of this chapter discusses the aspects which make models and model-making processes ambiguous and which makes them unambiguous.

5.2 In which ways model-making and models can and cannot be ambiguous?

In the first part of this chapter, it is shown that the ambiguity of models and the ambiguity of model-making is two different notions effecting the conceptual design process differently. While ambiguity of models enable generation of new ideas and lateral transformations, the ambiguity of model-making process

sometimes prevents gaining control over the process. The second part of this chapter, therefore, inquires in which ways model-making processes and models can and cannot be ambiguous and how this two types of ambiguity interrelate. This inquiry is done through reviewing the cam-recordings along with the Linkographs depicting the lateral transformations. The snapshots of the related instances are provided to document the design moves that the subjects generate using models that result with lateral transformations.

5.2.1 Discussing the ambiguity of physical models and physical model-making

D1, at the beginning of the protocol asked whether she can change her position relative to the site model and set her view as depicted in Figure 12. She claimed that when looked from this angle, the site evokes different ideas. To give the opportunity of perceiving the whole (site) from different viewpoints is a much appreciated feature of physical model-making. It gives way to new interpretations. Goel (1992) relates lateral transformations to reinterpretations of the existing situations. Therefore, the property of physical model-making to enable interaction with physical models from different views is an ambiguous aspect of the physical model-making process, since it enables reinterpretations, in other words, lateral transformations in the solution space.

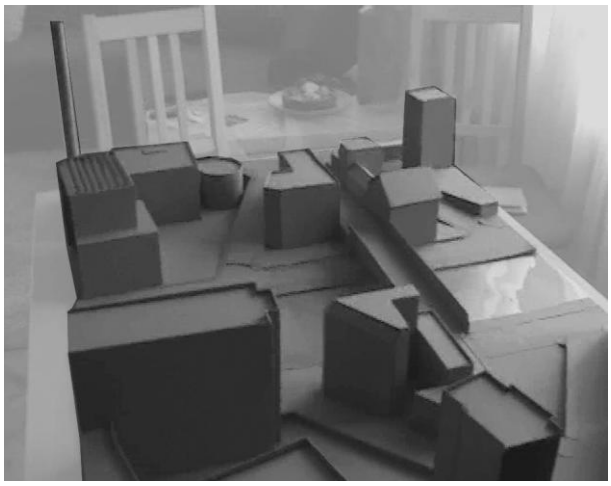


Figure 12 D1's selective position relative to the physical site model

During the physical model-making process, designers interact with physical models through their haptic senses. This is also valid while communicating the design ideas. At certain points, haptic movements replace verbalizations. Pointing out, instead of verbally explaining in detail, eases the design communication and lightens the cognitive loads on behalf of the designers. Figure 13 shows how D1 makes use of her hands while she communicates her ideas. If there was no model in front of her, this communication would be much harder, since instead of pointing out the parts she wants to show, she would need to attribute certain words, i.e., the buildings at the right side of the site, the acute angle part, the level of the canal, etc.

Figure 13 D1 using her hands to point out certain places on the site model

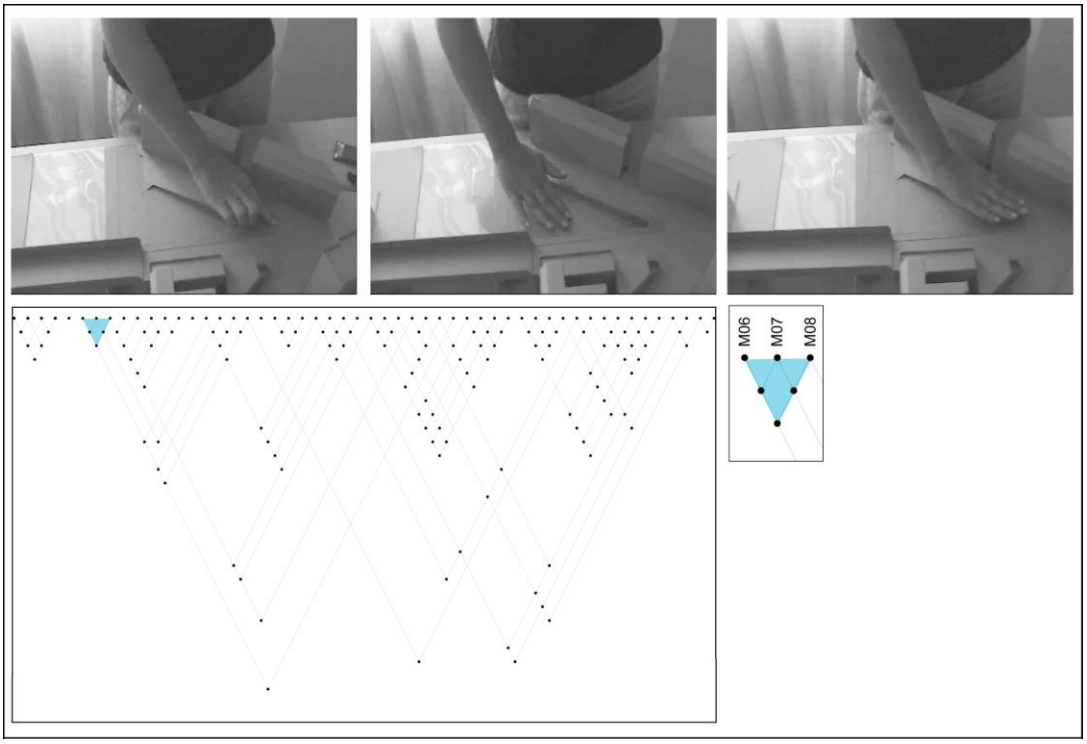


Figure 14 D1 discovering the level differences

With the help of the three-dimensionality of the physical model, D1 makes the discovery of the level differences within the given site. She decides to use these level differences as a departing point to work with planes (Figure 14):

> **M06:** But the first thing that comes to my mind when I look at the site, is to use the upper level –she points out the level of the bridge—to expand that area…
> **M07:**and to use the lower level –she points out the level of the canal—to expand this area…
> **M08:**So, I have the idea of working with planes… layer over layer like this…

From this specific example, the following argument can be deduced: the property of physical models of representing the reality in three dimensions enables three-dimensional interpretations of reality. It consequently gives way to three-dimensional discoveries. Therefore, physical models can be considered dense and ambiguous in the way they contain the information in three-dimensions and enable three-dimensional inquiries.

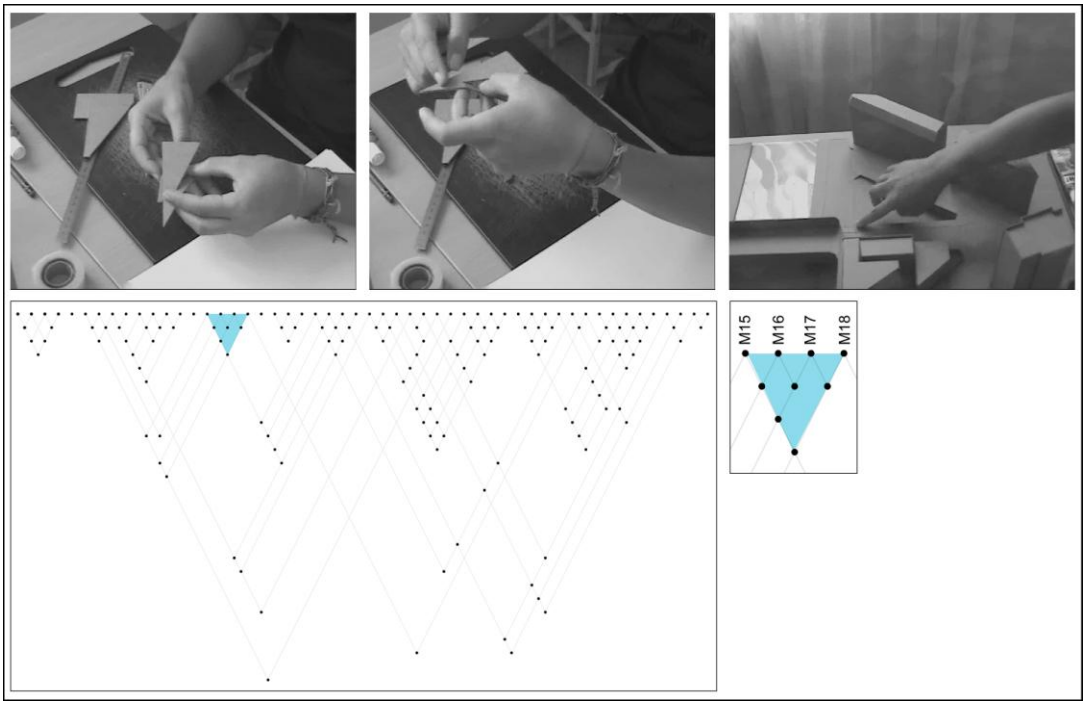


Figure 15 D1 introducing the idea of connecting the levels via ramps

There are also certain instances captured within physical model-making protocols that are specific to the situations and cannot be generalized, but are important to exemplify in which ways physical models can be ambiguous.

D1, while working on her conceptual model, cuts and folds the cardboard. Through this cutting and folding act on the cardboard, she discovers that there can be a ramp connecting the two levels available on the site. Further, through this discovery, the idea to connect all the levels with each other emerges (Figure 15). Cutting and folding the cardboard is a design move which is quickly performed. Cardboard models are flexible in this sense that they accommodate quick changes. This flexibility of the cardboard models enables the widening of the solution space, therefore makes cardboard models ambiguous.

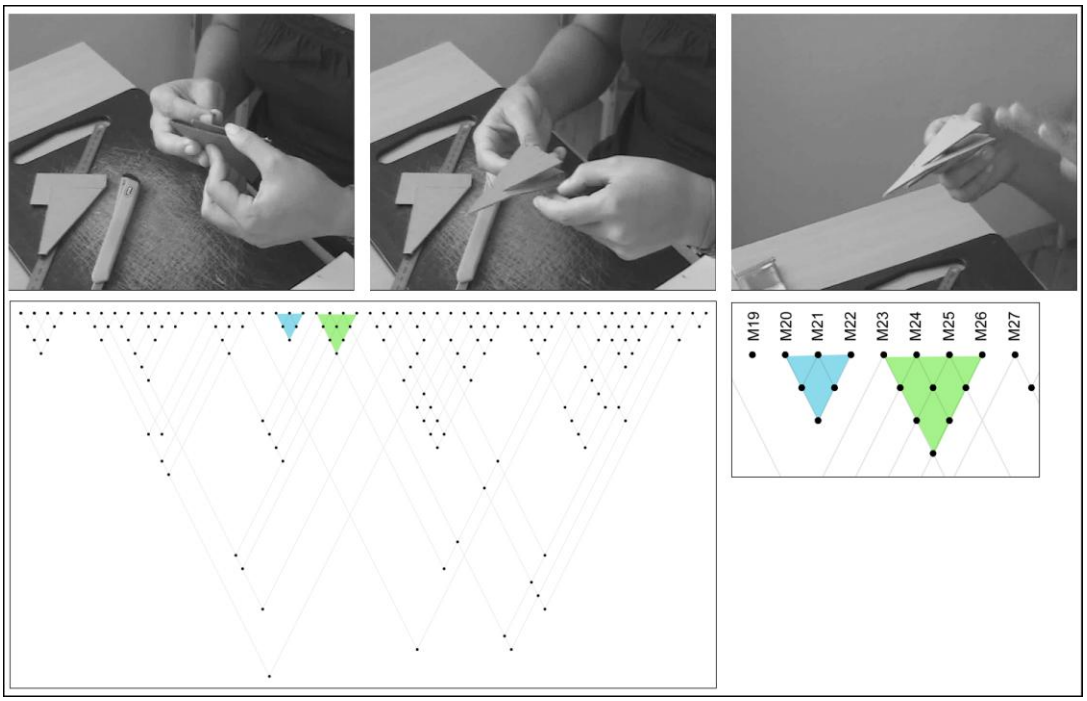


Figure 16 D1 coming up with the idea to use the ramps on the façade

While working on the model, D1 makes use of needles to connect the planes. She states that putting cardboard between the planes creates a massive effect that she does not prefer. Using needles instead enhances the planar effect of her conceptual design, but more importantly, is faster and it makes the cardboard model flexible. It also makes further additions to model possible. Through the use of needles, D1 makes the discovery of using ramps as the primary façade element (Figure 16). The first triangular part depicted on the Linkograph from Figure 16, corresponds to her justification of using needles. The second triangular part corresponds to her decision of using ramps as façade elements. Therefore, as can be seen on Linkograph, the decision of using needles led to a discovery concerning the façade design. This again is an example of how flexibility of the cardboard model makes lateral transformations possible.

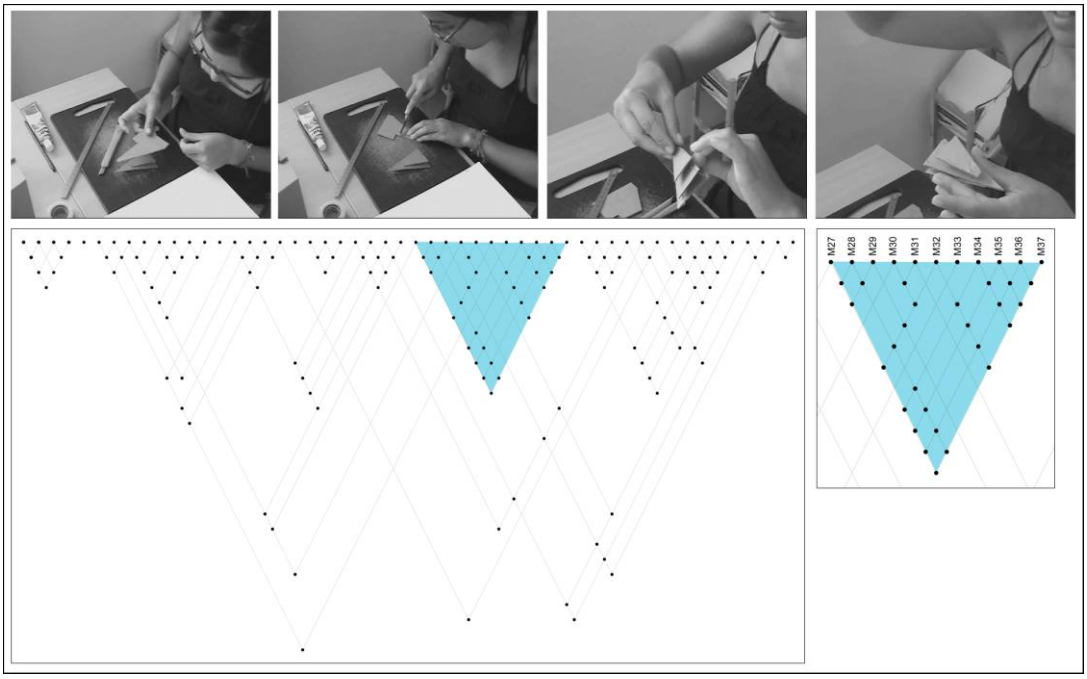


Figure 17 D1 introducing the gallery openings after accidentally cutting one plane smaller

As in free-hand sketching, model-making also enables discoveries through accidental moves. D1, at an instance during the design process, cuts a triangular plane smaller than she plans to cut. She does not give away with that triangular plane and *tries it* on her model. Consequently, she comes with the idea that in the upper levels, these planes can get smaller or bigger giving way to gallery openings. She then elaborates this idea.

A small mistake led to the generation of the densest chunk on the Linkograph of D1's protocol with physical model. Therefore, making mistakes and attributing new meanings to those mistakes is one of the ambiguous aspects of physical model-making processes.

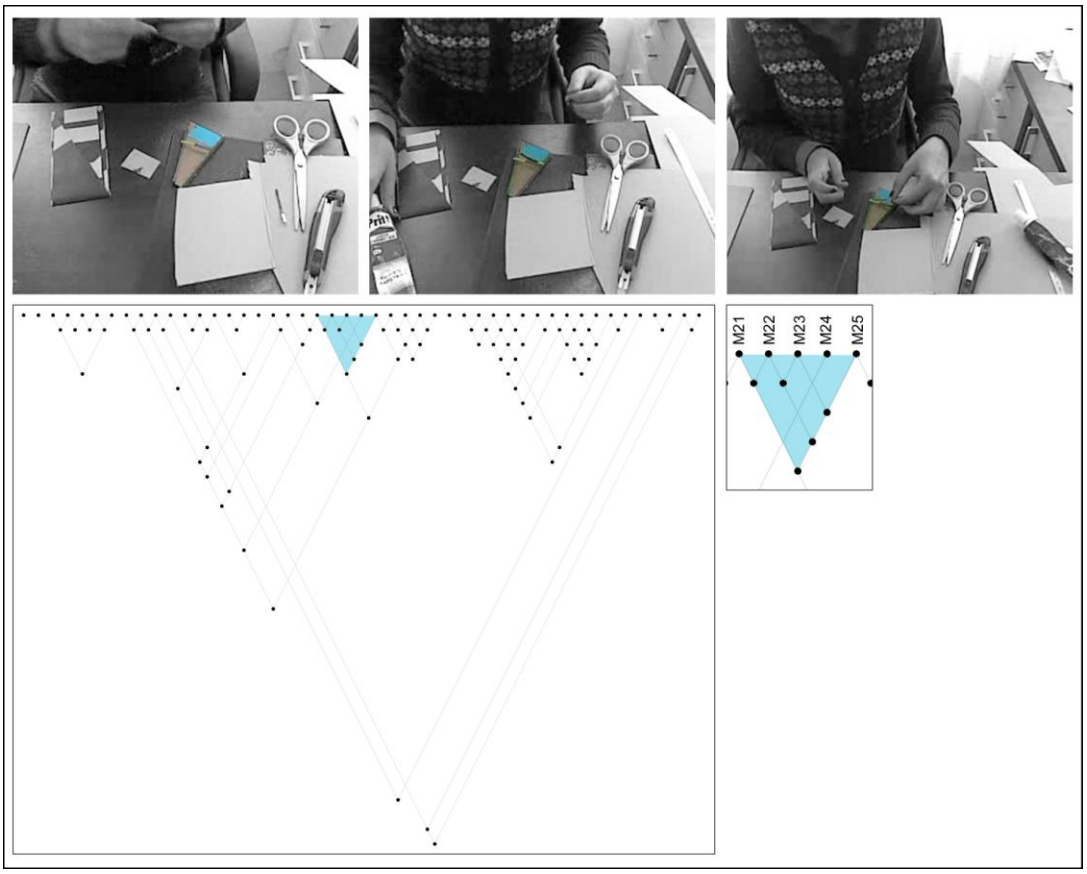


Figure 18 D3 displacing the parts of the model

D1 is the subject who obtained the highest link index value in physical model-making session, but D3 also benefitted from the ambiguity of physical models to discover new ideas. In an instance during the conceptual model-making phase, she cuts and puts a strip on her model. After considering its place, she decides to take it off and put it on the other side (Figure 18). Physical models generally consist of different pieces. The possibility to play with these pieces by taking them off, and displacing, rotating, changing, dislocating them makes way to new discoveries. Therefore, the property of physical models of being consisted of different pieces is another aspect which makes them ambiguous and the possibility to play with these pieces is one of the conditions that enhance the ambiguity of physical model-making.

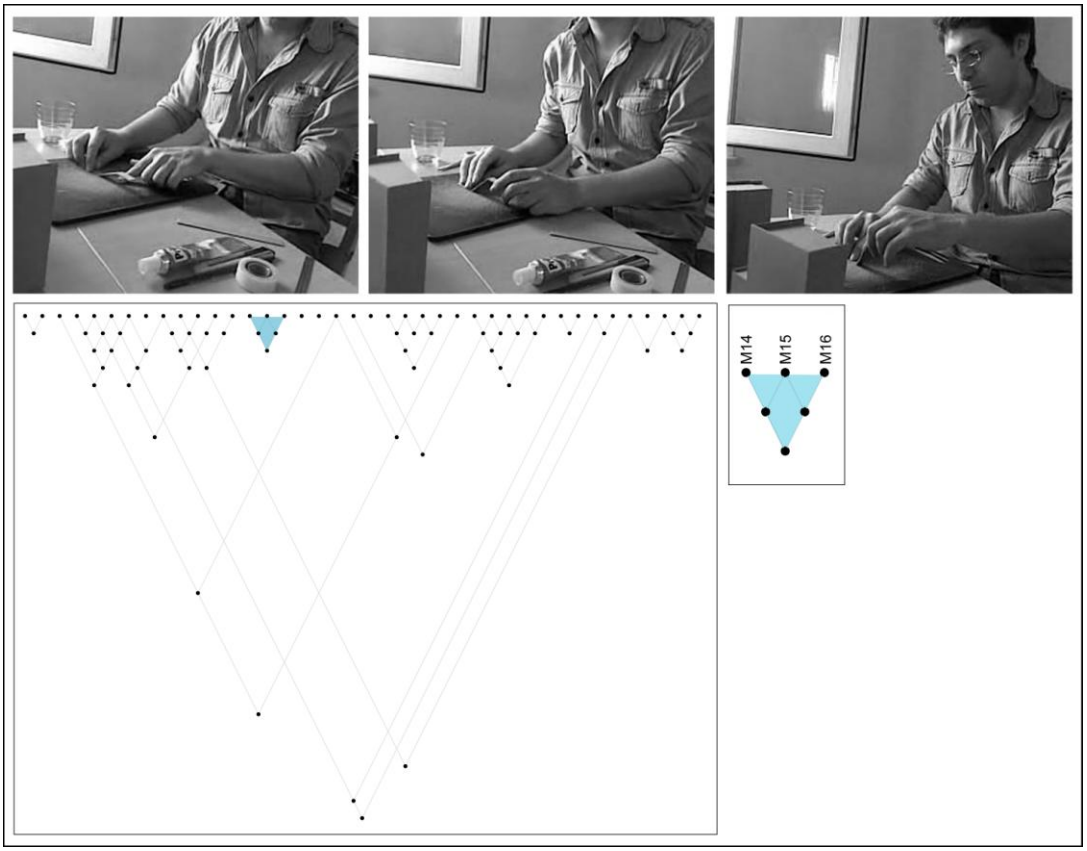


Figure 19 D2 expanding the solution space through folding

D2 is the subject who obtained the lowest link index value in the physical model-making session. As previously cited, D2 did not totally benefit from the ambiguity of physical model-making. He came up with a formal idea and did not search for any alternatives. The design ideas are early crystallized in his case. Still, while searching for the form, he made use of the ambiguity of physical models. In the instance exemplified in Figure 19, he folds a piece of paper in different angles and searches for a correct spatial relation. Therefore, as pointed out previously, the flexibility of the modeling material (cardboard) enables different situations to be tested, another indication for the ambiguity of physical model-making.

The studies through the protocols with physical model-making condition justified certain assumptions about physical model-making and physical models. It showed that the property of physical model-making to enable interaction with physical models from different viewpoints enables reinterpretations and therefore is an ambiguous aspect of the physical model-making process. To ease the design communication by allowing haptic movements is another aspect of physical model-making. Also, it is shown that the property of physical models of representing the reality in three dimensions enables three-dimensional interpretations of reality which consequently gives way to three-dimensional discoveries. Furthermore, subjects benefitted from the flexibility of the cardboard model to test and generate ideas. Via cutting and folding, displacing the pieces of the model and using needles to assemble the pieces, subjects made quick discoveries that changed the course of the design processes. These are examples that show how flexibility of models enable lateral transformations. How accidental design moves during model-making lead to generation of new ideas is also exemplified. D1 generated her densest chunk with the help of a mistakenly small cut plane. To sum up, physical models (cardboard models) are ambiguous because by enabling quick and flexible changes, by representing the reality in three dimensions, they allow new interpretations to be made. Physical model-making processes are ambiguous, because by enabling the examination of the model from different angles, and by giving possibility to mistakes, they allow generation of new ideas and interpretation of the existing ones.

Consequently, important questions arise: If the physical model is not ambiguous in its nature, can the designer benefit equally from the ambiguity of physical model-making process? Therefore, can an unambiguous medium handle the ambiguity of the process? These are in fact questions concerning the relations between ambiguity of mediums and ambiguity of processes. Answers to these questions will be sought further in this chapter, through examples of ambiguous model-making processes with unambiguous mediums: digital model-making process and digital models.

5.2.2 Discussing the ambiguity of digital models and digital model-making

D2 has the highest link index value with digital model medium, while D3 has the lowest. However, it is previously cited that the design moves that D2 realized during the protocol study constitute mostly his verbalizations and not his trials through model-making software, although he does not have any problem using the software. Linkography method, hence, is not useful in revealing this difference. It is consequently, hard to initiate, with D2's protocol, a quest for the aspects of digital model-making which cause ambiguity.

D1 has her lowest link index value and vertical transformation value in digital model-making session. However it is also digital model-making session during which she made the most lateral transformations. This indicates that she generated many ideas that she could not develop. Goldschmidt (1992) relates these kinds of design processes to non-productive processes and associates random trials, large amount of moves that do not interlink with others and less structured thinking processes where issues are not systematically investigated with these processes. D1's situation with digital model-making medium, thus, corresponds to a non-productive process. She made quite a lot of random trials which she abandoned without developing in the initial conceptual design search (Figure 20).

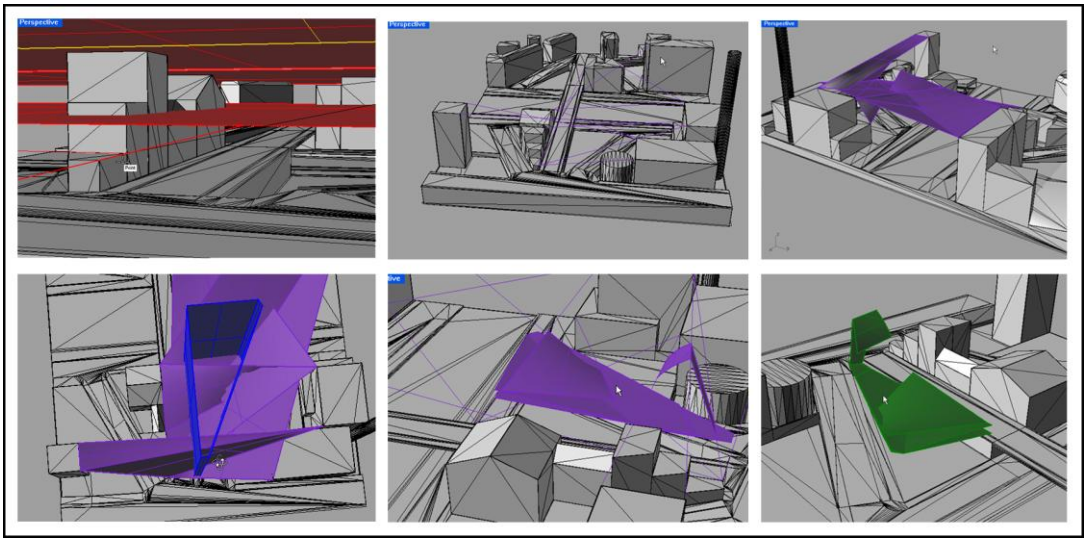


Figure 20 The conceptual design process of D1 in digital model-making session

The high value for lateral transformations, in this case, is not an indication of the ambiguity of digital model, but an indication of the ambiguity of the digital model-making process. In this case, lateral transformations do not emerge because of reinterpretations of existing situations, but emerge because of random trials. As the proof is also given with physical model-making protocols, while ambiguity of mediums lead to more productive designs, the ambiguity of processes lead to less productive ones. Therefore, what is it that makes digital model-making ambiguous and digital models unambiguous?

By previous research, the computer, is claimed to be unable to provide appropriate support in the early phases of the design process. The reason is cited to be the well-definiteness of the current CAD programs which are judged to force the designers to produce well-defined representations in a phase where they should make use of ambiguous ones (Paynter, Shillito, Wall, & Wright). This current study also points out that digital models are unambiguous design tools, or at least, all the three subjects' protocols do not show any clue of ambiguity of digital models. Compared to free-hand sketches and physical models, digital models are clear cut representations. This sharpness evokes a feeling of completeness and causes the early crystallization of design ideas. D1, while searching for alternatives, made use of several commands of the CAD program: she drew planes, connected lines, created surfaces, intersected and subtracted these surfaces, etc. The outcomes of these moves, however, do not evoke the feeling of a sketch, since they look already complete, therefore, well-defined.

Free-hand sketching and physical model-making in the early phases of the design process, enable haptic manipulations. Most of the current CAD programs, on the other hand remain incapable of providing such relations (Sener, 2007). This lack of haptic interaction can be a reason for the unambiguity of the digital models since, instead of an haptic interaction, with CAD programs, designers are supposed to make use of strict interfaces to generate ideas. Therefore current CAD programs are accused for preventing designers from rapidly externalizing their design ideas because of these complex interfaces that interrupt their creative process (Paynter, Shillito, Wall, & Wright). Although D1 and D2 did not face that problem, D3 claimed having problems with the interface of the software. She spent considerable time searching for the right commands and ended up by generating her design through very few of them. She claimed that this caused too much discomfort during the design session and that probably while searching for ways to control the interface of the software, she lost the sequence of the design process and missed good ideas. Therefore, in her case, beside the unambiguity of CAD

software, not being used to the interface made the digital model-making process unambiguous as well. Figure 21 shows the digital model D3 could generate at the end of 9 minutes and 30 seconds in the conceptual design phase. Its formal simplicity is basically due to D3's unfamiliarity with the interface and depicts why the number of lateral transformations done is very low when compared to D1's protocol.

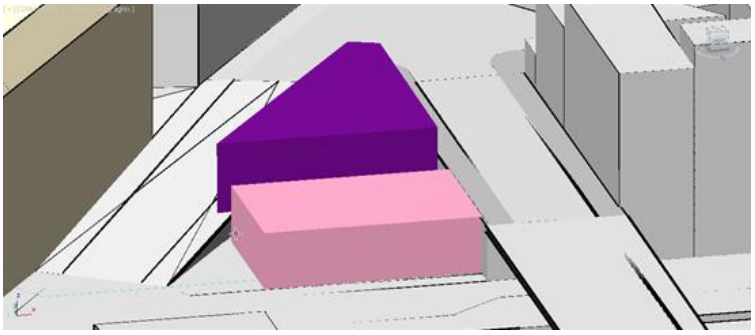


Figure 21 The digital model of D2 generated at the end of the conceptual design phase

Although, CAD software is deemed not to be useful for developing ideas in the initial conceptual design phase, it can be more useful in the idea development process, where the ideas are refined. The latter phases of the design processes are not examined in detail, in this study, as the conceptual design phases. Therefore, the arguments concerning the latter phases could only be developed through the examination of the end products (Figure 22). Since the focus of this study is on the processes, instead of products, a discussion on the latter phases is not preferred to be presented.

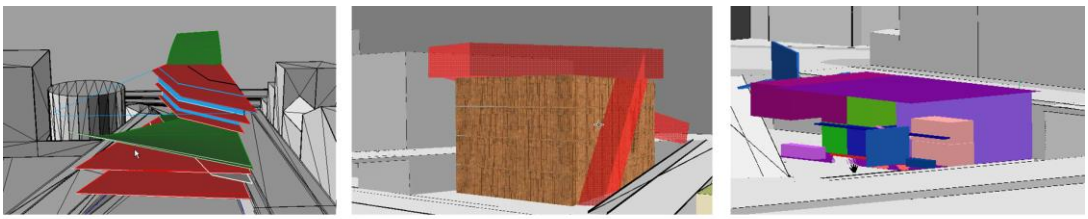


Figure 22 Digital models of t19he subjects presented at the end of digital model-making sessions

CHAPTER 6

CONCLUSIONS

This study intended to contribute to the understanding of model-making in the early stages of the architectural design process and the dearth of research on model-making in design cognition field was the primary motivation of this study. With this intention, the development of a methodology to discover the relationship between the designer and the models done during the initial phases of the design process, became one of the objectives of this study. This methodology and discussions on certain specific terms associated with this methodology, at certain times, exceeded the inquiry on model-making. This is due to the various limitations of the empirical research on model-making, which prevented generation of concrete facts. Therefore, this research presents itself as an experimental study, rather than a concluded theory on model-making in architectural design.

In this chapter, first, the conclusions concerning the methodology used is presented. Consequently, the outcomes of the empirical research in behalf of model-making process and models are given. The possible contributions of this study to design cognition field and to *architectural learning environment* are also discussed. The chapter, then, concludes by suggesting further research topics related to the presented study.

6.1 Outcomes of the methodology and discussion on specific terms

Departing from Goel's (1992) study, this research built its questions on the argument that ambiguous media enable lateral transformations. However, through protocol studies realized, it is found that ambiguity can be two-sided: the ambiguity of the design medium vs. the ambiguity of the design process. This study showed that the ambiguity of a design process with unambiguous media also makes way to lateral transformations. Therefore, lateral transformations are not solely the product of ill-defined representations, but can also be the products of ill-defined design processes. This research, with this conclusion, makes contribution to Goel's study.

The methodology used within this study, gave evidence that Linkography technique can be used to assess the transformations within a design process.

Therefore a link between Linkography technique and transformations in Goel's sense is constructed.

Constructing the link between Linkography and transformations opened way to other debates as well. Linkography is used by Goldschmidt to assess design productivity. Therefore, by using it to also depict transformations, the productivity of the transformations can be discussed. This study revealed that, the design processes which consist of a large number of lateral transformations which are accompanied by vertical transformations are the most productive ones. Hence, the design processes with many lateral transformations but with few vertical transformations are not productive.

This discussion on the relation between productivity and transformations leads to a discussion on the relation between productivity and ambiguity. The protocol studies held showed that the ambiguous design mediums make way to productive processes. However, it is also shown that ambiguous processes with unambiguous media do not lead to productive processes but lead to non-productive ones.

6.2 Outcomes of the protocol studies in behalf of model-making inquiries

Although the various limitations of the empirical study prevent generation of concrete facts concerning models and model-making in architecture, the outcomes of the research can be discussed with reference to the presented protocol studies and not as universal arguments about model-making.

The initial research question of this study was whether *models for* architecture could be considered as sketching in the early phases of the architectural design process. Regarding the protocol studies held with physical model-making situation, for all of the three subjects, physical model was an ambiguous medium which enabled creative shifts to new alternatives. Therefore, for all of the subjects, physical model-making was a form sketching. This is, however, not the same for digital model-making.

The study showed that digital models are well-defined, or at least, if they are ambiguous in some way, the subjects could not benefit from this ambiguity. The well-definiteness of digital models made digital model-making processes ill-defined in one occasion. Two of the subjects obtained their lowest link index values with digital model-making condition, therefore their design process with digital model-making was not productive, hence not creative. Consequently, with also the help of observational data through cam recordings, it can be said that digital

model-making, for none of the subjects, was a form of sketching. Therefore, for these subjects, digital models stand somewhere in between *models for* architecture and *models of* architecture.

6.3 Possible contributions of this research

This study points out the necessity for research on model-making in design cognition field. By pointing this need out, it can contribute to design cognition field through opening way to further research on model-making.

The methodology used in this study is adopted from design cognition field and further interpreted. By making deductions concerning certain specific methods (i.e. think aloud method, Linkography, protocol analysis), by pointing their deficiencies, and by developing them, this study makes another contribution to design cognition field. Also, by building the links between certain specific terms and methods (i.e. Linkography & transformations, transformations & productivity, productivity & ambiguity, productivity & creativity) it can open way to new debates within cognitive studies in design.

The study also can contribute to design computing field by its discussion on the shortages of CAD programs. This discussion being nourished from quantitative and observational data gathered from protocol studies makes it more reliable.

The ambiguous aspects of physical models and physical model-making processes are exemplified through snapshots from protocol studies. This can lead to questioning of the place of physical model-making in *architectural learning environment* and contribute to the understanding of physical model-making in this context. One implication can be, for example, to expand the limits of short sketch problems where students are mostly asked to submit free-hand sketches at the end of the session, by also allowing the submission of physical models.

Finally, this study can be an example in terms of the methodology used to discuss ambiguity, for future researchers who wish to inquire this notion. It provides the links between previous research and constructs a new method upon them.

6.4 Suggestions for further research

I would like to conclude this thesis by introducing new research questions that this study evoked. The answers to the following questions can be sought by future research:

- How can new manufacturing technologies (rapid-prototyping) effect the conceptual phase of the design process by constructing the bridge between

digital media and haptic media?

- Does physical model-making process differ in ambiguity with the use of different modeling materials and techniques?
- Are there any differences between different CAD software in terms of contributing to the design process?
- Do novice and expert designers benefit from models similarly or are there any differences related to the experience as in freehand sketching?

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APPENDICE A

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF PHYSICAL MODEL-MAKING PROTOCOL OF DESIGNER 1 (D1)

00:03 M01:
I have to first think about the dimensions.

00:05 M02:
For example, in 1/200 scale, how much space a cinema or theatre occupies?

00:07 M03:
Are there any constraints concerning the housing units?

00:15 M04:
Maybe I'll start by first making them as boxes… Then I can assemble them… Then I can find a concept…

01:05 M05:
Also can I turn this (site model) so that I can face the design area? Or I can sit that way…

00:53 M06:
But the first thing that comes to my mind when I look to the site, is to use the upper level –she points out the level of the bridge—to expand that area…

00:55 M07:
and to use the lower level –she points out the level of the canal—to expand that area…

01:10 M08:
So, I had the idea of working with planes**…** layer over layer like this…

01:20 M09:
But how am I going to stabilize those plane one over the other? For example, while making a sketch, we draw it easily but here, we have to also think about the connections underneath.

01:55 M10:
We can first make the triangle in the base… of course in a similar way. I am going to make it roughly.

02:20 M11:
This is the scaled down situation of the site –she shows the triangle she has cut—If this is the area we have for the base…

02:25 M12:
we can have a similar triangle at the upper level –she cuts another triangle—For the moment, I assume it is the same triangle..

02:45 M13:
But in the upper level, the road… one moment…what do we have in the upper level?

03:00 M14:
Haa, I can also use the basement?

03:08 M15:
By the way, now I'm thinking that, since there is this road going downwards… then… I am also thinking of uniting this part –the acute angle in the upper level—in the upper level… so I am going to show it that way in the model…

03:15 M16:
The lower triangle will be united with the road in the level of the canal…

03:20 M17:
In the upper level, it will be united with this level —she points out the acute angle…

03:35 M18:
It can even be united with the road along the bridge, since it is in the same level as here –acute angle…

04:07 M19:
Do I have to draw the surroundings? Oh, I am saying "draw", I mean "cut"…

04:13 M20:
Ok… Can I make use of needles to stabilize this?
It will be much easier with needles now of course…

04:35 M21:
Because, when I try to separate these two triangles by putting cardboard in between, it has a really massive effect…it also limits the eyesight… and also, it has a big effect on form… but the needles are like invisible elements, I think… it is more flexible, I am trying to say.

05:14 M22:
I am putting them from the lower level to the upper level… as in a real construction… to enable adding further levels.

05:40 M23:
This effect of continuity with the ramps can also continue through the upper levels…

05:45 M24:
so maybe in the façade, or maybe in the relations of the levels inside…

05:50 M25:
with stairs or ramps… that can be this way…

05:55 M26:
So, maybe, from this elevation, it will not only be horizontal strips but ramps following the slope of the road.

06:18 M27:
Then in the upper levels, these –triangles—can get smaller, or bigger…

06:25 M28:
So there might appear galleries this way.

06:48 M29:
These galleries can be in the places like theatre entrances, foyers, cinema entrances…the most crowded places I mean..

07:59 M30:
So, what I want to say is…if we have a triangular base like this, there can be repeating planes one over the other…

08:10 M31:
and there can be ramps beside the road, like ramps cut out from the planes…

08:15 M32:
but by reducing or increasing the dimensions of these triangular planes, and changing their locations, galleries can be added…

08:23 M33:
And of course, in this area –the acute angle part—to extend the square, that area can be prolonged inside…

08: 32 M34:
For example, I have cut the upper level like this, but maybe instead of the back, there can be a gallery in front…

08:37 M35:
and on the second level, there can be a gallery in the back…

08: 45 M36:
So at the level of the canal, there will be a two-storey high open area, and also here –the acute angle—there can be another two-storey high area…

08: 55 M37:
So the mass will start to get empty at some parts, and full at some other parts like this…

09:04 M38:
But, this time, the location of the housing units is important…

09:08 M39:
As far as I have seen in the photos, these buildings are low-income housing blocks…

09: 10 M40:
But these are housing blocks as well, right?

09:16 M41:
All of them are housing blocks… So in fact we can locate the housing units facing all the sides.

09:25 M42:
But, since I am thinking of this part –acute angle, and this part –canal entrance, to be public areas, and since there will be at this side, ramps or stairs, I don't know…

09: 37 M43:
Since we are trying to relate those areas with ramps or stairs, I think actually, the best place to locate the housing units will be the way to the bridge…

09:54 M44:
Which way is North?
This way? Ok. So this way is South.

09:55 M45:
So, in fact, maybe placing the housing units this way –she points out the way through the canal—will be more logical maybe…

10:04 M46:
And this way is East… East is fine as well…

10:10 M47:
Actually South will be too hot for housing…

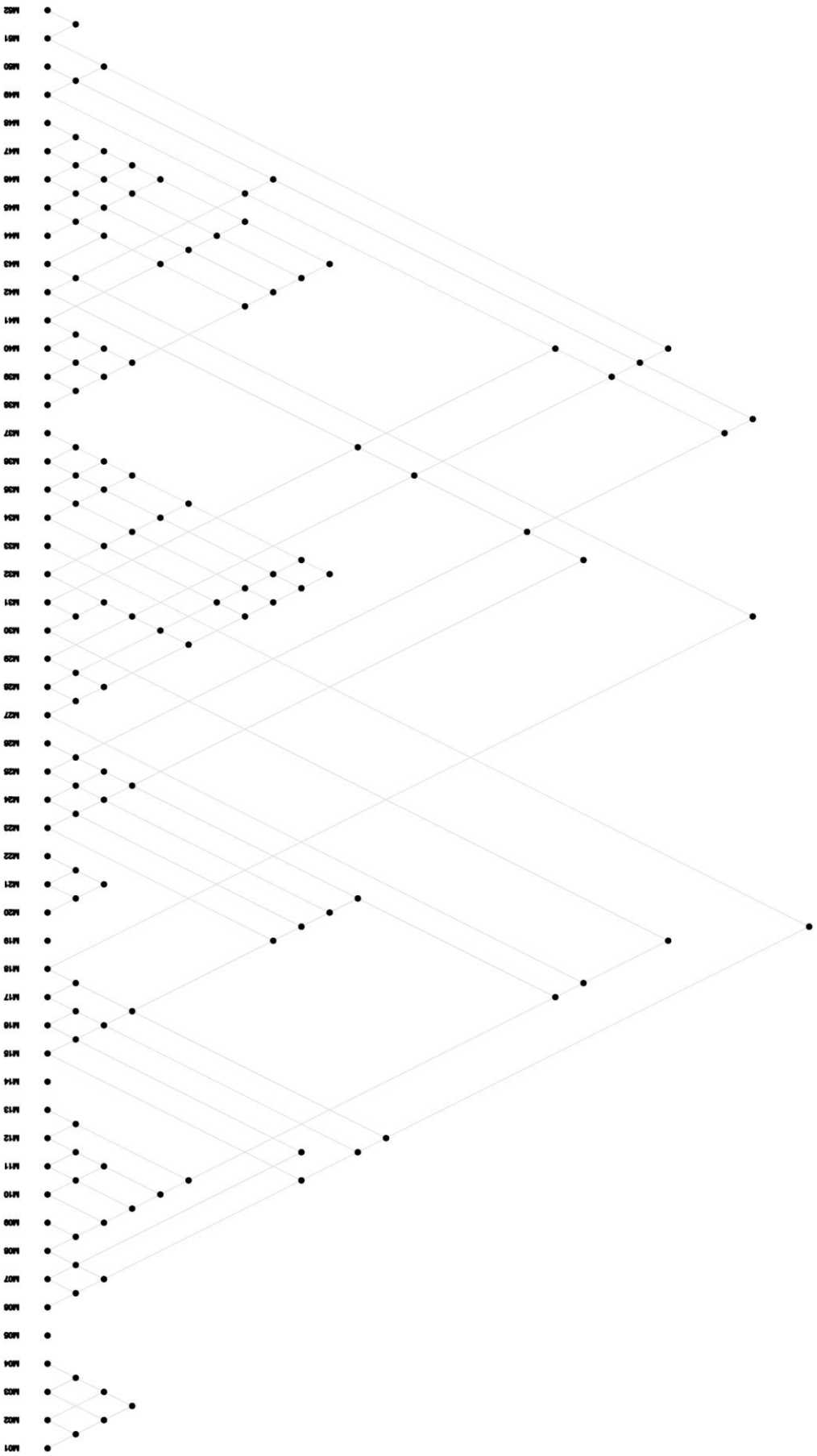
10: 15 M48:
or maybe I can locate the housing units facing both these ways –she points out East and South.

10:23 M49:
And after creating two public spaces, they can be related with the help of the ramps…

10:28 M50:
For example if the café faces this square –acute angle—,with the help of the ramps, from here –canal level—there can be a passage to the theatre…

10:34 M51:
And the area beneath the café, umm, if this part –canal level--will be the foyer of the theatre,

10:45 M52:
and since it will be underground where there will be no natural light like in theatres and cinemas, can be a large area for theatre… I think…



Appendix A Linkograph of physical model-making session of D1

APPENDICE B

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF FREEHAND SKETCHING PROTOCOL OF DESIGNER 1 (D1)

00:05 M01:
Can I also draw a section as a conceptual diagram?

00:11 M02:
Ok... then.. we are making an exhibition gallery, so I prefer to think in section in terms of its dimensions.

00:20 M03:
Also, since it is an exhibition gallery, it will be more appropriate and easy to use the inclination of the site I think..

00:27 M04:
I suppose there is a level difference of 1 storey. Hmm.. 5m...

00:50 M05:
There can be a ramp going upstairs.

00:53 M06:
What is the percentage of the inclination of the site? Ok, but it doesn't seem too steep. I think it is a soft inclination.

01:04 M07:
That inclination can be used. Then, this flatness.

01:12 M08:
There can be a zig-zag ramp going downwards...

01:18 M09:
I mean, this can go one storey down as well.

01:23 M10:
If it is going to be something like a modern art museum, we can make use of the dark areas for film projections.

01:28 M11:
Or we can use these spaces...--she draws something--

01:29 M12:
And in these places, there can be installations.

01:37 M13:
Those installations can even expand through outside on the level of the canal.

01:45 M14:
Then, in the upper level, there can be exhibition spaces at the same level wih this road --she shows it in the plan, the road leading to the bridge--.

01:49 M15:
So in fact, if I am to show it in the plan... it can be something of this sort...--she starts to draw-- This is a ramp like this... going upwards.

02:29 M16:
But I want it to go side by side with the adjacent road, so that it can unite with the road.

02:35 M17:
So, maybe there will be a break here.

02:42 M18:
This will be a prolonging ramp like this, co-linear with the road beside. So that the passage will be always possible. Even it is not a physical passage, there won't be any visual obstruct, so there will be a visual relationship.

03:02 M19:
And with this road -road leading to the bridge-, if there will be a platform here, there will be a relation...

03:07 M20:
I mean, the zig-zags that we see in the section are the ramp going upward here, then becoming a flat area here, then maybe there will be another ramp going upwards from here -on top of the other ramp-

03:18 M21:
It will be one storey below... this is the level of the bridge, it will be the same in the level of the canal... so there will be a flat area here, at the entrance, and again there will be a ramp going downwards... So, if I draw a section passing from here -the ramp-, it will always be like this -she draws parallel ramps one on top of the other-

03:49 M22:
And if I draw a section from here, it will always be like this -she draws horizontal parallel lines-.

04:01 M23:
And at some point, these ramps will become flat and function as housing units.

04:12 M24:
Maybe at the ground floor... Can I add some other functions to this building?

04:15 M25:
Ok, then maybe, here, at this level, the level of the canal... here, at the flat area, there can be, entrance, services, etc... placed adjacent to the retaining wall through some point

04:15 M26:
... I don't know.. -she draws a line-.. it seems a bit too long but...

04:33 M27:
At some point, there must be an information desk, toilets, also elevators and staircases leading upstairs, umm, also cloak room..

04:45 M28:
there can also be a small cafe.

05:00 M29:
That's it. And at some level, these zigzags become flat and serve as housing units.

05:06 M30:
How will be the appearance of this building?

06:30 M31:
So this will be the first floor... This ramp will probably start like this.. with the first floor I mean the ground floor... the level of the canal..

06:45 M32:
It will take the visitors from here..

06:52 M33:
The entrance to the exhibition will be from here.

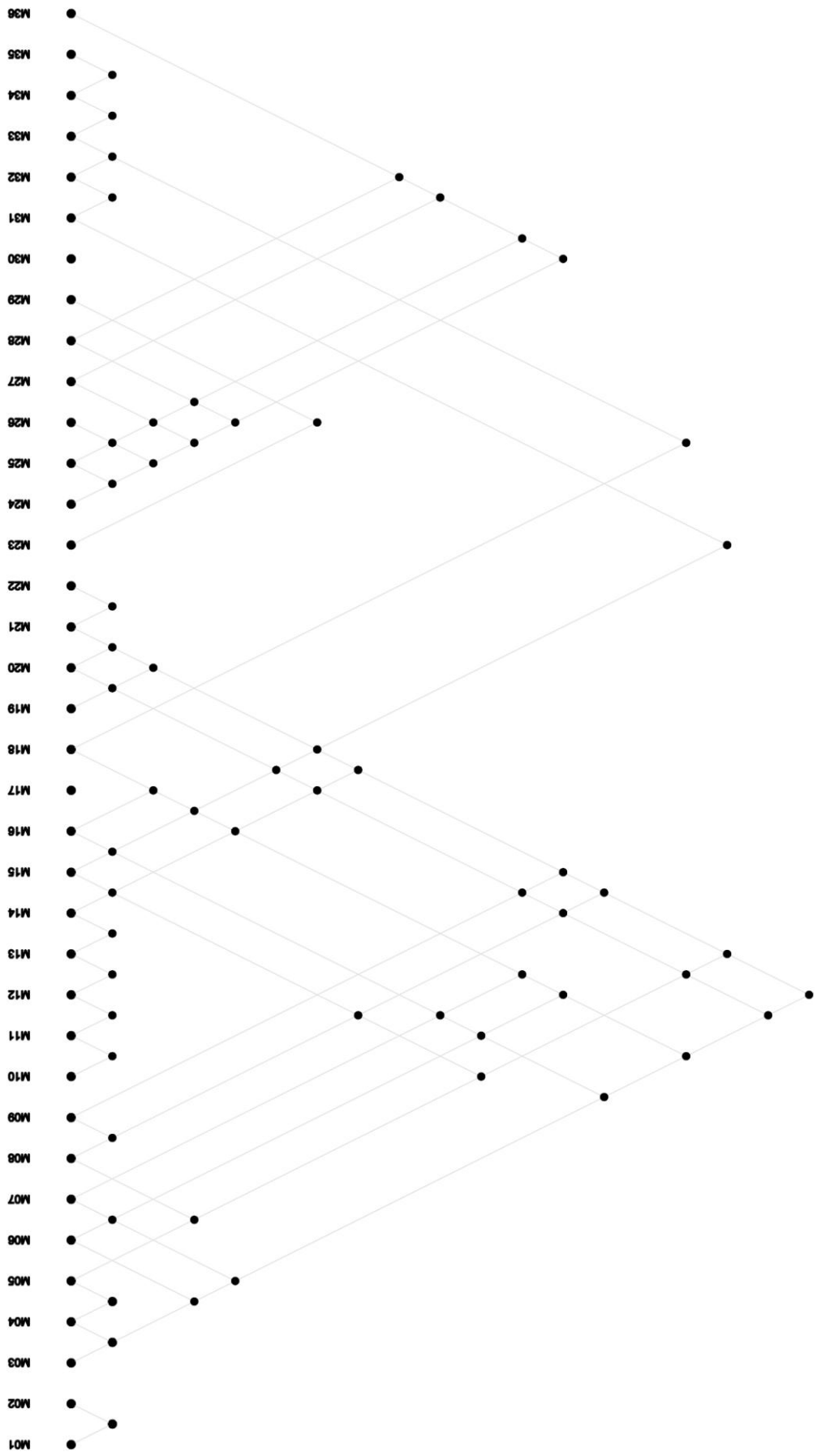
07:02 M34:
The entrance to the housing units can be from the upper level.

07:09 M35:
Or it can be from both levels.

07:12 M36:
At this level, we will have side by side, as I said before, the info, cafe, wc, staircase, elevators, cloakroom, and maybe some storages..

07:45 M37:
At this level, we'll have a ramp going upward from here... and a ramp going downwards from here...

08:24 M38:
It will be understood when I will draw it properly -and she takes a ruler!-



Appendix B Linkograph of free-hand sketching session of D1

APPENDICE C

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF DIGITAL MODEL-MAKING PROTOCOL OF DESIGNER 1 (D1)

00:09 M01:
I will start first of all with a formal research.

00:12 M02:
And I will be using environmental data because I don't have any other concepts for the moment...like I am influenced by this or by that...

00:21 M03:
What are the directions by the way? West and East? Maybe I can make use of it... but I am not sure for the moment.

00:44 M04:
So, let's zoom to that area and make a tour around.

01:09 M05:
I am thinking of making some research about the height of surrounding buildings in order to find some clues about how high our building will be.

01:17 M06:
Maybe I can make use of some planes for this purpose. -she starts drawing some planes-

01:31 M07:
Let's change the layer of this plane...

01:51 M08:
I am going to put one plane on top of this building (the factory building). I started with this one **since it is the closest building to the site.**

02:16 M09:
But we also see that the buildings get smaller through the site... This building, is it some sort of a barrel?

02:24 M10:
Then, I'll copy this plane... let's put this one over here. Another one here. ..and here...

03:19 M11:
They do not have to correspond to the heights of the building... I can use them as a different input... as an independent information... it can have an effect only on the façade maybe.

03:33 M12:
Let's take this small building then... it looks a bit complex but...

03:55 M13:
I am thinking whether I should put a plane on top of every building on the site..if I want such a movement on the façade.

04:14 M14:
Maybe I should use different layers for these planes. Because the buildings that are far should have a different effect then the buildings that are close.

05:06 M15:
Let's check the level differences between these planes. If they correspond to heights between each storey... I have to measure the distance.

08:54 M16:
--after several attempts to measure the distance between planes-- I am actually technically obsessed now... can each of those planes correspond to a storey of the building... let's try.

09:44 M17:
So this one is 5.38m... this one 8.61, and this one 7m..

10:35 M18:
5.38 is in fact too high for one storey...

10:40 M19:
we can divide 8.61 to two storey..it is even too high.. can it be 3 storey?..yes..

10:55 M20:
this one 7m.. so we can have 2 storey from here.

11:05 M21:
But we haven't done anything about the ground floor.

11:12 M22:
So each floor has a different height in this case. And that is not good.

11:20 M23:
So maybe these levels will only effect the façade.

11:30 M24:
I want to think of something else --and she hides the layer of the planes--

12:01 M25:
I am now thinking...well...instead of using planes while comparing the heights of the buildings, we can maybe make use of their relations with each other.

12:13 M26:
For example we can relate this point -the corner of the factory- with this one -the corner of the building adjacent to the site- (and she draws a line). I am randomly drawing these lines for the moment... randomly choosing which point will correspond to which other point.. searching for a conceptual idea..

13:58 M27:
Actually at this point, I am trying to have intersections around the site.

14:13 M28:
So, let's look at it... let's hide the layer of the site model... We can create surfaces to fill between the lines...

15:16 M29:
I am not happy with this surface... It revolved too much... I didn't like it.

15:35 M30:
Let's choose this one with that one. This one, with this one... --and she goes on--

16:10 M31:
I'm not sure... but let's unhide the site model and see..

16:50 M32:
I will draw a poly-line around the site and extrude it. And then, I will use it to cut the lofted surfaces.

17:44 M33:
Let's see what will be left over if I cut it... what was the command... "surface trim"...

18:13 M34:
Let's see... hmmm... We are left with such a thing...well it looks awkward.

19:07 M35:
I will then take it and put it on the ground.

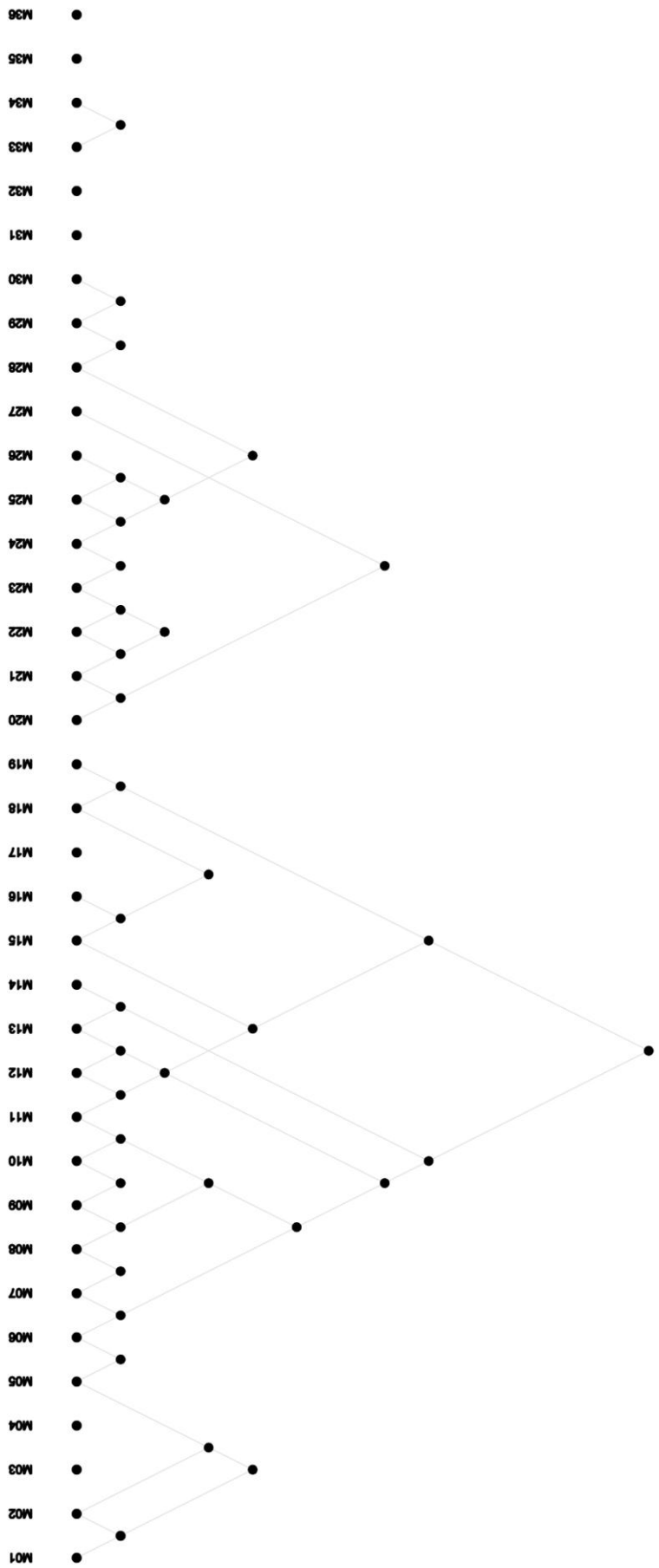
19:49 M36:
well, this part --road leading to the bridge--can be used as an entrance to the dormitory.

20:00 M37:
Here, we have an opening through the canal... there, I can locate the café...

20:05 M38:
it is a bit too large, but, I can figure that out later...

20:18 M39:
Here, we have a good area... the surface is too inclined, but it's ok.. it can be the lobby.

20:54 M40:
And at this part, I can maybe locate the vertical circulation...



Appendix C Linkograph of digital model-making session of D1

APPENDICE D

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF PHYSICAL MODEL-MAKING PROTOCOL OF DESIGNER 2 (D2)

00:12 M01:
As far as I can see, the surrounding buildings are in fact higher than the site within this axis and there is a massive pull-over in this site compared to its surroundings...

00:25 M02:
But I think this is challenging. Within a dense linear axis, such reduction is good and should be preserved.

00:31 M03:
That's why, I think one of the primary decisions should be to have the same height with the surrounding buildings.

00:43 M04:
There is a secondary thing... as far as I can see (his pointing out the canal), all the buildings are co-linear with and attached to the axis. There is a void here (pointing out the pedestrian and vehicular roads) but beside that void, there is not a gap. Everybody is using that axis.

00:56 M05:
So the site can itself become, can be used as an interior void.

01:10 M06:
That's why, in the ground floor, I am thinking to preserve that space as a void.

01:21 M07:
I think these two decisions are enough to take a form. They already provide some information about the form.

01:53 M08:
I'd be very happy if I had styrofoam actually.

02:09 M09:
I think the problem consists of two things: one, we have this void we want to preserve,

02:20 M10:
but also it would be good if we could reach the building from the road level. So, we will probably want to reach this building, this mass, from this axis, and also from the upper level.

02:40 M11:
They both will be different.

02:45 M12:
The first one will be a more public void.

02:50 M13:
The latter, the one we will reach from the upper level, can also be public, but rather it will can used as an entrance to the building.

02:55 M14:
So when we do this, that way (he is folding a piece of cardboard),

03:00 M15:
and add some thickness, it must be somehow a little thicker probably... with this thickness, I think we will probably perceive what I am talking about.

03:09 M16:
This can also be more steep (he plays with the cardboard).

03:12 M17:
The thing in fact is to have a plane, and leave the other plane empty, I have this in mind.

03:27 M18:
Can we use these as modelling materials?

04:19 M19:
This is 20m high... and this is, from this level... hmm.. 30m..

04:47 M20:
What are the directions here, I mean which way is north and which way is south? Ok, north, south, east, west...

05:40 M21:
---his taking the measures of the site.--- 28,5cm, so 57m..

06:44 M22:
I started by cutting the ground floor, the plan of the ground floor. I will put two walls on top of it. Then what I am aiming to do will be much clear.

06:44 M23:
This, from the very beginning, maybe here must be a bit more slim, let me correct it...

08:00 M24:
Now, I am cutting the upper trace.. The roof I mean.

08:22 M25:
And later, maybe this two, are united like this, and uniting there traces, we can have...

08:30 M26:
... How much did we say for here? 30m from the ground level, yes..

09:10 M27:
In the same time, in order not to block these buildings right here,

09:15 M28:
because there is a good eastern light here, we may want them to have much sun light here..
09:35 M29:
If we put there directly this wall, if the mass will be straight up this way, there won't be light there which actually is the situation.

09:45 M30:
We can have an emptiness there with this break.

09:50M31:
This will also provide them a wider vista.

12:21M32:
Now, I can glue them. But we also need this wall, if I also cut it, it will be done.

14:42 M33:
Actually I realized I could have done it with one single strip of cardboard.

14:50 M34:
By doing this like that, we will be using this lower part.

14:55 M35:
It will be located like this on the site. So we will be using the level of the canal this way.

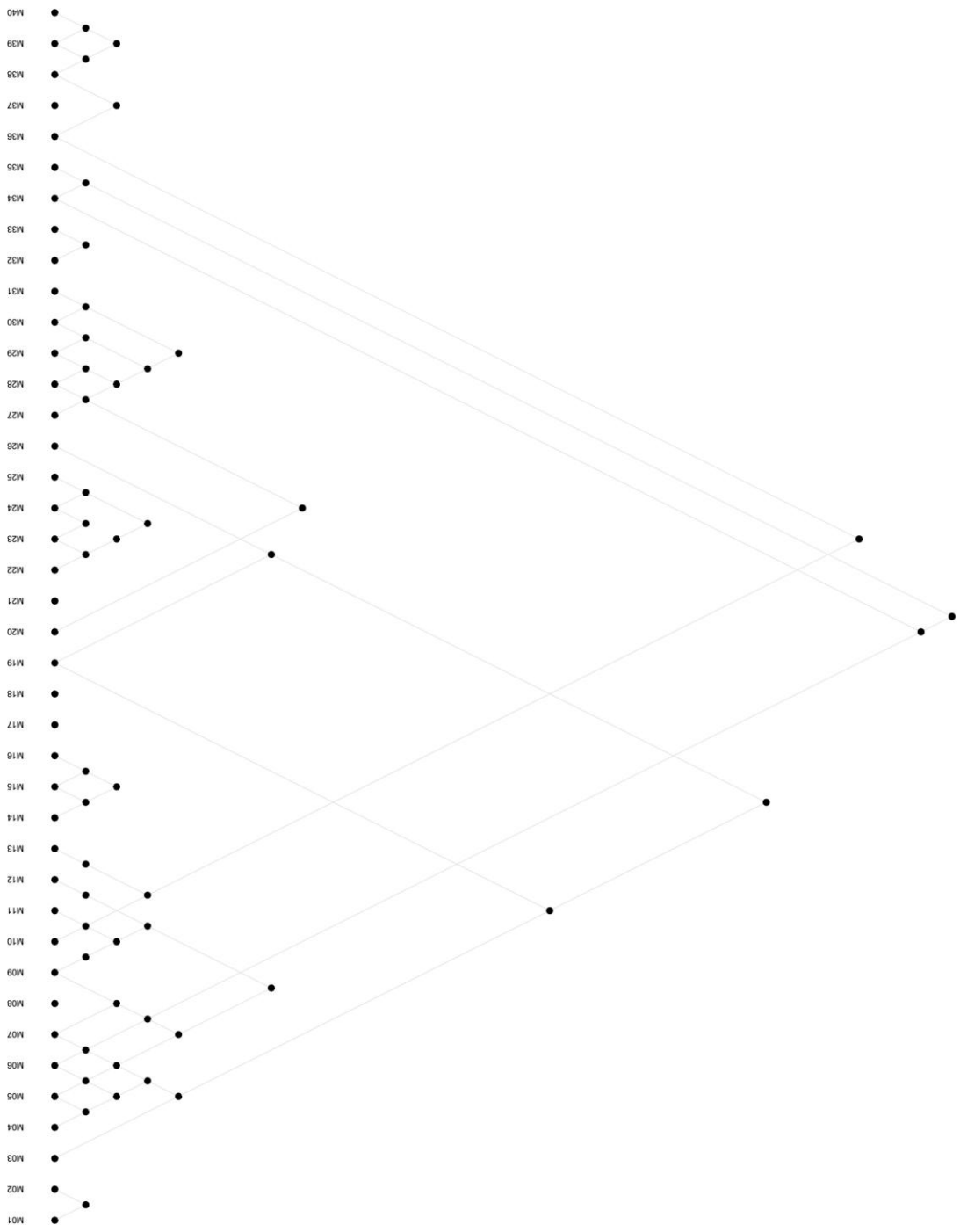
15:00 M36:
And from here, we will be reaching the building from the upper level.

15:15 M37:
So in some way, we can say that the level of the canal has stood up and broke.

15:18 M38:
This way we are providing access from both sides.

15:31M39:
And probably, there will be a passage between the upper level and the lower level inside the building.

15:35 M40:
Either with staircases or ramps, directly. So from there can be a passage not from the surroundings but from the building it self.



Appendix D Linkograph of physical model-making session od D2

APPENDICE E

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF FREEHAND SKETCHING PROTOCOL OF DESIGNER 2 (D2)

00:32: I think this task is rather a more difficult task than the previous one. Because generally cinema and housing units are not combined functionally. A big contrast exists between two. Cinema and housing units are not in fact interrelated in a program.

00:50: This in fact can guide the design. I don't say it in a negative way, it can even be a challenge for the project. A bit more thinking is required for this.

01:03: I can say it this way... This is I guess the main road that we will make a connection. But in fact they all are entrance points. If here, it is 5m high, well, that is also a main road apparently...

01:19: Cinema is an enclosed environment, a function. So, it will be more convenient to face this way (he starts to draw) and the housing units to face this way.

01:30: But a break is not necessary in the plan (he draws other diagrams). It can be like this (he outlines the first diagram he has done), or like that (another diagram). These are all thoughts of mass... It can also be the opposite, like this (he plays with the latter diagram)... These are all different trials about the relations between cinema and the housing units.

02:07: In fact this is the question I've been asking to myself from the beginning... How these two will be related with each other? What should be done here, frankly, is... what I do generally in these sort of short exercises is, I try to eliminate all the data I have to none, to very few. Without concerning too much about the practical problems, I try to make the relations of the parts with each other. I don't think for example about how the sound will be there, but rather I think of programmatic relationships.

02:45: My other concern is context. What is the relationship between the surrounding buildings with our site. In this manner, this in fact is a good example, because having courtyards is a typology. We should use it and preserve that texture.

02:50 : But to who that courtyard will belong to and what it will serve is a question.

03:09 : I think I'll be using this road (he draws the sloped road).

03:15 : Positioning the cinema in the lower level and the housing units in the upper level can be a good start when their unrelated situation is taken in to concern.

03:25: I'm thinking of, if we take this as the cinema, what is on top of it can be housing units. Housing units can use that level. These units and the cinema do not have to be related.

03:55: And if we think of these borders -the surrounding site's borders- as some traces, as some sort of a mirror image of the neighboring site... I'm only making a trial drawing...

04:10 : The neighboring plan.

04:20 : I think I can come up with an idea afterwards.

04:58 : - he draws hatches.- If we take these parts in the cinema level...

05:24: I am thinking that, there will be an underground level... and in that level we'll position the cinema. --he draws a section--. But that cinema will be a cover. So in section, this is the road level, and this is the canal... As I have previously said, we can create a cover for the cinema, place the cinema right there, and later on top of it we can place the housing units.

06:33: But here, the height of the buildings do not have to be the same as the neighboring site that we have mirrored the plans. I mean, in the neighboring site, it has 3floors, 5floors and 7 floors like this. I think should be the opposite...7 floors, 5 floors and 3 floors.. So we will be preserving the slope. So for these 7 floor buildings, we can provide a vista...

07:00 : Ok.. we will also be preserving the courtyard... yes.

07:32: What I have done here is a very fait accompli situation. It doesn't have to be this way. The position of the neighboring blocks is virtual, it is maybe very arbitrary. I don't know what taking them as references will enable us. But there is definitely something behind their placement.

08:03: According to me, this is... well there is a courtyard that all the three blocks are using together. They are somehow related with the street. This is I think a good relationship, all of them having some private spaces as well.--he drew an axonometric of the plan he has generated--

09:01: This can have 7 floors, this one 5, and this one 3. So what is the advantage of this change? This one (7 floors) can use the roof of this one (5 floors) as a terrace and this one (5 floors) can use the roof of the other (3 floors). So we are creating a terracing effect.

09:19: But here (the courtyard) it is already a terrace. I mean the roof of the cinema is also a terrace.

09:35: I think that the cinema can also have a relation with the street. --he develops the section he has drawn--. Here -façade facing the sloped street-, it can be totally transparent. So, the area beneath the cover, can be transparent. This, when we look from outside will be something like this...-he draws another axonometric drawing-... this is in the inside.. sorry, I drew this wrong...

10:13: So, here there will be an opening... when we are in this level, we enter the building from here... and the cinema itself, maybe can be a bit further as an enclosed box. And here we see the foyer of the cinema. So, in a manner, we are emptying the street level by putting the cinema like this.

11:35: This is in fact a small rift. On top of it will be placed the blocks I recently have drawn... and it goes like this.

11:50: Hmm... well this block has in fact a connection from this level --upper level, acute angle part--. And that creates a circulation within the site actually. So, something like this can be done, a path entering from here, and turning this way...

12:19: Or something more linear... We can reach the courtyard somehow within that block and than we can go to each of the block independently from that courtyard.

12:35: If we start solving the plans of the housing units, a bit more thinking is required.

12:54: I think something like this will be better. There will be some sort of a ramp passing through the building... ah sorry no, it is not a ramp, they are on one level.

14:20: So, they can be something like this.. If our plans are this way --he draws another plan-- If this is the entrance level here, and if we are approaching from here..

Here, there can be a housing unit... this can become a block like this... the inside should not be the same with the neighboring block...that is just a figure... my block do not have to totally replicate those blocks.

15:19: So, one block can be like this, the other can be like that...one other can be like this, and like that... The one on top of it, can be placed like this. So, what will be the outcome of this? Well if we check it with an elevation drawing..

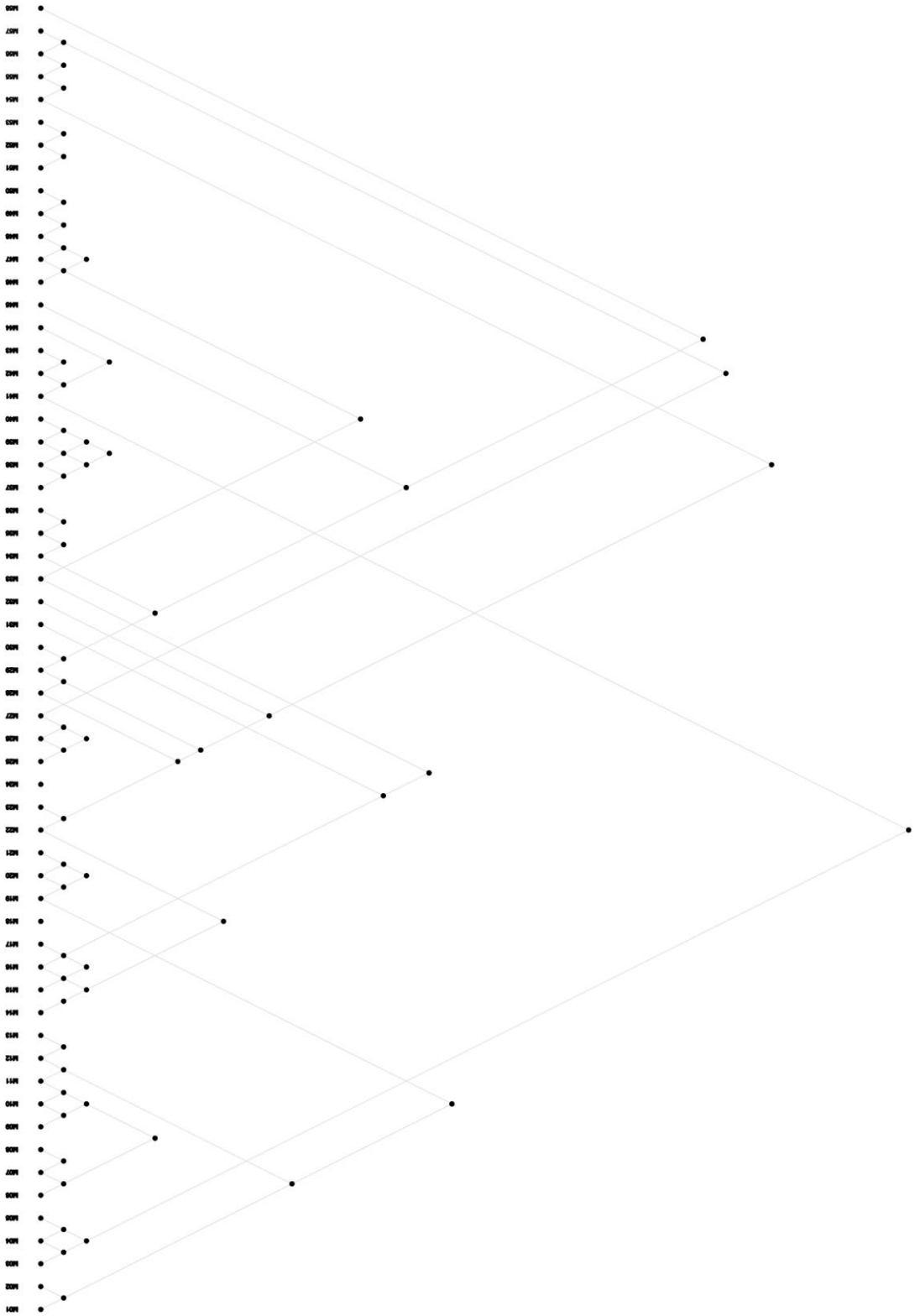
15:51: Here we see a cover(kabuk) . Not like that --and he erases--. The one behind is the tallest.

17:31: It will be something like this actually.

he is drawing the elevation

19:36: Well, honestly what I will be drawing for the free hand sketching part would be this. Afterwards I start solving the plans. Or I would make a physical or a digital model to see what comes out in 3d. So this is what I would do in conceptual design

part.



Appendix E Linkograph of the free-hand sketching session of D2

APPENDICE F

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF DIGITAL MODEL-MAKING PROTOCOL OF DESIGNER 2 (D2)

01:00 M01:
This is a similar situation to what I have done in the free-hand sketching task.

01:38 M02:
Mostly, here, I find the idea to have a passage to the level of the canal very appropriate in this site.

01:45 M03:
Because for example, in order not to elevate the building too high, some sort of a ramp can be used for the exhibition gallery.

01:47 M04:
To have the appropriate height in the exhibition gallery.

01:51M05:
No, going down from the level of the upper street to the exhibition area.

02:28M06:
Actually, putting the housing units in the upper level and the gallery space beneath it is very rational.

02:35 M07:
Approaching the exhibition area from the level of the street is good.

02:43 M08:
But frankly, this is always the situation... we have the exhibition gallery on the street level, and we have whatever there is upper...

02:52 M09:
This site has this interesting situation: the environment can be better observed from above.

03:05 M10:
So, placing the exhibition gallery in the upper levels could also be a good idea.

03:10 M11:
But in order to do that, we should create good relations with the level of the street.

03:14 M12:
So maybe, putting the exhibition gallery in the upper level and creating an organic connection with the level of the street...

03:33 M13:
And make it show up there...

03:36 M14:
The exhibition will show itself up there, and the rest will seem more silent.

04:04 M15:
How I will explain such an idea... without designing a building, simply, I will do something of this sort: Not on the site model... --he pans through the other side--

04:26 M16:
--he draws a box--

04:30 M17:
--he changes the height--

04:35 M18:
--he changes the width--

04:37 M19:
--he changes the width once again--

04:42 M20:
--he changes the length--

05:10 M21:
--he draws another box with the same height and lenght adjacent to the previous box--

05:23M22:
Let's consider these boxes as symbolizing program: housing units and exhibition gallery.

05:31M23:
I am talking about these boxes one over the other.

05:35 M24:
--he elevates the latter box--

05:36 M25:
the exhibition gallery will go over the housing units.

05:40 M26:
but while we are reaching that exhibition gallery, we'll go over some sort of a promenade, by perceiving the environment while going up.

05:52 M27:
and that exhibition gallery can become some sort of a stopping place.

05:57 M28:
I mean it can become part of the promenade

06:00 M29:
For example, we enter from the street level, then we go up... this movement towards the upper level, can become the exhibition itself.

06:08 M30:
Then, while, we are up, we will be reaching the top point, there, we can have a more enlarged exhibition area.

06:26 M31:
Then, while again going downwards, that exhibition gallery can be ended.

06:30 M32:
So, in fact this is a building with housing units, and somehow we have an exhibition gallery on top of it which envelops it.

06:38 M33:
how can I say... a mutualist relation between two programs...

06:40 M34:
The housing program is passive here...

06:47 M35:
um, I don't know, maybe it takes rent from the exhibition gallery, but the exhibition gallery climbs up thanks to the housing units.

07:03 M36:
--he draws another box on top of the first box, expanding from the second box--

07:12M37:
--he draws another box next to the last box, projecting from the first box--

07:22 M38:
--he draws another box, going downwards from the projected part of the last box--

07:24 M39:
let's not think of this in formal terms..

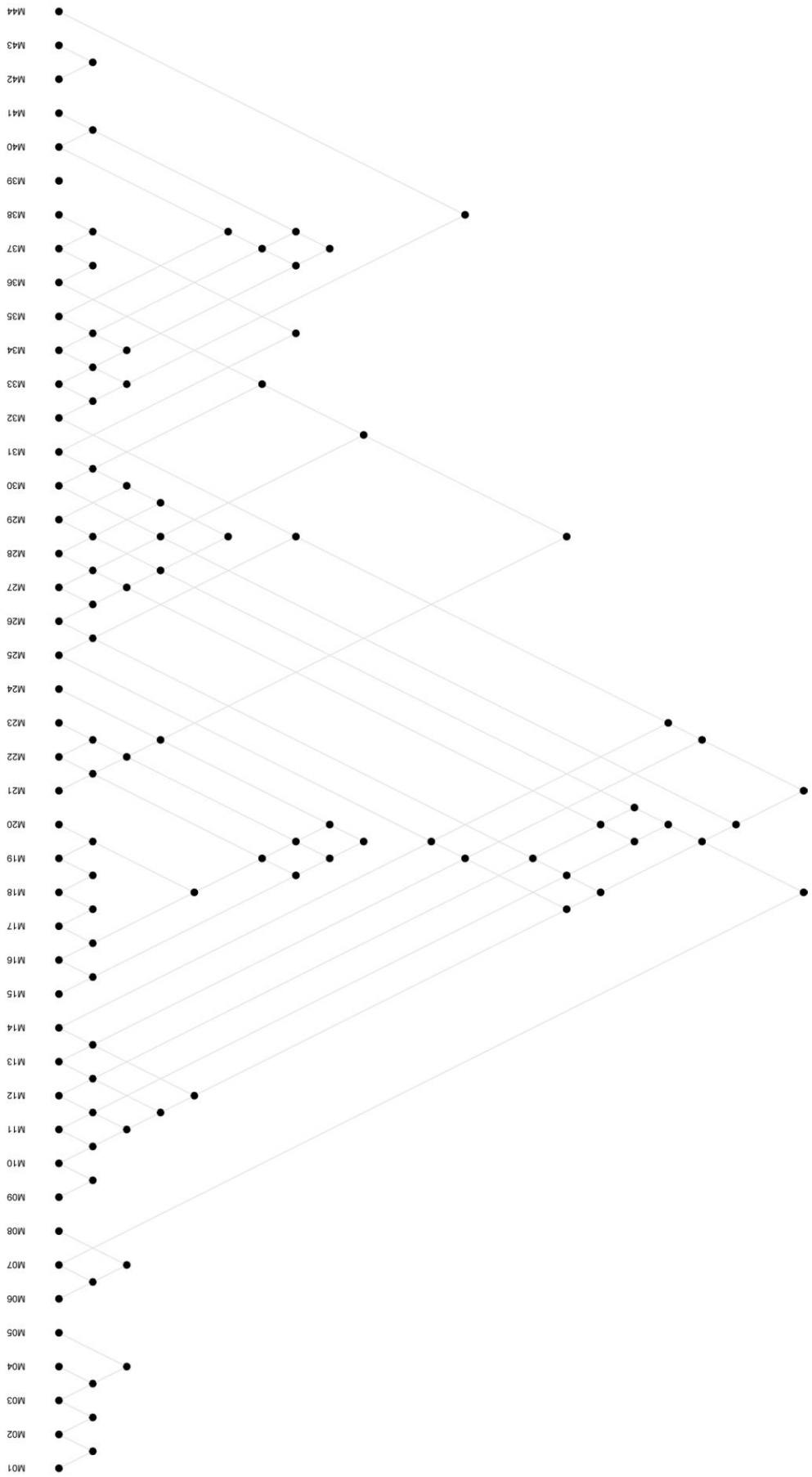
08:37M40:
now we can put it on the site model and explore how this mutual relationship can be...

08:44 M41:
because I am assuming that the housing units are totally passive.

08:50 M42:
well, of course we can think of something like a student project, here in these dwellings, artists will live.

09:00 M43:
but, I am not after such an idea, because it is too strict. because, those artists can move out, and someone else can come to live. what will we do in such a situation with the exhibition gallery and the housing units? They won't have any relations in that situation...

09:19 M44:
So, in our case, we will have the housing units and the exhibition gallery program enveloping it.



Appendix F Linkograph of the digital model-making session of D2

APPENDICE G

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF PHYSICAL MODEL-MAKING PROTOCOL OF DESIGNER 3 (D3)

00:56 M01:
Can I remove this part of the site model? I want to see the site from the front, that's why.

01:43 M02:
I am thinking about the directions... which way is South...

01:53 M03:
It seems to me that this --road beneath the canal-- is the crowded area... and these are not... well because this is the factory building, this is an housing block...

02:02 M04:
But in fact, this road must also be crowded since it is linked to the bridge..

02:45 M05:
Is this -road leading to the bridge- a two-way street?

02:47 M06:
This one -sloped road- also?

02:53 M07:
So, they're all two-way streets.. It goes from here, and turns from here..

02:56 M08:
I thought it to be a passage as well if visitors come here by walking or by car.. they get in, make a stop, and while they are going, they will go from the inside of the building.

03:27 M09:
Indeed... how will it be...if this is the area used by pedestrians -canal side-, this area here -she points out the level of the canal-...since there is a level difference of 5m...the exhibition gallery can be located here.

03:56 M10:
And the car entrance can be from that level, with the exhibition gallery.

04:05 M11:
And the housing units are likely to be here --she makes a movement with her hand, pointing the upper levels--

04:16 M12:
But this, in relation with the site, without scale...I will cut it without using a ruler, it will be more comfortable...--she cuts a triangle similar to the site-- So, this here is my site.

04:53 M13:
--she takes colored papers-- I will consider this triangle as 0.00 level.

05:01 M14:
and beside, there is a height of 5m, here...I should elevate it... -she takes cardboard and cuts-

05:38 M15:
Well, I could make use of it.. because, it will be quicker with needles I think.

06:04 M16:
--she glues the wall-- --she puts the needles on the walls she has glued--

08:34 M17:
--she takes the ruler and measures the site-- 13cm, so 26m... So, in fact the site is quite big.

09:07 M18:
and the level difference is 5m... but they should be able to enter from this level according to what I have been thinking...

09:58 M19:
--she puts the strip between the two glued walls-- so, this... will be a passage --she glues it--

10:30 M20:
Then... --she takes another colored paper, cuts a rectangle and puts it on the triangle she has cut-- this will be like an "explicit" area.--and glues it--

11:09 M21:
And from this passage -from the level of the bridge- --she places another strip-- people can go down to that "explicit" area.

11:15 M22:
that is a ramp.

11:19 M23:
but probably, such a ramp can't exist...

11:31 M24:
In that case, they are entering that area from only one side and that's not what I have indicated...

11:46 M25:
But if they are coming from this side -from the sloped road-, they can reach that area with a ramp.--she takes back the last strip, and glues it to the other side-

12:06 M26:
Then...here, also, there is a... umm.. well this -the latter strip- is in fact a platform.

12:37 M27:
since they are also entering from this level -level of the bridge- to the inside of the building... here, there is a two storey high space... like a mezzanine... at the point where they will enter in the 5.00 level.

12:55 M28:
So, they will be entering from there, but also, that platform is tied to this - the passage-.. so people will be able to pass from here (sloped road) to here (bridge-road), hang around a bit, and also go down to the "explicit" area.

13:10 M29:
--she takes another colored paper and cuts another rectangle-- the platform is in fact something like this... --she puts the rectangle on the latter passage and cuts it again to reduce the size-- but not this big. -she glues it-

14:30 M30:
Now I can elevate it..

14:44 M31:
I am thinking how the housing units will relate with this and how it will be... but have nothing in mind yet.

15:50 M32:
If we think that they will enter from the same level again...

15:57 M33:
this in fact.. ha.. yes, that can be... umm.. there will be entrance of the housing units from this level --level of the canal--

16:05 M34:
and that will be from here... --she searches for another colored paper--

16:21 M35:
So, in fact, the housing units will also have 2 entrances...

16:35 M36:
--she cuts a strip-- --she puts the strip-- so it will be like this..this will be the entrance of the housing units..

16:46 M37:
--she cuts a cardboard strip-- well this is a border, but that won't be a concrete border like this.. it is more transparent..

17:06 M38:
--she puts away the cardboard strip and cuts another strip from the transparent paper--

17:07 M39:
While the dwellers are going to their apartments, they will be able to see what is happening inside...so they will also be part of the "explicit" area. --she glues the strip--

17:58 M40:
From some point, they will be able to enter to the "explicit area" also...

18:08 M41:
Since this place now belongs to dwellers, here also we will have a transparent border. --she cuts and glues another transparent strip--

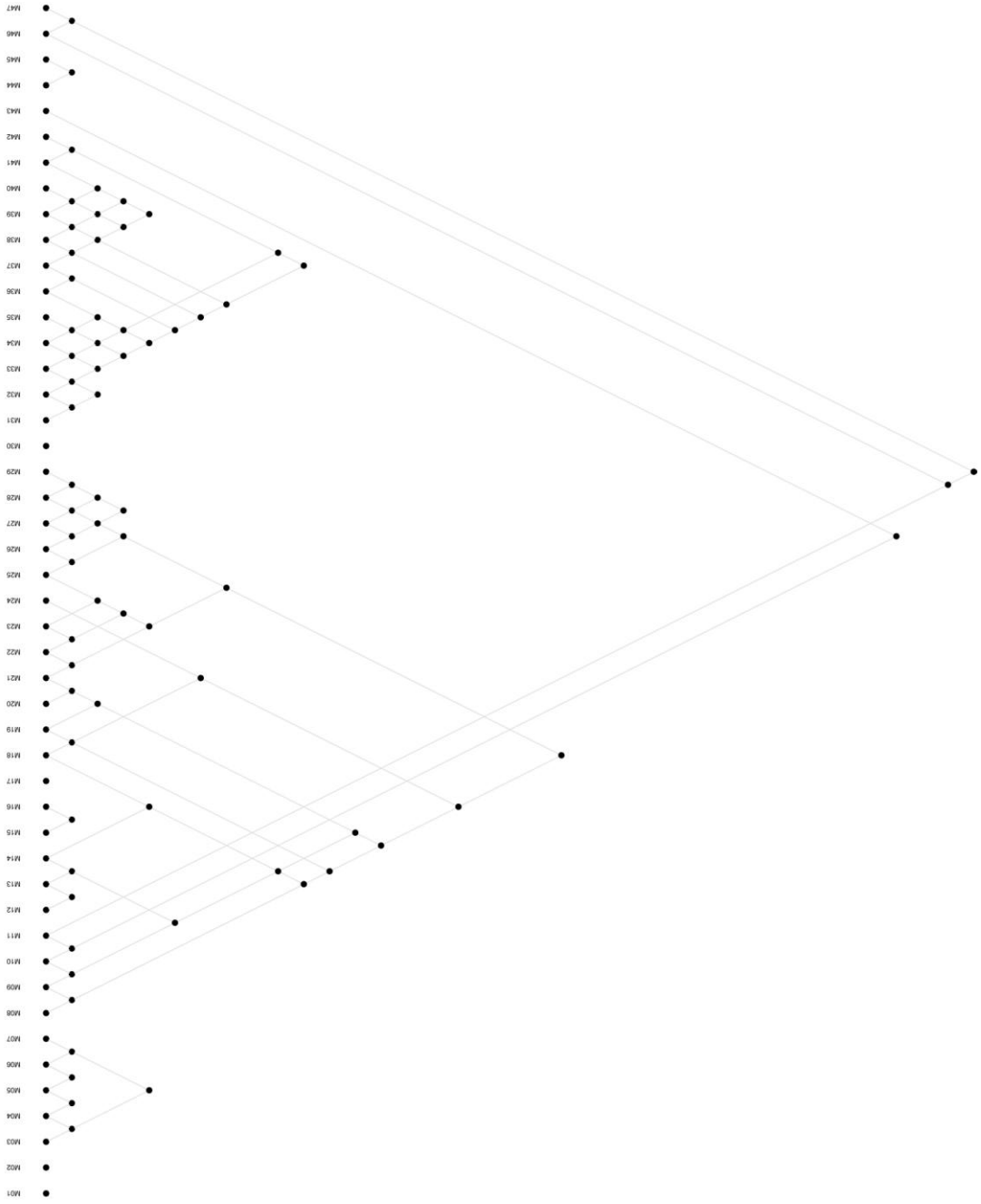
18:30 M42:
like this.. and later, this place now belongs to dwellers..

18:54 M43:
: hmm...umm.. well... cars will be able to enter here. so, this place-she points it on the model- can be used by cars..
20:05 M44:
well, to sum up.. this will be something like this.. -she puts a rectangular paper on top of the model-- housing units will become united with the "explicit area"

20:12 M45:
it is either with the passages, or they are directly united.

21:27 M46:
--she cuts a smaller triangle from colored paper-- --she puts it on top of the area she reserved for the entrance of the housing units and glues it--

21:51 M47:
this will have several storey



Appendix G Linkograph of physical model-making session of D3

APPENDICE H

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF FREEHAND SKETCHING PROTOCOL OF DESIGNER 3 (D3)

00:49 M01:
What was the scale of this drawing?

01:37 M02:
How many students will live in this dormitory?

01:53 M03:
Ok, let me look at the site once again...you told me not to draw in scale but... let me draw it like this --the draws a triangle-- this is my site.

02:11 M04:
Here it is 0.00 level, here it is +5.00

02:14 M05:
Here we have the factory building.

02:22 M06:
This road goes to the bridge, and beneath we have another road...

02:36M07:
So, if this is the road, the entrances will be... from where will we enter this site? Yes, concept... I was not going to start solving plans but I must think of the entrances.

03:08 M08:
If the café is in public use, and it is also used by the students of the dormitory... how will the dormitory be?

03:24 M09:
First... What do we have in a dormitory?

03:26 M10:
We have a study room, we have common spaces, we have the rooms...

03:43 M11:
Also, it is nourished by the café...

04:03 M12:
Do public also interfere with the dormitory.. not at all...

04:15 M13:
What will they do in public spaces? They will mostly sit and chat, such general social activities...

04:38 M14:
The rooms... how can the rooms be? let me not think of how many people will live in each room now...

05:23 M15:
Some part of the ground floor can also be the common spaces of the dormitory and
05:31 M16:
And everyone can go down to that common space from their rooms -she draws the diagram-

05:33 M17:
The study area is more likely to be --she draws a line on top of the diagram to indicate it can be on the upper floors--

05:39 M18:
But well, they can also eat in the study area...

05:44 M19:
So it is better not to separate it too much from the café...

05:53 M20:
But this area -she points it out in the section- will be noisy...

06:01 M21:
So I think that the study area can be close but somehow separated.

06:10 M22:
Will the rooms have connection with the common space here, café?... Well yes...

06:30 M23:
So we can have something like this: --she starts working on the plans-- if we have something like this here --she divides the ground floor in two parts- I don't know the exact dimensions but.. café can be located here -she hatches the front area-

06:50 M24:
And the common spaces will be somewhere here, --she hatches the other half of the plan--

06:53 M25:
The study area can be located on top of the common space..

07:05 M26:
What are the directions?

07:13 M27:
So this way is south then.. let me hold the paper in that direction -and she rotates the paper-..north... south..

07:21 M28:
Later on... the rooms can face these ways --she draws a V shape facing north on the plan-- let me see...

07:35 M29:
Yes, it is appropriate... the study room will be somewhere beneath the rooms and,

07:46 M30:
This part can be used as an empty place...

07:49 M31:
I have drawn this in plan... in section this will be like... This is the café here... there are people and tables and so on...
08:33 M32:
Then on an upper level, we will have the study area here.. .

08:36 M33:
Then we'll have the rooms...

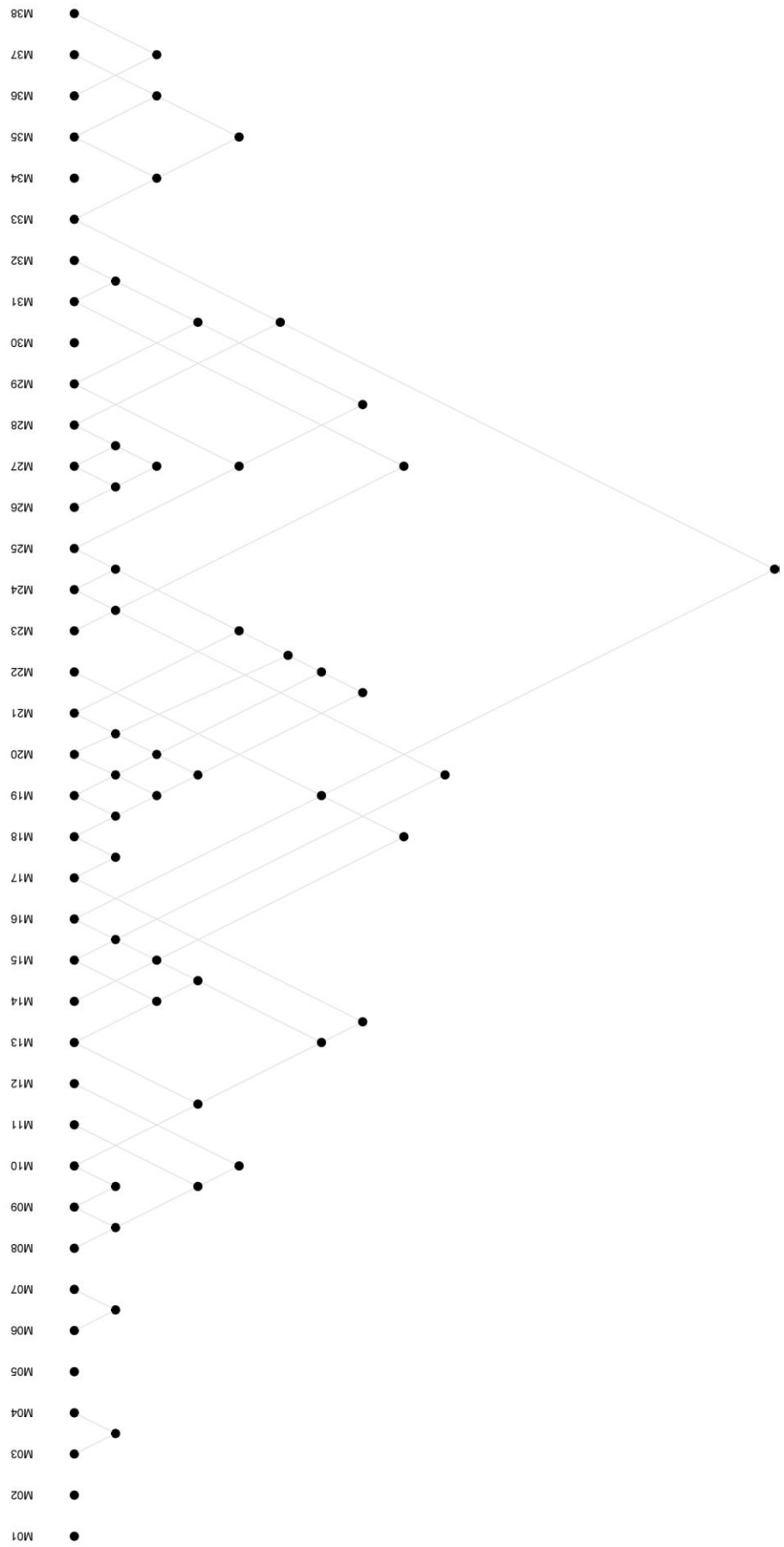
08:42 M34:
--she draws the retaining walls in both sides-

08:47 M35:
The rooms will be like this here -she draws two blocks on both sides-

08:53 M36:
--she draws bridges between the blocks--

09:03 M37:
these are things like this.. -she draws the floors-

09:10 M38:
I think of them as connections if here, there is a gap...



Appendix H Linkograph of free-hand sketching session of D3

APPENDICE I

PROTOCOL TRANSCRIPT AND LINKOGRAPH OF DIGITAL MODEL-MAKING PROTOCOL OF DESIGNER 3 (D3)

01:37 M01:
When we say "theatre", is it a conventional one, with a stage for example?

01:42 M02:
It can also be a cinema.. hmm..

03:32 M03:
let me first start by drawing the line around this area... -the triangle of the site-

03:48 M04:
then, I will extrude it.. how do we do it...-she tries to find the extrude button but she can't and she gives up- ok, whatever.

04:22 M05:
for the housing units' area... not one on top of the other, but this area... -the area behind-

04:28 M06:
and this area can be the cinema area, I think...

05:40 M07:
the cinema will occupy such a space, this will be 5m high...

05:48 M08:
it won't be too big. it will be a cinema serving only this building.

06:23 M09:
later... umm.. if I can do this... where was the line command? -she searches for about 15 sec- So, this area... Is it drawing that line? I don't think it is... -she switches to top view- -she draws a quadrilateral- ok..later... how will I elevate it... hah extrude is here... oh.. finally. -and she tries to extrude the quadrilateral she has drawn- hmm ok.. 5m then. I have first decided to extrude that 5m..

09:15 M10:
That will be a bit higher...-she extrudes it more-

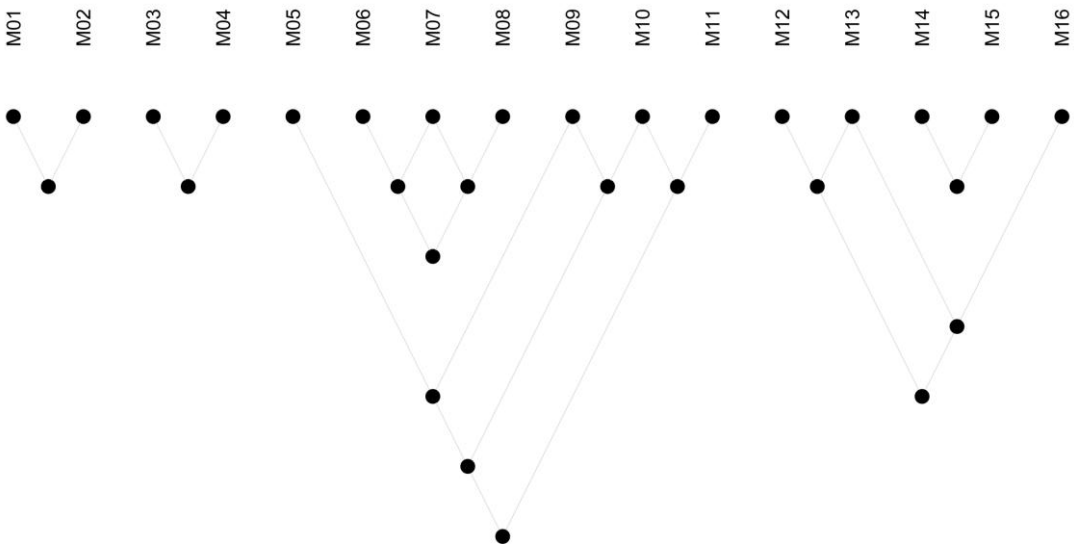
09:24 M11:
The entrance of the housing unit is here -the acute angle part-

09:40 M12:
The entrance of the cinema will be from this road here. -the road beneath the canal-

09:58 M13:
This, here, can be the entrance -she points out the left over triangular part- this is the entrance area...

10:05 M14:
The area in front of the housing units, here, I mean the roof of the cinema can be used.
10:34 M15:
It will belong to the housing units.

10:37 M16:
And this area -the triangular entrace- will belong to the cinema.



Appendix İ Linkograph of digital model-making session of D3