ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

DESIGN ACTIVITIES AND DECISIONS IN CONVENTIONAL AND COMPUTER AIDED ARCHITECTURAL DESIGN PROCESSES

Ph.D. Thesis by
Burak PAK

Department : Architecture
Program : Architectural Design

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Burak PAK
(502032003)

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Supervisor (Chairman) : **Assoc. Prof. Dr. Arzu ERDEM (ITU)**
Prof. Dr. Ömer AKIN (CMU)
Members of the Examining Committee : **Prof. Dr. Nüzhet DALFES (ITU)**
Asst. Prof. Dr. Hüseyin KAHVECİOĞLU (ITU)
Asst. Prof. Dr. Togan TONG (YTU)
Asst. Prof. Dr. Esra FİDANOĞLU (KU)

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BİLGİSAYAR DESTEKLİ VE GELENEKSEL MİMARİ TASARIM SÜREÇLERİNDE EYLEMLER VE KARARLAR

DOKTORA TEZİ

Burak PAK
(502032003)

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Tez Danışmanı : Doç. Dr. Arzu ERDEM (İTÜ)
Eş Danışman : Prof. Dr. Ömer AKIN (CMU)
Diğer Jüri Üyeleri : Prof. Dr. Nüzhet DALFES (İTÜ)
Yrd. Doç. Dr. Hüseyin KAHVECİOĞLU (İTÜ)
Yrd. Doç. Dr. Togan TONG (YTÜ)
Yrd. Doç. Dr. Esra FİDANOĞLU (KÜ)

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FOREWORD

This thesis originated from two main sources: digital design workshops that we held together with Arzu Erdem and research studies with Ömer Akın during the year 2007.

I would like to express my deepest appreciation to Arzu Erdem for her supervision, advice and guidance from the very early stages of this research. Her involvement with her originality has triggered and nourished my intellectual maturity.

I gratefully acknowledge Ömer Akın for his advice, supervision and vital contribution, which made him the backbone of this thesis. I have learned not only research methods from him, but also more importantly, how to think like a researcher.

I would also acknowledge the members of my dissertation committee; Nüzhet Dalfes and Hüseyin Kahvecioğlu have generously given their time and expertise to enhance my work. I thank them for their contribution and their good-natured support.

My special thanks go to my sister, father and mother for their support and encouragement during all my life. This dissertation could not have been written without them.

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December 2008 Burak Pak

Architect, M.Sc.

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ABBREVIATIONS

CAD	**:** Computer Aided Design
CAAD	**:** Computer Aided Architectural Design
PA	**:** Protocol Analysis
ITU	**:** Istanbul Technical University
ICT	**:** Information and Communication Technologies
OAD	**:** Overall Analysis Duration
3D	**:** Three Dimensional
2D	**:** Two Dimensional
STM	**:** Short Term Memory
LTM	**:** Long-Term Memory
SM	**:** Sensory Memory
DIPS	**:** Design Information Processing System
NURBS	**:** Non-uniform rational B-Spline

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DESIGN ACTIVITIES AND DECISIONS IN CONVENTIONAL AND COMPUTER AIDED ARCHITECTURAL DESIGN PROCESSES

SUMMARY

The aim of this study is to explore the possible reflections of the design domains on the students' design behavior by analyzing the similarities and differences between the computer-aided and conventional architectural design process.

A hybrid theoretical model is used to combine two major approaches to design research (rational problem solving by Simon and reflection-in-action by Schön) for investigating the design process.

The focus of this study is on certain topics of design activities, strategies, decisions and their organization in these two different cases. The sub-categories of these topics are inferred from the key findings of previously conducted studies and analysis of pilot experiments.

A comprehensive literature review was conducted before starting to design the research method. Theoretical concepts and empirical findings were revised with the focus on possible dimensions of measurement, analysis and evaluation methodologies. It is found that, although there is a variety of unstructured observations and assumptions about computer-aided design process, only a limited number of empirical studies have been carried out in the related research area. In all of the empirical studies, CAAD process was evaluated in comparison to the conventional design process (these are extensively reviewed in the Section 4.1).

Thus, different descriptions of the design activity by different researchers were reviewed and considered in all research phases, especially while determining the preliminary and final dimensions of measurement.

After a general survey of former empirical research on CAAD, it was decided to conduct a controlled experiment with two conditions: first experimental condition (C01), the subjects were obliged to design with the software they prefer while participants in the control condition (C02) were only allowed to utilize only conventional tools.

The sample population was determined as 16 senior students of ITU Faculty of Architecture. This decision was based on the homogeneity of design expertise and software use among the students, shared design terminology between the researcher and the students, high accessibility of subjects and the possibility of contributing to the architectural design approaches in ITU.

The duration of the experiment was defined as 120 minutes, due to the feasibility issues and time length of previous studies.

The experiments were conducted in ITU Faculty of Architecture and a total of 1890 minutes of protocol recordings were obtained. In terms of the number of participants and length of the experiments, this research is one of the most comprehensive studies ever undertaken among the indexed publications.

The design problem for the experiment was formulated considering the characteristics of the research question, sample population, the duration of the experiment and the problems that were used in similar surveys. The problem description is decided to be relatively short in order to motivate the participants to restructure and redefine requirements.

Analysis of the experiments revealed that there is significant difference between the means of decisions on representation, decisions on the design process, concepts, structure and textual representations in conventional design and CAAD conditions.

Moreover, the overall decisions of the subjects that designed using CAAD software were organized differently throughout time. All of the subjects in this condition took numerous decisions about the design process but very few conceptual ones. They were focused more on creating detailed representations of the existing context. On the other hand, subjects in the conventional design condition used simpler representations and their conceptual decision making process was more continuous.

BİLGİSAYAR DESTEKLİ VE GELENEKSEL MİMARİ TASARIM SÜREÇLERİNDE EYLEMLER VE KARARLAR

ÖZET

Bu çalışmanın amacı bilgisayar destekli ve geleneksel mimari tasarım süreçlerindeki benzerlikler ve farklılıkları analiz ederek, tasarım araç ve ortamlarının öğrencilerin tasarım davranışı üzerindeki etkisini araştırmaktır.

Tasarım süreçleri incelenirken, tasarım araştırmaları alanındaki iki ana yaklaşımı (Simon'ın rasyonel problem çözme ve Schön'ün eylemde yansıma) birleştiren bir teorik model kullanılmıştır.

Bu çalışma, bilgisayar destekli ve geleneksel mimari tasarım süreçlerindeki belirli tasarım eylemleri, stratejiler, kararlar ve bunların organizasyonuna odaklanmıştır. Bu başlıklar ve alt kategorileri, teorik modellerden, literatürdeki diğer çalışmalardan ve pilot çalışmaların analizi sonucunda belirlenmiştir.

Araştırma metodu tasarlanmadan önce kapsamlı bir literatür araştırması yapılmıştır. Mevcut teorik kavramlar, deneysel bulgular ve olası ölçüm biçimleri analiz ve değerlendirme metodolojilerine odaklanarak gözden geçirilmiş, bilgisayar destekli tasarım sürecine ilişkin birçok informel gözlem ve varsayım olmasına karşın, kısıtlı sayıda deneysel çalışma gerçekleştirildiği sonucuna varılmıştır.

Bu sebeple, tüm araştırma safhalarında, özellikle başlangıç ve sonuç aşamalarındaki ölçüm kriterleri belirlenirken, tasarım eyleminin çeşitli araştırmacılar tarafından yapılan farklı tanımları değerlendirilmiş ve göz önüne alınmıştır.

Mimari tasarım araç ve ortamlarına ilişkin tüm deneysel çalışmalarda bilgisayar destekli mimari tasarım süreci geleneksel mimari tasarım süreci ile karşılaştırılarak değerlendirilmiştir (Bölüm 4.1'de ayrıntıları incelenebilir). Genel literatür taramasından sonra, iki deneysel kuruluş içeren kontrollü bir deney yürütülmesi kararlaştırılmıştır: birinci deneysel durumda (C01), denekler yalnızca tercih ettikleri yazılım(lar)la tasarım yaparken, ikinci deneysel durumda (C02) deneklerin yalnızca kalem, kağıt, cetvel gibi geleneksel tasarım araçları ile tasarım yapmasına izin verilmiştir.

Bu tasarım göz önüne alınarak 16 mimari tasarım öğrencisi üzerinde her biri 120 dakika süren bir deney çalışması gerçekleştirilmiştir. Tüm tasarım deneyleri aynı laboratuar ve aynı saatlerde gerçekleştirilmiş ve aynı kayıt cihazları kullanılarak ölçüm yapılmıştır. Deney çalışmasında yer alan deneklerin tamamı İTÜ Mimarlık Fakültesi son sınıf öğrencisidir. Eğitimsel ve mesleki deneyim farklılıklarını en aza indirgemek için deneklerin tamamı benzer demografik yapılarda seçilmiştir.

Deneyler İTÜ Mimarlık Fakültesi'nde gerçekleştirilmiş, ve toplam 1890 dakikalık protokol kaydı elde edilmiştir. Bu bağlamda bu deneysel çalışma, indekslenmiş yayınlar göz önüne alındığında şimdiye kadar gerçekleştirilmiş en kapsamlı tasarım deneyidir. Bu da sonuçların güvenilirliğini pozitif yönde etkilemiştir.

Araştırma sorularının karakteristikleri, denekleri profilleri, deneyin uzunluğu ve benzer çalışmalarda kullanılan problemler dikkate alınarak yeni bir tasarım problemi oluşturulmuştur. Problem tanımı deneklerin tasarım şartlarını yeniden yapılandırıp tanımlamalarına olanak sağlayacak şekilde (göreceli olarak) kısa tutulmuştur.

Deneylerin istatistiksel analizi sonucunda temsiller, konseptler ve strüktür ilgili kararlar ve metinsel temsilerin ortalamaları arasında anlamlı farklar bulunmuştur..

Ayrıca bilgisayar ortamında tasarım yapan deneklerin kararlarının zaman içindeki düzenlerinde gözle görülebilir farklılıklar bulunmaktadır. Bu deneklerin tamamına yakını üç boyutlu temsil üretme aşamasında tasarım sürecine ilişkin sayısız karar vermelerine rağmen çok az sayıda kavramsal karar vermişlerdir. Söz konusu denekler mevcut tasarım mekanının ayrıntılı üç boyutlu temsillerini üretmeye odaklanmışlardır. Öte yandan geleneksel yöntemlerle tasarım yapan denekler çok daha basit temsiller kullanarak tasarım yapmış ve kavramsal karar verme süreçleri kesintiye uğramamıştır.

1. INTRODUCTION

1.1 Motivation

Design behavior has been the subject of research for a long time. Due to its complex nature and modal variety, it is definitely a challenging area of investigation. The design process involves a broad range of activities including creating and representing ideas, making decisions and solving different types of problems.

During the past three decades, following the establishment of Design Research Society and Design Studies Journal, researchers improved and used diverse inquiry methods to get a clearer insight, but there are countless aspects of the design process waiting to be discovered.

Furthermore, the developments in Information and Communication Technologies led to the emergence of a new domain: computers.

Today, architects are extensively utilizing digital technologies for concept development, planning, drafting, visualization, simulation, parametric design and fabrication. Virtually all of the design offices replaced most of their drawing boards with computers, scanners and plotters. These technologies also gained acceptance by architectural design schools.

The motivation of this study stems from the proclaimed facts and the following questions:

- How do designers use the digital domain to design?
- Are there indicators that characterize this behavior especially in contrast to manual patterns of design?
- Can these differences or indicators provide a “fingerprint” for modes of design?
- How can these fingerprints be used?

1.2 Aims, Scope and Limitations

The aim of this study is to explore the possible reflections of the design domains on the students' design behavior by analyzing the similarities and differences between the computer-aided and conventional architectural design process.

A hybrid theoretical model is used to combine two approaches (rational problem solving by Simon and reflection-in-action by Schön) for investigating the design process. Different descriptions of the design activity are reviewed and considered in all of the research phases (as recommended by Cross (2007)).

The focus of this study is on certain topics of design activities, strategies, decisions and their organization in these two different cases (Table 1.1). The sub-categories of these topics are inferred from the key findings of previously conducted studies and analysis of pilot experiments.

Table 1.1: Dimensions of measurement (detailed version is reviewed in Chapter 3)

	Dimensions of Measurement	**Sources**
Activities and Strategies	Tools of Action Tools of Representation Problem Transformation Referencing Textual Representations	(Simon, 1969) (Schön, 1992) (Goel, 1995) (Akin, 1996) (Song and Kvan, 2003) (Lawson, 2005) (Cross, 2007) Analysis of the pilot studies
Decisions	Concepts Elements / Material – Non-material Context (Place, Environment) Organization of Spaces Magnitudes of building and elements Languages and notations Structures, technologies and processes	(Simon, 1969) (Schön, 1992) (Ericsson and Simon, 1993) (Akın and Lin 1995) (Bilda, 2001) (Bilda, Gero et al. 2006) (Lawson, 2005) (Stones, 2007) (Cross, 2007) Analysis of the pilot studies

The subsidiary objectives can be summarized as follows:

- Improving and developing novel methods for observing and analyzing the computer-aided design process.
- Providing means for cross evaluating the use of digital and analogue tools in Istanbul Technical University (ITU) design studios.
- Seizing the opportunity to track a potential shift in students' design behavior by repeating the observations annually (promoting further research)

Design is a context dependent practice, as extensively reviewed in the research background section of this thesis. Findings are generalizable only to a specific domain as they are limited by the number of participating students and specific to the design problem used in the experiments.

The analysis method (protocol analysis) that is used in this study reflects participants' design activity rather than revealing personal thoughts (Lawson, 2005). This is consistent with the fact that theoretical focus of this thesis is mainly on the design praxis - the practices and processes - not the design episteme, the designerly ways of knowing.

1.3 Methodology

Protocol analysis method is employed for documenting and observing the design behavior in digital and conventional environments. This method is based solely on the assumption that verbal reports are reliable sources of information (Ericsson, 2002). This approach is frequently utilized in different studies with different approaches (which are reviewed in Section 3.1.2).

The hypotheses tested in this work are drawn from the previous empirical findings, theoretical assumptions and pilot experiments on the computer-aided and conventional conceptual design processes (which are reported in Chapters 2 and 3).

After a comprehensive review of similar studies, a double-conditional experiment has been designed and a pilot study was carried out with five participants. In the first experimental condition (C01), the subjects were allowed to design with the software they prefer while participants in the control condition (C02) were only allowed to utilize only conventional tools.

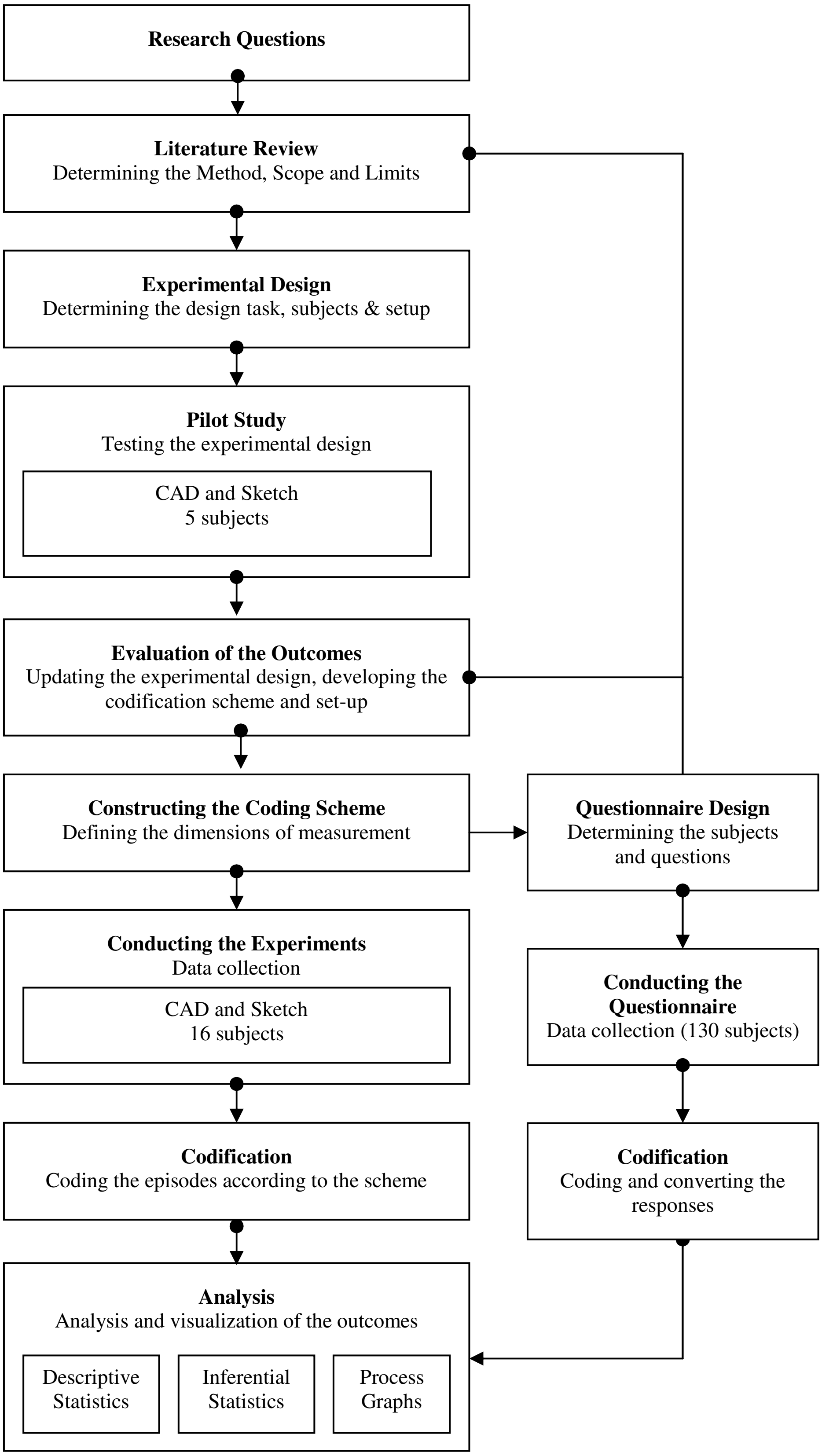


Figure 1.1 : Research process flowchart

Due to limited experiment duration, a relatively simple design task was introduced to the participants. The participants were expected to design a permanent art gallery in Istanbul Technical University School of Architecture. This problem is selected in order to promote diverse solutions and rich representations.

The sample population is determined as senior students of ITU School of Architecture. This decision is based on the following facts:

- The relative homogeneity of design expertise and software use
- Shared design terminology between the researcher and the students
- The high accessibility and willingness of experiment subjects
- Possibility of contributing to the evaluation of tool use in ITU architectural design studios by providing empirical findings

After the pilot experiment, the design sessions were transcribed, codified and the outcomes were evaluated. According to those findings, the coding scheme (dimensions of measurement) was finalized and the experimental setup was updated.

Following the evaluation phase, sixteen additional experiments were performed. The design process was recorded by a video camera and a voice recorder. In computer-aided design experiments, additional software was used to capture the participant’s design activity.

All of the recordings were transcribed and segmented. The observed activities and decisions were grouped into analysis categories based on the previously developed scheme.

At the last phase, descriptive statistics such as mode and mean of the dataset were used to summarize the data, while inferential statistics are used to test the hypotheses and significance of the outcomes.

In order to enhance the generalizability of the research, a questionnaire was specifically designed to suit the dimensions of measurement and significant findings gathered from the protocol analysis. 130 architectural design students from ITU School of architecture participated in the survey. The results are evaluated in comparison with the outcomes of the protocol studies.

A flowchart of the research process can be seen in Figure 1.1.

2. RESEARCH ON ARCHITECTURAL DESIGN

In order to establish a theoretical basis, a systematic literature review is essential. This section begins with a general survey on scientific methods of inquiry. It is followed by the discussion of theoretical models and assumptions on the architectural design process, revealing the subjective nature and deficiencies of these contributions.

Consequently, major paradigms and critical concepts in design research are extensively reviewed which are used as a basis for constructing a hybrid theoretical model and defining the dimensions of measurement.

In the last part of this section, analysis methods are critically reviewed and findings are summarized.

2.1 Scientific Methods of Inquiry

A comprehensive review on architectural design studies reveals that researchers use three different types of scientific inquiry methods:

1. Theoretical inquiry
2. Empirical inquiry
3. Semi-empirical inquiry (relying on observations or experiments to some extent)

Theoretical inquiry is crucial to all disciplines. Theories formalize observations in a unique form, and attempt to predict future behavior. This type of research may include a body of hypotheses, unproved assumptions, postulates or axioms but it is more systematic than a brain storming activity.

Theoretical research starts with standpoints, a body of existing knowledge, and critiques, uncovers, integrates, creates meanings, theories, models, paradigms or fields of knowledge (Ferrer, 2005). Induction is the major reasoning form in this type of studies (Figure 2.1). Relying on observations, scientists discover patterns and regularities, formulate tentative hypotheses and finally, develop general conclusions or theories (Trochim and Donnelly, 2007).

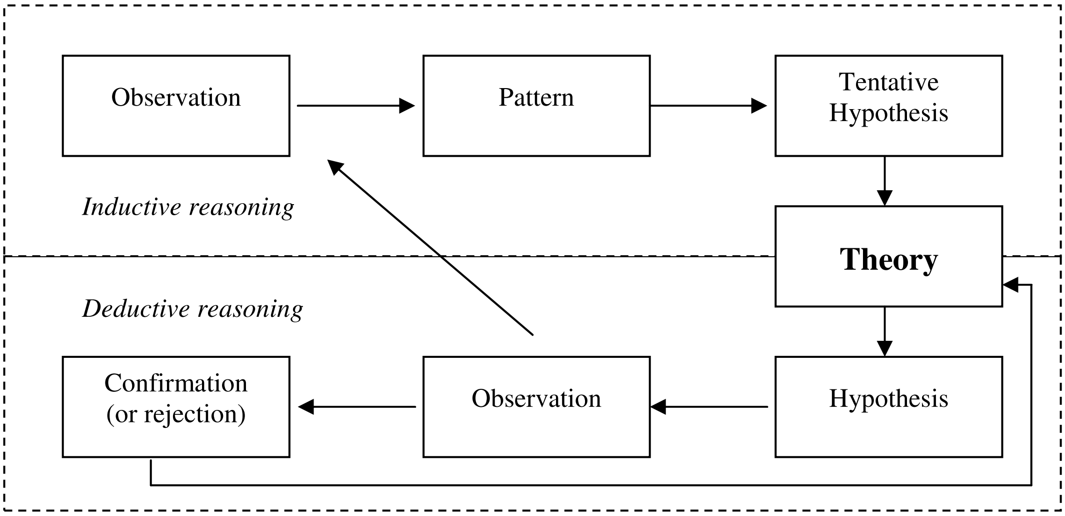


Figure 2.1 : Inductive and deductive reasoning in empirical and theoretical research

The common properties of "good" theories are summarized by Schick and Vaughn, (2002) as:

- Testability or falsifiability
- Simplicity (Occam's razor: All other things being equal, the simplest solution is the best)
- Wide scope of applicability
- Fruitfulness of predictions
- Consonance with existing body of knowledge

A theory is regarded as "scientific" only if it is falsifiable. An unfalsifiable theory is pseudo-scientific (metaphysical) and falls out of the scope of science (Popper, 1963). A "good" theory provides a wide range of predictions that can lead to future research while being consonant with the existing ones. Moreover, it has to be consistent and reproducible.

Primary publications on architectural design theory are Architectural Review, Architectural Design Profile (AD), Architectural Record, Journal of Architecture, Design Issues and Architectural Theory Review.

Empirical inquiry and theoretical inquiry are alternative and complementary concepts. Researchers that perform empirical inquiry start with deriving a hypothesis from existing theories and then test it using scientific methods (Figure 2.1). They rely on experiments or observations to obtain data. The basic steps of empirical research are (Saint-Germain, 2008):

1. Problem Statement, Purposes, Benefits
2. Theory, Assumptions, Background Literature
3. Research Design and Methodology (Defining variables and hypotheses, measurement units, sampling type and instrumentation)
4. Data Collection
5. Data Analysis
6. Conclusions, Interpretations, Recommendations

Primary publications that involve empirical studies are Design Studies, Automation in Construction, Environment and Planning B and Journal of Architectural Planning and Research.

Empirical research methods are discussed more extensively in Chapter 3.

Semi empirical inquiry relies on observations or experiments only to some extent. This method is widely used among disciplines such as Chemistry and Physics in which complex systems are investigated in different time scales and where it is nearly impossible to make observations or conduct experiments to confirm the reliability and validity. Architectural design research is a similar area of study. Most of the publications in Computer Aided Architectural Design (CAAD) research can be categorized in this group. This issue is detailed in Section 2.2.

2.2 Models and Assumptions on the Architectural Design Process

The term “architectural theory” was coined by Vitruvius in first century AD in order to differentiate between intellectual and practical knowledge.

Until the mid-eighteenth century, architectural theory and history were treated as similar research areas. These theories were primarily concerned with the architecture of the antiquity and sixteenth century, in order to reveal the design principles and the superior artisanship of them, with the purpose of "attaining certain environmental ideals" (Collins, 2008). During the eighteenth and nineteenth centuries, Ecole de Beaux Arts and Ecole Polytechnique were the dominant architectural design schools. The teaching methods developed by these schools covered an intermediate systematic description of the architectural design.

During the "esquisse" sessions, the masters (patrons) of Ecole de Beaux Arts imposed a methodology consisting of three design stages (Rowe, 1987):

1. Systematic analysis and interpretation of the program (Analysis)
2. Investigation of the different possibilities of meeting the program (Synthesis)
3. Elaboration and representation of the process through plans, sections and elevations (Evaluation)

Founded by Walter Gropius in 1919, Bauhaus school at Wiemar (Hochschule für Gestaltung; Academy of Form Giving) radically departed from Ecole de Beaux Arts in its approach to design. Heavily influenced by modern movements such as functionalism, the school was dedicated to producing buildings that "efficiently" provided services predefined by the customer and the architect – just like a machine.

Looking at the curriculum of Bauhaus (Figure 2.2), we can infer that the School members viewed architectural design process as a practice involving observation, composition, representation and verification. Building and engineering sciences were the core elements in the curriculum and they were seen as the primary analysis and testing methods.

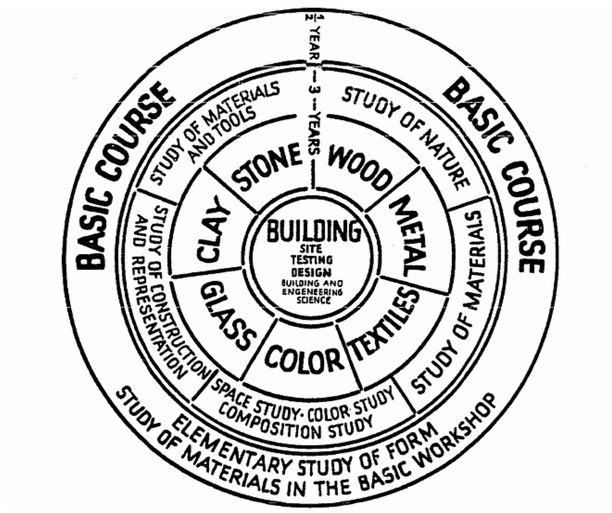


Figure 2.2 : Diagram of the Bauhaus curriculum, published in 1923.

An industrial engineer, Morris Asimow, has pioneered the modern theories emphasizing the design process. He proposed an iconic model with three dimensions: abstractness, analysis-synthesis-evaluation activities and communication. (Figure 2.3)

Vertical dimension involves activity phases that are relatively more abstract in the early stages and better pronounced ad finem. Design is communicated visually and verbally as the designer follows the traditional analysis-synthesis-evaluation procedures repeatedly. The host environment "E" is defined as a volume containing all possibilities and combinations of these activities.

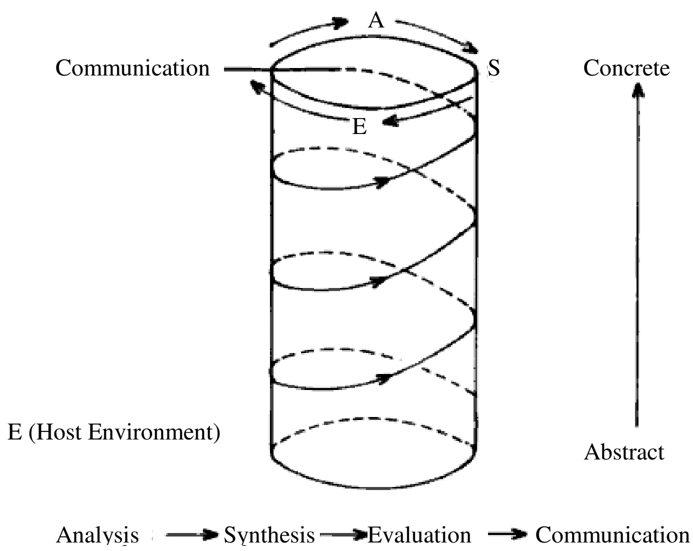


Figure 2.3 : Asimow's iconic model of design represented (Rowe, 1987).

According to Lawson (2005), The Royal Institute of British Architects' (RIBA) handbook covers one of the first formal approaches to describe the design process. In this model, the design process consists of four phases: assimilation, general study, development and communication. The process is neither "necessarily" sequential nor linear. There are unpredictable jumps between the phases, except the communication phase (Figure 2.4). One can definitely say that this map is a version of the traditional analysis-synthesis-evaluation model.

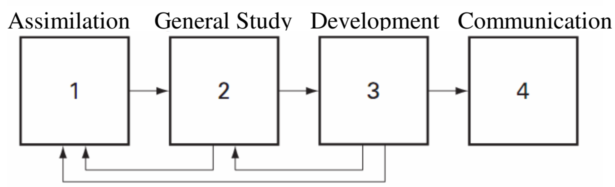


Figure 2.4 : Design process according to RIBA handbook, published in 1965.

Christopher Alexander is another notable figure in the history of architectural design theory. In his doctoral thesis, "Notes on the synthesis of form" he described architectural design as the process of creating solutions and organizing them in relation with the building program.

For Alexander (1964), architectural design is "the adaptation of forms to human needs and demands". This is truly a creative problem-solving approach to the design process. He developed a model based on the (mathematical) set theory to represent and redefine the design problem and create new concepts that correspond to the subsystems of the whole process. He applied this method to an Indian village for requirement modeling (Figure 2.5). Alexander was criticized for his "mechanical" approach; describing the design problem as a set of equally valued requirements and the design product as "the solution". Today, his work stands as an icon displaying the inadequacy of the positivist design models (Lawson, 2005).

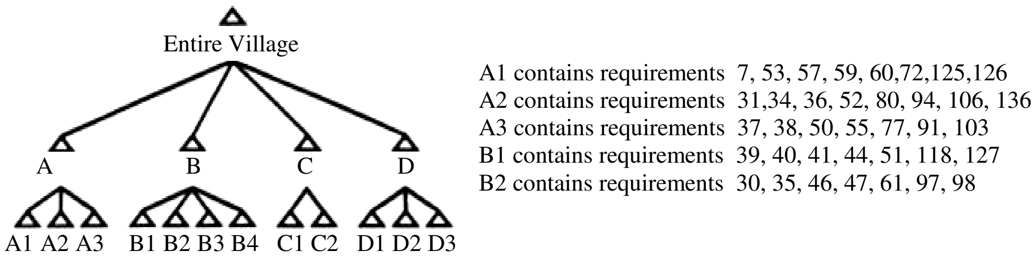


Figure 2.5 : Alexander's relational requirement model of an Indian village

Nevertheless, his approach is unique and the most comprehensive of them all. Alexander's theory covers a model and a methodology, so we can say that it is at once descriptive and prescriptive. Although his model is unsatisfactory, some of his ideas on design representation have the potential to be used in developing CAAD applications.

Bruce Archer (1965), an industrial designer, suggested a model of the design process, based on the classical analysis-synthesis-evaluation scheme (Figure 2.6). Compared with the former ones, Archer's model provides a better insight into design. He grouped the activities into three different phases: analytical, creative and executive. However, there is a problem with this map: in controlled experiments, it has been observed that designers interpret and redefine the design problem. So, programming should also be considered as a creative process.

Furthermore, in the communication phase, designers produce a variety of representations such as drawings, models, etc. Nearly all design activities involve creative thinking. On the other hand, Archer's assertion about the design reasoning sounds logical. In the beginning of the process, there should be more activities containing an element of inductive reasoning compared with the last stages. This hypothesis is worth testing, but it may be difficult to trace the different types of reasoning involved in design.

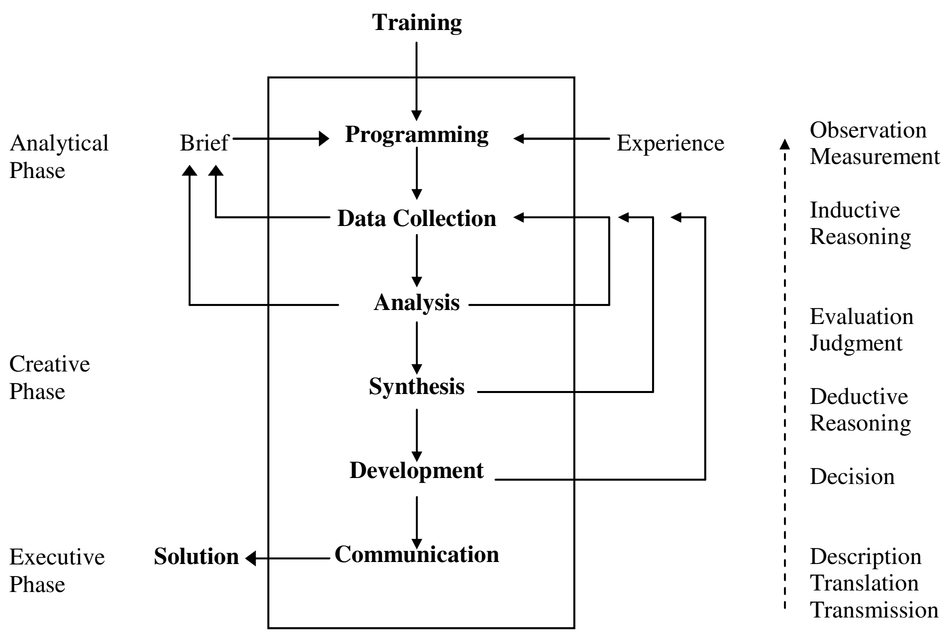


Figure 2.6 : Archer's Design Process Map (1965)

Archer's work is important because it is the first process map that discusses the different types of logical reasoning used in different phases of design.

In 1970, Tom Maver brought the traditional analysis-synthesis-evaluation model to another level by introducing a new process map for architectural design. They suggested that design process consists of three episodes: outline proposals, scheme design and detail design. In each episode, the designer performs analysis, synthesis, appraisal and decision activities consecutively (Figure 2.7).

This model is criticized for its incapacity to reflect the reality, and especially for the missing return loops between the activities and episodes. It is common among the designers to go back and re-analyze the design problem, requirements, environment, etc. Therefore, it is nearly impossible to tell where the analysis phase starts or where the synthesis phase ends.

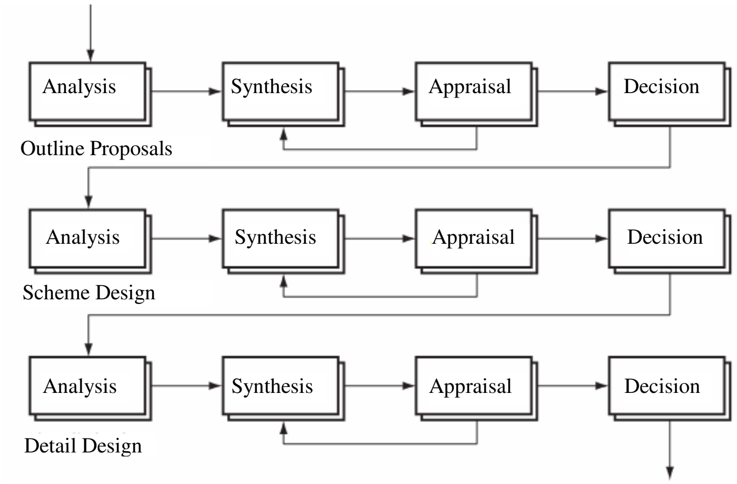


Figure 2.7 : Design Process according to Tom Maver (1970).

Twenty years later, Carl Steinitz, a professor of landscape architecture and planning developed a framework for a collaborative design studio (Figure 2.8). Similar to Alexander's model, his approach is at once descriptive and prescriptive.

According to Steinitz's process map, the designers use six different types of models: representation models, process models, evaluation models, change models, impact models and decision models. The designers "visit" these models (which are mentioned above) at least three times: first, downward in defining the questions (analysis), second; upward in deciding how to answer the questions (synthesis) and third; downward in providing the answer (solution) (Steinitz, 1990). If the answer is insufficient, it means that they have to review the models or change the scale of inquiry and start the whole process from scratch.

Steinitz's framework is important because it is first theory to assert that the designers construct and utilize a range of models through the design process. Thus, his study can be described as "a meta-model of design" or "a model of design models".

In 1990, another remarkable contribution to design theory was made by John Gero from Sydney University. He published a paper featuring a schema for design knowledge representation in eleventh volume of the Artificial Intelligence magazine. In his paper, the three different characteristics of the design object are defined as function, behavior and structure.

"Function" describes the purpose for which it was designed; "behavior" refers to the expected actions performed by; and, "structure" illustrates the components and their relationships of the artifact (Figure 2.9).

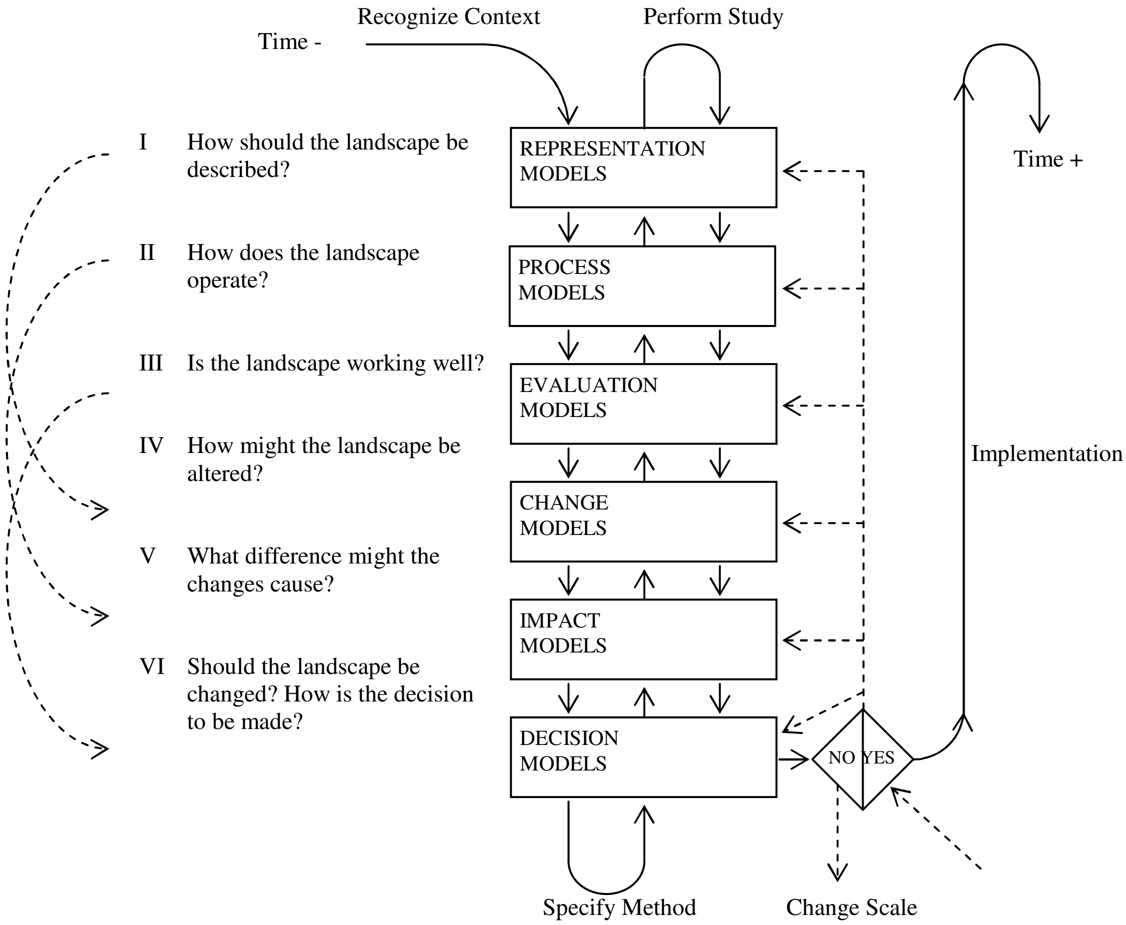


Figure 2.8 : C. Steinitz's design framework, applicable to landscape design education (1990).

Gero claims that, during the design process, the designer establishes connections between the three aspects mentioned above (function, behavior, structure). He describes eight fundamental processes that involve different ways of transforming and comparing these characteristics.

These fundamental processes are:

1. Formulation
2. Synthesis
3. Analysis
4. Evaluation,
5. Documentation

6-7-8. Reformulation (types 1, 2, 3).

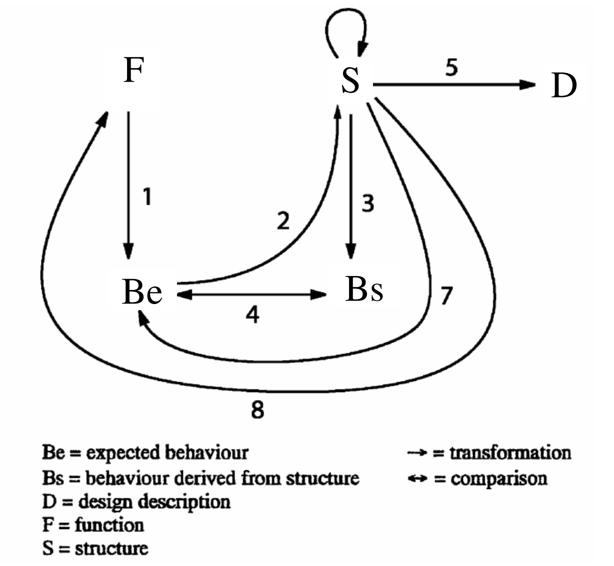


Figure 2.9 : John Gero's FBS schema for design knowledge representation (1990)

In a more recent study, Rivka Oxman (2006) developed a schema of components, relationships and properties for modeling the design process in different environments. She categorized the traditional design activities into four classes: representation, generation, evaluation and performance. (Figure 2.10) (In the original paper, "digital representation" is mistakenly included in the paper-based model, so, Figure 2.10 is updated corresponding to her written descriptions.)

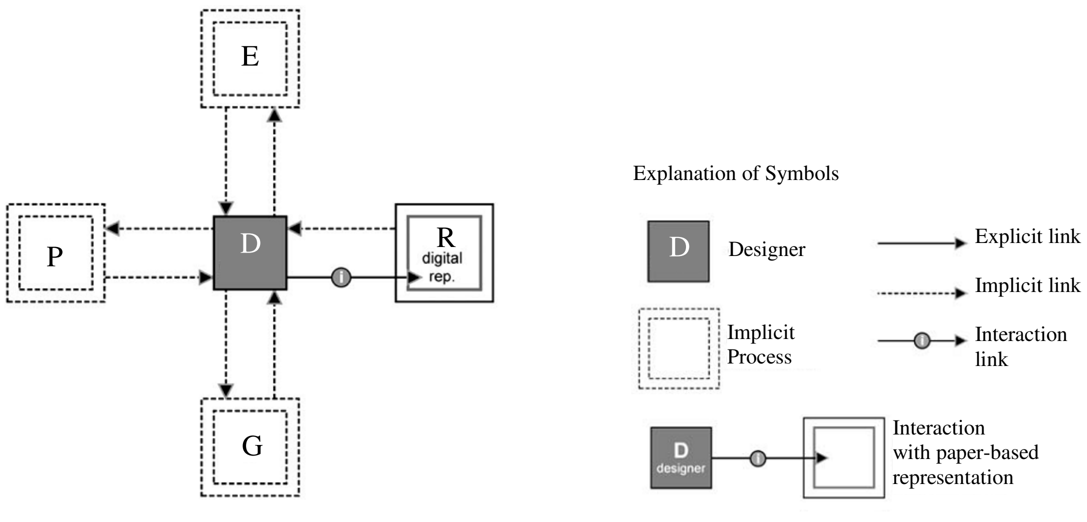


Figure 2.10 : Design activity classes and their relations (Oxman, 2006).

According to Oxman's conception, the activity classes are linked implicitly and/or explicitly in different design modes. In the paper-based mode, the designer "implicitly" incorporates performance requirements, generative and evaluative procedures while explicitly interacting with the paper based representations.

2.2.1 Assumptions on computer aided architectural design

All the theories that are reviewed in the previous chapters are partially or completely applicable to the CAAD process, but at this point, it is more useful to look at the progression of theories that exclusively concerned with the digital modes of design. The relationship between Information and Communication Technologies (ICT) and architectural design has been the subject of much debate for nearly 45 years.

Developed by Ivan Edward Sutherland in 1963, the first man-machine graphical communication system (Sketchpad) made it possible for the users to interact with computers through the medium of line drawings (Sutherland, 1963). It is still considered as one of the most influential computer programs ever written by an individual. In his PhD thesis, "Sketchpad: A man-machine graphical communication system", Sutherland (1963) introduced the concept of Computer Aided Design (CAD) and claimed that drawing with Sketchpad is "itself a model of the design process". Sutherland's pioneering research defined conventions of CAD such as real-time generation, transformation and manipulation of parametric drawing objects and editable block instances (which actually lead to object oriented programming).

Since the publication of the proceedings of the 1989 CAAD Futures conference as "The Electronic Design Studio", experiments about using computers in the studio have become widespread. Information and Communication Technology has started to be integrated in undergraduate studios. During 1990's, ICT have advanced rapidly enabling the development of advanced representation environments and complex interconnected networks. The computation performance has increased more than ten times in ten years (Brenner, 1996). Different kinds of interfaces have been developed and they became commercial. Computer aided manufacturing technologies have improved and became more precise. Today, architects use these technologies to design, evaluate and manage complex architectures following a new process called "file to factory" (Oosterhuis, 2004). This digitally mediated design process ends up with new products that are named as "blobs", "hypersurfaces", "transarchitectures" or "non-standard architectures".

Based on these observations, Jencks (2003) suggested that there is a "paradigm shift" in architecture.

Following Jencks, Eisenman (2005) has stated a similar point of view several times, most notably in International Union of Architects Conference.

It seems that there is a consensus on the existence of an emerging architectural paradigm among many architectural theoreticians and professionals.

The idea of a paradigmatic shift in a specific discipline was first introduced by Thomas Kuhn. Although the notion of "paradigm shift" was initially used to describe the structure of scientific change (Kuhn, 1970), today, it is widely referred to as a thought pattern in an epistemological context by theoreticians from different disciplines.

Nowadays, architectural designers are extensively utilizing digital technologies for drafting, simulation and fabrication, which are heavily influenced by Sutherland's system. Contemporary architectural theory is preoccupied by discussions on the role of ICT as a tool, medium and an adjunct actor (Lawson, 1994), (McCullough, 1996), (Asanowicz, 1997), (Ataman & Bermudez, 1999).

Architect-researchers tend to make big statements and generalizations based on informal observations (Table 2.1). For instance, Stipech and Mantaras (2004) states that media had a strong impact on the creativity of the design students. As an accepted theory of creativity does not exist, the impact of digital media is not measurable in this aspect. Similarly, Liu and Lim (2006) claimed that, "digital media are stronger for design development" without any empirical evidence or a criteria of evaluation.

Likewise, John Marx (2000) asserted that, in digital medium, often hand sketching is not necessary. His assumption is also based on informal observations. Marx's interpretation signifies a common biased approach among CAAD researchers, confusing the descriptions of an existing situation and their own prescriptions.

According to Bermudez and King (1998), the digital media "bias the design process towards an aesthetic formalism". Similar to many of the ones above, this statement is a pseudo-scientific hypothesis and it falls out of the scope of empirical design research.

Although papers on CAAD lack empirical evidence, nearly all of the researchers agree that designers follow a different process in the digital medium. The important question here is that how does the digital media affect the design process.

Table 2.1: A selection of assumptions on Computer Aided Architectural Design Process

Assumptions	**Source**	**Empirical Evidence**
"Digital media are stronger for design development, as they demand higher levels of geometrical definition and abstraction, and the elaboration and coordination of complexity and details."	New tectonics: a preliminary framework involving classic and digital thinking Yu-Tung Liu and Chor-Kheng Lim, Design Studies, Volume 27, Issue 3pp. 225-422 (May 2006)	No
"The media had a strong impact in the creative processes of broad range of students."	The Digital Media and New Technologies in Visual Arts Studio, Alfredo Stipech and Guillermo Mantaras, IJAC 2004	No
"Digital system decreases the amount of time a designer allocates to non-creative production tasks."	Kyle W. Talbott (2004).Divergent Thinking in the Construction of Architectural Models International Journal of Architectural Computing, vol. 2, issue 2, pp. 263-286(24)	No
"Students are exploring new ways of designing."	Henri Achten (2003) New Design Methods for CAAD Methodology Teaching, IJAC, Volume 1, Number 1, pp. 72-91(20)	No
"Digital design does not replicate the traditional approach of designing in plan, section and elevation."	Digital design studios, (2000) Thomas Seebohm Skip Van Wyk, Automation in Construction, Volume 9, No1 pp. 1-4	No
"Designers think and act in 3D to a greater degree." " Digital Medium allows easy access and manipulation of information." " In the digital process, often even preliminary hand sketching is not necessary. " "The design evolves from the earliest possible stages in a 3D digital format, and remains digital throughout the design process."	John Marx, A proposal for alternative methods for teaching digital design, Automation in Construction 9 (2000) 19–35	No
"Put differently, the sensuality of digital depictions begins to bias the process towards an aesthetic formalism."	Bermudez J. and King K. (1998) Media Interaction and Design Process: Establishing a Knowledge Base, ACADIA 98 Conference Proceedings (pp. 7–25)	No

Seebhom and Wyk (2000) observed that designers do not follow the traditional plan-section-elevation methodology while working in the digital medium. As design software offers a wide range of 3D modeling tools, some of the 2D representations may be impractical in this medium. On the other hand, one needs at least a plan or a section in order to produce a 3D model. Therefore, it is expected that the computer-aided designers will use plan, sections and/or elevations more frequently in the early design phase.

CAAD researchers' assumptions on the design products are nearly impossible to verify since architects have no consensus on the qualities of the architectural design projects. Moreover, there is anecdotal evidence that most of the designers follow "a hybrid" design method (a CAAD and Sketching), so there is a question mark as to whether the latest blobby architectural designs are a result of the digital design tools or not.

Table 2.2: Analysis methods and falsifiability of the assumptions on the affects of digital media on the design process

Assumptions on	**Analysis Methods**	**Falsifiability**
Design Process	Task Analysis Protocol analysis Surveys Questionnaires Ethnographic methods Others	High
Designer	Psychoanalysis Protocol analysis Surveys Questionnaires Others	Medium-Low
Design Product	Individual Observations Phenomenological Analysis Surveys Questionnaires Others	Medium-Low

In summary, we can classify the hypotheses related to CAAD as assumptions on the design process, design product and the designer. Assumptions on the process are highly testable, while it is hard to verify the hypotheses on the product and the designer (Table 2.2).

2.3 Major Paradigms in Design Research

Two major paradigms dominate design research: “Reflection-in-action” by Donald Schön and “Problem Solving” by Herbert Simon. Based on the findings of Dorst and Dijkhuis (1997) and observations of Cross (2007) and Lawson (2005), it is decided to discuss the hybrid theoretical models as a third category.

2.3.1 Design as “ill structured” problem solving

According to the founder of the Design Research Society (DRS), Nigel Cross, design research studies started during the Second World War, when operational research methods of decision-making techniques were first implemented. The foremost conference on design research was held in London in 1962, soon, DRS was established.

“The Sciences of the Artificial”, a famous book by Herbert Alexander Simon, is definitely one of the milestones in design research history. The book is based on lectures that he gave at Massachusetts Institute of Technology in 1968.

Simon’s (1969) primary thesis is that, “certain phenomena in our world are artificial in a very specific sense: they are as they are only because a system’s molded, by goals or purposes, to the environment in which it lives”.

Heavily influenced by Aristotle as well as Dewey, Simon emphasized the ontological distinction between the artificial and the natural. According to Simon, natural sciences are descriptive and they are focused on how things are. Therefore, there is a need for a new category of science dealing with how things might be, “the science or sciences of design”.

For Simon (1969), thinking and problem-solving behavior is artificial. We learn how to think and improve our strategies through the invention of designs. He coined the word “satisficing” to describe a kind of decision-making strategy that can be summarized as “the practice of searching for a satisfactory solution rather than the best or the optimal”.

In summary, Simon suggested that it is possible to study the design process in a disciplined and empirical manner.

The first known controlled architectural design experiment aimed at observing the design process was conducted by Eastman at Carnegie Mellon University (Cross, 2006). The design problem was to remodel a bathroom. Eastman used psychological tools applied by Newell and Simon in human problem-solving research (Eastman, 1969). By using protocol analysis methods and problem behavior graphs, Eastman uncovered "generate and test strategies" throughout the whole design process. He extended information-processing theory to include "ill-defined problems" and shown that the specification process is essential for ill-defined problem solving (Eastman, 1969). Eastman was followed by Krauss and Myer (1970), Foz (1973), and Akın (1978).

In 1978, Ömer Akın used an information-processing model of design (DIPS) (Figure 2.11) to study the mechanisms responsible for behaviors of architectural designers. He applied a set of analysis and observation methods, including protocol analysis and calibrated various components of this model to fit into the area of architectural design. This is an approach adopted from cognitive psychologists, who divide memory into three parts: sensory memory (SM), short-term memory (STM) and long-term memory (LTM). A designer has effectors and receptors, which transfers the information to/from a processing unit, in which information is transformed from one state to another. Then it is stored in the long-term memory and retrieved if necessary.

In his Ph.D. thesis, Akin (1978) asked four subjects to design a single-occupant house and analyzed the design process using the protocol analysis method. He also invented a processing model to codify the design process itself.

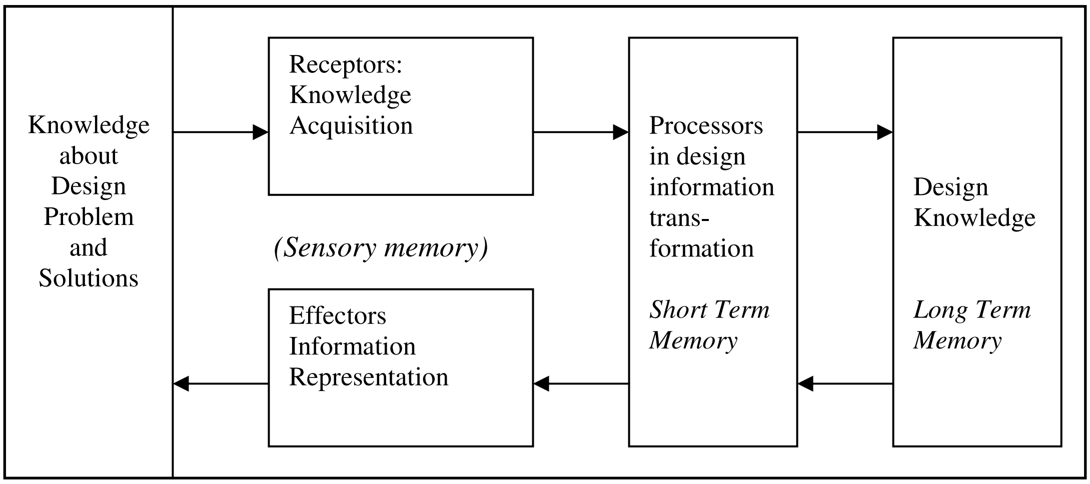


Figure 2.11 : Design Information Processing System (Newell and Simon, 1972)

According to this theory, designers transform problem states by applying individual strategies. Design problems are ill defined and designers redefine to formulate and restructure the design problem's specifications during the design phase.

Compared with well-defined problems, design problems are far more complex. It takes a considerable effort for an architect (or a group of architects) to create a design concept and refine the drawings to meet the customer's requirements and expectations. The objectives, premises and methods are open-ended. (Akin, 1986)

Akin's well-known book, "Psychology of Architectural Design" (1986) is a comprehensive review of his empirical and theoretical studies on design research, which he conducted between 1976 and 1986. In this book, Akin (1986) pointed out the importance of examining the differences as well as the similarities between problem solving and design. (Table 2.3)

Bryan Lawson (2005) confirms Akin's evaluation of the dissimilarities between design problems, solutions and the design process. Furthermore, he adds that design solutions are often "holistic responses" and they are integrated into, (parts of) other problems.

Table 2.3: The similarities and differences between problem solving and design (Akin, 1986)

Similarities between Problem Solving vs. Design	Initial State	*The problem has an initial state*
	Problem States	*Design problems go through states*
	State Transformations	*Each State is transformed into other states*
	Search Strategies	*A number of search strategies are used by designers*
Differences between Problem Solving vs. Design	Problem Definition	*Design problems are ill-defined*
	Goal State	*Design problems are inadequately specified*
	Complexity	*The design problem is far more complex than well-defined problems like puzzles*
	Representations and Transformations	*Creative design solutions are often linked to the redefinition of conventional interpretations of design*

2.3.2 Design as "reflection in action"

In 1983, Philosopher Schön proposed a different approach to design which he called "Reflection in Action".

Analyzing the protocols from participant-observation studies of a design studio directed by William Porter of the MIT School of Architecture and Maurice Kilbridge of the Harvard Graduate School of Design, he argued that design is "a reflective conversation with the situation".

According to Schön (1987), architects often think about what they are doing, even while doing it. They communicate with the design drawings reflecting their ideas – back and forth. Designers change their opinions about the design itself while generating and interpreting representations (Gero and Kannengiesser, 2008).

Table 2.4: Normative design domains (Schön, 1983)

Domain	**Definitions**
Program Use	Functions of the buildings or building components; uses of a building or site; specification of use
Siting	Features elements, relations of the building site
Building Elements,	Building components of buildings
Organization of Space	Kinds of spaces and relations of space to one another
Form	(1) Shape of building or component (2) Geometry (3) Markings of organization of space (4) Experienced felt-path of movement through spaces
Structure/Technology	Structures, technologies and processes used in building
Scale	Magnitudes of building and elements in relation to one another
Cost	Cost of construction
Building Character	Kind of building, as sign of style or mode of building
Precedents	References to other kinds of buildings, styles or architectural modes
Representation	Languages and notations by which elements of other domains are represented
Explanation	Context of interaction between designer and others

Through his observations, Schön argued that architectural design has a language. Design language consists of verbal and non-verbal layers, which are interrelated. Differences of language and style can be associated to the variety of design paradigms in architectural schools. (Schön 1987) Moreover, certain actions are related to elements of design. We are sometimes unaware of our previously "learnt" actions or skills and mostly unable to describe "the knowing which our action reveals" (Schön, 1983).

Schön (1983) introduced thirteen categories to describe the concerns of the architects during the design phase: program use, siting, building elements, organization of space, form, structure/technology and scale, cost, building character, precedent, representation, and explanation. He called these categories as "normative design domains" (Table 2.4).

Schön's theory suggests that, by analyzing specific reflective actions in the design process, researchers can make different inferences about design. However, we should be aware that design problems are unique and the knowledge involved in the process cannot be generalized to other types of problems.

In his book "Educating the reflective practitioner" (1987) he explored protocols from three "interpersonal" professional educational disciplines (music, management consulting and psychoanalysis) and he claimed, "All professions are design-like" (Waks, 2001).

2.3.3 Hybrid models of design research

Dorst and Dijkhuis (1997) used and compared two approaches to analyze the data extracted from a carefully executed design experiment (in Delft University) (Table 2.5). They concluded that rational problem solving approach worked better particularly for the "clear cut problems" and describing design as a process of reflection-in-action worked particularly well in the conceptual stage of the design process.

Simultaneously, Akin and Lin (1995) proposed an approach in which actions and design decisions are evaluated together. They developed a framework and criteria set to evaluate design decisions. As a result, they discovered that there is a correlation between certain design activities and novel design decisions.

Cross (2007), claimed that design researchers need to be knowledgeable of both types of the design paradigms mentioned above, because they have the potential to uncover different types of information related to the design process. He also references to Dorst and Dijkhuis' complementary research methodology as a comprehensive way of understanding.

Similarly, Lawson (2005) proposed a hybrid model of design thinking. In order to allow richness and variation, he combined Schön's theory of reflective action with the theory of problem solving. In the epilogue of his book "How Designers Think", he stated that analyzing both models of the design process would yield a better view about the actual design practice.

In brief, different descriptions of the architectural design process provide different concepts that can be used to analyze the design activities and decisions. These concepts will be used for construction of the research hypotheses in Section 3, in which the methodological basis of the dissertation is discussed.

Table 2.5: Comparison of design research paradigms (Dorst and Dijkhuis, 1997)

	Rational Problem Solving Paradigm	**Reflection in Action Paradigm**
Designer	Information processor	Person constructing his /her reality
Design Problem	Ill-defined, unstructured	Essentially unique
Design Process	A rational search process	A reflective conversation
Design Knowledge	Knowledge of design procedures and "scientific laws"	Artistry of design: when to apply which procedure / piece of knowledge
Example / Model	Optimization theory, natural sciences	Art/ social sciences

2.4 Critical Concepts in Design Research

2.4.1 Memory

The idea of a distinction between two different types of memory goes back to William James, who proposed that conscious mental activity requires a different form of memory. He postulated that, "for a state of mind to survive in memory it must have endured for a certain length of time" (James, 1890).

George A. Miller, a well-known researcher from Princeton University, made an important discovery in 1956. By observing the results of a number of experiments, he concluded that, on one exposure, an average human being can remember up to five to nine items (seven plus or minus two), depending on the content. Later on, this phenomenon became known as "Miller's magical number seven" (Miller, 1956) and is verified by numerous researchers.

In an experiment conducted by Peterson and Peterson (1959), subjects were presented a set of three letter combinations and instructed to perform algebraic computations. The analysis showed that, as the participants worked longer on computations, they were less likely to give correct answers (Figure 2.12).

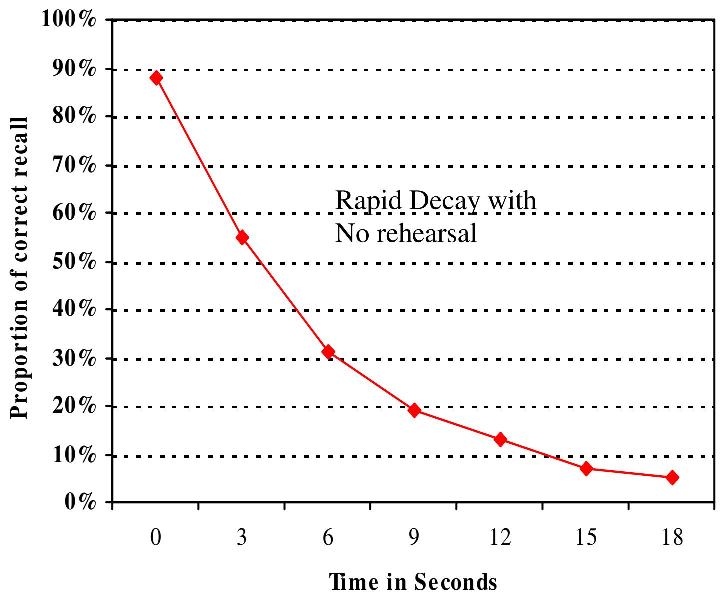


Figure 2.12 : Proportion of recall decreases in time (Peterson & Peterson, 1959)

Murdock (1962) presented his subjects a list of ten to thirty words one at a time , each word for one second and asked to recall them. He found out that the participants remembered the words presented at the beginning and at the end of the experiment more frequently. This is called the serial position effect, and it is accepted as an evidence for the existence of different memory modes. Words in the middle (after the fifth word) were less likely to be stored in the short-term memory and to be held in long-term memory (Figure 2.13).

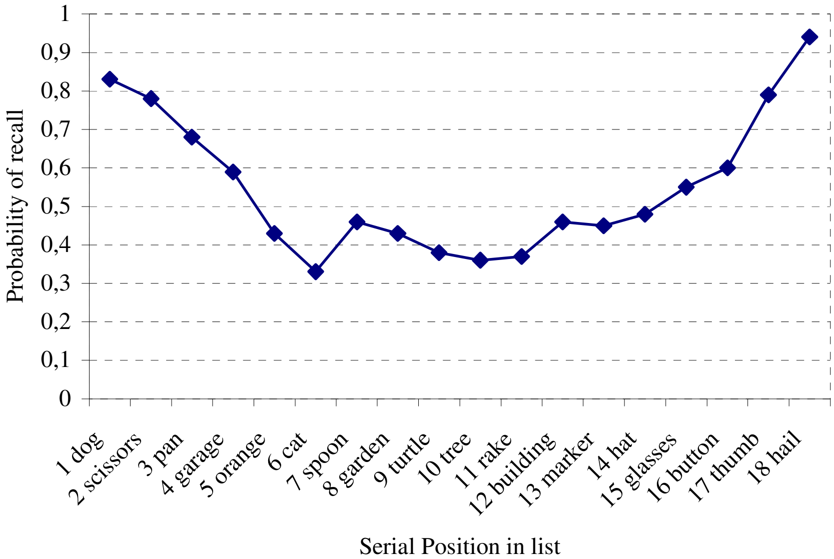


Figure 2.13 : The words at the beginning of the list and those at the end are most easily recalled (Murdock, 1962).

In 1968, Richard Atkinson and Richard Shiffrin proposed a memory model to explain how memory processes work. According to the researchers, memory is divided into three stores (Figure 2.14):

1. Sensory store
2. Long-term store
3. Short-term store

Sensory organs store the incoming information for less than a second and pass it to short-term memory. Information stays in short term store between 15 to 30 seconds and then it is transferred to long-term store. Some of the strongest empirical evidence for Atkinson-Shiffrin memory model comes from analysis of anterograde amnesic patients. Typically caused by brain damage, patients suffering from this disease cannot learn new facts while they are capable of remembering previous events or skills (Squire Et al., 2004).

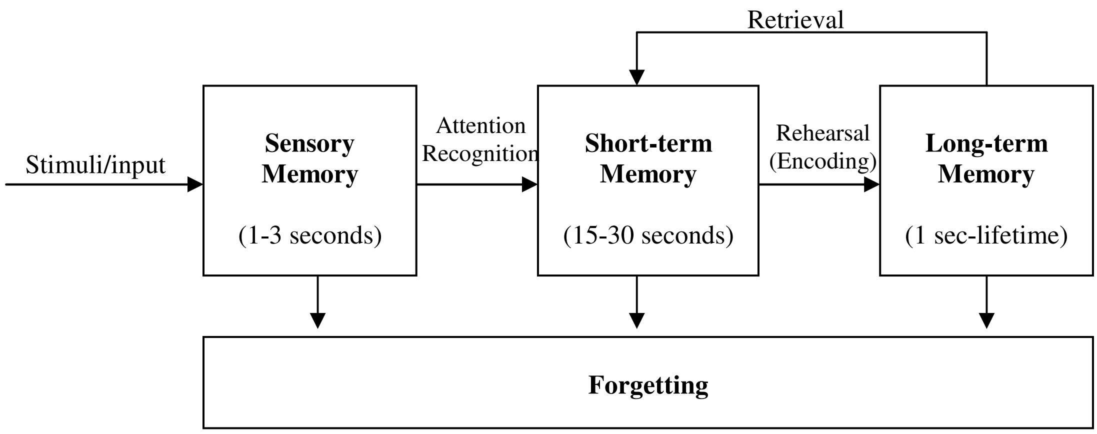


Figure 2.14 : An improved version of Atkinson-Shiffrin multi-store memory model (The Sensory stage is devised later)

Atkinson-Shiffrin model is also supported by H.M.'s case study, a memory-impaired patient who had lost his ability to retain new memories. Suzanne Corkin studied and tested H.M. for 43 years. The patient could not remember who she was. When presented his older photos, he could not recognize himself even though he remembers that the stock market crashed in 1929 (Corkin, 2002).

Based on H.M.'s analysis, scientists proved that declarative and procedural memory are also separate. In an experiment carried out by Milner (1962), H. M. was trained on a mirror-drawing task. The patient's learning curve was normal: H.M.'s procedural memory was working normally. This finding is also observed by Cohen and Corkin with a Tower of Hanoi task (Kolb & Whishaw, 1996).

A similar case in the literature is E.P., a patient that became heavily amnesic after a viral infection that damaged his brain permanently. Empirical analysis of E.P. revealed that, although his short-term and non-declarative (procedural) memory were working properly, he had severe amnesia for personal semantic knowledge (Stefanacci Et al, 2000).

As described above, patients' have a wide range of memory loss. These tragic cases led to cognitive scientists to conclude that long-term memory consists of episodic, semantic and procedural memory.

Episodic and semantic memories are declarative, while procedural memory is non-declarative (Parkin, 1999) (Figure 2.15).

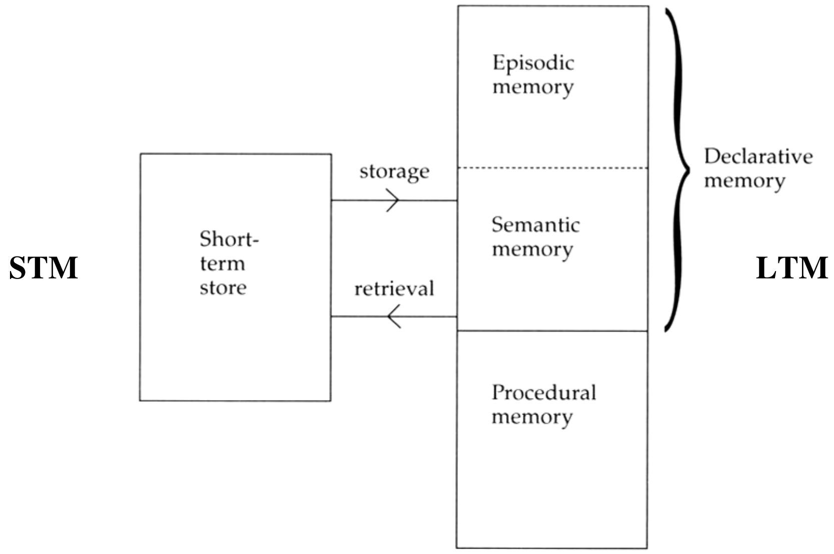


Figure 2.15 : The organization of memory (Parkin, 1999) Short-term store on the left and long-term store on the right

2.4.2 Design knowledge and expertise

Design knowledge is an ill-defined and continuously changing domain that covers an unknown range of concepts. Different from well-defined disciplines, there is no defined list of expertise areas for architectural designers (Lawson, 2005). The term "design knowledge", in the narrow sense, is used to describe the design expertise or skills acquired by experience, education or theoretical understanding (Ericsson, 2002). Although the scope and limits of design knowledge are undefined, certain knowledge representation classes can be helpful in explaining its different aspects.

Design knowledge can be categorized according to its scope: general or specific knowledge. General knowledge is applicable to many different circumstances whereas specific knowledge is relevant to a specific context. For instance, design knowledge about deductive, inductive or abductive inference is general while design knowledge about attributes of a building element is more specific. Akin (1986) classified design knowledge according to their "subtype-supertype" relationships (Table 2.6).

Design knowledge can also be categorized according to its content: declarative and procedural. Declarative knowledge covers the description of objects, their attributes and relations between them while procedural knowledge refers to "all of the things that describes or predicts actions or a plan of action" (Akin, 1986).

Table 2.6: Taxonomy of design knowledge representations (Akin, 1986)

	Specific knowledge	**General Knowledge**
Declarative "things"	Tokens	Schemata
Declarative "relationships"	Attributes	Rules of inference
Procedural	Transformations	Heuristics

In various design experiments (which are reviewed in Section 3.4), these two distinct types of design knowledge are observed and analyzed in detail. It is found that novice and expert designers approach differently to the design problems and follow different routes. In the conceptual design phase, novices prefer to explore alternative solutions in depth, whereas experts consider a wide variety of possibilities (Cross, 2007).

Expert architects rely more on their procedural experiences compared to novices (Akin, 1996). Therefore, it is evident that the level of expertise affects the way designers use their knowledge and the variety of procedural strategies employed.

2.4.3 Representation

Representation has been an important notion in design research for a long time. The pioneers of the two major design research paradigms, Simon and Schön attributed great importance to this concept.

Simon (1969) stated that, representation of the design problem is the key to final product. Designers deal with the complexity of the problem by creating partial representations of the problems.

According to Schön (1993), designing is a reflective conversation with the design situation: designers "see" the existing representation, draw and, "see" the modified representation. The ability of the designer to evaluate the modified situation and recognize the unexpected results of the modification allows him or her to develop continuously new ideas and designs.

There are two basic modes of architectural representation:

1. Internal representations
2. External representations

Internal representations are reflections of the concepts on the human mind. Akin (2001) distinguished between two types of internal representations: verbal and visual. Verbal representations are related to conceptual thinking whereas visual representations are related to visual thinking (which is reviewed in the next section). It is very common among the designers to take notes during the analysis of the design problem (information retrieval) and concept development phase.

Bilda and Gero (2005) conducted an empirical study to test the need for external representations in the conceptual design phase. They found out that, with the help of internal representations, architects can design blindfolded. Therefore, external representations are not essential for concept development.

A designer minimizes the internal representations related to the design problem while producing external representations by thinking about other concepts. There is anecdotal evidence that designers usually focus on other subjects while creating labor-intensive representations. This mode of thinking is significantly different from the thinking process during conceptual design in which the designers quickly create freehand representations (The difference between these two thinking modes is discussed in Chapter 4).

Architects use a wide variety of external representations: sketches, diagrams, maps, texts, photographs, perspective drawings, physical models, virtual 3D and 4D models, sound and video recordings and many more. For Goel (1995) the most important property of the conventional external design representation is its ambiguity because it allows the designers to generate more ideas.

External representations can also be taken as a way of extending the use of long-term memory, perfectly encoding and elaborating the related concepts.

2.4.4 Visual thinking

Visual thinking is an essential tool that allows designers to use and transform imaginary visual symbols to represent concepts. Designers can reflect their thoughts on both through internal and external visual representations, and then re-evaluate the transformed representation continuously. Schön (1992) described this process as a cyclic development process in which “seeing that-moving-seeing as” actions are performed iteratively. His theory is partially grounded on McKim’s (1980) explanation of visual thinking process during problem solving: seeing-imagining-drawing. Likewise, Goldschmidt (1991) observed similar behaviors and preferred to call them as “interactive imagery”.

Based on protocol studies of expert designer and Wittgenstein’s “philosophical investigations”, Schön and Wiggins (1992) distinguished between different kinds of seeing: seeing-as and seeing that.

Seeing-that involves judgments such as “this room is too small”. It is followed by a performing a move and seeing-as which is described by Schön (1993) as “the carrying over of frames or perspectives from one domain of experience to another”.

Seeing-that actions depend on the ability of designers to make qualitative evaluations, whereas seeing as is related with using metaphors and establishing analogies. The power of “seeing-as” is that, it generates new ways of seeing.

From a different perspective, Arnheim (1969) observed that vision is selective and intentional. Human consciousness discards “constant factors” and focuses on the relative or interesting (which is called “selective attention”). Moreover, he developed a three staged model to represent visual problem solving behavior: humans start by finding candidates for problem solving, search for a specific pattern (eye movements) and finally test it at a rate of about twenty per second (fixation). Arnheim’s model can be implemented to design research and used for analyzing the perception of external representations.

2.4.5 Design strategies

The commonly observed procedural strategies used by expert designers in dealing with complex or partial problems, or inventing new designs are (Akin, 1996):

1. Decomposition (Breadth and Depth Search)
2. Recomposition (Pairwise Integration)
3. Problem restructuring

As architectural design problems are ill defined and extremely complex in most of the circumstances, architects decompose them into smaller parts and explore them one by one. Some of the decisions depend on “higher-level” decisions such as specifying the orientation of the building in the project site, so they start with dealing with general problems and search for different possibilities without detailing them. Once the general decisions are made, experienced architects come up with different alternatives.

Akin (1996) observed that, after decomposition of the problem and finding particular solutions, architects recompose them to more general ones. In this phase, architects combine partial solutions in pairs. This behavior may be related with the limited cognitive abilities of the humans and subject to future research.

The third design strategy is also closely related to the ill-defined nature of the design problems. As the requirements can never be specified perfectly, architects make assumptions and sometimes redefine them (Akin, 1986, 1996). This behavior is also referenced as "problem framing" and "co-evolution" in different resources. Akin (1996) carried out an experiment to reveal the relation between the architects' restructuring behavior and their level of expertise (Figure 2.16). He observed that experienced architects reformulate the design problems more frequently compared with novice and non-architects.

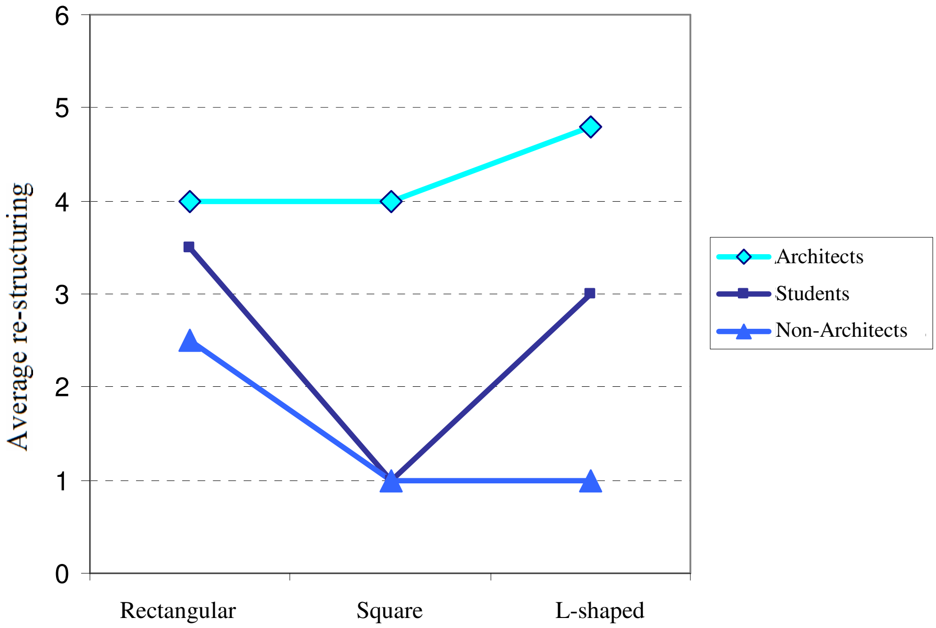


Figure 2.16 : Problem restructuring frequency by subject and by the subject of the design problem (Akin, 1996)

Song and Kvan (2003) performed a different study on problem restructuring behavior. The researchers found out that the design medium might affect the frequency of problem framing activity. During the conceptual design phase, the designers that used computer-aided design software restructured the design problem less frequently compared with the designers that followed the conventional sketching method.

There are also other classical assumptions about the order of the activities in the design process, such as the analysis-synthesis-evaluation episodes and plan-section-elevation representations (which are reviewed in Section 2.2) waiting to be analyzed through different experiments.

2.5 Analyzing the Design Process

The range of research methods for analyzing the design activity is countless. Starting with Eastman (1969), formal studies are conducted in various disciplines, including Architecture, Industrial Design, Mechanical Engineering, Electronic Engineering and Software Design (Table 2.7). Common analysis methodologies are:

- Protocol analysis
- Interviews
- Ethnographic observations
- Surveys and questionnaires
- Self reports
- Others

Regardless of the theoretical model that design researchers use, protocol analysis has been proved to be the most common and effective method of studying the design process (Cross, 2007). Both Schön (1983) and Simon (1969) based their theories on their own interpretations of empirical protocols derived from specific design tasks.

Surveys and questionnaires are useful in measuring the attitudes and perceptions of the designer whereas interviews may help the researcher to develop new questions and offer highly individual knowledge.

There are other rarely utilized analysis methods such as eye tracking for measuring fixation points and evaluation of design drawings for eliciting designers' thought processes.

Table 2.7: Protocol and other Formal Studies of Design Activity 1970-1999 (Cross, 2001) Studies between 1999 and 2008 are added by the author.

	Architecture	Industrial Design	Mechanical Engineering	Electronic Engineering	Software Design	Various/ Other
1970	Eastman					
1973	Foz					
1978	Akin					
1979	Lawson					Thomas
1981					Jeffries	
1983	Schön				Adelson	
1985						
1987		Ballay	Staufer			
1988			Ullman			
1989			Radcliffe			
1990	Chan		Tang , Visser		Guindon	
1991	Goldschmidt		Jansson,Purcell	Colgan		
1992		Christiaans	Ehrlenspiel		Davies, Olson	Goel
1993			Fricke			
1994			Lloyd	Ball		
1995		Dorst				
1997	Gero, Suwa					Goker
1998		Valkenburg,Dorst	MacNeill			Smith
1999						Atman
2000						
2001	Gero, Tang					Hakkarainen
2002	Kavakli, Gero					Taura,Yoshimi
2003	Bilda, Demirkan				Turner,Turner	
2004	Akin,Moustapha					Atman,Cardella
2005						Cardella,Atman
2006	Menez, Lawson		Jin,Chulsip			
2007	Bilda, Gero					
2008	Kim, Maher	Liikkanen,Perttula				

2.5.1 Protocol analysis

Protocol analysis (PA) is a psychological research method used to investigate subjects' design thinking process according to their verbal reports of their thoughts. This method is based on the assumption that verbalizations of the subjects are reliable sources of information from which an extensive analysis can be performed. (Ericsson, 2002)

Research in this area moved historically through three theories: behaviorism, information processing, and constructivism. (Hall (2001) points out to similar occurrences in education theory.)

As reported by Ericsson and Simon (1993), the earliest protocol studies are conducted by behaviorist researchers Watson (1913), Duncker (1926), Bulbrook (1932) and Durkin (1937). At that time, voice-recording devices were not widely available so researchers had to transcribe the verbalizations in real-time.

Starting with the studies on human cognition and information processing "Limits on Our Capacity for Processing Information" by Miller (1956), Newell & Simon (1972) used PA as the principal method in their research. These studies are based on the model that human knowledge is stored in different buffers: sensory register (SR), short-term memory (STM) and long-term memory (LTM) (Anderson, 2004).

Donald Schön, the founder of "reflection in action" theory, analyzed protocols from participant-observation studies of a design studio directed by William Porter of the MIT School of Architecture and Maurice Kilbridge of the Harvard Graduate School of Design. He applied constructivist thinking to his analysis and accordingly, he was able to develop a new theory.

Dorst and Dijkhuis (1995) proposed a hybrid model of design research combining a variety of theories. They analyzed the protocol data gathered from an international workshop held in Delft University and concluded that it is possible to extract different types of knowledge with different theoretical approaches.

PA is an analysis method that can be applied independent of any design model. The only assumption behind PA is that, subjects' verbalizations somehow reflect the performed task.

The phases of a conventional think-aloud protocol study can be described as follows:

1. Defining the research question
2. Designing the experiment(s) (materials and method)
3. Conducting the pilot study
4. Building the coding scheme
5. Conducting the experiment(s)
6. Transcription
7. Segmenting
8. Codification
9. Analysis

Formulating a research question is the first step for constructing the conceptual framework of a PA study. A good research question is conceptually straightforward, clear and specific. Using this framework, a hypothesis (or hypotheses) can be derived from the research question. For all scientific analysis studies including PA, it is essential to check the falsifiability of the hypothesis (or the hypotheses) before moving on to the next phase. Falsifiability can be summarized as "the logical possibility that a hypothesis can be proved false" (Popper, 1963).

Experiment design involves defining the controls, treatments, variable(s), sample group and data collection and analysis procedures. After establishing the experiment design, a pilot study should be carried out to test the whole framework for reliability, practicality, relevance and convenience.

The best way to develop a coding scheme is to extract the related analysis categories by observing the pilot experiment. The major experiments can be performed following the scheme formulation step and the initial evaluation of the entire setup. Prior to the major experiments, it is crucial to give a short training session to the subjects on how to verbalize while performing the given task. Practicing may help the subjects to understand the difference between different levels of verbalization (Level 1, 2 and 3).

As the subjects are instructed to "think aloud" in PA studies, the transcription of verbalizations is necessary for further analysis. The transcriptions are organized into segments and units, depending on the research question and the purpose of the experiment. The length of the segments may vary from several seconds to several hours. For instance, a study on perception may require dividing the transcription into seven-second segments, while a holistic process analysis may involve variable segment lengths.

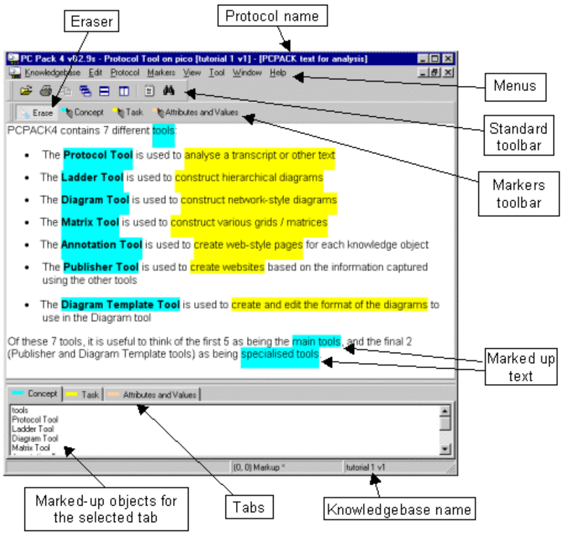


Figure 2.17 : PCPACK5 software interface, transcription and knowledge objects

During the codification process, researchers interpret the transcriptions, video, audio recordings and drawings using codification scheme and group them into analysis categories and segments. This task can be done faster by using the PCPACK5 software (Figure 2.17) developed by Epistemics Company for knowledge management. As a result of this phase, protocols are formatted into tables and prepared for statistical analysis.

In the analysis phase, researchers perform descriptive and inferential statistics to evaluate the collected protocols. Descriptive statistics such as mode, mean, median, variance and standard deviation of the dataset are used to summarize the data, while inferential statistics like t-test and chi-square test are used to test hypotheses and make inferences about the population.

There are other alternative analysis methods such as “linkography” to map the protocol data and assess the cognitive actions and design productivity (Goldschmidt, 1990), (Kan and Gero, 2005). In this method, the design process is represented as moves, links, nodes and layers. Measuring entropy of these fore links and back links can be used to evaluate productivity.

2.5.1.1 Think-aloud, Talk-aloud, concurrent and retrospective probing

There are three different types of verbal analysis, depending on the time of the verbalization:

1. Think-Aloud, Talk-Aloud
2. Concurrent probing
3. Retrospective probing

According to Simon and Ericsson (1991), in direct one to one verbalization, information is gathered from short-term memory (STM). Theoretically, this type of verbalization should provide more accurate information on the design process than many-to one verbalization (Table 2.8).

Table 2.8: A Classification of Different Types of Verbalization Procedures as a Function of Time of Verbalization (Ericsson & Simon, 1980)

	Relation between heeded *(attended)* and verbalized information			
Time of verbalization	**Direct one to one**	**Many to one**	**Unclear**	**No relation**
While information is attended	Talk aloud Think aloud	Intermediate inference and generative processes		
While information is still in short-term memory	Concurrent probing (synchronous gathering)			
After the completion of the task-directed processes	Retrospective probing	Requests for general reports	Probing hypothetical states	Probing general states

Ericsson and Simon (1993) have identified three different levels of verbalization:

1. At the first level of verbalization, subjects are not directed to express their thoughts. Hypothetically, subjects do not make any special effort to communicate. This method is called **"talk-aloud".**
2. In Level 2 verbalization, subjects describe their thoughts, to **"think aloud"**. It is postulated by Ericsson and Simon that this type of verbalization will take more time compared with a normal task.
3. The third level of verbalization involves explanation of subjects' actual thought processes and revealing their relations to the former ones.

Researchers concluded that, level 1 verbalization (talk-aloud) involves no intermediate training and has no performance effects.

In, level 2 verbalization, subjects spend more time than their usual tasks, but it does not change the cognitive processes. Level 3 verbalization affects the cognitive process since it requires the subject to reflect on his or her thoughts when prompted (concurrent probing) (Table 2.9).

Table 2.9: Levels of verbalization and their effects on learning performance, summarized by (Bannert and Mengelkamp, 2007)

Levels of verbalization	**Effects**
Level 1 : Talk-aloud (Verbal encoding) - No intermediate processes	No performance effects
Level 2 : Think-aloud (Verbal encoding) - Longer processing time	Time, but no other performance effects
Level 3: Reflect when prompted (Inference, filtering, verbal encoding) - Changes cognitive processes	Time and performance effects

In experiments based on Level 3 verbalization, subjects recall from long-term memory. Scientists observed that this type of communication interrupts the thinking process and decreases performance (Bannert and Mengelkamp, 2007).

Similarly, Ericsson (2002) reported that verbal reports are more reliable when subjects verbalize thoughts concurrently, while carrying out the task.

Gero and Tang (2001) conducted an experiment to compare retrospective and concurrent protocols. During the retrospective analysis, the designers had the opportunity to watch the video recordings, but they could not extensively recall what they were thinking at that time (Figure 2.18). The scientists concluded that think-aloud and retrospective protocols are correlated with each other and in terms of the process-oriented aspects of designing, concurrent protocols "are still the most efficient and applicable methods in exploring the design process". Concurrent protocols expose more information in the early stages of the design process, when the designers are analyzing the problem (Gero and Tang, 2001).

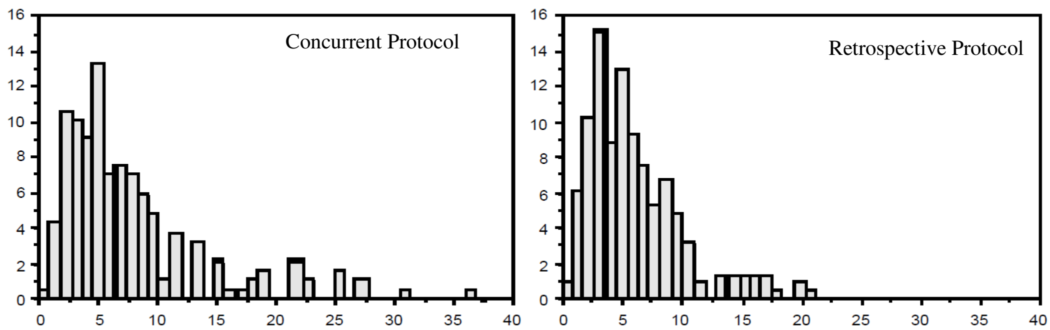


Figure 2.18 : Spectrum of segment lengths in the concurrent protocol (left), and the retrospective protocol (right) (Gero and Tang, 2001)

2.5.2 Effects of training, instructions and reminders on the experiment

While conducting a protocol study, researchers must pay particular attention to the pre-experiment training as well as the instructions and reminders given to the subjects. Pre-experiment training includes introducing the notions of thinking or talking aloud, a short verbalization practice and an evaluation session.

The aim of the training session is to test how the participant performs and reacts to the think-aloud task, which he or she has probably never performed before. In addition, it provides an opportunity for the experimenters to check the recording equipment and the setup. For the training session, the subjects are presented a design problem and instructed to verbalize their thoughts.

The instructions are usually very short, such as "try to think aloud. I guess you often do so when you are alone and working on a problem" (Duncker, 1926) or, "think, reason in a loud voice, tell me everything that passes through your head" (Claparède, 1934), which will obviously result in Level 2 verbalizations.

In contrast, directing the subjects to talk aloud will result in Level 1 verbalizations. Therefore, the experimenters must be careful with the content of the instructions to ensure consistency between the aim of the study and collected protocols.

One of the problems with the protocol analysis experiments is that the participants frequently forget to verbalize their thoughts during the experiments. After fifteen seconds to one minutes (depending on the study), it is common for the experimenters to remind the participants to reflect on their thoughts. These reminders take two main forms: “keep on talking” or “what are you thinking about” (Simon and Ericsson, 1993). The latter reminder interrupts the subjects’ natural thought flow, forcing them to make a self-observation (concurrent probing), while the former has minor effects. Overall, compared with classical introspective studies, the effects of the instructions are negligible (Simon and Ericsson, 1993).

One of the most noteworthy criticisms of PA studies is about a probable conflict between the verbalization process and performed task, in other words, the probable side effects of thinking aloud. Concerned with this question, Karpf (1972) carried out an experiment with forty students. He split them into two groups and instructed them to solve five problems. During the experiment, the first group of students verbalized their thoughts while the control group remained silent. Eventually, Karpf did not find a significant difference between the numbers of correct answers given by both groups. However, the first group (think-aloud) spent 50% more time than the second group.

No studies have been done about the effects of thinking aloud on performance while designing. On the other hand, there is anecdotal evidence that, a concurrent probing interrupts the design process, as the participants are not used to observing and reporting their ideas verbally, especially during the conceptual design phase. Further research is needed in this area.

2.5.3 Questionnaires

A questionnaire is a scientific instrument for collecting information from human subjects using a series of questions. Questionnaires are widely used in different research areas including design research.

The basic steps of designing and conducting a typical questionnaire are: (Oppenheim, 2000)

1. Setting the goals and defining the research question
2. Estimating the sample size
3. Determining the interview methodology
4. Designing the questions
5. Conducting the questionnaire
6. Analyzing the outcomes

Defining a research question allows the researchers to determine the contents of the questionnaire and target population. Similar to other research areas, when it is not feasible to collect information from all members of the target population, researchers conduct the questionnaire with sample subjects. Sample size can be estimated using statistical methods.

Questionnaires should be designed to fit the medium: the number and types of the questions and the interview method are specified according to the demographic characteristics of the subjects. The questions should be clear, specific and easy to understand.

There are two types of questions that are frequently used in questionnaires (Gillham, 2008):

1. Open-ended questions
2. Closed questions

In open-ended questionnaire design, subjects are expected to answer the questions in their own words. Open-ended questions are useful for gathering less structured information and explore a topic in-depth, but it is difficult and time consuming to analyze them.

Closed questionnaires offer multiple-choice answers to the respondents. The number of choices may be odd or even numbered and differ between two to ten depending on the purpose and limits of the study. In order to obtain answers that are more objective, leading questions and loaded answers must be avoided. There is evidence that respondents are inclined to agree with leading questions (which is called “the social desirability bias”) (Gower, 1996).

In closed questionnaires, answer choices can take the form of a checklist, a ranking (comparison) or a rating scale. A comprehensive literature review reveals that, Likert-type psychometric response surveys are effective in evaluating the respondents’ level of agreement to a specific statement (Dannevig and Thorvaldsen, 2007) (Hahn et. al., 2007).

In Likert method, five to ten agree-disagree choices are given for each question. Depending on the design of the study, respondents may be directed to choose a rating category or to place a tick mark anywhere on the line (Figure 2.19).

A typical Likert item consists of five ratings (Guion, 1998): “Strongly agree”, “agree”, “undecided”, “disagree” and “strongly disagree”.

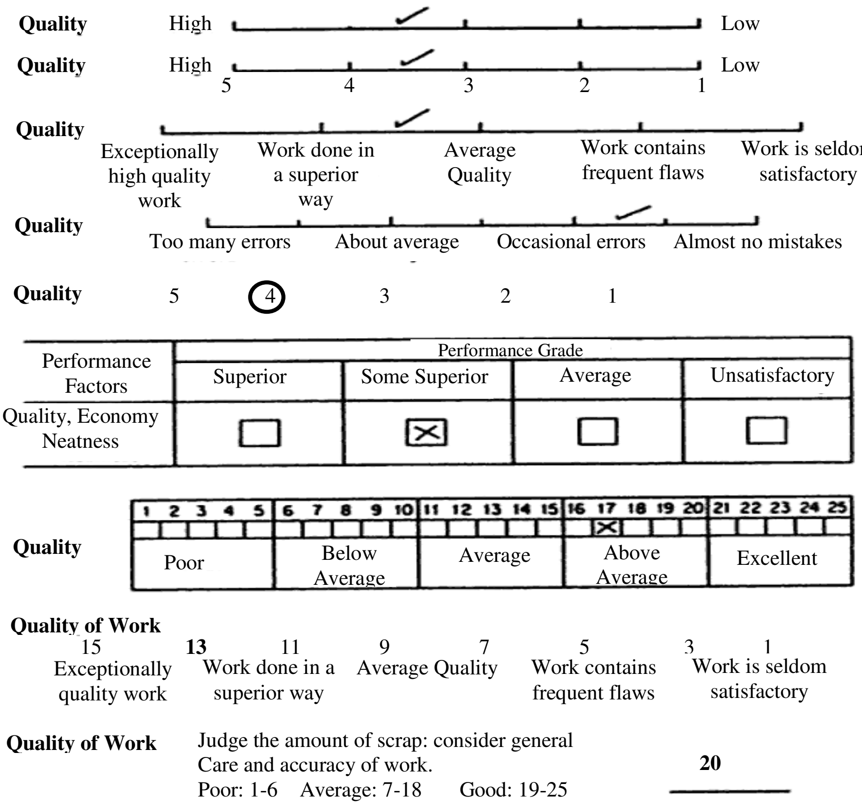


Figure 2.19 : Variations of a graphic rating scale (Guion, 1998)

Odd-numbered scale divisions allow the respondents to remain neutral or undecided. This may be useful for gathering more sensitive reports while it may also encourage the respondents to avoid the extreme answers and choose the middle category for most of the items (which is called “end-aversion bias” or “central tendency bias”) (di Lorio, 2005).

Questionnaires can be administered in many different ways: face-to-face interviews, postal surveys, telephone surveys, internet and others. Whitehead (2007) observed that the interview method affects the return rate and web-based surveys are responded less frequently than postal versions. Postal surveys are less intrusive since the subjects can answer the questions in a convenient time. In all cases, the anonymity of the respondents should be guaranteed and protected.

In the analysis phase, descriptive and inferential statistics are used to describe and illustrate the responses to the questions. Central tendency is usually measured by median or mode while significance levels are derived from parametric tests such as Chi-square test. It is very common to report the outcomes of Likert type questionnaires using a box plot.

Questionnaires are frequently used in design research to collect information about the designers’ attitudes, experiences and perceptions of certain concepts. Hanna and Barber (2001) conducted a questionnaire-based survey with thirty students to analyze the use of computers as a design medium. Students were divided into two equal groups. The first group was given a seven-day tutorial on AutoCAD and computer aided design. Their attitudes towards the design process were recorded “before using the computer and after using the computer”. Remaining students served as a control group. A five-point Likert scale was used in the survey.

Hanna and Barber (2001) found out that students’ response to several aspects was significantly different in two different cases. Students reported that CAD software helped design cognition, creativity and intuition. The impact of CAD software on student’s attitudes was evident and positive in composition, drafting, lighting, presentation and sun studies. On the other hand, their ideas about sketching were not affected.

Pektaş and Erkip (2006) carried out a similar questionnaire based survey with sixty students. The analysis of the responses revealed that there is a major difference of attitudes between male students and female students. Male students were more positive towards using computers in design while female students were found to be less willing to take a CAD courses. In general, students' attitudes were positive with some variation.

In conclusion, it is important to emphasize that questionnaires reflect the reality as it is perceived by the subjects. Therefore, the results of this kind of research should be evaluated considering this fact and crosschecked with other analysis sources.

2.6 Summary of the Findings

A comprehensive review on CAAD literature revealed that, there is a variety of hypotheses on the digital design process. However, only a few of the studies followed formal evaluation methods and used empirical data. There is little recorded evidence of investigation into CAAD (Koutamanis, 2004).

Thomas W. Maver points to this problem in his famous paper "CAAD's Seven Deadly Sins". Maver (1995) states that, "in any other discipline, the generation of hypotheses without testing, would be laughed off". Lack of evaluation, validity and criticism are the main challenges for design research.

Similarly, Flemming (2004) noted that there is a huge difference in the quality of the works presented in the journals. Therefore, the outcomes of CAAD research should be evaluated carefully.

It is obvious that Simon's problem solving approach and Schön's reflection in action framework are the most rigorous theoretical attempts to describe the architectural design process. These theories are well documented and tested through empirical observations and experiments, providing a reliable basis for analysis, synthesis and discussion.

The conclusions of these studies are considered as the highest level of scientific evidence that exists in the research domain and used primarily while constructing the hypotheses and theoretical basis of this dissertation.

The findings of the major theoretical studies and citation indexed empirical research can be summarized as follows:

- Researchers can extract more information from the analysis of the design protocols by using hybrid theoretical models (Cross, 2007) (Dorst and Dijkhuis, 1997).

- Design is representation (Simon, 1969).
- Designing is a reflective conversation with the design situation (Schön, 1983).
- Design knowledge is an ill-defined domain (Lawson, 2005).
- Design problems are ill defined, unstructured and unique (Simon, 1969).
- Design is different than problem solving (Simon, 1969) (Akin, 1978).
- Design problems co-evolve with the solutions (Simon, 1969) (Akin, 1978).
- It is observed that designers employ different strategies for dealing with complexity (decomposition, recomposition, problem restructuring). They redefine and restructure the design problem in the design phase (Akin, 2001).
- Design process may be organized around episodes (Akin, 2001).
- External representations may not be essential for the conceptual design phase (Bilda and Gero, 2005).
- Designers' problem restructuring frequency may be related with their expertise level (Akin, 2001).
- Expertise level may affect the level of cognitive activities (Bilda, 2001).
- Protocol analysis is still the most reliable analysis method (Stones, 2007) (Lawson, 2005).
- Protocol analysis does not affect the thought sequence but affects performance (Ericsson and Simon, 1993) (Ericsson, 2001). It takes more time for the subjects to complete a certain task while verbalizing their thoughts.
- Protocol analysis does not reveal all of the participants' thoughts; rather it reflects the design activity (Lawson, 2005).
- Instructions and pre-experimental training affect the outcomes of the protocol studies (Ericsson and Simon, 1993).
- Concurrent protocols expose more information in the early stages of the design process (Gero and Tang, 2001). There may be nonlinear order in retrospective protocols.

- Freehand sketches can be more ambiguous then CAD drawings (Goel, 1995).
- Design medium may affect the design process and design strategies (Bilda, 2001) (Song and Kvan, 2003) (Won, 2001).
- Design medium may affect the frequency of problem restructuring activity (Song and Kvan, 2003).
- Designers may be cognitively more active while designing in traditional media (Bilda, 2001) (Goel, 1995). In Won's (2001) experiments, designers were (visually) more active in the CAD sessions.
- The number of design solutions may be significantly less while designing with CAD software in the conceptual design phase (Stones, 2007).
- Computer representations may not sufficiently reflect the cognitive activity of the designers (Goel, 1995).
- Designers may be using internal representations to overcome the defects of CAD software (Goel, 1995).
- Questionnaires are useful in collecting information about designers' attitudes, experiences and perception (Hanna and Barber, 2001).
- Design students' attitudes towards computers may be significantly positive (Hanna and Barber, 2001).
- Students' attitudes towards computers may be gender-related (Pektaş and Erkip, 2006)

3. COMPARING COMPUTER AIDED AND CONVENTIONAL DESIGN PROCESSES : A DESIGN EXPERIMENT

3.1 Constructing the Method

Conducting research on students' use of the digital domain in the conceptual design process is essential for the development of new design education strategies, evaluating the effects of the existing CAAD software and creating new design environments. The motivation of this study comes from authors' observations on students' design behavior during the computer aided design workshops, discussions with thesis advisors and literature review. The primary research questions are as follows:

- How do designers use the digital domain to design?
- Are there indicators that characterize this behavior especially in contrast to manual patterns of design?
- Can these indicators provide a "fingerprint" for modes of design?
- How can these fingerprints be used?

A comprehensive literature review was conducted before starting to design the research method. Theoretical concepts and empirical findings were revised with the focus on possible dimensions of measurement, analysis and evaluation methodologies. It was concluded that there is a lack of consensus in the research area. (This statement is also shared by well-known researchers in this area such as Flemming, Kvan and Cross.)

Two major paradigms dominate design research: Reflection-in-action by Donald Schön and Problem Solving by Herbert Simon. Based on the findings of Dorst and Dijkhuis (1997) and observations of Cross (2007) and Lawson (2005), it was decided that different theoretical models can be combined to reveal different aspects of the design process.

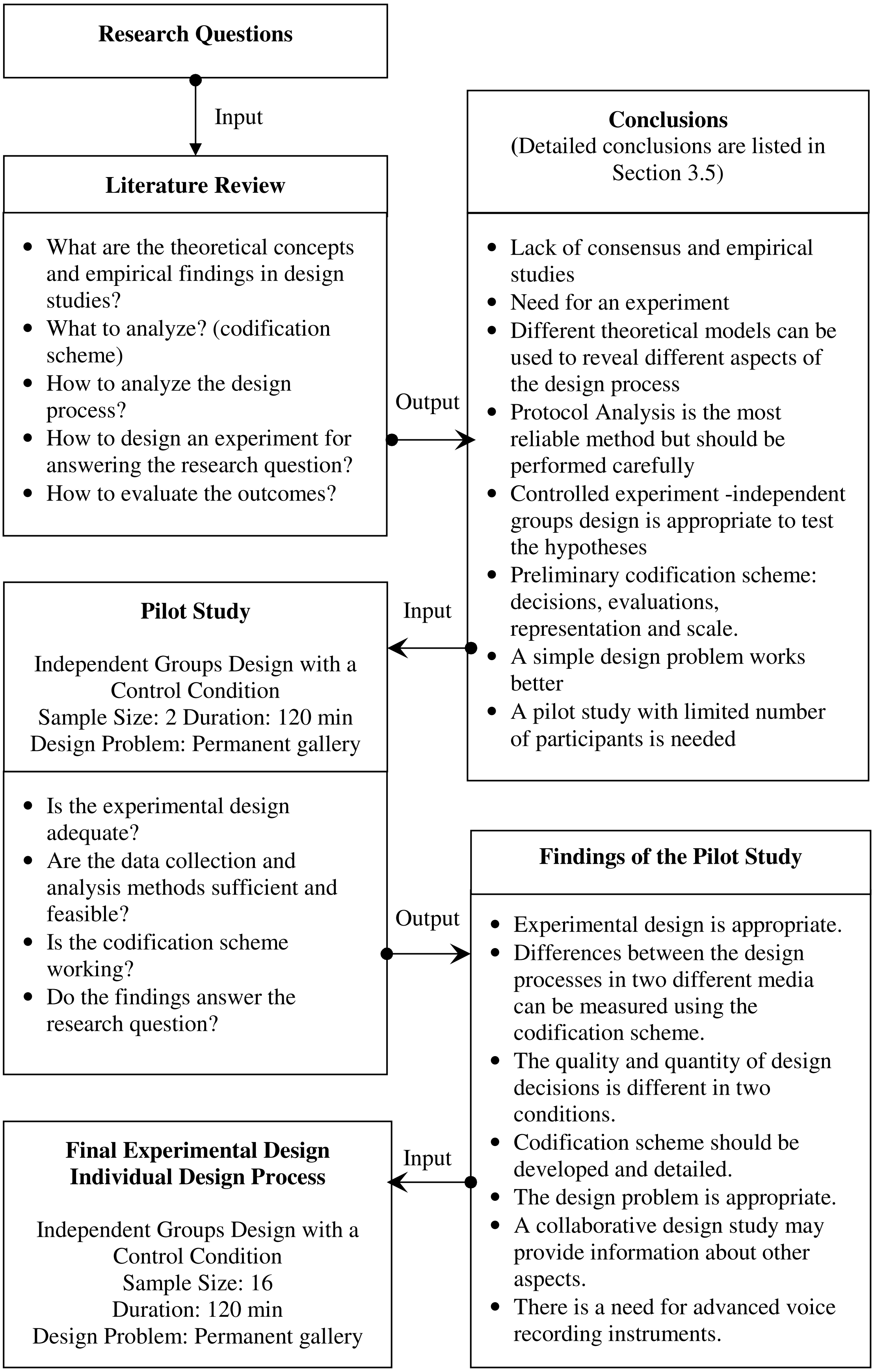


Figure 3.1 : Development process of the experimental design

Thus, different descriptions of the design activity were reviewed and considered in all research phases, especially while determining the preliminary and final dimensions of measurement (Figure 3.1).

Although there is a variety of unstructured observations and assumptions about computer-aided design process, only a limited number of empirical studies have been carried out in the related research area. In all of the empirical studies, CAAD process was evaluated in comparison to the conventional design process (these are extensively reviewed in the Section 4.1). After a general survey of former empirical research on CAAD, it was decided to conduct a controlled experiment under two conditions: first, under experimental condition (C01), the subjects were obliged to design with the software they prefer while participants in the control condition (C02) were only allowed to utilize only conventional tools.

The sample population was determined as senior students of ITU School of Architecture. This decision was based on the homogeneity of design expertise and software use among the students, shared design terminology between the researcher and the students, high accessibility of subjects and possibility of contributing to the architectural design approaches in ITU.

The duration of the experiment was defined as 120 minutes, due to the feasibility issues and time length of the previous studies).

A design problem was formulated considering the characteristics of the research question, sample population, the duration of the experiment and the problems that were used in similar surveys. The chosen problem description is relatively short in order to motivate the participants to restructure and redefine requirements.

Detailed information about the design problem, duration, sampling, setup is presented in Section 3.2.

A careful inspection of previous studies revealed that PA is the most reliable method for analyzing the design process. Rationales for conducting a protocol analysis study can be summarized as follows:

- It is the only formal analysis method for gathering procedural information.
- Both of the paradigm founders (Schön and Simon) used this method to support and develop their theories.

- The analysis results are comparable with other studies.
- A variety of concepts can be measured by using this method.
- Protocol analysis studies are accepted and conducted across different design disciplines.
- Protocol studies are theory independent. The only assumption is that verbal reports are reliable sources of information.
- Protocol studies are replicable. Therefore, it is possible to conduct the same study in the future and observe changes.

Similar to other analysis methods, protocol analysis has certain disadvantages. First of all, the designer is forced to think-aloud continuously an activity, which he or she has probably never performed before. There is significant evidence that concurrent verbalization does not affect the thought sequence but affects performance (Ericsson and Simon, 1993) (Ericsson, 2001). It takes more time for the subjects to complete a certain task while verbalizing their thoughts.

Another problem with this method is that it is not feasible in terms of time and resources. Transcription and codification are labor-intensive tasks. This issue limits the scope of protocol studies. Moreover, the outcomes of protocol analysis are generalizable only to a specific domain as they are limited by the number of participating students and are specific to the design problem used in the experiments (as design problems are unique). Therefore, a pilot study is needed to test the sufficiency of the experimental design, data collection and analysis methods.

Considering these facts, a pilot experiment was carried out. In this study, two participants were tested on the individual level. The first participant was instructed to design with CAD software they preferred (condition C01) whereas the second participant was allowed to use only conventional design tools (control condition C02). Both sessions were recorded with a video camera. In condition C01, additional software was utilized to document the design process.

The analysis results revealed that, the quality and quantity of design decisions were different under two conditions. Under computer aided design condition (C01), the participant made less design decisions compared with the participant under control condition (C02). In contrast, the statements about representation were significantly higher under C01.

After the protocol analysis phase, it is concluded that the codification scheme is reliable but should be improved, the design problem is appropriate and the differences between the design processes in two different media can be measured using the experimental setup.

The final experimental design was achieved by observing the findings of the pilot study and effects of the experimental setup on the outcomes. The codification scheme was improved and finalized based on the video and audio recordings. The experimental instruments were upgraded. Details of the final experiment format are reported in Chapter 3.2.

In order to enhance the generalizability of the research, a questionnaire was also designed to fit the dimensions of measurement and significant findings gathered from the protocol analysis. The results were evaluated in comparison with the outcomes of the protocol studies. A correlation analysis was also performed to test the relationship between the measurement categories.

The design of the questionnaire-based survey is reviewed in Section 3.2.

3.1.1 Experimental design of the protocol studies in the last decade: developing an overall perspective

Nineteen citation-indexed papers on design protocol analysis were published between 1998 and 2008 (Table 3.1). They cover a wide range of topics including sketch perception, strategic use of representation, cognitive actions, memory limitations, collaborative design and problem decomposition.

Studies focusing on collaboration, perception and communication mainly follow Donald Schön’s reflection-in-action approach, while studies directing toward problem solving use the ill-defined problem-solving framework. In addition, there are other papers based on hybrid theoretical models such as (Kim and Maher, 2008) and (Bilda and Gero, 2003) which combine the two different theories together.

Table 3.1: The experimental design of the citation-indexed protocol studies published between 1998 and 2008

Date	Title	Author(s)	Number of experiments	Duration
Sep 08	Exploring problem decomposition in conceptual design among novice designers	Lassi Liikkanen, Matti Perttula	**16**	**20'**
May 08	The impact of tangible user interfaces on spatial cognition during collaborative design	Mi Jeong Kim, Mary Lou Maher	**5** (in pairs)	**20'**
Nov 07	An underlying cognitive aspect of design creativity: Limited Commitment Mode control strategy	M.H. Kim, Y.S. Kim *Et al.*	**8**	**60'**
July 07	The impact of working memory limitations on the design process during conceptualization	Zafer Bilda, John S. Gero	**6**	**20'+x'**
Sep 06	How designers perceive sketches	Alexandre Menezes, Bryan Lawson	**30** (in pairs)	**5'** (estim.)
Sep 06	To sketch or not to sketch? That is the question	Zafer Bilda, John S. Gero *Et al.*	**3**	**45'**
Jan 04	Strategic use of representation in architectural massing	Omer Akin, Hoda Moustapha	**6**	**120'**
Jan 03	Design moves in situated design with case-based reasoning	Mao-Lin Chiu	**12**	**20'-30'**
Jan 03	An insight on designers' sketching activities in traditional versus digital media	Zafer Bilda, Halime Demirkan	**6**	**180'**
Jan 03	Specifications for computer-aided conceptual building design	K. Meniru, H. Rivard, C. Bédard	**8**	**45'**
Sep 02	Thinking in design teams - an analysis of team communication	Joachim Stempfle, Petra Badke	**3** (teams of 4-6)	**360'**
Jan 02	The structure of concurrent cognitive actions: a case study on novice and expert designers	Manolya Kavakli, John S. Gero	**2**	**Not stated**
July 01	An examination of the forces that generate a style	Chiu-Shui Chan	**6** (1 subject)	**300'**
May 01	The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process	John S. Gero, Hsien-Hui Tang	**2** (1 subject)	**240'**
Jan 01	Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts	Chun-Heng Ho	**2**	**90'** (longest)
Jan 01	Composition and construction in experts' and novices' weaving design	Pirita Hakkarainen Kai Hakkarainen	**4**	**60'**
Oct 98	Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions	Masaki Suwa, Terry Purcell *Et al.*	**1**	**45'**
Jul 98	The reflective practice of design teams	RianneValkenburg Kees Dorst	**3** (teams of 4)	**30'** (analyzed)

Each year, an average of 1.6 PA studies was published. The number and duration of the experiments vary by the research question (or hypothesis) or research design. For instance, Menezes and Lawson (2006) carried out 30 experiments with 60 subjects to measure the perception of design sketches.

On the other hand, for Bilda and Gero (2007), three experiments were enough to discuss the importance of sketching in the preliminary design phase. The outcomes of these investigations will be extensively discussed in the next chapter.

Researchers performed an average of 7.05 experiments per study. The cumulative mean of experiments increased 135% in ten years. The average duration of experiments is 92 minutes, while the longest experiment lasted for 360 minutes. The overall mean of analysis durations increased until 2002, and started to drop afterwards.

The most important reason for this increase seems to be Chiu-Shui Chan and Joachim Stempfle's relatively extensive studies, which were published the same year. The cumulative mean of experiment durations went up 208% in the last decade, indicating that researchers tend to conduct longer experiments with more subjects.

Overall analysis duration (OAD) can be used to evaluate the length of the protocols in PA studies. OAD is calculated by multiplying the number of experiments and experiment durations. In citation-indexed protocol studies published between 1998 and 2008, the average OAD is 455 minutes. The minimum OAD is 45 minutes whereas the maximum OAD is 1800 minutes.

The number of experiments and experiment durations are inversely proportional (Figure 3.2). When number of experiments increases, the length of the experiment decreases. This relationship may suggest that protocol studies are limited by time and feasibility issues or by the amount of time that researchers spend for conducting experiments.

It is important to state that the shortest study (in terms of OAD) is conducted by Suwa et al. (1997) and it is one of the most cited papers in design studies journal. The longest protocol analysis study (in terms of OAD) is performed by Chan (2001). The researcher used the same subject in all of the experiments (repeated measures design).

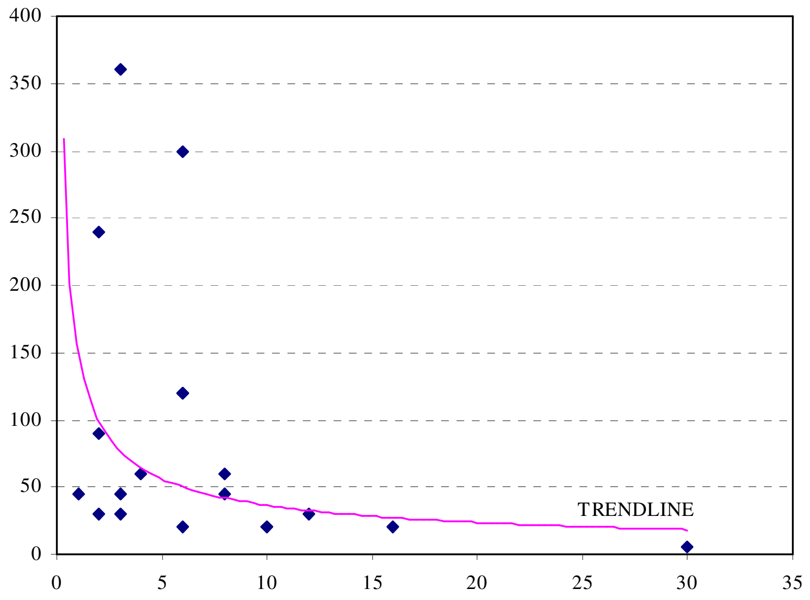


Figure 3.2 : Number of experiments versus experiment durations (minutes) in citation indexed design protocol studies published between 1998 and 2008.

3.1.2 Discussion of the methods and findings of key studies related with the research area

One of the earliest experiments comparing computer aided and conventional design processes was carried out by Vinod Goel in 1995. In this study, he analyzed twelve subjects' design behavior while using different media. Six subjects were graphic designers; the other six were industrial designers; they had different backgrounds and different levels of education. Graphic designers were expected to design three different posters: one for Berkeley Cognitive Science Program, one for the Shakespeare Festival and one for Canadian tourists. Industrial designers were given two problems: creating a toy for a fifteen-month-old baby and a desk timepiece to commemorate the Earth Day. In each experiment, two sessions were conducted. Six participants did the sketching first, followed by computer-aided drafting and the other subjects used computers in the first session, followed by a sketching session.

Goel's hypotheses can be summarized as:

1. Freehand sketches are more dense and "closely ordered"
2. Freehand sketches are more ambiguous
3. Representation of the ideas in freehand drawings are more dense and "closely ordered"

Vinod Goel's experimental design is balanced, but extremely complicated (Table 3.2). The main problem with this study is the poor comparability of the design tasks.

The experimenter ignored that different disciplines use different strategies and approaches in the design process. For instance, an industrial designer may use more three-dimensional representations compared with a graphic designer. Therefore, the results are comparable only among similar design tasks and disciplines. After codifying the PA sessions, Goel (1995) presented the protocol transcriptions to three different researchers and requested to perform the same task for verification purposes. Comparison of the results revealed that researchers agreed on 85 percent of the observations.

Table 3.2: Summary of Vinod Goel's experimental design

		Session 1	**Session 2**
Subject 1 Industrial Designer	Media	Sketching	MacDraw software
	Task	**Toy design**	
Subject 2 Industrial Designer	Media	MacDraw software	Sketching
	Task	**Toy design**	
Subject 3 Industrial Designer	Media	Sketching	MacDraw software
	Task	**Toy design**	
Subject 4 Industrial Designer	Media	MacDraw software	Sketching
	Task	**Timepiece design**	
Subject 5 Industrial Designer	Media	Sketching	MacDraw software
	Task	**Timepiece design**	
Subject 6 Graphic Designer	Media	MacDraw software	Sketching
	Task	**Timepiece design**	
Subject 7 Graphic Designer	Media	Sketching	MacDraw software
	Task	**Type 1 poster design**	
Subject 8 Graphic Designer	Media	MacDraw software	Sketching
	Task	**Type 1 poster design**	
Subject 9 Graphic Designer	Media	Sketching	MacDraw software
	Task	**Type 2 poster design**	
Subject 10 Graphic Designer	Media	MacDraw software	Sketching
	Task	**Type 2 poster design**	
Subject 11 Graphic Designer	Media	Sketching	MacDraw software
	Task	**Type 3 poster design**	
Subject 12 Graphic Designer	Media	MacDraw software	Sketching
	Task	**Type 3 poster design**	

Goel (1995) found no significant difference between the number of new solutions, duration and number of the design episodes was found. From these observations, he deduced that the designers had no difficulty in using MacDraw software and freehand sketches were more ambiguous and semantically denser (Table 3.3).

Goel (1995) interpreted these findings in two ways:

1. Computer representations may not be reflecting the cognitive activity of the designers' freehand sketches.
2. The thought processes may be simpler in computer-aided design compared with conventional media.

The first interpretation is reasonable since the computers and Macdraw software used in the experiment are primitive versions of their kinds. Moreover, digital systems are still limited in terms of interaction, portability, working space resolution, size etc. Therefore, the participants may be constructing internal representations instead of reflecting all of their ideas externally. Gero and Bilda (2005) observed this type of behavior in their relatively short experiments. (The outcomes of this study are reported on page 66). The second interpretation contradicts with Won's (2001) findings that while sketching, designers' cognitive behavior is simpler compared to drafting in digital medium. On the other hand, lack of reflection in the design process may lead to efficiency and performance problems. Participants may be distracted by computer responses that are outside his or her domain of interest.

Table 3.3: The analysis results of design processes in two different media (Goel, 1995). (S stands for standard deviation)

	Freehand (Sketching)	**MacDraw**
Duration of sessions (min.)	57.5 (S = 11.5)	56.25 (S = 14.2)
Duration per episode (min.)	2.5 (S = 1.1)	2.8 (S = 0.6)
Number of episodes	16.3 (S = 6.9)	14.4 (S = 5.9)
Number of new solutions (syntactic level)	5.4 (S = 3.4)	4.4 (S = 1.8)
Number of new solutions (semantic level)	5.7 (S = 3.3)	4.6 (S = 1.8)
Syntactic density	10.8 (S = 4.7)	2.4 (S = 3.1)
Semantic density	10.3 (S = 3.7)	4.3 (S = 3.6)
Ambiguity	2.9 (S = 3.3)	0.75 (S = 0.87)

In summary, Goel's experiment revealed that the subjects' computer aided and conventional design processes were different, at least in terms of reflective thinking. The syntactic and semantic density of the sketches was higher than that of computer drawings. As expected, the freehand sketches were more ambiguous.

Surprisingly, there was no correlation between ambiguity of the representations and number of new solutions found. The subjects might have compensated the deficiency of the computer tools with internal representations and thoughts, but Goel focused more on the external representations in his experimental study.

It is important to note that computer and conventional representations are hardly comparable. Furthermore, it is nearly impossible to make objective deductions about the design ideas by analyzing final drawings.

Compared with drawings, verbalizations are more reliable information sources. Therefore, the most dependable outcomes of Goel's experiment came from the analysis of episodes and sessions, which indicated that there was no significant difference between the thought processes when using different media.

Bilda (2001) conducted a similar experiment in order to observe the similarities and differences between computer-aided and conventional design processes. The experiment consisted of three phases: training, design and retrospective analysis.

In the first phase, the participants attended a two-week training program on using the Design Apprentice software (which is discontinued). Six interior designers were split into two groups and each participant was observed in three sessions (Table 3.4). In session one, designers started to work on problem (1) and they were interrupted after sixty minutes. After a five-minute break, a different problem (2) was presented and the subjects were expected to design in a different medium for the same amount of time. In the third session, they were instructed to go back to the previous problem (1) and design medium. The whole experiment lasted three hours. The layout and requirements of problems 1 and 2 are identical except the orientation of the entrance.

Many aspects of Bilda's study can be criticized. First of all, the training sessions may affect the subjects and result in a change in their design strategies. In this case, the experiment will be measuring the effects of the software training on the digital and conventional design process instead of comparing the effects of the two different media, as stated in the research question.

Table 3.4: Bilda's experimental design (2001). Software: "Design Apprentice"

	Design Problem A flat for four friends	**Group 1** (3 interior designers)	**Group 2** (3 interior designers)
Session 1 (60 minutes)	Problem 1 Entry configuration (1)	CAD	Manual
Session 2 (60 minutes)	Problem 2 Entry configuration (2)	Manual	CAD
Session 3 (60 minutes)	Problem 1 Entry configuration (1)	CAD	Manual

Secondly, the design problems are nearly identical. It is apparent that, after completing session 1, the participants will be experienced in that specific task. Session 2 will be influenced by session 1 and session 3 will be influenced by session 2.

Another problem with Bilda's study is that, the experiments were carried out in two different places and possible effects of the physical environment were discarded. In other words, subjects had to change places between the sessions. There is significant evidence that visual stimuli influence the design process (Goldschmidt, 1999), so the experimental setup might have had an uncontrolled effect on the participants.

For coding the protocols, Bilda used the codification scheme proposed by Suwa et al. (1997) which is based on Gero's Function-Behavior-Structure framework. This scheme refers to Suwa and Gero's research questions rather than Bilda's. Despite these facts, Bilda's experiment is still the most extensive PA study that primarily focuses on the conventional and digital design process. The results of this study should be considered carefully.

Bilda (2001) found out that designers are cognitively more active while designing in traditional media. Two of the participants' cognitive activity was clearly different from the other four participants. The reason for these findings may be the diversity of the designers' expertise levels. In the traditional design process, designers' goals and intentions changed more frequently and there were more perceptual actions. Bilda (2001) stated that these results are consistent with Goel's observations about the ambiguity of sketches.

Table 3.5: The average number of actions in traditional and computer-aided design activities (Bilda, 2001)

	Physical	Perceptual	Functional	Conceptual
SKETCH	82	58,78	20,78	14,89
CAD	73,11	40,44	15,89	10,89

On the other hand, Bilda did not detect any significant difference between the occurrences of action categories in different media. In addition, the average number of physical, perceptual, functional and conceptual actions was higher in the traditional design process, but the difference was not statistically significant (Table 3.5). As expected, subjects in this experiment used diverse strategies in the design process and did not follow a specific pattern except that they had common sub-goals and intentions.

Another study questioning the affects of design media on the conceptual design process is conducted by Won in 2001. In this research, Won (2001) used the theoretical framework proposed by Schön and focused mainly on visual thinking – reflective processes. Won's hypothesis was that the visual and cognitive actions of the participants were significantly different in traditional and computer aided conceptual design. He grouped and analyzed these actions in three categories: "seeing-imagining-drawing", "seeing-as and seeing-that", "total and partial" (Table 3.6).

"Seeing-imagining-drawing" theory was postulated by McKim in 1980. According to the researcher, drawing "is the kind of thinking that we draw or paint", imagining "is the kind that we imagine in our mind's eye, as when we dream" and seeing is ""the kind we see; people see images not things". The difference between "Seeing-as" and "Seeing-that" actions was first analyzed by Goldschmidt in 1995.

Two industrial designers participated in Won's experiment. They were expected to design a simple, efficient and portable shelf and generate at least five sketches in sixty minutes. The first subject used paper, pens and rulers for sketching while the second used Pro-Engineering software.

Table 3.6: Codification scheme of Won's (2001) experiment (the word imaging is corrected as imagining)

Coding scheme	**Clarification**	**Source**
S–I–D	S: seeing I: imagining D: drawing	McKim (1980)
SA–ST	SA: seeing as ST: seeing that	Goldschmidt (1991)
T–D	T: total D: partial	Self deduction

Compared with the former studies, Won's experiment is quite limited in many respects. The researcher can be criticized for misinterpreting McKim's theory and discarding the possibility that of the designers can perform more than one action at the same time (McKim (1980) states that three types of visual thinking overlap). The word "imagining" is misspelled eleven times as "imaging" in Won's paper. Moreover, the sample size is extremely small and the expertise levels of the designers are different. These issues affect the generalizability and validity of Won's findings negatively.

After analyzing the protocols, Won found out that Subject A spent more time on "drawing" than "seeing" and "imagining" while Subject B spent more time on "imagining" and "drawing" than "seeing". In addition, Subject A performed more "seeing-that" actions than "seeing-as" while Subject B's activity in both cases were the same. Subject A's approach was more holistic compared with Subject B.

Won also stated that while using conventional tools, subject's cognitive activity was simpler. These findings contradict with the findings of Goel and Bilda. Both of the researchers observed that their subjects were cognitively more active while designing in traditional media. Furthermore, as sketches were more ambiguous than computer representations, there should be more "seeing-that" activity than "seeing-as" in the computer-aided design process.

In a different study, Bilda and Gero (2005) attempted to test whether CAD is "needed" in the conceptual design process or not. They conducted an experiment under two different conditions with three expert architects. Under experimental conditions, the participants were asked to design a residential house for a painter and a dancer while wearing a blindfold. In the control condition, participants were expected to design a residential house for a family with five children.

Table 3.7: The design of Bilda and Gero's experiment (2005)

	Experiment Conditions	Control Conditions
Activity	Blindfolded designing, externalizing at the end of the session	Sketching
Design Brief	Design a residential house for a painter and a dancer	Design a residential house for a family with five children
Data collection	Time-stamped video recording	Time-stamped video recording
Reporting	Think-Aloud	Think-Aloud
Coding Scheme	Imagery Coding Scheme	Sketch Coding Scheme

In this experiment, Bilda and Gero aimed to question the importance of external representations in the conceptual design phase and hypothesized that when blindfolded designers will "conceptually explore the problem space well". The design outcomes were double blind reviewed by a jury of three different architects and graded according to their creativity, practicality and how well they satisfy the design brief (Table 3.8).

The results of Bilda and Gero's experiment were based on reviewers' evaluations. There is anecdotal evidence that jury members frequently disagree while reviewing the competition entries. Therefore, grades may not indicate the actual performance of the designers.

Table 3.8: Grades for the design outcomes of blindfolded and sketching sessions (Bilda and Gero, 2005)

Criteria	Blindfolded Sessions				Sketching Sessions			
	A1	A2	A3	Av.	A1	A2	A3	Av.
Creativity	5.3	6.0	6.3	**5.9**	5.0	5.7	7.3	**6.0**
How well it satisfies the design brief	7.7	6.3	7.7	**7.2**	6.3	6.3	6.3	**6.3**
Practicality	7.7	7.0	7.0	**7.2**	6.0	5.7	5.3	**5.7**
Average score	**6.9**	**6.4**	**7.0**		**5.8**	**5.9**	**6.3**	

The design problems were nearly identical, so the subjects might have been influenced by the previous session. For instance, subject A1 produced similar designs in both sessions. It is not surprising that the grading of these two designs was similar.

Moreover, the analysis phase should be shorter in the second (sketching) session as the subjects became familiar with the site. This means that uncontrolled factors affect the outcomes.

At the end of the blindfolded sessions, the subjects were asked to sketch their ideas "as quickly as possible". Participants may have improved their design through this process, which was an unintended consequence of the experiment. For these reasons, Bilda and Gero's experiment is of questionable reliability.

In a different study, Song and Kvan (2003) analyzed designers' reflective problem-solving activities in conventional and digital media. Based on Schön's (1983) theory of reflective action, researchers focused on three behaviors: framing, moving and reflecting. Their hypothesis was that digital media interrupted problem-framing activities. Different from previous researchers, they interpreted conceptual design as a social activity. For this reason, they constructed an experiment in which the participants design in pairs (Table 3.9). Subjects were tested under two experimental conditions with different communication modes: "face to face CAD" and "chat line" CAD. Researchers gave a loosely defined (open-ended) design problem to the subjects in order to encourage them to determine and redefine the limits (and to maximize the number of problem-framing activities).

Song and Kvan's experiment entails many problems. The sample size was extremely small (2 students for each condition) and the duration was short (40 minutes), but there is no reason to categorically discard results.

Table 3.9: Song and Kvan's experimental design

	Paper media	**Digital Media 1**	**Digital Media 2**
Duration	40 minutes	40 minutes	40 minutes
Subjects	2 M Arch students	2 M Arch students	2 M Arch students
Design tools	Paper; pencils; rulers; etc.	Hardware: two computers with keyboard and mouse; Software: Microsoft Netmeeting	Hardware: two computers with keyboard and mouse; Software: Microsoft Netmeeting
Communication	Face to Face	Chat line	Face to Face

As result of the analysis of design protocols, Song and Kvan (2003) found that, participants communicated less frequently in DM1 (chat line) session compared with the other two. Conversely, under the same conditions, the ratio of problem-framing activities was the highest among the three sessions. In DM2 session (face-to-face CAD), the number of framing-moving-reflecting actions was nearly the same, while in PM (sketch) session, frequency and ratio of reflective activities were higher than other two conditions (Table 3.10).

Researchers performed a statistical test (t-test) to reveal the quality of the differences between the activities among three sessions. They found out that there was significant difference between the activities in DM1 (CAD–chatline) - DM2 (CAD–face to face) and the activities in DM1 (CAD–chatline) - PM (Sketch–face to face).

Table 3.10: The proportion and frequency of framing, moving and reflecting actions in digital and conventional media (Song and Kvan, 2003)

	proportion			count			
	Framing	**Moving**	**Reflecting**	**Framing**	**Moving**	**Reflecting**	**Total**
DM1 CAD Chatline	0.478	0.261	0.261	22	12	12	46
DM2 CAD Face to face	0.340	0.362	0.298	48	51	42	141
PM Sketch Face to face	0.273	0.227	0.500	41	34	75	150

Stones (2007) carried out an experiment with ninety-six graphic designers to compare the effects of different media on designers. Different from previous studies, the researcher attempted to make deductions about the design process by analyzing the final drawings. The participants were split into two groups and were expected "to elegantly combine number six letter e" in fifteen minutes. The first group was allowed to use any software of their preference while the second group was directed to use traditional tools.

Stones (2007) concluded that, "paper-based working allowed more solutions to be discovered, of all synthesis types, than digital working" (Table 3.11). It seems that participants using digital tools failed to implement some of the strategies while synthesizing the solutions (such as formal contribution).

The outcomes of this study are limited with the design problem and graphic design profession. As architects deal with more complex problems, their design behavior may not follow the same pattern.

Table 3.11: Total number solutions made in paper and computer media (Stones, 2007)

	Paper	Computer
Total number of solutions	1196	552
Number of diverse solutions using 'contribution' as a strategy (including solutions in both media)	88	16
Number of diverse solutions using 'contribution' as a strategy (exclusively paper or computer-based solutions)	78	6

3.2 Method of the Proposed Design Experiment

The goal of this study is to explore the possible reflections of the design domains on the students' design behavior by analyzing the similarities and differences between computer-aided and conventional architectural design processes. A hybrid theoretical model offers two main dimensions of measurement for analyzing the design process: decisions and activities. There is an infinite number of aspects that can be measured, but only a few are comparable for two different experimental conditions, referenced in various publications and could be observed in pilot studies. These aspects are grouped into eleven measurable and falsifiable hypotheses (Table 3.12). All hypotheses predict that there is a statistically significant difference between the measured activities and decisions in two different experimental conditions.

The first hypothesis (H_{E1}) is about making evaluations. The use of different representation types in both conventional and computer-aided design processes should affect the mean number of evaluations made by the designer. Schön (1993) used the word "seeing-that" to describe this category of activities. Different than "seeing-as", seeing-that involves judgments such as "this room is too small". Won (2001) conducted an experiment to test this hypothesis and he found that the participants in the control conditions (sketching) made more evaluations compared with those under experimental conditions (CAD) (Outcomes of this research are reviewed in the previous chapter). The unit of measurement for this hypothesis is defined as the mean number of evaluations per minute.

Table 3.12: Categories and sources of hypotheses (Rejecting Null hypotheses $H_{0(N)}$ will confirm the hypothesis)

Category	Hypothesis	Below are <u>different</u> in experimental and control condition.	Sources
Activities and **Strategies**	HE 1	Making Evaluations	(Simon, 1969) (Schön, 1992) (Goel, 1995) (Akin, 1996) (Won, 2001) (Song and Kvan, 2003) Analysis of the pilot studies
	HE 2	Problem redefinition	
	HE 3	Referencing precedents	
	HE 4	Making notes (textual reflections)	
Decisions on	HE 5	Representation	(Simon, 1969) (Schön, 1992) (Ericsson & Simon, 1993) (Akın and Lin 1995) (Bilda, 2001) (Bilda and Gero, 2005) (Lawson, 2005) (Stones, 2007) (Cross, 2007) Analysis of the pilot studies
	HE 6	the Design Process	
	HE 7	Concepts	
	HE 8	Elements, their organization and dimensions	
	HE 9	Structure	
	HE 10	Materials	
	HE 11	Lighting	

The second hypothesis (HE 2) is related with problem restructuring behavior. (Song and Kvan) 2003 observed that the design medium could affect the frequency of problem framing activity. During the Song and Kvan's experiments, the designers that used computer-aided design software restructured the design problem less frequently compared with the designers that followed the conventional sketching method. Therefore, the mean number of problem redefining activities should vary according to the medium. The unit of measurement for this hypothesis is defined as the mean number of problem restructuring activities per minute.

Hypothesis (HE 3) is about drawing references to existing solutions. This behavior is described by Schön (1993) as “one of the normative design domains”. The scope of this activity includes references to other kinds of designs, styles or design modes. During the pilot experiment, it was observed that the mean number of referencing activities were significantly different under CAAD and sketching conditions. The same pattern hypothesized to exist in the final experiment. The unit of measurement for this hypothesis is defined as the mean number of precedent referencing activities per minute.

The fourth hypothesis (HE 4) is derived from the analysis of pilot studies. In pilot studies, it has been noticed that there is a difference between the mean numbers of textual representations carried out under experimental and control conditions. The unit of measurement for this hypothesis is defined as the mean number notes (as words) per minute.

The rest of the hypotheses involve design decisions. The total number of design decisions in conventional and computer aided design sessions is found to be dissimilar in pilot studies. Therefore, in order to reveal the quality of this difference, design decisions are categorized according to their contents.

It is hypothesized that there should be a difference in the mean number of various decision categories (which are explained below) under experimental and control conditions.

Hypothesis (HE 5) is about representation. For Simon (1969) and Schön (1993), representation of the design problem is essential for the design process. Designers use and transform imaginary visual symbols for representing concepts.

It is obvious that computer representations and interaction patterns are different from the conventional ones. Therefore, it is expected that there should be a difference in the mean number of statements about representation in two different conditions. The unit of measurement for this hypothesis is defined as the mean number of decisions on representation per minute.

Hypothesis (HE 6) is about making decisions on the design process. This decision type is about planning the next phases of design. The unit of measurement for this hypothesis is defined as the mean number of decisions on the design process per minute.

Hypotheses H_{E7}, H_{E8}, H_{E9}, H_{E10} and H_{E11} are related with the decisions on architectonics: the organization and co-location of concepts, materials, structures, technologies, magnitudes and components of the proposed architecture.

In pilot experiments, participants made different mean number of decisions on the concepts (H_{E7}), architectural elements, their organization and dimensions (H_{E8}), structure (H_{E9}), materials (H_{E10}) and lighting (H_{E11}) in two different experimental conditions (These decision categories are also identified by Schön (1993) as "particular fields of interest in design"). The unit of measurement for these hypotheses is defined as the mean number of decisions per minute.

For each category, a null hypothesis (H_{0n}) is constructed to reject the difference in experimental and control conditions. To accomplish the research objectives and answer the guiding questions, a controlled experiment is designed.

In this design, each participant is exposed to only one of the two experimental conditions on an individual basis (between participants design). The independent variable is determined as the "design tools", which is assumed to cause changes in the dependent variables: design decisions and activities (Figure 3.4).

Under the first condition, participants design with computer aided design tools. Under the second condition, participants design with conventional tools.

The same design problem is introduced under experimental and control conditions in order to eliminate a possible effect of uncontrolled variables. Moreover, all of the experiments are planned to take place in the same lab and at the same time of the day.

The design problem is formulated considering the character of the major research question, sample population, the duration of the experiment and the problems that are used in similar surveys. The problem description is decided to be relatively short in order to motivate the participants to restructure and redefine requirements.

The participants are expected to design a permanent gallery for five sculptures and four paintings of Alexander Calder in ITU School of Architecture, TBT Laboratory. This problem is selected with the aim of promoting diverse design solutions and rich representations. It is important to note that the participants are not required to submit a complete design at the end of the experiment because the time pressure can influence the design behavior.

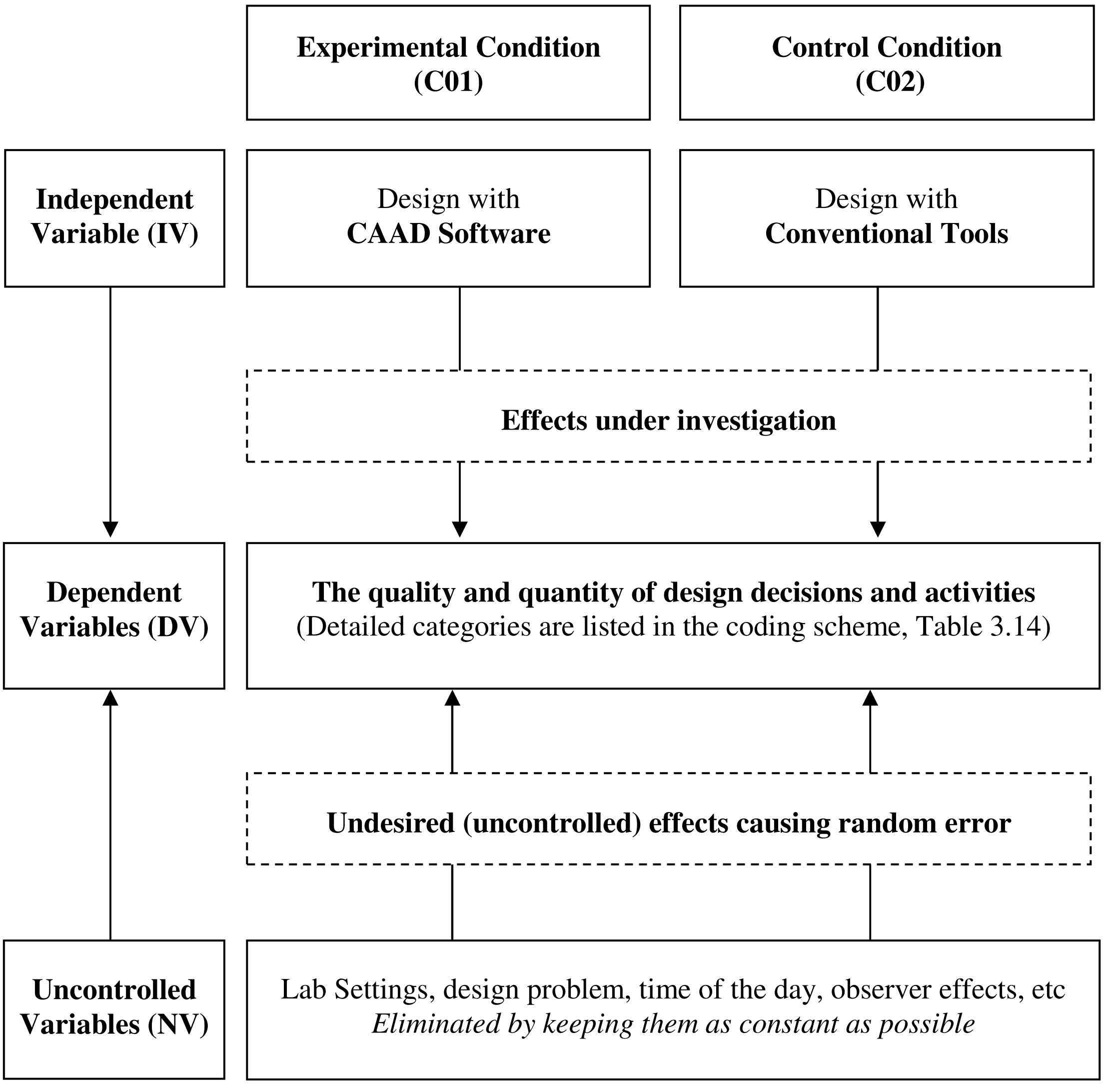


Figure 3.3 : Experimental design: variables and conditions

The design requirements are determined as follows:

- An exhibition space for the artworks
- An information space for presenting visual and textual materials about the gallery
- A storage area (10 m^2)

The participants (senior students in ITU School of Architecture) are assumed to be familiar with the surroundings. By choosing this context, the study aims to minimize the experimenter's participation to the design process.

Project space is located on the entrance floor, right across a busy conference hall in which the most popular meetings are held. It is 9.7 meters wide, 17.5 meters long, adding up to an area of 169 square meters. The ceiling height is unusually high: six meters. The room has six windows and three doors.

The participants are free to modify the existing building, which allows them to define the limits themselves without asking questions to the observer. In both of the pilot studies, the participants redefined the design problem and used spaces out of the project area in order to relate with the surroundings.

The plans of the school and the project area are made available to the participants. The drawings are provided in digital format under the experimental condition (CAAD) and as A4 size print outs under the control condition (Figure 3.4). No section drawings are given to the participants.

The problem description is presented both orally and in written form as follows:

> "The problem is to design a permanent gallery. You are familiar with ITU School of Architecture (showing the plan of the building) and the TBT Laboratory (pointing out the laboratory on the plan). Here are the artworks that will be exhibited in the gallery (presenting photos). These are the mobile sculptures and these are the paintings. The required functions are an exhibition space for the artworks, an information space for presenting visual and textual materials about the gallery and a storage area.
>
> There is no cost limit put on this project. You are free to modify the existing building. You can ask questions about the requirements during the design phase."

Based on the comprehensive review and analysis of the previous empirical studies, the duration of the design session is decided to be 120 minutes (Table 3.13). In pilot studies, the experiment duration is found to be appropriate for observing the differences between two design conditions.

The experiments are conducted in three sessions: training, test and design. In the first session (training), participants learn and practice the think-aloud method. The second session involves testing the experimental instruments and customizing the design tools for the participants. In the final session, the participants think-aloud while designing. There is also an optional five-minute break for the subjects in case that they may feel uncomfortable (They are explicitly instructed to think about other things during the break).

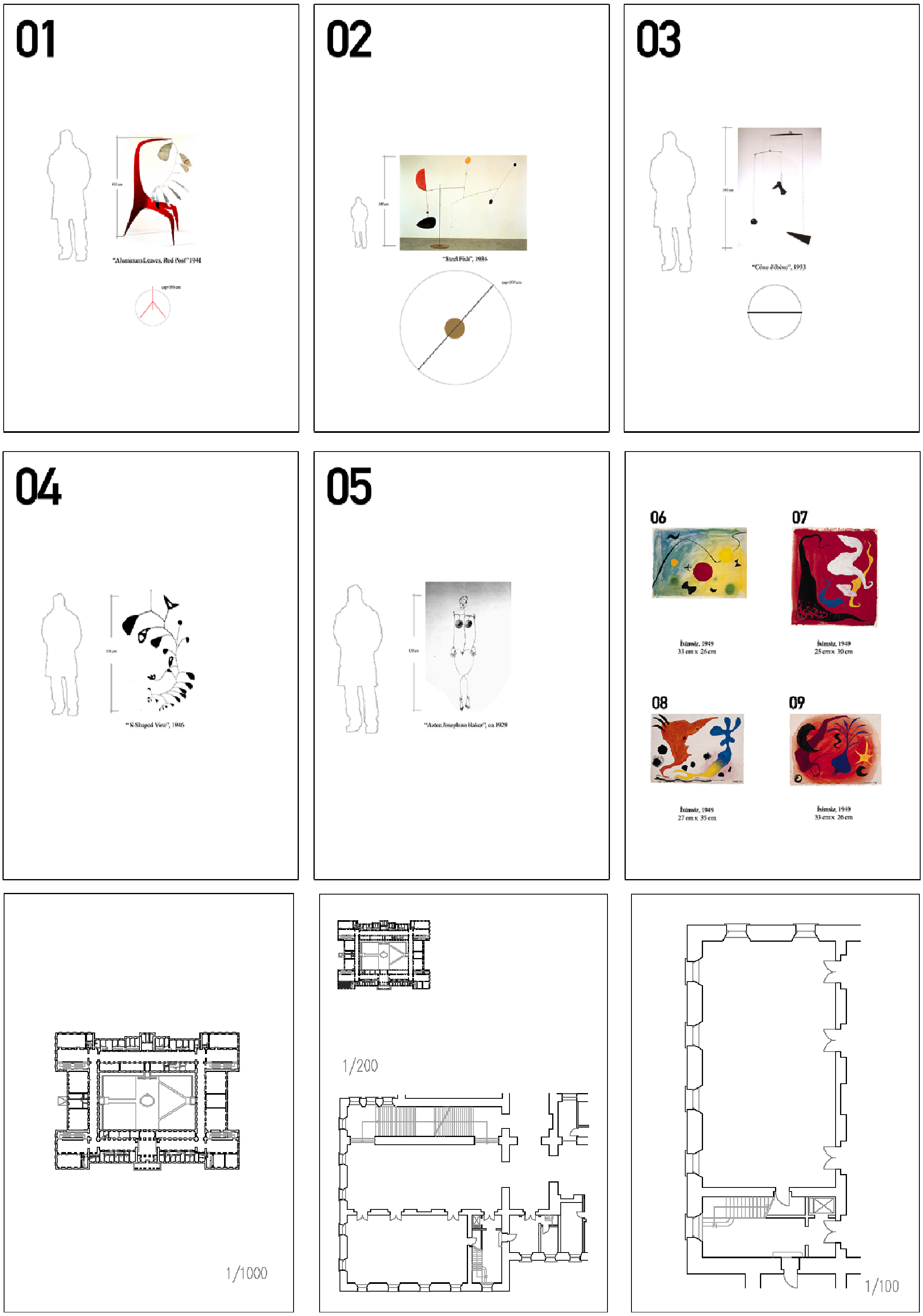


Figure 3.4 : The document set that is presented to the participants: photos and dimensions Alexander Calder's artworks, the plan of TBT Laboratory and the ITU School of Architecture.

The sample population is determined as senior students of ITU School of Architecture. This decision is based on the following facts:

- The relative homogeneity of design expertise and software use
- Shared design terminology between the researcher and the students
- The high accessibility and willingness of experiment subjects
- Possibility of contributing to the evaluation of tool use in ITU architectural design studios by providing empirical findings

Sixteen students were split into two groups and analyzed at the individual level. The average age of the participants is 22.875. All of them have studied in ITU School of Architecture for four years and they have had very little professional experience.

Table 3.13: Sample size and duration of protocol studies related to the research area.

	Sample Size	**Duration**
(Goel, 1995)	12	60’
(Won, 2001)	3	60’
(Bilda, 2001)	6	180’ (60’ for each session)
(Song and Kvan 2003)	6	40’
(Bilda and Gero, 2005)	3	60’

Different setups are prepared for two different experimental conditions: setup S01 and setup S02.

A specific setup (S01) was designed for the experimental (CAAD) conditions. In this design, a high-performance laptop computer and a 21-inch CRT monitor are made available to the participants (Figure 3.5).

The interaction devices are limited to a mouse and a keyboard (which are suitable for left-handed and right-handed use). In the test sessions, the participants are given the opportunity to customize the system particular to their needs. The participants’ software preferences are gathered by a short questionnaire before the experiments.

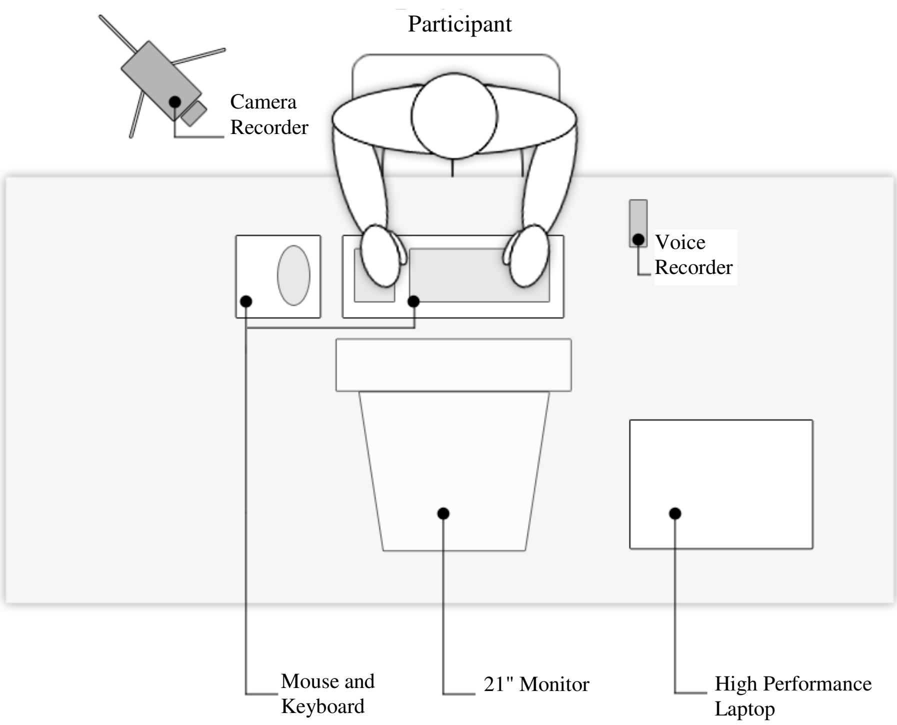


Figure 3.5 : Experimental setup for the CAAD condition (S01)

CAD software and the operating system that is installed on the laptop computer are as follows:

- Microsoft Windows XP Professional Operating System
- Autodesk AutoCAD 2004
- Autodesk 3dStudioMAX R.9 (with a v-ray plug-in)
- Autodesk Maya 2008
- Google SketchUp 7
- Rhino 3.0
- Adobe Photoshop CS3
- Adobe Illustrator CS3

The participants' design activities are recorded using a video camera and an advanced voice recorder. Moreover, TechSmith Camtasia Studio software is utilized to document the design process in detail. This software facilitates full resolution screenshots without disturbing the participants.

Once the recording is complete, the entire design session can played be as a movie. The position of the mouse pointer and keyboard logs are recorded by a macro-recorder. In order to discard the possible negative affects of a blackout, all of the equipment is connected to an uninterrupted power supply.

A different setup (S02) is designed for the control conditions (C01). In this design, the participants are provided with a variety of conventional drafting tools and materials such as different types of sketching papers, rulers, pens and pencils (Figure 3.6).

The participants are told that modeling materials and tools are also available anytime, but these are not placed on the desk since they take a lot of space. Similar to setup (S01), a video camera and an advanced voice recorder is used to record the design activities of the participants. All of the drawings are labeled and filed for future evaluation.

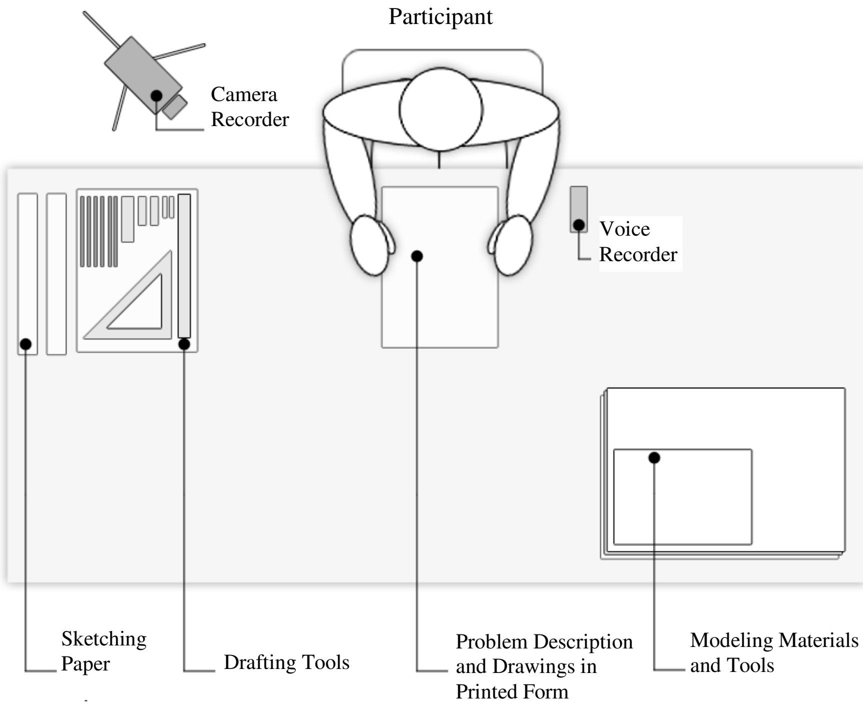


Figure 3.6 : Experimental setup for the control condition (S02)

All experiments are held in exactly the same laboratory space using the same equipments. The windows are covered with white paper in order to isolate the participant from external distractions. A coding scheme is created for the codification of the transcriptions (Table 3.14).

The code for each measure consists of two letters. The uppercase letter resembles the major category (activities or decisions) whereas the lowercase letter represents the variable.

Table 3.14: The codification scheme

Code	Measure of dependent variables	Description
Ae	Making Evaluations	"These paintings are really small"
Ap	Problem redefinition	"I will exhibit these artworks outside of the building" *This is a change from a previous assumption about where they should be placed.*
Af	Referencing precedents	"I remember the ramp in the Guggenheim Museum"
An	Making notes	"I am writing these decisions down to remember them."
Dr	Decisions on Representation	"Let's represent these artworks with circles"
Dp	Decisions on the Design Process	"I am going to look at those requirements first"
De	Decisions on Elements, their organization and dimensions	"There will be a desk here" "The information space will be located outside" "This wall will not be that high…Maybe 4 meters"
Dc	Decisions on Concepts	"Contrast is essential in this design"
Ds	Decisions on Structure	"The artworks are supported by steel cables"
Dm	Decisions on Materials	"The windows will be covered with a special fabric"
Dl	Decisions on Lighting	"These paintings are illuminated by spotlights"

3.3 Questionnaire Design

Protocol studies provide a detailed view of the different design activities in specific conditions. Therefore, the generalizability of the findings is limited.

In order to overcome this problem, a questionnaire-based survey is designed to collect general information about the research area and measure the respondents' perception of his or her activity.

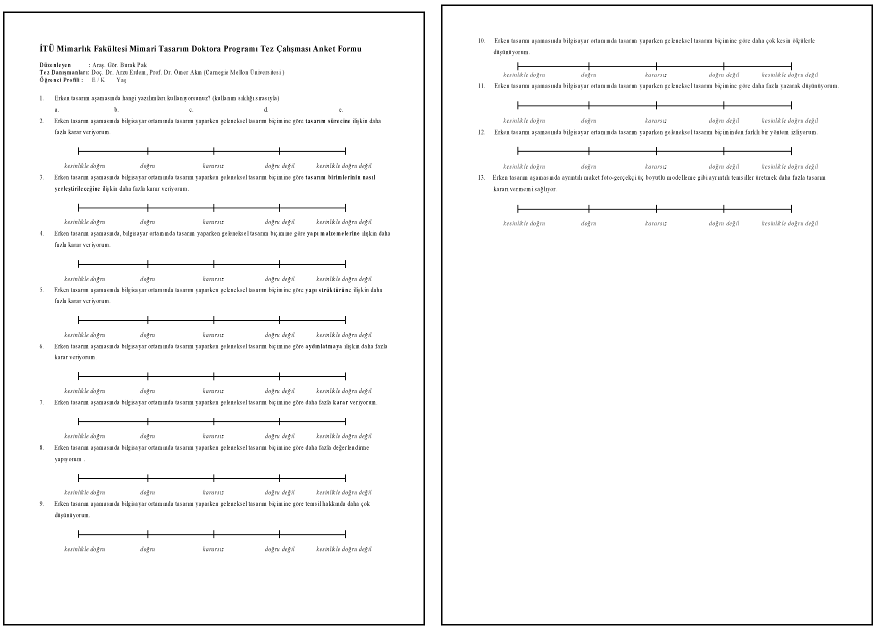
Hypotheses are transformed into closed-format multiple choice survey questions. For instance, hypothesis HE 2 predicts a significant difference in the number of evaluations made by the subjects in experimental and control condition. This hypothesis is converted into a statement as follows:

"When I use CAAD software during the preliminary design phase, I make more evaluations than the conventional design process."

It is expected from the respondents to rate this statement using a five-point Likert Scale. The rating choices (Likert items) are “strongly agree”, “agree”, “undecided”, “disagree” and “strongly disagree”.

In order to limit the “leading affect”, half of the questions are designed to confirm and the other half to reject the findings of the pilot study. In addition, positive phraseology is used while preparing the questions.

The target population is decided to be the undergraduate students of ITU School of Architecture, in order to obtain data that can be compared with the results of the previous PA study.



İTÜ Mimarlık Fakültesi Mimari Tasarım Doktora Programı Tez Çalışması Anket Formu

Düzenleyen : Araş. Gör. Burak Pak
Tez Danışmanları: Doç. Dr. Arzu Erdem, Prof. Dr. Ömer Akın (Carnegie Mellon Üniversitesi)
Öğrenci Profili : E / K Yaş

1. Erken tasarım aşamasında hangi yazılımları kullanıyorsunuz? (kullanım sıklığı sırasıyla)
   a. b. c. d. e.
2. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre **tasarım sürecine** ilişkin daha fazla karar veriyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
3. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre **tasarım birimlerinin nasıl yerleştirileceğine** ilişkin daha fazla karar veriyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
4. Erken tasarım aşamasında, bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre **yapı malzemelerine** ilişkin daha fazla karar veriyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
5. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre **yapı strüktürüne** ilişkin daha fazla karar veriyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
6. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre **aydınlatmaya** ilişkin daha fazla karar veriyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
7. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre daha fazla **karar** veriyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
8. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre daha fazla değerlendirme yapıyorum .
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
9. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre temsil hakkında daha çok düşünüyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
10. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre daha çok kesin ölçülerle düşünüyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
11. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçimine göre daha fazla yazarak düşünüyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
12. Erken tasarım aşamasında bilgisayar ortamında tasarım yaparken geleneksel tasarım biçiminden farklı bir yöntem izliyorum.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil
13. Erken tasarım aşamasında ayrıntılı maket foto-gerçekçi üç boyutlu modelleme gibi ayrıntılı temsiller üretmek daha fazla tasarım kararı vermemi sağlıyor.
   kesinlikle doğru — doğru — kararsız — doğru değil — kesinlikle doğru değil

Figure 3.7 : The questionnaire format

According to the university database, there are 893 architectural design students in total. The ideal sample size is estimated as at least 130 subjects to get a 95 percent confidence level with a ±8 percent error (±0.4 units in Likert Scale) (Sani and Todman, 2006).

The confidence interval depends on the percentage of the subjects that picks a particular answer; therefore, the worst-case percentage (50%) is used for the estimation. The error rate needs to be recalculated after the survey with the observed data and it is expected to be below 5 percent.

The questionnaire is designed to be self-administered to discard the possible affects of the observer. It is presented in a written format on letter-sized paper. The survey is tested on five students and followed up with a post-questionnaire interview. Based on the participants' comments, minor revisions are made to the questions and the presentation format (Figure 3.7).

3.4 Findings of the Design Experiment

The experiments were conducted with sixteen architectural design students using the methods described in the previous section. These studies took place in a controlled environment at TBT Laboratory, which is located in ITU Faculty of Architecture.

The characteristics of the participants; their ages, education and professional experience levels are well defined so that other subject variables do not influence the results of the research (Table 3.15). All of them are educated in ITU Faculty of Architecture and they are randomly assigned to one of the two experimental conditions. The rationale of this decision is to increase the population validity of the measurements.

Table 3.15: The characteristics of the participants

		Age	**Education (Months)**	**Professional Experience (Months)**
C01 **CAAD Group**	Subject 01	22	48	6
	Subject 02	23	48	4
	Subject 03	25	48	12
	Subject 04	21	54	12
	Subject 05	23	48	1,5
	Subject 06	24	48	12
	Subject 07	23	48	1,5
	Subject 08	24	54	6
Means		**23,125**	**49,5**	**6,875**
C02 **Conventional Design Group**	Subject 09	20	40	4,5
	Subject 10	23	42	3
	Subject 11	22	48	3
	Subject 12	23	48	3
	Subject 13	24	60	3
	Subject 14	23	48	6
	Subject 15	23	48	3
	Subject 16	23	48	6
Means		**22,625**	**47,75**	**3,9375**

Special attention is given to the experiment settings, recording equipment and design tools to minimize the effects of extraneous factors and increase the internal validity. Situational nuisance variables such as time of the day and environmental distractions are controlled (Figure 3.8). For instance, all of the sixteen experimental sessions were carried out on weekends between 10 a.m. and 12 p.m. The participants were presented identical sets of drawing tools and modeling materials in conventional design sessions. Similarly, subjects utilized the same hardware and software in all of the computer aided architectural design sessions.

Moreover, identical camera and voice recorders, screen capturing and macro analysis devices are utilized in all sessions. The protocol data is stored in both digital and analog format. The participant designers' activities are recorded on 32 Hi-8 videotapes at thirty frames per seconds. In CAAD sessions, the whole design process is also recorded in real-time as screenshots and saved to the participants' computer.

An overall duration of the records that are obtained from the sessions is 1890 minutes. The experiment allowed the longest observation ever undertaken under controlled conditions, considering the citation-indexed studies that are reviewed in chapter 3.2. This advantage is expected to affect the reliability of the outcomes positively.

The analysis of each experimental session took an average of 15 hours. Excluding the statistical tests, codification and analysis of the protocol took 240 hours. The administering of every session lasts at least three hours. The author has spent an estimated overall time of 400 hours for conducting and analyzing the whole study (reporting is not included).

Figure 3.8 : The experimental setup of CAAD (on the left) and Conventional Design conditions (on the right).

The budget allocated to this study was limited; therefore, the author financed a large portion of the expenditures. Each participant was given 30 Turkish Liras to take part in a study. As a result of the protocol analysis phases, valuable information concerning the research questions and hypothesis is obtained. Other unexpected findings are also discussed along with the implication of the research for future work.

Table 3.16: Mean number of decisions and activities under control and experimental conditions

	Hypothesis	**CAAD Condition (C01)**	**Conventional Design Condition (C02)**
HE1	Making Evaluations	231,63	201,25
HE2	Problem Redefinition	4,12	8,62
HE3	Referencing precedents	1,37	0,75
HE4	Making notes (textual reflections)	10,50 (Words)	56,62 (Words)
HE5	Decisions on Representation	109,00	21,50
HE6	Decisions on the Design Process	49,75	22,37
HE7	Decisions on Elements, their organization and dimensions	51,50	81,50
HE8	Decisions on Concepts	15,12	32,12
HE9	Decisions on Structure	3,12	11,12
HE10	Decisions on Materials	5,12	12,12
HE11	Decisions on Lighting	3,50	7,87

The findings of the protocol analysis are summarized in Table 3.16. It is important to note that this table itself does not imply significance. Statistical tests are performed to evaluate the differences in means and infer conclusions.

The null hypotheses are designed to reject the difference under two conditions (adjusted for ties). As a result of the statistical tests, the probability of making a decision to reject the null hypothesis (p-value) is obtained. If p-value is less than the significance level, then the null hypothesis is falsified.

For the statistical analysis, it was decided to perform a non-parametric test because the analysis of the pilot study protocols revealed that the variance of the samples in the experimental condition is more than four times greater than the control condition. Moreover, the frequency distribution of certain variables resembles a non-normal distribution and a sample of less than twenty per condition is used (Figure 3.9).

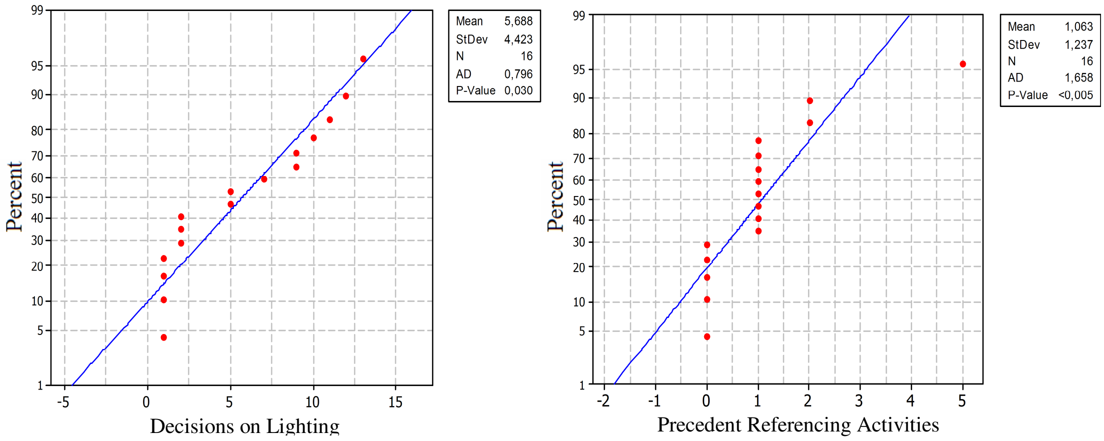


Figure 3.9 : Probability Plots of Precedent Referencing Activities (on the left) and Decisions on Lighting (on the right) Both p-values are lower than 0,05. (Evidence for non-normal distribution)

Mann-Whitney U test is recommended for independent groups experimental designs when parametric requirements are not met (Sani and Todman, 2006). In this statistical method, the distributions of the samples are compared. This method tests the null hypothesis that two data sets under two different conditions are randomly sampled. Mann-Whitney U actually calculates “the probability of the imbalance in sums of ranks” (Sani and Todman, 2006). The level of statistical significance is evaluated by comparing the predefined critical value (alpha) and the output value.

In addition, Monte Carlo analysis method is used for specifying a statistic to describe the patterns in the observed data. This method involves randomization and reassignment of the observations to the different experimental conditions (Gotelli and Ellison, 2004). After this process, a distribution of the test statistic (simulated values) is created and analyzed. The strongest part of this method is that, no assumptions are made about the underlying distribution of the data. Therefore, it is one of the most convenient methods for non-parametrical analysis.

3.4.1 Analysis of the hypothesis-related protocol data

In this section, two statistical analysis methods will be used to evaluate the outcomes: Mann-Whitney U test to draw inferences and Monte Carlo Analysis to describe the patterns in the obtained data. The significance of the difference will be examined using the p value that is obtained from the Mann-Whitney U test. If this value is lower than the alpha error (0,05), then the difference is found to be significant. For this test, the confidence interval is 95.9 and alpha error value is determined as 0,05. The detailed reports of the Mann-Whitney U tests are presented in Appendix 1.

The mean differences will be compared with the distribution of the statistics derived from Monte Carlo Simulation. If the probability of the observed difference is small, then it is considered as remarkable. The results of the Monte Carlo Analyses are presented in Appendix 2. The findings will be evaluated below for their significance for each hypothesis and the protocol data will be discussed in relation with the verbal reports of the participants and other observations. A brief interpretation will be provided along with the findings, as the detailed discussion of these issues are included in the next chapter.

Hypothesis HE1 is related with making evaluations during the design process. Under CAAD condition, participants made an average of 231 evaluations whereas the participants in the conventional design condition performed 201 evaluations. Although a difference can be observed in the overall mean and median, the outcomes of the Mann-Whitney U test showed that it is not statistically significant (p=0, 1563). Monte Carlo Analysis also supports this finding (Figure A.1).

Table 3.17: Hypothesis HE1: Total number of evaluations under two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	311	233	141	251	217	262	194	244	**238,50**	**231,62**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	202	227	255	178	207	197	175	169	**199,50**	**201,25**

Hypothesis H_{E2} is about problem redefinition. The overall occurrence of this activity is relatively low. In these cases, Monte Carlo Analysis provides estimates that are more reliable. Statistical tests tend to result in rejection of the hypothesis in these cases.

Table 3.18: Hypothesis H_{E2}: Total number of problem redefinitions under two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	1	4	2	1	1	13	4	7	**3,00**	**8,62**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	13	7	6	16	15	10	1	2	**8,50**	**4,12**

As expected, Mann-Whitney U test indicated that the mean difference is insignificant (p=0,1415). The findings of Mann-Whitney U test are verified by the Monte Carlo Analysis (Figure A.2). This means that, although a difference is observed in the results, it is not statistically significant.

Hypothesis $H_{E\,3}$ predicts a difference in referring precedents in the design process. The participants mostly referred to architectural materials and elements that are used in the ITU faculty of architecture. It is obvious that the obtained data is insufficient for performing a statistical test. Nevertheless, a Mann-Whitney U test was conducted to document the unfalsifiability of the null hypothesis. As expected, the test indicated no significant difference between two means .

Table 3.19: Hypothesis H_{E3}: Total number of precedent referring activities under two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	1	0	2	0	1	1	1	0	**1,00**	**0,75**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	1	1	0	1	1	2	0	5	**1,00**	**1,37**

Hypothesis HE4 is on the use of textual representations. Participants in the conventional design condition made an average of 19 notes while participants in the CAAD condition made an average of 4 notes. Mann-Whitney U test indicated that this difference is statistically significant (p=0,0274). The outcome of the Monte Carlo analysis showed that the probability of randomly obtaining the observed mean is low (Figure A.4). This finding supports the Mann-Whitney U test. The total numbers of words in textual representations are also recorded. During the design sessions, the participants in CAAD and conventional design conditions noted a mean number of 10 and 56 words respectively.

Table 3.20: Hypothesis HE4: Total number of textual representations (words) under two different experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	39	28	2	39	15	18	0	16	**3,00**	**10,50**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	129	76	4	137	40	35	0	32	**37,50**	**56,62**

Hypothesis HE5 predicts a difference in activities that focus on representation. It is observed that participants under the CAAD condition performed an average of 74 activities of this type whereas participants in the conventional design condition performed an average of 74. Results of the Mann-Whitney U test indicated that there is a statistically significant difference between the means (p=0, 0027).

Table 3.21: Hypothesis HE5: Total number of decisions on representation in two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	247	63	139	170	56	72	76	49	**74,00**	**109,00**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	10	6	68	21	18	3	21	25	**19,50**	**21,50**

In accordance with the Mann-Whitney U test, the results of Monte Carlo Analysis illustrate that the probability of randomly obtaining the observed mean is low (Figure A.5). The observed difference is significant.

Hypothesis HE6 concerns the designers' decisions on the design process. Under CAAD condition, the participants made an average of 49 decisions of this type whereas the participants under conventional design condition made an average of 22.

Mann-Whitney U test showed that the mean difference between the two groups is significant at 0,0019. This level of significance is considered relatively high. The results of the Monte Carlo Analysis also confirm these findings (Figure A.6).

Table 3.22: Hypothesis HE6: Total number of decisions on the design process under two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	51	48	59	37	29	65	67	42	**49,00**	**49,75**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	21	6	19	28	12	35	31	27	**24,00**	**22,37**

During the analysis of the protocols, it is noted that the participants under CAAD condition spent most of their time planning the representation process. This observation points to a "process focused" design approach instead of a "product focused" approach and will be discussed in chapter 3.4.3.

Hypothesis HE7 predicts a difference in means of conceptual design decisions. Participants in CAAD condition gave an average of 15 decisions of this type while participants in the conventional design condition gave an average of 32. The difference is clearly visible.

In order to document this observation, a Mann Whitney U test is performed. The results show that means under both conditions are significantly different (p=0,0136).

Table 3.23: Hypothesis HE7: Total number of conceptual design decisions under two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	9	35	9	10	10	16	5	27	**10,00**	**15,12**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	44	19	17	31	37	54	24	31	**31,00**	**32,12**

Hypothesis HE8 is involved with decisions on design elements their organization and dimensions. In CAAD condition, participants made an average of 55decisions on design elements whereas the participants in the conventional design condition performed 81 decisions on design elements. Mann Whitney U test indicated that there is no significant difference between two means (p=0,0831). This probability is also observed in Monte Carlo Analysis (Figure A.8).

Table 3.24: Hypothesis HE8: Total number of decisions on design elements under two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	58	63	47	66	51	43	61	55	**56,00**	**55,50**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	84	96	44	143	88	93	24	80	**86,00**	**81,50**

Hypothesis HE9 is related with making decisions on the structure. Participants under CAAD conditions made an average of 3 decisions of this type while participants in the conventional design condition gave an average of 11.

Mann Whitney U test is conducted for comparing the difference of means and the difference is found to be significant at 0,0019. Similar results are obtained from the Monte Carlo Analysis (Figure A.9).

Table 3.25: Hypothesis HE9: Total number of decisions on structure in two experimental conditions

CAAD Condition (C01)	S01	S02	S03	S04	S05	S06	S07	S08	Median	Mean
	0	2	6	2	7	2	3	3	**2,50**	**3,12**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	11	18	8	20	4	8	11	9	**10,00**	**11,12**

Hypothesis HE10 predicts a difference in the means of decisions on materials in two different domains. Under CAAD conditions, participants made an average of 5 evaluations whereas the participants under conventional design conditions performed 12 evaluations.

Mann Whitney U test showed that the difference is insignificant (p=0,1278). Similar results can be seen in Monte Carlo Analysis outcomes (Figure A.10).

Table 3.26: Hypothesis HE10: Total number of decisions on materials in two experimental conditions

CAAD Condition (C01)	S01	S02	S03	S04	S05	S06	S07	S08	Median	Mean
	2	24	2	2	0	4	3	4	**2,50**	**5,12**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	22	10	2	17	17	16	2	11	**13,50**	**12,12**

Hypothesis HE11 is related with making decisions on lighting. Participants in CAAD condition gave an average of 3,5 decisions of this type while participants in the conventional design condition made an average of 7,8.

Mann Whitney U test indicated that there is no significant difference between two means (p=0,066). This probability is also observed in Monte Carlo Analysis (Figure A.11).

Table 3.27: Hypothesis HE11: the total number of decisions on lighting in two experimental conditions

CAAD Condition (C01)	**S01**	**S02**	**S03**	**S04**	**S05**	**S06**	**S07**	**S08**	**Median**	**Mean**
	1	2	1	2	9	2	1	10	**2,00**	**3,50**
Conventional Design Condition (C02)	**S09**	**S10**	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**Median**	**Mean**
	11	13	1	12	9	7	5	5	**8,00**	**7,87**

3.4.2 Analysis of the questionnaire-based survey

A questionnaire study has been conducted with students from ITU School of Architecture using the method that is presented in Section 3.3. 130 participants completed and returned their questionnaire. The average age of the sample population was 23,01 years of age and ranged between 20 and 28. The gender distribution of participants was % 41,3 male and 58,6 % female.

13 questions were presented to the participants (Table 3.28). The first question (Q1) was an open-ended one about the design software preferences. The responses to this question were used to determine the software that will be used in the protocol analysis study.

The questions from Q2 to Q11 are designed in relation with previous hypotheses. Five of those questions are stated as supporting the pilot study findings, and the five are designed to reject the pilot study outcomes. Q12 covers a general statement about the main research question whereas Q13 covers one of the key findings of this study that creating detailed representations may negatively affect the quantity and quality of design decisions.

Analysis of the outcomes are carried out by the author. 6 response sheets were discarded due to missing answers. The responses to the first question (Q1) indicated that 34% of the students preferred using Autodesk AutoCAD, 18,68 preferred Google SketchUP, 16,18% Adobe Photoshop, 12,9% Autodesk 3dsMAX software in the conceptual design phase. 8,79 % of the participants responded that they did not use computer software for conceptual design (The other responses are below 3%).

Results indicate that most of the participants remained undecided for the questions Q2 to Q8 (Figure 3.10) (Blue symbols represent the mean values and red circles represent the median values.). Since the validity of undecided answers in questionnaire responses are low, these have not been included in the evaluations (Sani and Todman, 2006). Analysis of the responses to the question Q9 revealed interesting outcomes. 21% of the respondents agreed and 37% of the respondents strongly agreed that they focused more on representation while designing with CAAD software. The median response was “agree” .This finding is consistent with the results of the design experiment.

Table 3.28: The statements and questions that are used in the survey

Q1	Which **software** do you use during the conceptual design phase? (Open-ended)
Q2	When I use CAAD software during the preliminary design phase, I make more **decisions about the design process** compared with the conventional design process.
Q3	When I use CAAD software during the preliminary design phase, I make more **decisions about the design elements** compared with the conventional design process.
Q4	When I use CAAD software during the preliminary design phase, I make more **decisions about materials** compared with the conventional design process.
Q5	When I use CAAD software during the preliminary design phase, I make more **decisions about structure** compared with the conventional design process.
Q6	When I use CAAD software during the preliminary design phase, I make more **decisions about lighting** compared with the conventional design process.
Q7	When I use CAAD software during the preliminary design phase, I make more **conceptual decisions** compared with the conventional design process.
Q8	When I use CAAD software during the preliminary design phase, I make more **evaluations** compared with the conventional design process.
Q9	When I use CAAD software during the preliminary design phase, I focus more **on representation** compared with the conventional design process.
Q10	When I use CAAD software during the preliminary design phase, I make more **decisions on scale and size** compared with the conventional design process.
Q11	When I use CAAD software during the preliminary design phase, I make more **notes** compared with the conventional design process.
Q12	When I use CAAD software during the preliminary design phase, I **follow a different method**
Q13	**Producing detailed representations** like models, or photo-realistic visualizations during the preliminary design phase **allows me to commit to more design decisions**

When participants responded to the question Q10, 47% agreed and 35% strongly agreed that they made more decisions on scale and size while they are designing with CAAD software. The median response was “agree” .This outcome is inconsistent with the analysis results of the design experiment.

The responses to question Q11 revealed that 47% of the respondents disagreed, 25% strongly disagreed with the statement that they made more notes while using computers. The median response was “disagree”. This finding is consonant with the results of the experimental study.

Analysis of the responses revealed that 40% of the participants agreed and 22% of the participants disagreed with the statement Q11. The median response is noted as “agree”. This means that majority of the respondents agree that they follow a different process while designing with CAAD software. This observation verified the results of the design experiment.

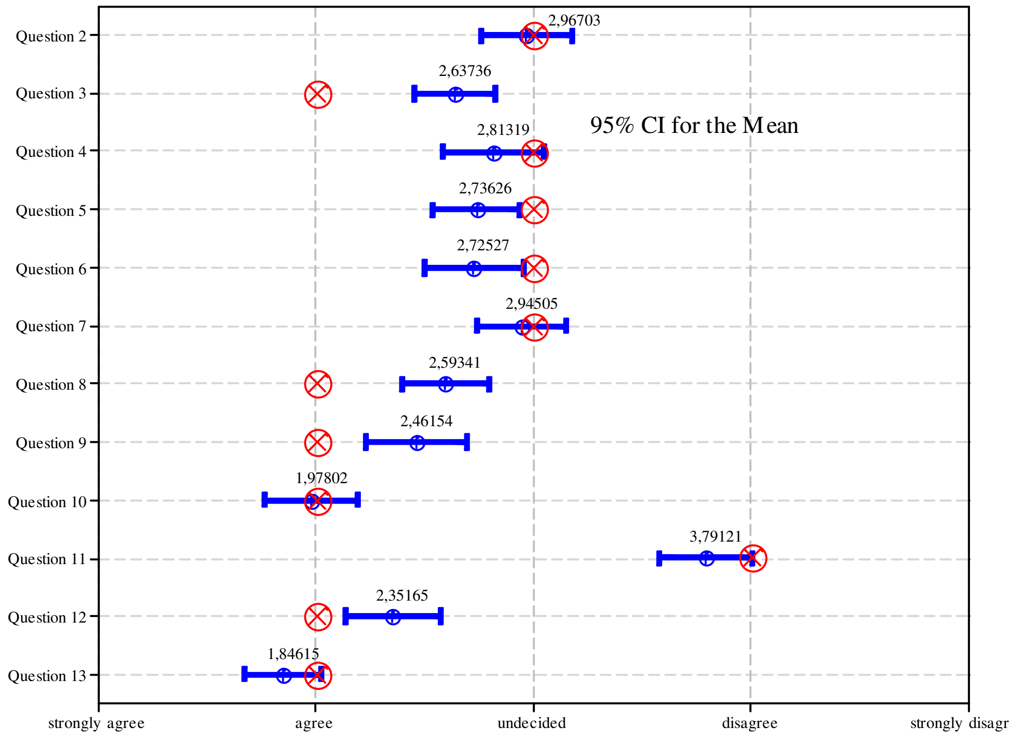


Figure 3.10 : Interval plot of the responses to the closed ended questions.

In question Q12, the participants were asked to rate the statement that producing detailed representations allowed them to commit more design decisions. 48% of the participants agreed and 37% of the participants strongly agreed with this statement. This finding is inconsistent with the observations gathered from the design experiment.

3.4.3 Evaluation of the findings and additional observations

The findings indicated that certain design activities and decisions were significantly different in experimental and control conditions. The participants in CAAD conditions focused more on representational aspects, made less notes, committed more decisions concerning the design process and gave less decisions about concepts, structure and lighting.

During the CAAD sessions, the participants spent substantial effort to design the representation itself. Therefore, it is not surprising that the number of activities that focus on representation is significantly high in the experimental (CAAD) condition.

All of the participants in CAAD condition have created a detailed 3D model of the project environment and it took an average of twenty minutes for the participants to be satisfied with result. In this process, they mainly focused on the complicated virtual structures and geometric features of the digital domain.

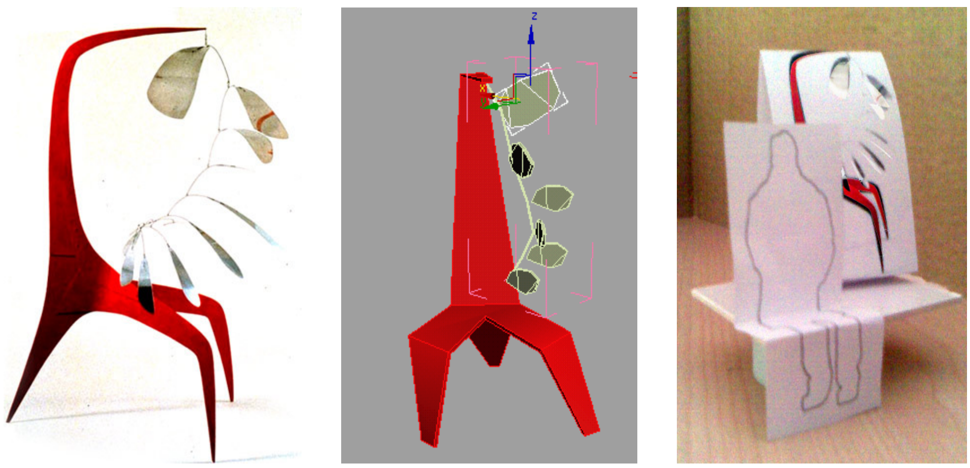


Figure 3.11 : (From left to right) The photo that is presented to the participants, representation of the artifact by subject S04 (in 9 minutes) and by Subject 15 (in 45 seconds)

On the other hand, in the control condition (conventional design), participants spent less time thinking on representing the existing environment and more time thinking on new concepts (The difference is significant and discussed in Hypothesis HE5).

In CAAD Session 01, Subject S01 performed an exclusive number of 247 activities that focus on representation (highest in both groups). Subject used complex representation types that required redrawing the existing plan and took fifty minutes to create a complete 3D model of the site. In contrast, he made only nine conceptual design decisions (second lowest in both groups).

It is obvious that, the primary objective of the conceptual design phase is to develop new concepts and integrate them into a framework. For this reason, the evaluation of the conceptual design decisions provides important clues about the focus of the participants in different conditions.

It seems that there is a strong relation between the quality of the representational activities and conceptual design. As reviewed in the previous chapters, verbal thinking is related to conceptual thinking.

Subject S09, who took the highest number of conceptual design decisions, made notes more frequently than all other participants did. The differences in the use of textual representations (making notes) can be explained by a lack of conceptual thinking during the design process.

Moreover, insufficiency of the present interaction devices, poor usability of the CAAD software and the lack of advanced annotation tools may have caused such a huge difference. It is obvious that there is a strong need for software that supports conceptual representations and ambiguous drawings. This seems to be a fruitful area for future research and will be discussed in the next section.

Although CAAD software provides a significant number of transformation and modification tools, the participants in this condition gave fewer decisions on organization of space. Participants that followed the conventional design methods used 2D models to examine different arrangements and evaluated a variety of alternatives in a short amount of time. Moreover, translucent sketching paper allowed them to superimpose and combine those alternatives.

The analysis of the results illustrates domain independent activities as well as domain dependent ones. These findings may be related with the limited capacity of the designer to process the design in a limited amount of time. In addition, the relative well-defined character of the design problem may also have limited this activity. Further research is needed to explain these types of domain independent activities.

Results of the questionnaire based survey indicates that the participants were aware that they followed a different design process, made more notes and focused more on representation while using CAAD software.

On the other hand, majority of the participants agreed with the statement that creating detailed representations allowed them to commit to more design decisions. These findings illustrate a common misconception among the architectural design students on the role of representation in conceptual design phase.

Implications that are related to architectural education will be discussed in the next section.

Several findings that are related with psychology and human computer interaction are also notable. During the CAAD experiments, participants exhibited distinct behaviors, which have not been observed in the conventional design condition.

These can be listed as follows:

- Personification of the software, objects or representations
- Oral communication attempts with computers
- Anxiety and excitement due to undesired results
- Continuously creating and testing hypotheses for explaining the reason of outcomes

Further research can be performed in these topics to analyze the psychological effects of the digital domain on the design process.

4. CONCLUSIONS AND RECOMMENDATIONS

In this dissertation, similarities and differences between conventional and computer aided architectural design processes are analyzed based on eleven hypotheses. Analysis of the experiments revealed that there is significant difference between the means of decisions on representation and textual representations in conventional design and CAAD conditions.

Moreover, the mean differences of the decisions on the design process, concepts, structure in two experimental conditions were found to be statistically significant.

Table 4.1: Overall evaluation of the hypothesis tests

	Hypothesis	**Mann Whitney P Value**	**Significant Difference (Alpha error 0,05)**
HE 1	Making Evaluations	0,1563	no
HE 2	Problem Redefinition	0,1415	no
HE 3	Referencing precedents	0,5286	no
HE4	Making notes (textual representations)	0,0274	**yes**
HE 5	Decisions on Representation	0,0028	**yes**
HE 6	Decisions on the Design Process	0,0019	**yes**
HE 7	Decisions on Elements, their organization and dimensions	0,0831	no
HE 8	Decisions on Concepts	0,0136	**yes**
HE 9	Decisions on Structure	0,0019	**yes**
HE 10	Decisions on Materials	0,1278	no
HE 11	Decisions on Lighting	0,0661	no

4.1 Interpretation of the Findings

Findings of this study can be interpreted in numerous ways. In this section, it is intended to make a multi-faceted review of the observations and results of the protocols.

It is important to note that findings of this study are generalizable only to a limited domain as they are limited with the number and profiles of participating students and specific to the design problem and setup used in the experiments.

All of the observations reflect the conceptual design phase; therefore, they cannot be generalized to the whole design process.

In addition, the participants' design expertise is limited; therefore, it is assumed that the conclusions relate to the novice designer's behavior in two different domains.

Table 4.1 points out to the existence of a general difference in two different experimental conditions. Subjects under CAAD experimental conditions performed different design activities and employed distinct strategies for representing and developing their designs. They gave more decisions on the design process, focused more on planning the design process and representing the existing environments.

These observations may be related to the unique properties of CAAD media. The potential of the medium to create automated reproductions, complex representations and rich visual content may have led the subjects to focus more on the design process and the medium itself.

The expertise level of the students that participated CAAD experiments may also have affected the findings, as their awareness in this area is lower than professional architects. Therefore, it may normal for them to think more about the design process. A future study on expert architects with the same experimental setup may reveal more information about this issue.

Another possible reason of the difference in the mean number of decisions on design process can be the fact that sketching is a goal-directed automatic behavior. In contrast, CAAD processes require human computer interaction, conscious reasoning, thinking about the tools and process planning. The interactive nature of the medium may be shifting the focus of the subjects to the process itself, as they are obliged to use a certain format, which can be transformed, processed and stored by the computer.

During the CAAD sessions, the participants spent substantial effort to design the representation itself. The range of CAAD representations are so diverse that, before starting to design, one needs to decide the type of the representational model which will be used and optimize it considering the performance of the hardware, operational limits and other design specific issues such as the required detail level for simulation, the size of the building, context and surroundings.

On the other side, certain properties of the digital medium can also serve as a source of inspiration. For instance, Subject 04 used a special representation model for generating and representing curves and surfaces (NURBS) and transformed it into a design concept; a group of free-formed surfaces that contrast with architectonics of the existing building. While subject 04 was designing the representation, he was also designing the formal configuration of the architectural elements (these elements are named by Lynn (1995) as “blob architecture” or “blobitecture”).

The analysis of the protocols also revealed that subjects under CAAD conditions used textual representations less frequently. The reason for this finding may be the poor usability of CAAD software, inefficient text tools or interaction devices. It is observed that in order to start writing a small note on the digital drawing, subjects needed to define different formats and take numerous decisions.

Moreover, some of the subjects (such as subject 05) have complained about the poor compatibility of the different software and inability to transfer text from one medium to another.

In contrast, in CAAD medium, subjects do not need to write down calculations or dimensions because they can perform these operations in seconds, anytime they want.

The difference in the mean number of textual representations may also be linked with the difference in the mean number conceptual design decisions. These two observations may be interacting with each other as conceptual thinking is directly related with verbal thinking,

The observed difference in the mean number of conceptual decisions illustrates the characteristics of the subjects’ design approaches in CAAD and conventional media.

Although the number of conceptual design decisions cannot be used as performance criteria, this difference may point out to a different thinking model and different levels of abstraction.

During the CAAD sessions, subjects took additional decisions on the virtual structures, materials and lighting. participants in CAAD condition made an average of 13 decisions on the geometric structure of the representations instead of the real structure of their designs. These decisions were mainly related with the construction of polygons, curves, patches, meshes and surfaces. Similar observations were also recorded concerning choices of materials and lighting.

The virtual medium has its own constraints. Virtual representations are independent from some of the physical limitations such as gravity. As architects use these representations more frequently, some of those properties are translated to the physical medium. Novak (1998) references this process and calls it "eversion". The findings about the decisions on geometric and material structure of the representations can be interpreted as empirical evidence supporting this theory.

Moreover, it is observed that two different modes of representation were used by the participants:

- Productive representation
- Reproductive representation

These representation types can be used to characterize the design activities in different domains. In productive representation, the designers developed new ideas and concepts while creating a sketch, model or a drawing.

Reproductive representation activity can be described as a routine process in which the designers are focused on representing the existing situation. This behavior is characterized by the lack of conceptual design decisions and consecutive actions of process planning, representation and evaluation.

In Figure 4.1, the design processes of Subject 03 and Subject 09 are compared. Subject 03 used a variety of software to represent her ideas. At certain points, she stopped making decisions and she was only focused on the detailed representations (shaded areas in the figure).

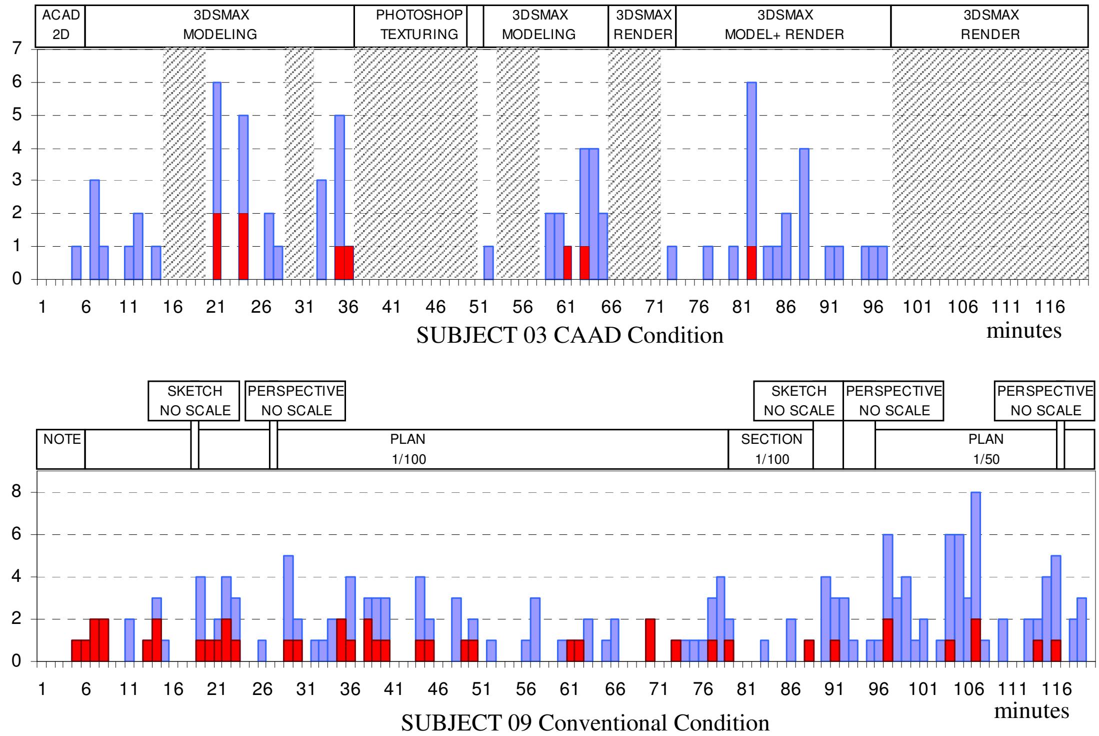


Figure 4.1 : Time series graph of design decisions in experimental conditions. (Blue bars represent overall decisions, red bars represent conceptual decisions and shaded areas indicate reproductive representation activity. In grayscale prints, conceptual decisions are darker)

Reproductive representation activity is not specific to the design domain, it can also be observed during the conventional design process, but at low levels. It is observed that, the average duration of this activity was longer in CAAD conditions. The longest recorded reproductive representation episode lasted 24 minutes.

Subjects also verbally described this type of representation activities several times during the experiments.

- SUBJECT 11 0:35:00 “I cannot think about the design till I complete this model…. I am thinking about my cat right now”
- SUBJECT 02 0:26:14 “I usually watch cartoons while I am 3D modeling”

These findings provide clues about the difference between representational activities in relation with conceptual design activities.

4.2 Comparison of the Outcomes with the Previous studies

The findings of this study is consistent with Bilda's (2001) finding that designers using CAD software perform less conceptual actions than the designers that used conventional methods.

The outcomes are also consonant with Song and Kvan's (2003) observations that there is significant difference between the activities in digital and conventional environments. Similar to the findings of this dissertation, researchers observed that the number of problem framing activities was the almost the same in CAAD setting and Sketch setting.

Some of the analysis results are not harmonious with Goel's (1995) study for several reasons. Goel's (1995) experiments were conducted MacDraw, a primitive sketching software not CAAD software. The design problem was about graphic design and industrial design. In addition, the subjects that participated in those experiments had different experiences with computers compared with senior ITU students.

4.3 Future Research

Further research on the use of digital domains in the design process is needed for a clearer insight into architectural education and professional practices.

Further experiments can be conducted to investigate "the hybrid design process" in which architects are allowed to design with both digital and conventional media.

The analysis of the outcomes indicates that more effort should be put into experimental tools and environments that support conceptual thinking and to improve the existing interaction devices.

Unfortunately, the most frequently used software in architectural design (Autodesk AutoCAD, 3dsMAX and Google Sketchup) are not specifically designed for architects.

New software and plug-ins can be developed for customizing the software environments, especially to be used in the conceptual design phase.

Furthermore, an automated protocol analysis system model can be constructed specifically for architectural design to support research studies in this area.

REFERENCES

Achten, H., 2003. New Design Methods for CAAD Methodology Teaching, *International Journal of Architectural Computing*, Volume 1, Number 1, pp. 72-91.

Akın, Ö., 1978. How do architects design? *Artificial Intelligence and pattern recognition in computer aided design*, IFIP/North Holland, New York.

Akin, Ö., 1986. *Psychology of Architectural Design*, London: Pion Ltd.

Akın, Ö., 1994. The Computer as a Catalyst for New Educational Paradigms in Architecture, *METU Journal of Faculty of Architecture*, Vol. 15, No 1-2.

Akin, Ö., Lin, C., 1995. Design Protocol Data and Novel Design Decisions, *Design Studies*, Vol. 16, pp 211-236.

Akin, Ö, Sen, R. 1996 Navigation within a structured search space in layout problems, *Environment and Planning B: Planning and Design*, Vol. 23, pp 421-442.

Akin, Ö., 2001. Variants of design cognition, *Design Knowing and Learning: Cognition in Design Education*, pp. 105-124. New York: Elsevier.

Alexander, C. A., 1964. *Notes on the Synthesis of Form*, Cambridge, MA: Harvard University Pres.

Andrade, J., May, J., 2005. *Instant notes in cognitive psychology*, New York, NY: BIOS Scientific Publishers

Anderson, J., R., 2004. *Cognitive psychology and its implications*, New York: Worth

Archer, L. B., 1965. *Systematic Method for Designers*, London: The Design Council

Arnheim, R., 1969. *Visual thinking*. Berkeley: University of California Press.

Atkinson, R.C., Shiffrin, R.M., 1968. Human memory: A proposed system and its control processes, in K.W. Spence and J.T. Spence (Eds.), *The psychology of learning and motivation*, Vol. 8. London: Academic Press.

Asanowicz, A., 1997. Incompatible Pencil Chance for Changing in Design Process, *First International Conference AVOCAAD*, Brussels.

Ataman, O., Bermúdez, J., 1999. Media and Design Process, *ACADIA '99 Proceedings*

Atkinson, R., C., and Shiffrin, R., M., 1968. Human memory: A proposed system and its control processes. *The psychology of learning and motivation* Vol. 2, pp. 89–195.

Bannert, M., Mengelkamp, C., 2007. Effects of metacognitive strategy training and accuracy of monitoring on learning outcome, *EARLI-Conference*, Budapest.

Bermudez, J., King, K., 1998. Media Interaction and Design Process: Establishing a Knowledge Base, *ACADIA 98 Conference Proceedings*, pp. 7–25.

Bilda, Z., 2001.Traditional versus digital design medium: A case study on interior design process, *Masters Thesis,* Bilkent University Department of Interior Architecture and Environmental Design.

Bilda, Z., Demirkan, H, 2003. An insight on designer's sketching activities in traditional. versus digital media, *Design Studies*, Volume 24, pp 27-50.

Bilda, Z., Gero, J. S. and Purcell, A. T., 2006. To sketch or not to sketch: That is the question, *Design Studies*, Vol. 27 (5), pp. 587-613.

Brenner, A., 1996. The Computing Revolution and the Physics Community, *Physics Today*, 49, No. 10, pp. 24-30.

Bridges, A., 1983. Course Description - University of Strathclyde - Msc In Building Science (Computer Aided Building Design), *International Conference eCAADe European Computer Aided Architectural Design Education*, Brussels, pp. 40-51.

Bulbrook, M., E., 1932. An experimental inquiry into the existence and nature of insight, *The American Journal of Psychology*, Vol. 44, pp.409-53

Casakin, H., Goldschmidt, G., 1999. Expertise and the use of visual analogy: implications for design education, *Design Studies*, Vol. 20, pp 153-175

Claparède, E., 1934. *La genèse de l'hypotheses*, Geneva: Kundig.

Collins, P., 2008. Theory of Architecture, *Encyclopaedia Britannica Online edition*, Retrieved, 15.07.2008 from http://www.britannica.com/eb/article-9110410.

Corkin, S., 2002. What's new with the amnesic patient H.M.?, *Nature Reviews Neuroscience 3*, Volume 2, pp. 153–160.

Cross, N., 1997. Creativity in Design: Analyzing and Modeling the Creative Lea*p, Leonardo*, Vol. 30, No. 4 (1997), pp. 311-317.

Cross, N., 1999. Natural Intelligence in Design, *Design Studies*, Vol. 20, pp. 25-39

Cross, N., Christiaans H., Dorst K., 1994. Design Expertise amongst Student Designers, *Journal of Art and Design Education,* Vol. 13(1), pp. 39-56

Cross, N., Christiaans, H., Dorst, K., 1996. *Analyzing Design Activity*, John Wiley & Sons, Chichester, UK

Cross, N., Christiaans, H., Dorst, K., 1996. Introduction: The Delft Protocols Workshop. In *Analyzing Design Activity* (N. Cross, H. Christiaans and K. Dorst, eds.), pp. 1-14. John Wily & Son: Chichester.

Cross, N., 2007. *Designerly Ways of Knowing*, Springer, London

D'Amato, M. R. 1970. *Experimental Psychology: Methodology, Psychophysics, and Learning*, New York: McGraw-Hill,

Dannevig, T., Thorvaldsen, J. A., 2007. Immersive Virtual Reality in Landscape Planning*, Joint Masters Thesis*, Department of Landscape Architecture and Spatial Planning, Norwegian University of Life Sciences.

Demirbas, O. O., Demirkan, H., 2003. Focus on architectural design process through learning styles, *Design Studies*, Volume 24, pp. 437-456.

Dennett, D., 1991. *Consciousness Explained*. Boston, Little, Brown & Co.

Di lorio, C.K., 2005. *Measurement in Health Behaviour: Methods for Research and Evaluation*. Jossey-Bass (Wiley & Sons), San Francisco.

Dorst, K. & Christiaans, H., 2007. An empirical study into design thinking. in Cross, N.G., Dorst, C.H. and Roozenberg, N.F.M. (eds), *Research in Design Thinking*, Delft University Press, Delft.

Dorst, K. & Cross, N., 2007. Co-evolution of Problem and Solution Spaces in Creative Design, in Gero, J. Maher, M.L. (eds), *Computational Models of Creative Design*, Key Centre of Design Computing and Cognition, University of Sydney, Sydney.

Dorst, K. & Hendriks, D., 2007. The role of the design context in practice and in design methodology, in Lloyd, P. Christiaans, H.H.C.M. (eds), *Designing in Context*, Delft University Presss, Delft.

Dorst, K. & Roozenburg, N., 1998. Describing design as a reflective practice: observations on Schon's theory of practice, in Frankeenberger, E., Badke-Schaub, P., Birkhofer, H. (eds), *Designers: The key to successful product development*, Springer, London.

Dorst, K., 2007. But, is it art?, in Coles, A. (eds), *Design and Art*, Whitechapel Ventures Limited, London, UK, pp. 10-18.

Dorst, K., 2007. The Problem of the Design Problem, in Cross, N.G. Edmonds, E. (eds), Expertise in Design, *Design Thinking Research Symposium 6 Creativity and Cognition*, Studios Press, Sydney.

Dorst, K., Dijkhuis, J., 1995. Comparing Paradigms for Describing Design Activity*, Design Studies*, Voli 16, pp. 261-274.

Dorst, K., Stappers, P., de Vries, B. & Achten, H.H., 2005. A decade of Design Research in the Netherlands*, Design Research in the Netherlands*, Faculteit Bouwkunde, Eindhoven.

Dorst, K., Valkenburg, A., 1998, The reflective practice of design teams, *Design Studies*, Vol. 19, no. 3.

Duncker, K., 1926. A Qualitative Experimental and Theoretical Study of Comprehensible Problems, *Journal of Genetic Psychology,* Vol. 33, pp. 642-708

Durkin, H., E., 1937. Trial-and-error, gradual analysis, and sudden reorganization. *Archives of Psychology*, Vol. 30 (210), pp. 1–85.

Eastman, C. M., 1969. Cognitive Processes and Ill-defined Problems: a case study from design, *International Joint Conference on Artificial Intelligence*, Washington DC, pp. 669-690.

Eastman, C. M., 1970. *On the Analysis of Intuitive Design Processes, Emerging Methods in Environmental Design and Planning*, G T Moore (ed), MIT Press, Cambridge, MA.

Eastman, C., McCracken, M., Newstetter, W., 2001. *Design Knowing and Learning: Cognition in Design Education*, Oxford: Elsevier Science

Eastman, Charles M., 1981. Computers in Architecture, Design, and Fine and Performing Arts Education, *CADline* Vol.5.

Eisenman, P. 2005, Keynote Speech, *International Union of Architects Conference,* Istanbul

Ericsson, K. A., Simon, H. A., 1993. *Protocol analysis: verbal reports as data,* MIT Press, Cambridge, MA

Ericsson, K.,, A., 2002. Attaining excellence through deliberate practice: Insights from the study of expert performance. *The pursuit of excellence in education*, pp. 21-55.

Ferrer, J. N., 2005. Theoretical Research, *Spirituality in Higher Education*, Volume 2, Issue 2 , Page 2.

Flemming, U., 2004. Computer Aided Architectural Design: Looking Forward, Looking Back, *Generative CAD Systems, Proceedings of GCAD '04,* Carnegie Mellon University.

Flemming, U., Akin, Ö., Woodbury, R., 1985. A Comprehensive Computing Environment for Architectural Education, *Proceedings of the World Conference on Computers in Education,* Washington, DC (K. Duncan and D. Harris, eds) New York: Elsevier, pp. 637-642.

Foz A., 1973., Some observations on Designer Behavior in the Parti, *DMG-DRS Journal: Design Research and Methods*, Vol. 7, pp. 320-323.

Frankenberger, E., Badke-Schaub, P., 1998. Integration of Group, Individual and External Influences in the Design Process, *Designers - The Key to Successful Product Development*, E Frankenberger P Badke-Schaub and H Birkhofer (ed), Springer, London, UK

Gero, J. S., Kannengiesser, U., 2004. The situated function–behavior– structure framework, *Design Studies*, Vol. 25 No. 4

Gero, J. S., 1980. The Diploma in Architectural Computing at the University of Sydney, *CAD80 Conference*, IPC Press, Guildford, pp. 293-296.

Gero J. S., Rosenman, M. A. 1990. A Conceptual Framework for Knowledge-Based Design Research at Sydney University's Design Computing Unit, *Artificial Intelligence in Engineering,* Vol. 5(2), pp. 65–77

Gero, J. S., Lindemann U., 2005. *Human Behaviour in Design'05*, Key Centre of Design Computing and Cognition, University of Sydney, pp. 47-58

Gero, J. S., Tang, H., 1999. Concurrent and retrospective protocols and computer-aided architectural design, in J. Gu and Z. Wei (eds), *CAADRIA'99 Conference,* Shanghai Scientific and Technological Literature Publishing House, Shanghai, China, pp. 403-410.

Gillham, B., 2000. *Developing a questionnaire (real world research)*, London: Continuum

Goel, V., 1995. *Sketches of thought*, Cambridge, MA: MIT Press

Goldschmidt, G., 1994. On visual design thinking: the vis kids of architecture, *Design Studies*, Vol. 15, Issue 2, April, pp. 158-174.

Goldschmidt, G., Smolkov, M., 2006. Variances in the impact of visual stimuli on design problem solving performance, *Design Studies*, Vol. 27, Issue 5, pp 549-569.

Goldschmidt, G., Tatsa, D., 2005. How good are good ideas? Correlates of design creativity, *Design Studies*, Volume 26, Issue 6, pp. 593-611.

Goldschmidt, G., 1991. The Dialectics of Sketching, *Creativity Research,* Vol. 4(2), pp. 123-143

Goldschmidt, G., 1995. The designer as a team of one, *Design Studies*, Volume 16, Issue 2, pp 189-209.

Goldschmidt, G., 1997. Capturing indeterminism: representation in the design problem space, *Design Studies*, Vol. 18, Issue 4, pp 441-455.

Goldschmidt., G., 1990. Linkography: assessing design productivity, in R Trappl (eds), *Cybernetics and System '90*, World Scientific, Singapore, pp. 291-298.

Gotelli, N. J., Ellison A. M., 2004. *A primer of ecological statistics*. Sinauer Associates, Sunderland, Massachusetts, USA

Gower, A. R., 1996. *Survey Methods Workshop on Questionnaire Design,* Statistics Canada: Questionnaire Design Resource Centre.

Gross, M., Do, Ellen Y., 1999. Integrating Digital Media in Design Studio: Six Paradigms, *ACSA Annual Conference '99*, Minneapolis, MN, USA. pp 144-148.

Guion, R. M., 1998. *Assessment, Measurement, and Prediction for Personnel Decisions*, Lawrence Erlbaum.

Hahn, D. Shangraw, R., Keith, M., Coursey, D., 2007. Does Visualization Affect Perceptions of Ethically Complex Policy Decisions: An Experimental Study, *HICSS Conference*, Hawaii, USA.

Hanna, R., Barber, T., 2001. An inquiry into computers in design: attitudes before attitudes after, *Design Studies,* Vol. 22, pp. 255-281.

Heidegger, M., 1975. *The Basic Problems of Phenomenology*, Indiana University Press.

Heylighen, A., 2003. Close encounters of the architectural kind, *Design Studies,* Vol. 24, pp 313-326.

James, W., 1890. *The Principles of Psychology vol. 1*, Dover Publications 1950.

Jenks, C., 2003. *The new Paradigm in Architecture: The Language of Post Modernism.* London: Yale

Kan, J. W. T., Gero J. S., 2005. Design Behavior Measurement by Quantifying Linkography in Protocol Studies of Designing, JS Gero and U Lindemann (eds), *Human Behaviour in Design'05*, 2005 Key Centre of Design Computing and Cognition, University of Sydney, pp. 47-58.

Kantowitz, H., 1994. *Experimental Psychology: Understanding Psychological Research*, 5th ed. St. Paul: West Publishing Company

Karpf, F., B., 1932. *American social psychology: Its origins, development, and European background*, New York: McGraw-Hill

Kolb, Q., Whishaw, I. Q., 1996. *Fundamentals of human neuropsychology, 4th edition*, New York, NY: W. H. Freeman.

Koutamanis, A., 2004. CAAD's Seven Arguable Virtues, *International Journal of Architectural Computing*, Vol. 2, No. 1, pp. 51-65.

Krauss, R., and Myer, R., 1970. Design: A case history, in G.T. Moore (ed.), *Emerging Methods in Environmental Design and Planning*, MIT Press, Cambridge.

Kruger C., Cross, N., 2006. Solution driven versus problem driven design: strategies and outcomes, *Design Studies*, Vol. 27, pp. 527-548.

Kuhn, T., S., 1970. *The Structure of Scientific Revolutions*. Chicago: Chicago University Press.

Kvan, T., J. Yunyan, 2005. Students' learning styles and their correlation with performance in architectural design studio, *Design Studies*, Vol. 26, pp 19-34.

Lawson, B. R., 1994. *Design in Min*d, Oxford: Butterworth Architecture.

Lawson, B. R., 2001. *The Language of Space,* Oxford: Architectural Press

Lawson, B. R., 2005. *What Designers Know*, Oxford: Architectural Press

Lawson, B. R., 2006. *How Designers Think*, Oxford: Architectural Press

Lawson, B., M., Bassanino, et al., 2003. Intentions, practices and aspirations: Understanding learning in design, *Design Studies*, Vol. 24, pp. 327-339.

Lennertz, B., 2003. *The Charette as an Agent for Change, New Urbanism: Comprehensive Report and Best Practices Guide,* 3rd edition, New Urban Publications

Liu, Y. T., Lim, C. K., 2006. New Tectonics: A preliminary framework involving classic and digital thinking, *Design Studies,* Vol. 27, pp 267-307.

Lloyd, P., Lawson, B., Scott, P., 1996. Can Concurrent Verbalization Reveal Design Cognition?*, Design Studies,* Volume 16, pp. 237-259.

Lloyd, P., Scott, P., 1995. Difference in Similarity: interpreting the architectural design process, *Planning and Design,* Volume 22, pp. 383-406.

Marx, J., 1998. A Proposal for Alternative Methods for Teaching Digital Design, in Wyk, S.Van and Seebohm, T. (Editors), *Digital Design Studios: Do Computers Make a Difference?: ACADIA'98 Proceedings*, Québec City, Canada, pp. 59-73.

Maver, T. W., 1998. Prospects for CAAD: An optimistic perspective*, II Seminario Iberoamericano de Grafico Digital [SIGRADI]*, Mar del Plata, Argentina, pp. 6-13.

Maver T.W., 1970. Appraisal in the Building design process, *Engineering methods in environmental design and planning,* M.I.T Press, Cambridge, MA.

Maver, T.W., Smith, M., Watts, J. and Aish, R., 1979. Implications for Practice and Education, *Proceedings of PArC 79*, (Ed: J Chalmers), Berlin, pp. 221-232 .

Maver, T.W., 1995. CAAD's Seven Deadly Sins*, Proceedings of CAAD Futures 94 Conference*, pp. 21-22.

McCullough, M., 1998. *Abstracting Craft: The Practiced Digital Hand*. Massachusets: MIT Press

McCullough, M., Mitchell, W.J. and Purcell, P., (Eds.) 1990. The Electronic Design Studio: Architectural Knowledge and Media in the Computer Era, *International Conference on Computer Aided Architectural Design Futures*, MIT Press. Cambridge, Massachusetts.

Mckim, R. H., 1980. *Experiences in Visual Thinking,* Stanford, Wadsworth,

Miller, G.A., 1956. The magical number seven, plus or minus two: Some limits on our capacity for processing information, *Psychological Review*, Volume 63, pp. 81-97.

Mitchell, W. J., 1974. Computer-Aided Design and the Architecture Student in the United States, *NMG-GRS Journal: Design Research and Methods,* Vol 8, no 4, pp. 210-217.

Murdock, B., 1962. The serial position effect of free recall, *Journal of Experimental Psychology*, Vol. 64(5), pp. 482-488.

Newell, A., Simon, H.A., 1972. *Human Problem Solving*. Englewood Cliffs, New Jersey: Prentice-Hall.

Oosterhuis, K., 2004. File to Factory and Real Time Behavior in Architecture, Fabrication: Examining the Digital Practice of Architecture, *ACADIA'04 Fabrication: Examining the digital practice of architecture*, Canada. pp. 294-305.

Oppenheim, A. N., 2000. *Questionnaire design, interviewing and attitude measurement,*, London: Pinter.

Oxman, R. 2006, Theory and design in the first digital age, *Design Studies*, Vol. 27 (3) , pp. 229-265.

Parkin, A. J., 1999. *Memory: a guide for professionals*, Chichester: John Wiley & Sons Ltd.

Pektas, S. T., Erkip, F., 2006. Attitudes of Design Students toward Computer Usage in Design, *International Journal of Technology and Design Education*, 16.1, pp. 79-95.

Perella, S., 1998. (ed.) *Hypersurface Architecture*, (Architectural Design, n.133). London: Academy Editions.

Peterson, L.R. and Peterson, M.J., 1959. Short-term retention of individual verbal items, *Journal of Experimental Psychology*, Vol. 58, pp. 193-198.

Purcell, T. and Gero, J. S., 1998. Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology, *Design Studies*, Vol. 19, pp. 389-430.

Popper, K., 1963. Conjectures and Refutations, London: Routledge.

Rowe, P., 1987. *Design Thinking*, MIT Press, Cambridge, Massachusetts.

Saint-Germain, M. L., 2008. *PPA 696 Research Methods Course Notes, Dept. of Public Policy and Administration*, California State University at Long Beach.

Sancar, H. F., 1996. Behavioral knowledge integration in the design studio: an experimental evaluation of three strategies, *Design Studies*, Vol. 17, pp 131-163.

Sani, F., Todman, J., 2006. *Experimental Design and Statistics for Psychology: A first course*, Oxford: Blackwell

Schick, T., Vaughn, L., 2002. *How to think about weird things: Critical thinking for a new age*, Boston: McGraw-Hill.

Schmal, P. C., 2001. (ed.), *Digital Real – Blobmeister: First Built Projects*, Berlin: Birkhauser.

Schön, D. A., Wiggins, G., 1992. Kinds of seeing and their functions in designing. *Design Studies,* Volume 13, pp. 135-156.

Schön, D. A., 1983. *The Reflective Practitioner*, Harper Collins, USA.

Schön, D. A., 1984. The Architectural Studio as an Exemplar of Education for Reflection-in-Action, *Journal of Architectural Education*, Volume 38, pp. 2- 9.

Schön, D. A., 1984. Problems, Frames and Perspectives on Designing, *Design Studies*, Vol. 5(3), pp. 132-136.

Schön, D. A., 1985. *The Design Studio; an exploration of its traditions and potentials,* London, RIBA Publications for RIBA Building Trust.

Schön, D. A., 1987. *Educating the Reflective Practitioner: toward a new design for teaching and learning in the professions*, Jossey-Bass, San Francisco.

Schön, D. A., 1988. Designing: rules, types and worlds, *Design Studies*, Vol. 9, pp. 181-190.

Schön, D. A., 1992. Designing as Reflective Conversation with the Materials of a Design Situation, *Research in Engineering Design*, Vol. 3, pp. 131-147.

Schön, D. A., 1993. Generative metaphor: A perspective on problem-setting in social policy, in A. Ortony (Ed.), *Metaphor and Thought*, Cambridge, Cambridge University Press, pp. 137-163.

Seebohm, T., van Wyk, S., 2000. *Digital Design Studios*, Automation in Construction, Vol 9 (1), pp. 1-4.

Shih, S. G., Hu, T. P., Chen, C. N., 2006. A game theory-based approach to the analysis of cooperative learning in design studios, *Design Studies*, Vol. 27, Issue 6, pp 711-722.

Simon, H. A., 1969. *Sciences of the Artificial*, MIT Press, Cambridge, MA.

Simon, H.A., 1973. The structure of ill-structured problems, *Artificial Intelligence*, Volume 4, pp. 181-201,

Song, G., Kvan T., 2004. An analysis of problem framing in multiple settings. in *Design Computing and Cognition '04*, J. S. Gero (ed), Dordrecht, Kluwer Academic Publishers, pp. 117-134

Squire, L. R., Stark, C.E., Clark, R.E., 2004. The medial temporal lobe, *Annual Review Neuroscience*, Vol. 27, pp.279-306.

Stefanacci, E. A. Buffalo, H. Schmolck and L. R. Squire, 2000. Profound amnesia following damage to the medial temporal lobe: A neuroanatomical and neuropsychological profile of patient E.P., *Journal of Neuroscience,* Vol. 20, pp. 7024–7036

Steinitz, C., 1990. A Framework for Theory Applicable to the Education of Landscape Architects (and Other Environmental Design Professionals), *Landscape Journal,* Vol. 9, No 2.

Stipech, A., Mantaras, G., 2004. The Digital Media and New Technologies in Visual Arts Studio, *International Journal of Architectural Computing* Vol. 2, no. 3, pp. 389-401.

Sutherland, I., 1963. SKETCHPAD: A Man Machine Graphical Communication System, *Proceedings of the AFIPS Spring Joint Computer Conference.*

Suwa, M. Tversky, B., 1997. What do Architects and Students Perceive in Their Design Sketches? *Design Studies*, Volume 18, pp. 385-403.

Talbott, W. K., 2004. Divergent Thinking in the Construction of Architectural Models, *International Journal of Architectural Computing*, Vol. 2, pp. 263-286.

Trochim, W., Donnelly, J. P., 2007. *The Research Methods Knowledge Base*, 3rd edition, Thomson Publishing, Mason, Ohio.

Uluoglu, B., 2000., Design knowledge communicated in studio critiques, Design *Studies*, Vol. 21, pp. 33–58.

van der Lugt, R., 2003. Relating the quality of the idea generation process to the quality of the resulting design ideas, *International conference on engineering design*, pp. 19-21, Stockholm.

van Someren, M. W., Barnard, Y. F., Sandberg, C., 1994. *The think aloud method: a practical guide to modeling cognitive processes*, London, Academic Press

Watson, J. B., 1913. Psychology as the behaviorist views it, *Psychological Review*, Vol. 20, pp. 158-177.

Whitehead, L.C., 2007. Methodological and ethical issues in internet-mediated research in the field of health: an integrated review of the literature, *Social Science and Medicine*, Vol. 65, pp. 782–791.

Won, P. H., 2001. The comparison between visual thinking using computer and conventional media in the concept generation stages of design, *Automation in Construction,* Vol 10*,* pp. 319–325

Zellner, P., 1999. *Hybrid Space: New Forms in Digital Architecture*, New York. Rizzoli.

APPENDICES

APPENDIX A.1 : Mann-Whitney U Tests
APPENDIX A.2 : Monte Carlo Analyses
APPENDIX A.3 : Protocol Samples

APPENDIX A.1 MANN-WHITNEY U TEST REPORTS

Mann-Whitney Test for (HE1) **Making Evaluations**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	238,50
CONTROL CONDITION (CONVENTIONAL)	8	199,50

Point estimate for ETA1-ETA2 is 36,50
95,9 Percent CI for ETA1-ETA2 is (-12,97;75,00)
W = 82,0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,1563**

Mann-Whitney Test for (HE2) **Problem Redefinition**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	3,000
CONTROL CONDITION (CONVENTIONAL)	8	8,500

Point estimate for ETA1-ETA2 is -5,000
95,9 Percent CI for ETA1-ETA2 is (-11,999;1,003)
W = 53,5
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,1415**
The test is significant at 0,1391 (adjusted for ties)

Mann-Whitney Test for (HE3) **Referring Precedents**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	1,000
CONTROL CONDITION (CONVENTIONAL)	8	1,000

Point estimate for ETA1-ETA2 is -0,000
95,9 Percent CI for ETA1-ETA2 is (-1,000;1,000)
W = 74,5
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,5286**
The test is significant at 0,4932 (adjusted for ties)

Mann-Whitney Test for (HE4) **Making Notes**

	N	**Median**
CONTROL CONDITION (CONVENTIONAL)	8	37,50
EXPERIMENTAL CONDITON (CAAD)	8	3,00

Point estimate for ETA1-ETA2 is 34,50
95,9 Percent CI for ETA1-ETA2 is (3,00;124,00)
W = 89,5
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0,0274
The test is significant at 0,0263 (adjusted for ties)

Mann-Whitney Test for (HE5) **Decisions on Representation**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	74,00
CONTROL CONDITION (CONVENTIONAL)	8	19,50

Point estimate for ETA1-ETA2 is 57,50
95,9 Percent CI for ETA1-ETA2 is (38,01;148,98)
W = 97,0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,0028**
The test is significant at 0,0027 (adjusted for ties)

APPENDIX A.1 MANN-WHITNEY U TEST REPORTS (Continued)

Mann-Whitney Test for (HE6) **Decisions on the Design Process**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	49,50
CONTROL CONDITION (CONVENTIONAL)	8	24,00

Point estimate for ETA1-ETA2 is 28,50
95,9 Percent CI for ETA1-ETA2 is (13,00;40,00)
W = 98,0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,0019**

Mann-Whitney Test for (HE7) **Decisions on Concepts**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	10,00
CONTROL CONDITION (CONVENTIONAL)	8	31,00

Point estimate for ETA1-ETA2 is -16,00
95,9 Percent CI for ETA1-ETA2 is (-28,00;-4,00)
W = 44,0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,0136**
The test is significant at 0,0134 (adjusted for ties)

Mann-Whitney Test for (HE8) **Decisions on the Design Elements**

	N	Median
CONTROL CONDITION (CONVENTIONAL)	8	86,00
EXPERIMENTAL CONDITON (CAAD)	8	56,50

Point estimate for ETA1-ETA2 is 30,00
95,9 Percent CI for ETA1-ETA2 is (-10,98;45,01)
W = 85,0

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at **0,0831**

Mann-Whitney Test for (HE9) **Decisions on Structure**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	2,500
CONTROL CONDITION (CONVENTIONAL)	8	10,000

Point estimate for ETA1-ETA2 is -7,000
95,9 Percent CI for ETA1-ETA2 is (-14,001;-3,002)
W = 38,0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,0019**
The test is significant at 0,0018 (adjusted for ties)

Mann-Whitney Test for (HE10) **Decisions on Material**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	2,50
CONTROL CONDITION (CONVENTIONAL)	8	13,50

Point estimate for ETA1-ETA2 is -9,00
95,9 Percent CI for ETA1-ETA2 is (-15,00;1,00)
W = 53,0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,1278**
The test is significant at 0,1216 (adjusted for ties)

APPENDIX A.1 MANN-WHITNEY U TEST REPORTS (Continued)

Mann-Whitney Test for (HE11) **Decisions on Lighting**

	N	Median
EXPERIMENTAL CONDITON (CAAD)	8	2,000
CONTROL CONDITION (CONVENTIONAL)	8	8,000

Point estimate for ETA1-ETA2 is -4,000
95,9 Percent CI for ETA1-ETA2 is (-10,001;-0,001)
W = 50,0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at **0,0661**
The test is significant at 0,0629 (adjusted for ties)

APPENDIX A.2 MONTE CARLO ANALYSES

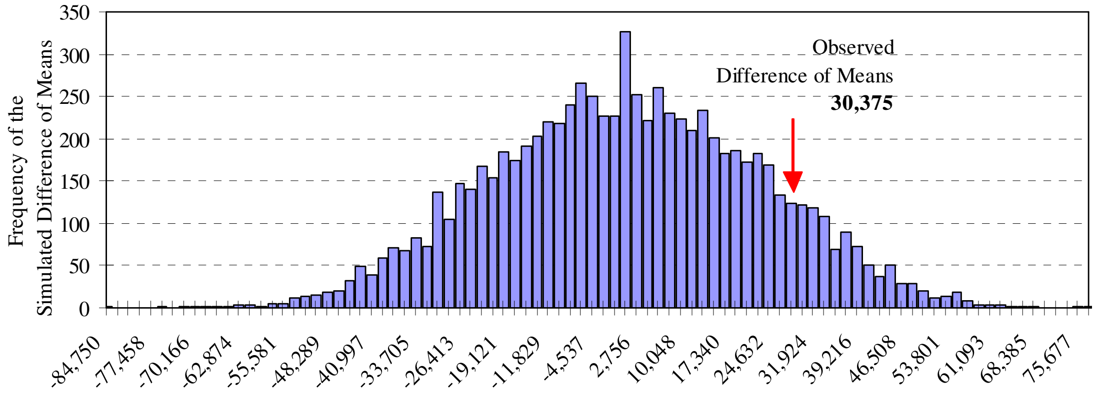


Figure A.1 : (HE1) Making Evaluations: comparison of the frequency of the simulated mean differences with the observed difference of means

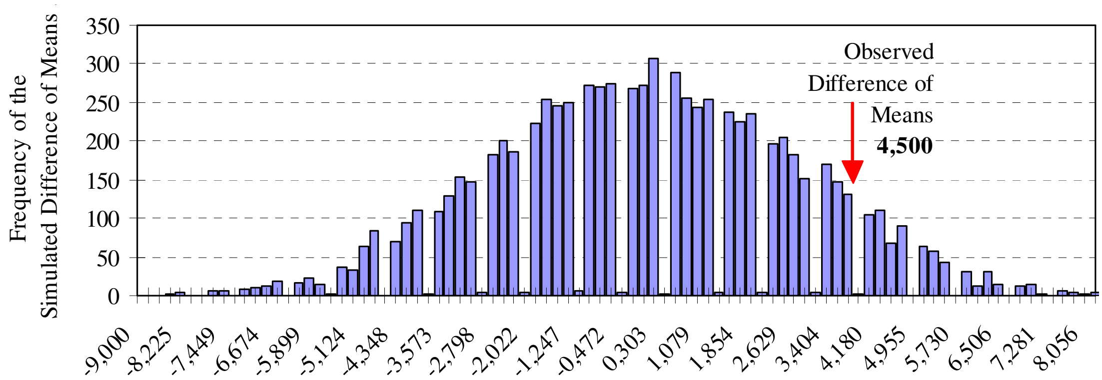


Figure A.2 : (HE2)Problem redefinition: comparison of the frequency of the simulated mean differences with the observed difference of means

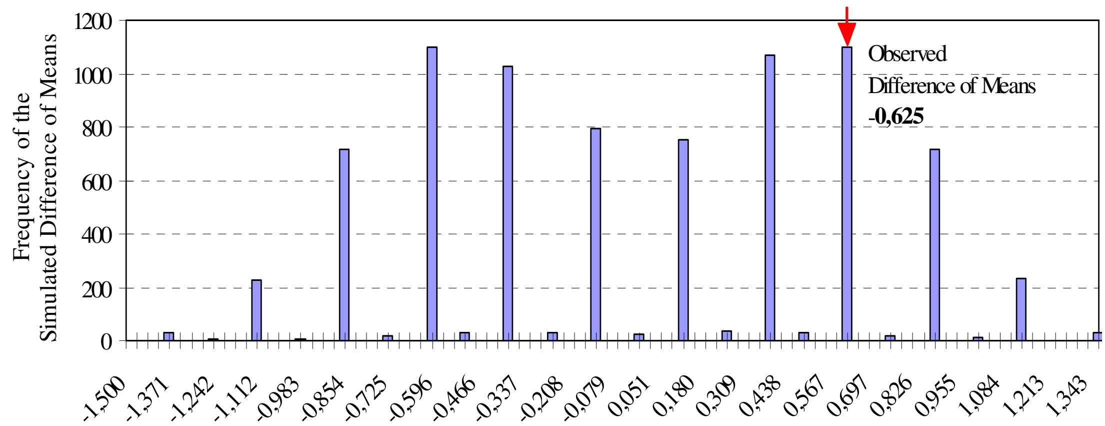


Figure A.3 : (HE3) Referring precedents: comparison of the frequency of the simulated mean differences with the observed difference of means.

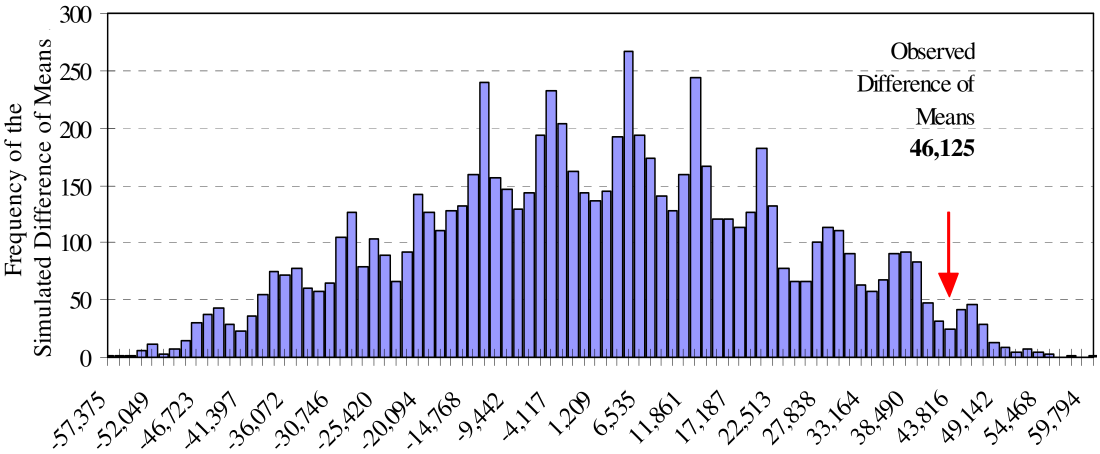


Figure A.4 : (HE4) Making notes: comparison of the frequency of the simulated mean differences with the observed difference of means.

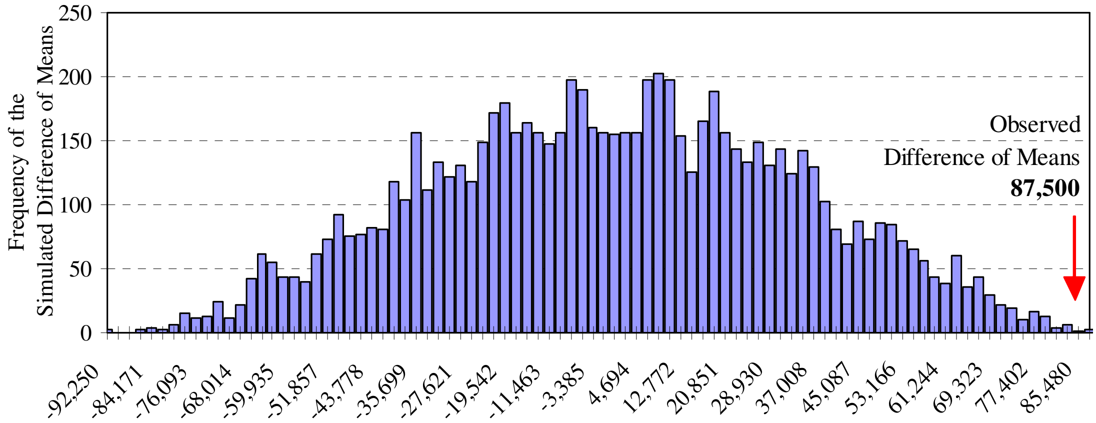


Figure A.5 : (HE5) Decisions on representation: comparison of the frequency of the simulated mean differences with the observed difference of means.

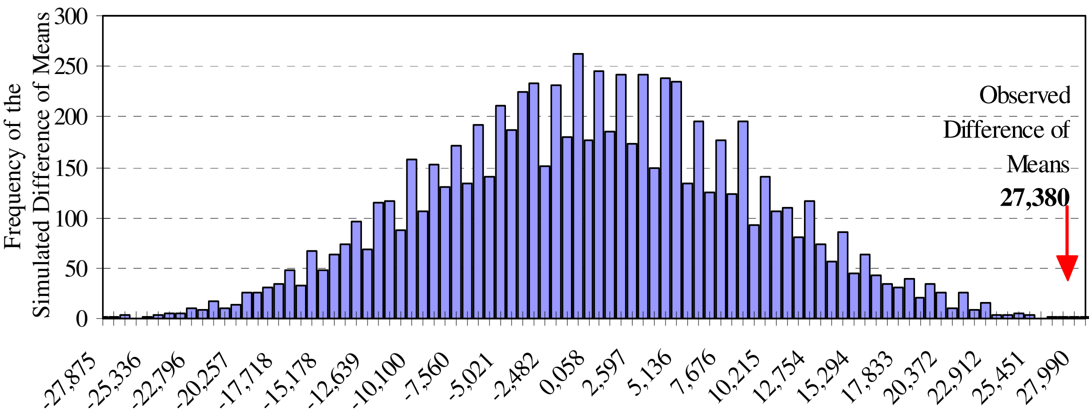


Figure A.6 : (HE6) Decisions on design process: comparison of the frequency of the simulated mean differences with the observed difference of means.

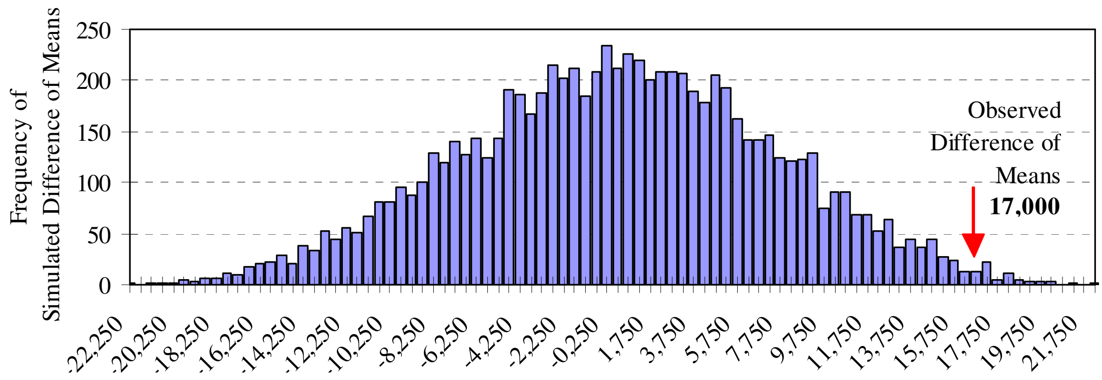


Figure A.7 : (HE7) Decisions on concepts: comparison of the frequency of the simulated mean differences with the observed difference of means.

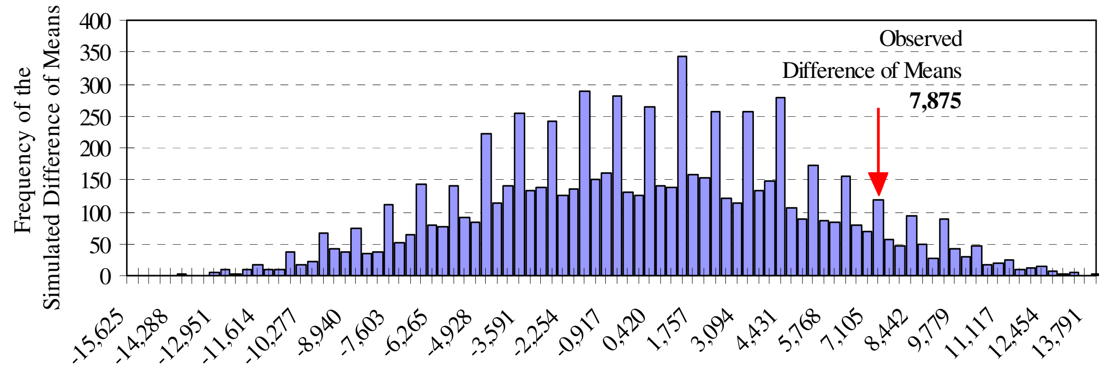


Figure A.8 : (HE8) Decisions on elements, their organization and dimensions: comparison of the frequency of the simulated mean differences with the observed difference of means.

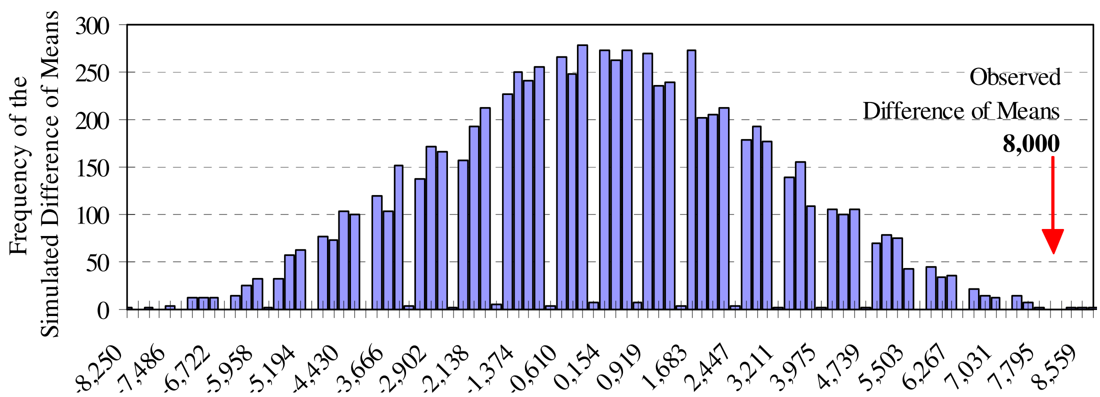


Figure A.9 : (HE9) Decisions on structure: comparison of the frequency of the simulated mean differences with the observed difference of means.

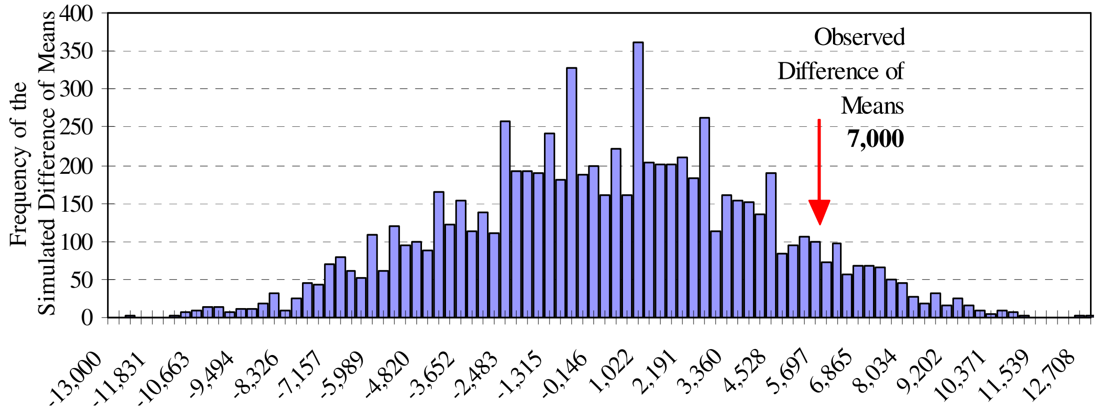


Figure A.10 : (HE10) Decisions on materials: comparison of the frequency of the simulated mean differences with the observed difference of means.

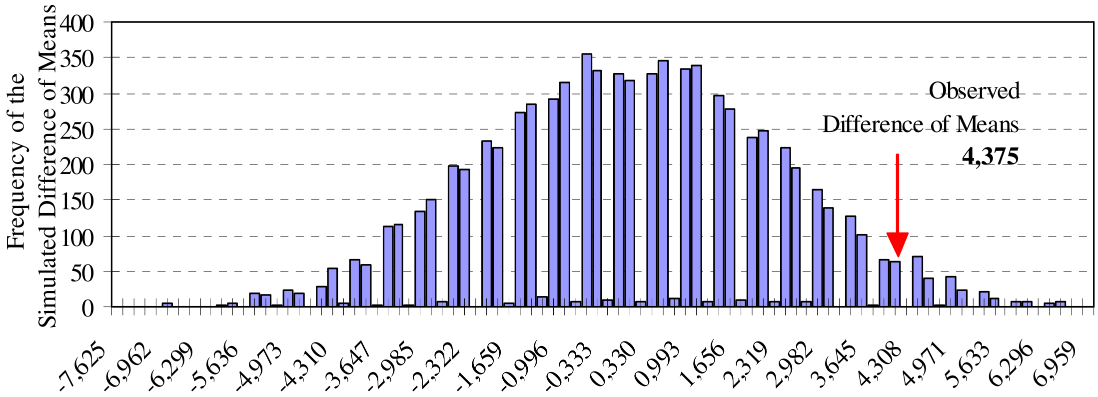


Figure A.11 : (HE11) Decisions Lighting: comparison of the frequency of the simulated mean differences with the observed difference of means.

APPENDIX A.3 PROTOCOL SAMPLES

Table A.1 : Protocols of Subject 04 (CAAD)

Time	Words	Code(s)
00:00:15	**BP:** The problem is to design a permanent gallery. You are familiar with ITU School of Architecture (showing the plan of the building) and the TBT Laboratory (pointing out the laboratory on the plan). Here are the artworks that will be exhibited in the gallery (presenting photos).	
00:00:30	**BP:** These are the mobile sculptures and these are the paintings. The required functions are an exhibition space for the artworks, an information space for presenting visual and textual materials about the gallery and a storage area. There is no cost limit put on this project. You are free to modify the existing building. You can ask questions about the requirements during the design phase.	
00:00:45	**M:**	
00:01:00	**M:** May I write those? **BP:** Of course you can. **M:** I was wondering if it is allowed to do so. Now. 10 m2 depot	Ae
00:01:15	**M:** A textual space at the entrance and other requirements.	Ae
00:01:30	**M:** Is there a requirement for a specific circulation area?	
00:01:45	**M:** OK	
00:02:00	**M:**	
00:02:15	**M:**	
00:02:30	**M:** This place will be totally emptied	Dc
00:02:45	**M:** In this drawing it is already removed isn't it?	Ae
00:03:00	**M:** OK	
00:03:15	**M:**	
00:03:30	**M:** Now I am defining the dimensions of the artworks. First of all, what do we have, I will reflect them on the drawing (process them)	Dp, Dr
00:03:45	**M:** Afterwards I will decide the rest All of those are radius, right? **BP:** Yes.	Dp, Ae
00:04:00	**M:** On this side 1/200 that side 1/100 Left is 1/200 isn't it? **BP:** Yes.	Ae
00:04:15	**M:**	
00:04:30	**M:** 79.5 1/200. What is your scale? I prefer to work here (drawing)	Ae, Dp
00:04:45	**M:**	
00:05:00	**M:** 58 1/5 Exit.	Ae

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

00:05:15	**M:** I have an obsession (talking about the font)	Ae
00:05:30	**M:** Gothic font. Couldn't find it. Ah here it is.	
00:05:45	**M:** It is easier to read for me. Let's continue. Our second sculpture diameter is 200	Ae, Dr
00:06:00	**M:** What's its name? let's write it. Steel fish.	Dp, An
00:06:15	**M:** Next, "Code d'ebene" 140	
00:06:30	**M:** Code d'ebene	An
00:06:45	**M:** The fourth one.	Ae
00:07:00	**M:** S shaped vine. This is sustained. Radius is not defined here. If we compare it with human size,	Ae,
00:07:15	**M:** Let's say 80 cm. sustained. As it is sustained I'll represent this as a hidden line.	Ae, Dr
00:07:30	**M:** 0, 2	
00:07:45	**M:** S shaped vine. Next, Aztec 134 cm.	
00:08:00	**M:** width is lets say 70 cm. Command MA. My favorite. The first letter of my name.	Ae, Dp
00:08:15	**M:** Aztec Josephine Baker.	
00:08:30	**M:** 4 pictures (there are) more. Will we assume that we will use all of these entrance points?	Ae,
00:08:45	**M:** totally up to me. Now, first of all the pedestrian ways (talking about circulation) I assume that they enter from here.	Ap
00:09:00	**M:** The visitors will use the foyer mostly. (talking about the corridor)	Ap
00:09:15	**M:** People who want to get out of here. This is the blind point.	Ae
00:09:30	**M:** Our depots, in respect to security- what are the requirements? Do they need to be extremely safe? May the visitors steal those artworks?	Ae
00:09:45	**M:** The simplest system is 2x5 meters. 10 m2	De
00:10:00	**M:** I can also make those transparent. Partially.	Dc
00:10:15	**M:** 200x500. You come over here.	De
00:10:30	**M:** 15 to 3. now I will order them randomly by thinking that I am visiting this space. If I came here what do I want to see, and where? At the start up I will not "show" those in the center. On the 2D I will use	Ae, Dp. Dc, Dr
00:10:45	**M:** Beautiful. I usually prepare (represent) the drawing as I like it to be on paper. It has to be black	Dr
00:11:00	**M:**	
00:11:15	**M:** Now there are the units that will be sustained.	Ae
00:11:30	**M:** The next will be exhibited on the floor. May be these will be	De, Dc

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

	used also as a separator.	
00:11:45	**M:** or from here, if it appears right at the front, these are placed here.	Ae
00:12:00	**M:** The ones on the floor will be bold (representation)	Dr
00:12:15	**M:** The others will be sustained.	Ae
00:12:30	**M:** Now as a scenario, if we assume how will I "approach" to this space, I will draw myself here and fill in (shape)	Dr, Dp
00:12:45	**M:**	
00:13:00	**M:** I come here, the first time, it is like this. I looked from a wider perspective	Ae
00:13:15	**M:** Afterwards, at this place a presentation – but a presentation is not needed I assume. If there was a need, I would use it.	Ae
00:13:30	**M:** Afterwards, we can bring this to inner space, instead of those quite corners. It may be like an arc.	Dc, De
00:13:45	**M:** We will check its area later.	Dp
00:14:00	**M:** I have to define a walking plan or scenario so that people will have that impression. I am thinking. People will be coming from here and go out from there and similarly they will come from the foyer. There may be a cocktail or something else.	Dp, Dc, Ap, Ae, De
00:14:15	**M:** Afterwards, if we put this as an entrance unit. As the first scenario. They can either go in here or there.	De, Ae
00:14:30	**M:** But in this case there will be congestion here. Because of this, it is useful to move this backwards. Let's check our walls.	Ae, De, Dp
00:14:45	**M:**	
00:15:00	**M:** I am increasing the line width of the walls.	Dr
00:15:15	**M:** to differentiate between the ones on the floor and the ones that are sustained. The ones on the floor are "obstructing" and the other "floating" ones are not. I came from here and enter.	Dc,
00:15:30	**M:** Afterwards. A text thing is required here. Entrance 10m2 depot,	Ae
00:15:45	**M:** The text will be "greeting" people. They can either be welcomed here or there. Here it is –too recessive. There it can be designed to be more	Dc,
00:16:00	**M:** Maybe as my first thought, a projection may be placed here.	Ae
00:16:15	**M:** The text will be presented with projection. It doesn't have to be like a conventional one.	De,
00:16:30	**M:** 8. I'll trim those.	Ae, Dp
00:16:45	**M:** People entered from here. May be with a separator or I'll make my text readable.	De, Dr
00:17:00	**M:** Can I discard this door? Up to me?. **BP:** Yes.	Ap

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

	M: And. I'll say.	
00:17:15	**M:** The orientation of people can be provided by something like this.	De
00:17:30	**M:** I will make you bolder and black.	Dr
00:17:45	**M:** May be you can be something like this.	De
00:18:00	**M:** The images will be presented this way. This will be like a "balloon", both orienting people and obstructing at the same time.	De, Dc
00:18:15	**M:** The sustained systems may be located more towards the center.	De
00:18:30	**M:** I remember Mimar Sinan's mosque. At the time of entrance you can see the top of the dome. This came up in my mind.	Af
00:18:45	**M:** Maybe I'll put this one here and that one there. This will be exaggerated.	Ae, De
00:19:00	**M:** I put the depot in the center. Maybe like an amorphous shape. Both it will fit in this. I'll make your colors different (lines)	De, Dc, Dr
00:19:15	**M:** What are the consequences? When this is in the center, the space is too much segregated.	Ae
00:19:30	**M:** That must be a big obstruction. Now what happened? I put two barriers here. What is the cost of those?	Ae, Dc
00:19:45	**M:** According to this scenario. I'll remove you from the center – projection	De
00:20:00	**M:** This will be hanged there. The other sustained artwork should be perceived by the people who enter from here or there.	De, Ae
00:20:15	**M:** May be you will be located here. People will go around you. What is you diameter?	De, Ae
00:20:30	**M:** Your area is 14 m2, may be we can make you a little bit smaller. I want these to be like furniture.	Ae, De
00:20:45	**M:** People must be able to walk around this. What can we do?	Ae
00:21:00	**M:** We will put you here.	De
00:21:15	**M:** Maybe we can make a distinction like this. I used something like this to orient people.	De
00:21:30	**M:** Suspension system. They come, they went around this way, they can either go this, that or the other way.	Ae
00:21:45	**M:** and we will place the paintings here, they can see those too. Both separating and like a furniture.	De, Dc
00:22:00	**M:** Afterwards, we need to write the names of these artworks. We may confuse them.	Dr, An
00:22:15	**M:** At the same time, we can also define and write the material of it. Balloon.	Dm, Dp

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

00:22:30	**M:** I will delete the projection. These pathways passing through the back. We will write the name of this "depot". Here is our depot.	Dp, Ae, An
00:22:45	**M:** The decisions that we have made: the depot will be like an exhibition element but won't noticed Like a scenery or a "décor"	Ae
00:23:00	**M:** Instead of cutting a piece from here, The photos, paintings can be hung on this. 33x36.	De
00:23:15	**M:** 36x20. We need to define these first. I'll draw a line 25 cm. wide and see how it works. 33x25	Dr, Dp, Ae
00:23:30	**M:** This is the first. 30, 33 and one more 33 and 35.	Ae
00:23:45	**M:** too big.	Ae
00:24:00	**M:** Should I hang the paintings?	
00:24:15	**M:** More transparent?	
00:24:30	**M:** For this. 11 m2 is sufficient.	Ae
00:24:45	**M:** I am stuck here. I'll start working in 3ds Max. Export. Dwg.	Ae, Dp, Dr
00:25:00	**M:** Max is launching.	Ae
00:25:15	**M:** Let's see the software. Import our file. What was its name "subjects name".	Ae
00:25:30	**M:** It is imported with outschemas. Noow.	Ae
00:25:45	**M:** Is there a section related to the floor height? No sections. Any information about the height?	Ae
00:26:00	**BP:** 6 meters	
00:26:15	**M:** I need to adjust. You, you & you.	
00:26:30	**M:** Attach. Group. Now we have to dissect you into layers.	Dr, Dp
00:26:45	**M:** In order to be seen, that allows for us to think analytically.	Dr, Ae
00:27:00	**M:** We will make the layer of each element will be different. Now, the ones on the floor. These three.	Dr, Dp
00:27:15	**M:** Attach, attach.	
00:27:30	**M:** Finally our sustained units are linked.	Ae
00:27:45	**M:** and the paintings are left behind. Let's take our paintings. Can we extrude them? Attach, attach.	Ae, Dr
00:28:00	**M:** Let's extrude.	Dp
00:28:15	**M:** Yes. 6 meters is the height.	Ae
00:28:30	**M:** We will fill in these gaps. We will save this one. Desktop "subject's name".	Dr
00:28:45	**M:** Now the first part is the human.	Dr
00:29:00	**M:** I am entering his height. 170.	Dr

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

00:29:15	**M:**	
00:29:30	**M:** His posture will be like "about to touch something"	Dr
00:29:45	**M:** Yes it is your turn. Our separators first. What was you? Where did we put you?	Dp
00:30:00	**M:** We will treat you as a depot. Let's say a box. 2.5 m. 4m.	Ae
00:30:15	**M:** 6 m. to 2 m. 10m. to 1.	Ae
00:30:30	**M:** Let's see what will come out?	
00:30:45	**M:** If we work on this	
00:31:00	**M:**	
00:31:15	**M:** I am trying to produce something about depot.	
00:31:30	**M:** How will the form be like ? I tried to make is as a box. It is not satisfactory for me. Afterwards, I am trying to make something with NURBS.	Ae, Dp, Dr
00:31:45	**M:** I wonder if I can get a hold of the shape in my mind? I selected them. Not poly.	Dr
00:32:00	**M:**	
00:32:15	**M:** Now I am trying to get a form by playing with the control points. I want this to look weird and different here.	Dp, Dr, Dc, De
00:32:30	**M:** Nor like an artwork. (will not be confused with them)	
00:32:45	**M:** Now we will close the start and end. Turn on snap. Make an ellipse.	Dr, Dp, De
00:33:00	**M:** We are preparing our depot. Attach left from you to you.	Dp, Dr
00:33:15	**M:** There is a problem.	Ae
00:33:30	**M:** Take it from you and I can complete it by scaling it to a smaller size. We come here. U loft from you to you.	De
00:33:45	**M:** Let's close it. (Error)	De
00:34:00	**M:** Whatever. It is not doing it because the line is not closed. We will get even with you later.(threatening)	Ae, Dp
00:34:15	**M:** You come over here. Do you fit here? Yes. We will connect you to someone else later. (talking with the line)	De
00:34:30	**M:** Afterwards, let's check here. Yes we did it. We will only be interested in this one.	Ae
00:34:45	**M:** We will turn you into NURBS and clone. Let's see what's going to happen.	Dr
00:35:00	**M:** Now, I am trying to design the projection-textual element. May be something like a garbage bag?	De
00:35:15	**M:** Let's put it next to the former one.	De
00:35:30	**M:** Neither should it attract attention, nor should it be isolated.	Dc
00:35:45	**M:** We need to draw it from scratch. Make spaces.	Dr

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

00:36:00	**M:** Ok. These are like this. A “wavy” thing.	De
00:36:15	**M:** I drew the sections again because they don’t work in 3dsMAX NURBS is selected.	Dr, Ae
00:36:30	**M:** Let’s “elevate” them. Compared to human proportions, this is too large.	Dp, Ae
00:36:45	**M:** Let’s make you smaller.	De
00:37:00	**M:** Let’s right click. Cause I want it to be at the size of a man. Yes. I know we can assign things (materials)	Dp, Dr
00:37:15	**M:** NURBS, NURBS, NURBS, Lets’s make you blue. And you too.	Dr
00:37:30	**M:** In order to think about it. We are at the point to evaluate our exhibition route. We are learning about the exhibition (entrance) There will be no doors. Afterwards we have a sculpture here	Ae, De
00:37:45	**M:** May be related text can be placed on the depot. Afterwards a sculpture here, and here.	De
00:38:00	**M:** Above this space. Elevated or? One of our sculptures is missing. We said it is the entrance. To attract attention	Ae
00:38:15	**M:** We will push you further. You stay here. This will be put here. From the entrance to exit.	De
00:38:30	**M:** The last word should be accented. If there is a space enough to go around this one. What will happen? They will see this across them. It will be towards the exit. This is the sustained unit. This can also be hung.	Dc, Ae, Ds
00:38:45	**M:** Let’s put it here. Put it there. After people walk under this, they will be walking around the others.	De, Ae
00:39:00	**M:** This is “lost” in the entrance. Maybe the projection of it is marked on the floor.	Ae, De
00:39:15	**M:** On the floor, I don’t know. It is too small may be we can accentuate it.	Ae
00:39:30	**M:** with some marks on the floor. We will place you	De
00:39:45	**M:** Now, first of all let’s see what we have in out hands? An artwork looks like a stool. Afterwards, steel fish.	Ae
00:40:00	**M:** This is large. This is sustained and that is too. Then we have three sustained ones.	Ae
00:40:15	**M:** From an area that is getting smaller and smaller,	Ae
00:40:30	**M:** 35,3 we selected and throw inside. Afterwards we attached it with this.	Ae, Dr
00:40:45	**M:** orthogonal workout. That “floats” in the air.	Dr
00:41:00	**M:** These need to be more spacious. I clone it towards down. After defining their heights, it will be more meaningful.	Dr, Dp
00:41:15	**M:** This one can be cut. This will not be sustained from here.	Ds, De

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

	What will be its height?	
00:41:30	**M:** We need to place those according to their heights. One of it is 140 cm. high. 100 cm is 170, 134 cm	De, Ae
00:41:45	**M:** Two 140 cm and 170. Which one is 170? The biggest sustained one.	Ae
00:42:00	**M:** This means that the height of this is 170. Let's draw something with 170 height. Box. Autogrid.	Ae, Dr
00:42:15	**M:** 170. Then we will clone one. 140. copy.	Dp
00:42:30	**M:** 140. Which meaning will it add to design in terms of space?	
00:42:45	**M:** Now I am scaling them to be more realistic.	Dr
00:43:00	**M:** OK. Your height is	
00:43:15	**M:** 140. Let's do it 20. You stay there.	Ae, De
00:43:30	**M:** I usually listen to music while designing. I felt a need for it.	
00:43:45	**M:** If I were human,	
00:44:00	**M:** The artworks will be placed at a height where they	De
00:44:15	**M:** can see but they won't bump their heads. Is it a good idea for these artworks to be perceived (observed)from the bottom?	Dc
00:44:30	**M:** This has to be hung from the top. This is the same. But the other one will be at Human scale. Maybe because it resembles a human. Which one is that?	Ae, Ds
00:44:45	**M:** The smallest. This one will "welcome" people as soon as they enter the exhibition. You should be placed at a human scale.	Ae
00:45:00	**M:** I am bringing you down. About here. Afterwards, you (the other artworks) need to be observed from a higher point. Then at those dimensions.	De
00:45:15	**M:** If we look from the human's eye, down or up sustained.	Ae
00:45:30	**M:** The height of the others. 155 OK.	Ae
00:45:45	**M:** What is your height?	
00:46:00	**M:** You, light structure. There are no massive things. You look like something like this.	Ae
00:46:15	**M:** I will make you smaller.	De
00:46:30	**M:** In order to make them more realistic. I want to make 3d models of them. I wonder. The thing that I'm drawing is its own mass. I shouldn't be evaluating it based on its outer borders.	Dp, Dr
00:46:45	**M:** A little bit higher	De
00:47:00	**M:** Z axis. OK. Extrude.	De
00:47:15	**M:** At the corner.	De
00:47:30	**M:** The height of this is 345 cms. 345x200. I'll scale you down	Ae, De

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

	to. 2m. You are not that important.	
00:47:45	**M:** You will be red. Red will disappear. We took the green. F4 F3.	Dr, Ae
00:48:00	**M:** Afterwards. I work with the lines in order to get faster solutions.	Dr
00:48:15	**M:** Made up of pieces.	Ae
00:48:30	**M:**	
00:48:45	**M:** I have to turn on snap. Gridline.	Dp
00:49:00	**M:** Except the gridpoints. I unchecked the tangent snap. These are OK.	Dp
00:49:15	**M:** I took you and put it here. Afterwards there is another object that hangs from here, polyline.	De
00:49:30	**M:** 1	
00:49:45	**M:** One down, one up. These are fragile artworks. Because of this.	De, ae
00:50:00	**M:** I did not want to "work" with masses (boundaries)	Dr
00:50:15	**M:** You will move towards inside.	De
00:50:30	**M:** Whatever. This representation is OK without masses on it.	Dr, Ae
00:50:45	**M:** Afterwards, a small thing.	Ae
00:51:00	**M:** These are planar. They can orient people.	Ae
00:51:15	**M:**	
00:51:30	**M:** What kind of a thing are you? Extremely ugly.	Ae
00:51:45	**M:** I am making you "cornered" OK. Converted to polyline.	Dr
00:52:00	**M:** Afterwards, we will design those furniture. Not to design but to manufacture. I mean the artworks.	Dp, Dr
00:52:15	**M:** The data in our hands. We are designing this space for those, at last.	Ae
00:52:30	**M:**	
00:52:45	**M:** OK. Now we can scale those.	De
00:53:00	**M:**	
00:53:15	**M:** 155. The diameter of this one. 155 from this side too. Whatever this is okay for me.	De, Ae
00:53:30	**M:** Now, Yes. I am saying that I first came and sow this artwork,	Ae
00:53:45	**M:** Stood there, read those texts, afterwards, I saw this. This should be orienting me.	Ae
00:54:00	**M:** Your perspective is ...nice from here. This one. People will go around you and observe. After they came, read the texts	Ae

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

00:54:15	**M:** saw this one. We will design your "orientation", an artwork with a single dimension, not a humongous thing.	Dp, De
00:54:30	**M:** we have to scale you down roughly. Afterwards we check the sustaining units.	De, Dp
00:54:45	**M:** The separator here might be placed somewhere in the center. This offended my eyes.	De, Ae
00:55:00	**M:** I will rotate you like this. Yes decision is made.	De
00:55:15	**M:** I change its place. At there, it offends my eyes less.	Ae
00:55:30	**M:** We will place you right next to this wall. Then we will design the sustaining units.	De,
00:55:45	**M:** The only things that I forgot are the paintings. Now we will check our paintings.	Ae
00:56:00	**M:** 33x26, 33x26.	Ae
00:56:15	**M:** We shall get rid of the polygons. This artwork is nearly at the size of a notebook.	Dr, Ae
00:56:30	**M:** 1 cm. thick. I will use the walls for exhibiting those.	Ae, De
00:56:45	**M:** The sizes differ. But I will not reflect it in the model. This is out of my criteria.	Ae, Dr
00:57:00	**M:** Probably it should be at that place.	De
00:57:15	**M:** I am planning my pictures. (Paintings)	
00:57:30	**M:**	
00:57:45	**M:** Yes generally speaking, my layout plan is like this.	Ae
00:58:00	**M:** A little bit more to here, more to there. People will see here, here. I want them to walk around like this. They should not miss that one while looking at the other.	De, Ae
00:58:15	**M:** That's my intention. Yes. It is good that this welcomes people.	Ae
00:58:30	**M:** Good that it conceals the details. I will put this a little bit further.	Ae, De
00:58:45	**M:** This artwork is on the floor. They read the texts afterwards. Does it offend my eye?	Ae
00:59:00	**M:** I should not create the impression that it can be "touched". They should look from down.	Dc
00:59:15	**M:** I wish we had agents we could put them in our model. There are no problems with the circulation	Ae
00:59:30	**M:** Apparent ones I mean.	Ae
00:59:45	**M:** We will put you down. OK.	De
01:00:00	**M:** Firstly	
01:00:15	**M:** the decision phase is completed. I will transform this sketch into a "cleaner" one.	Ae, Dp, Dr

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:00:30	**M:** Firstly I have to import a "clean" autocad drawing 1/100. I am continuing, but like this.	Dp, Dr
01:00:45	**M:** 4,8,2. I will not need you. Let's import.	Ae
01:01:00	**M:** This should fit on the sketch.	Ae
01:01:15	**M:** Then smartly, we delete the z axis	Dr
01:01:30	**M:**	
01:01:45	**M:** It is selected all this time. Let's group them so that we won't have any problems.	Ae, Dr
01:02:00	**M:** In the newer version it is different.	Ae
01:02:15	**M:** Firstly, I'll start modeling here. I will start drawing this from scratch. Autogrid off.	Dp, Dr
01:02:30	**M:** It is extremely important to see how this looks precise.	Ae
01:02:45	**M:** In the construction project, we modeled the design completely. Therefore, I know how useful it is to do so.	Ae
01:03:00	**M:** Tik, tik, tik (effects)	
01:03:15	**M:** we are modeling the space. That's our plan.	
01:03:30	**M:** Tik tik tik	
01:03:45	**M:** Snap on. Close.	Dr
01:04:00	**M:** Yes, we are drawing our polyline. But instead of attaching them I can extrude all of them.	Dr
01:04:15	**M:** Because the "foyer" can also be designed later. I am including the surroundings in the model because of this. I already said. Entrance and exit.	Dr, Ae
01:04:30	**M:**	
01:04:45	**M:** The height of the windows is 4 meters, under them 1.20 meters, height is 4-1.20 meters. Reaches to top	Ae
01:05:00	**M:** I'll close the top	Dr
01:05:15	**M:** Now you extrude 6 meters.	Dr
01:05:30	**M:** 3 meters- lets put a box. In order to model it	
01:05:45	**M:** easier. I hope Boolean functions. What was it? 600-120-150	Ae
01:06:00	**M:** 300 yes 61 141	Ae
01:06:15	**M:** height 330	Ae
01:06:30	**M:** 2 to outline, roughly.	Ae
01:06:45	**M:** We will have a slice here.	Dr
01:07:00	**M:** 90 degrees.	
01:07:15	**M:** Until we model this we will never know how much sunlight enters the space.	Ae
01:07:30	**M:** We will place our windows to their places.	Dp

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:07:45	**M:** 1.20 cm. 1.20. We will subtract you from our walls. Save it first.	Dr
01:08:00	**M:** Compound, Boolean, please god i hope it works. Subtract.	Dr
01:08:15	**M:** Boolean	
01:08:30	**M:** What is the height of our doors? Normally I don't work without numbers.	
01:08:45	**M:** Easy.	
01:09:00	**M:** Now. We will build the upper part of our doors.	Dp
01:09:15	**M:** Extrude.	Dr
01:09:30	**M:** Let's check. This	
01:09:45	**M:** wall is missing. Let's recover.	Ae, Dr
01:10:00	**M:** Yes.	
01:10:15	**M:** Yes I am modeling the other door.	Dr
01:10:30	**M:** Our doors and windows are OK.	Ae
01:10:45	**M:** Now we will put our "furniture elements in here". Decide the final shape of our depot. Our criteria will be the sculptures. (we will model) The paintings don't need to be	Dp, Dr
01:11:00	**M:** Saved it. Now our first element. 155x155.	
01:11:15	**M:**	
01:11:30	**M:** We started to model from the smallest element.	Dp
01:11:45	**M:** Let's rotate it like this.	De
01:12:00	**M:** I'll solve the problem that is causing difficulties. Viewpoint gizmo. Let's scale the gizmo up. 25.	Dr
01:12:15	**M:**	
01:12:30	**M:** We have to.	
01:12:45	**M:** We have to define a height for this. Let's define it. Cylinder, 155. OK.	Dr
01:13:00	**M:** with Alt x I transform you into transparent. Actually I can remove those and then draw them later.	Dr, Dp
01:13:15	**M:** I place it closer to one side.	De
01:13:30	**M:** Extrude.	Dr
01:13:45	**M:** Now.	
01:14:00	**M:** I can continue modeling this.	Dp
01:14:15	**M:** You to here.	De
01:14:30	**M:** Assign a mesh material.	Dr
01:14:45	**M:** Extrude.	Dr
01:15:00	**M:** We made up the length. Where are we now. It is a square.	Ae

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:15:15	**M:**	
01:15:30	**M:**	
01:15:45	**M:** Radius is not correct.	Ae
01:16:00	**M:**	
01:16:15	**M:**	
01:16:30	**M:** OK. Let's continue. We will reverse this. Reverse/flip	Dr
01:16:45	**M:** Let's model these.	Dp
01:17:00	**M:**	
01:17:15	**M:** You will come here.	De
01:17:30	**M:**	
01:17:45	**M:** A few small updates. All of them will connect together.	Ae
01:18:00	**M:** These are suspended with a suspension system.	Ae
01:18:15	**M:** This one goes up from here.	
01:18:30	**M:** Let's zoom in.	
01:18:45	**M:** Let's construct it now. This one, this one.	Dp
01:19:00	**M:**	
01:19:15	**M:** Selection. From here…	
01:19:30	**M:** a complicated way.	Ae
01:19:45	**M:** The design is more convenient is I "enter" all the data to the model.(representing as real as possible)	Ae
01:20:00	**M:** I come here.	
01:20:15	**M:**	
01:20:30	**M:**	
01:20:45	**M:** Mesh close. Close.	Dr
01:21:00	**M:** Every corner should be the same.	Dr
01:21:15	**M:** Actually I forgot something that I had to do. I could have taken it from photoshop. It is also a solution.	Ae
01:21:30	**M:** I like to do it in a detailed way.	Ae
01:21:45	**M:** Now we will crop now.	Dr
01:22:00	**M:** Our biggest supporter. Jpeg. What is the size in pixels? 712x522	Ae
01:22:15	**M:** In this box, 712… 522. I will draw these to 2-3	Dp
01:22:30	**M:** "Subject's name" folder. Inside 3D	
01:22:45	**M:** If we need to change it, we will change it.	Dp
01:23:00	**M:** Let's save it now. Firstly,	Dp
01:23:15	**M:** we will close this somehow.	Dp

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:23:30	**M:**	
01:23:45	**M:**	
01:24:00	**M:** The other "organs" of it. (we will model)	Dp
01:24:15	**M:** Somehow we will do it.	
01:24:30	**M:** Now we can start.	
01:24:45	**M:** Let's zoom it.	
01:25:00	**M:**	
01:25:15	**M:** Did the computer put it there?	
01:25:30	**M:** We can also put that file here and place it somewhere else but it can be 1 gigabytes or something like that.	Ae
01:25:45	**M:**	
01:26:00	**M:** I won't start from scratch. We have this advantage. Rotate it and	Dp, Dr
01:26:15	**M:**	
01:26:30	**M:** We are modeling the things at the end of it.	
01:26:45	**M:** The last element.	
01:27:00	**M:** Small. Let's make it properly.	Ae
01:27:15	**M:** Black. Another one.	Ae
01:27:30	**M:** You are red and you are black.	Ae
01:27:45	**M:** At the same time	
01:28:00	**M:** At this width- a cylinder.	
01:28:15	**M:** Yes axis is off.	Dr
01:28:30	**M:** We said that it should be realistic. But this is the best that it can get.	Dr
01:28:45	**M:** Not that bad.	Ae
01:29:00	**M:** Now cylinder.	
01:29:15	**M:**	
01:29:30	**M:** I am placing the artworks to where I have decided.	
01:29:45	**M:** For instance, depending on the forms of these artworks, the "things" are important	Ae
01:30:00	**M:** One moment. I am making these	
01:30:15	**M:** thicker so that they will be seen easily. Close.	Dr
01:30:30	**M:** Yes, this adds up to a significant total. It is not mentioned but it will make a difference to put it like this or like that.	Ae
01:30:45	**M:** Both the perception and orientation. I decided to put it in this direction because people will enter the space from this side.	Ae
01:31:00	**M:** Now we modeled this one, that one. Let's "close" (make)	Dr

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

	our floor.	
01:31:15	**M:**	
01:31:30	**M:** About the color of it (the artwork). There is no info about it.	Ae
01:31:45	**M:**	
01:32:00	**M:** Problems. What are our problems? I am thinking of how our perception will change..	Ae
01:32:15	**M:**	
01:32:30	**M:** Another human. In order to understand it, I am placing a human here.(Biped)	Dr
01:32:45	**M:** With five fingers on each hand and five toes on each foot. I have to adjust the size of it.	Dr
01:33:00	**M:**	
01:33:15	**M:**	
01:33:30	**M:** I like to render when some things are getting realized.	Dp
01:33:45	**M:** Sometimes, it also shows the thing that I don't see.	Ae
01:34:00	**M:** An ascending wall, depot and an entrance.	
01:34:15	**M:** There is a requirement for a projection there.	
01:34:30	**M:** I will shape this. The aim of this slope is unconscious. If we need to make it higher, extrude.	De, Dr
01:34:45	**M:** The part that I have positioned with the opening towards that side. Because of that I have this kind of a shape in my mind.	De
01:35:00	**M:** This is the aim. We will straighten this up and fillet the places that we don't want to intersect.	Dr, Dp
01:35:15	**M:** now I shifted my focus to the formal aspects.	
01:35:30	**M:** I will put this on the floor. There will be a nylon effect in these forms.	De, Dr
01:35:45	**M:**	
01:36:00	**M:** One by one.	Dp
01:36:15	**M:** Yes we are on the right track.	Ae
01:36:30	**M:** I am cloning this towards up. In order to create surfaces, I will make modifications.	Dp, Dr
01:36:45	**M:** Yes. Now we will close this up.	
01:37:00	**M:**	
01:37:15	**M:** 6 meters. We will assign material.	Dr
01:37:30	**M:** In order to show the texture I projected to this image.	Dr
01:37:45	**M:** This should be better.	Ae
01:38:00	**M:** Not as good as I want.	Ae

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:38:15	**M:** It has the feeling.	Ae
01:38:30	**M:** I am just representing this. A projection may be placed inside this. May be I can also represent the projection here.	Ae, Dr
01:38:45	**M:** Back projection device will be here.	De
01:39:00	**M:** It will project this way. We put it here.	Ae, De
01:39:15	**M:** Afterwards, I'll move this towards here to get rid of this heavy mass.	De
01:39:30	**M:** People will walk around here. Come from the right.	Ae
01:39:45	**M:** There is no problem in circulation. Afterwards,	Ae
01:40:00	**M:** A place that we think as a depot. May be as a continuation of this.	De
01:40:15	**M:** A more focused geometry.	Ae
01:40:30	**M:** These can go outside more. I want this as a decoration	De
01:40:45	**M:** Neither a huge thing that congest this place nor	Ae
01:41:00	**M:** small elements like this. Parametric design.	Ae
01:41:15	**M:** whatever. We will put another plane upwards.	De
01:41:30	**M:** Okay. Create surface. Tik tik.	Dr
01:41:45	**M:** It is just as I wanted.	Ae
01:42:00	**M:** This may go up more.	De
01:42:15	**M:** I want people to be able to pass from here or either here. Let's check.	Ae
01:42:30	**M:** If we can't find other data, we can use this.	Dr
01:42:45	**M:** Now you are generating textures. There can be texts on this. Information can be presented here.	Dr, De
01:43:00	**M:** Yes.	
01:43:15	**M:** I will.	
01:43:30	**M:** Sustained systems will be put here.	De
01:43:45	**M:** I discover this necessity as soon as I make the model.	
01:44:00	**M:** We don't evaluate this from different angles. More things are coming up as you investigate more. You can also hang to the ceiling, but it is not.	Ae
01:44:15	**M:**	
01:44:30	**M:** jpeg. 264 323 pixels.	Ae
01:44:45	**M:** In order to have a basis. I will assign this as a texture and make the models afterwards.	Dr
01:45:00	**M:** 464x324. This one. Just map	Ae, Dr
01:45:15	**M:** the reverse as a texture. I define this and assign afterwards.	Dr

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:45:30	**M:** It is time to model	Dp
01:45:45	**M:**	
01:46:00	**M:**	
01:46:15	**M:** Because it is easier to draw, I draw this over the existing bulding. It gives me the opportunity to work faster.	Dr
01:46:30	**M:** From there to there we go on like this.	Dr
01:46:45	**M:**	
01:47:00	**M:** I'll extrude this a little bit.	Dr
01:47:15	**M:** We are modeling the other sides.	
01:47:30	**M:** If it is consistent, generally, I don't need to think deeply about it.	Ae
01:47:45	**M:** Extrude, 2	Dr
01:48:00	**M:** Extrude 25 30.	Dr
01:48:15	**M:** The dangerous parts.	Ae
01:48:30	**M:** May be I can move them towards inside more..	De
01:48:45	**M:** I'll scale this.	De
01:49:00	**M:**	
01:49:15	**M:** For instance.	
01:49:30	**M:** What was	
01:49:45	**M:** The size of those?	
01:50:00	**M:** 716 cm. 27x20 cm	Ae
01:50:15	**M:**	
01:50:30	**M:** When you model the whole artifact	
01:50:45	**M:** you see the things clearer. The perception here and there (2D) is never the same.	Ae
01:51:00	**M:** Because this is 2D, Although it is originally 3D, it is projected to 2D. The lines behind it, contours, the openings will be perceived better.	Ae
01:51:15	**M:**	
01:51:30	**M:**	
01:51:45	**M:** Before modeling this I did not understand the different perceptions of this space. For instance the height of this thing might be blocking this person here.	Ae
1:52:00	**M:** Yes. 1,2,3,4,5	
01:52:15	**M:** How many are left. I'll focus on this.	Dp
01:52:30	**M:** I am saving this as jpeg. 476x479 pix.	Dr
01:52:45	**M:**	

Table A.1 : Protocols of Subject 04 (CAAD) (Continued)

01:53:00	**M:** 476x479 33 25cm. Copy. I can change this	Dr
01:53:15	**M:** Modeling is harder.	Ae
01:53:30	**M:**	
01:53:45	**M:** Yes, I modeled the hair of this artwork.	Ae
01:54:00	**M:**	
01:54:15	**BP:** Yes, keep on talking…	
01:54:30	**M:**	
01:54:45	**M:** I am making the lines poly line?	Dr
01:55:00	**M:** Close to the shape.	Dr
01:55:15	**M:**	
01:55:30	**M:** Tick, tick (Repeating ticks)	
01:55:45	**M:**	
01:56:00	**M:**	
01:56:15	**M:** An artwork like this. I am waiting for the system to catch up with my speed.	Ae
01:56:30	**M:** The plain (simple parts)	
01:56:45	**M:** The last one.	Ae
01:57:00	**M:** Left breast is done.	Ae
01:57:15	**M:** Tick, tick (Repeating ticks)	
01:57:30	**M:** I feel myself like a sculptor right now.	Ae
01:57:45	**M:** We spent a significant effort. Yes.	Ae
01:58:00	**M:** Now I am attaching those, first, second,	Dr
01:58:15	**M:** What are the dimensions?	
01:58:30	**M:** 134. I draw it without a scale.	Dr
01:58:45	**M:** This looks good here.	Ae
01:59:00	**M:** Yes now.	
01:59:15	**M:** I can increase the thickness of this.	Dr
01:59:30	**M:** Yes we rotated it too much…	De
01:59:45	**M:**	
02:00:00	**M:**	

Table A.2 : Protocols of Subject 11 (Conventional Design Condition)

Time	**Words**	**Code(s)**
00:00:15	**BP:** The problem is to design a permanent gallery. You are familiar with ITU School of Architecture (showing the plan of	

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	the building) and the TBT Laboratory (pointing out the laboratory on the plan). Here are the artworks that will be exhibited in the gallery (presenting photos).	
00:00:30	**BP:** These are the mobile sculptures and these are the paintings. The required functions are an exhibition space for the artworks, an information space for presenting visual and textual materials about the gallery and a storage area. There is no cost limit put on this project. You are free to modify the existing building. You can ask questions about the requirements during the design phase.	
00:00:45		
00:01:00	**S:** Considering the doors at the sides,	
00:01:15	**S:** OK. Let's start. Firstly I will check out the objects. 9 artworks will be exhibited.	Dp, Ae
00:01:30	**S:** A permanent exhibition space and a sculpture gallery. A visual presentation space is required at the entrance.	Ae
00:01:45	**S:** there are objects with a diameter of 155 cm – fairly wide - and approximately at the height of a human.	Ae
00:02:00	**S:**	
00:02:15	**S:** I will take a smaller ruler.	Dp
00:02:30	**S:** Ok. First of all, 1/200	
00:02:45	**S:**	
00:03:00	**S:** The first thing I will do is to find out the size of the objects at 1/200 scale.	Dp, Dr
00:03:15	**S:** Generally, the common length… Diameter is 10 centimeters.	Ae
00:03:30	**S:** At 1/200 Scale, half centimeters refer to 1 meter.	Ae
00:03:45	**S:** Now, as I have told before, I want to see which objects occupy how much space…	
00:04:00	**S:** Approximately reaches out to 1 meter. Approximately 140 centimeters…	Ae
00:04:15	**S:** is its height. Ceiling height is 6 meters, that's it	Ae
00:04:30	**S:** let's see. Will all of the doors be open?	
00:04:45	**S:** I will decide to those. Won't I? When a person visits Taskisla, it will be better to pass from this side	Ap
00:05:00	**S:** to see these stairs and most enjoyably to enter from this door. Entrance.	De,
00:05:15	**S:**	
00:05:30	**S:** 6, 7, 8, 9 (counting) artworks.	Ae
00:05:45	**S:** 4 of them are small, the size of a tile	Ae
00:06:00	**S:** this is designed to be suspended, that is too three of them will	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	be suspended.	
00:06:15	**S:** three suspended. Let's check what they are.170, 140 and 134 (centimeters)	Ae
00:06:30	**S:** Let's say approximately 170. The other two will be standing on the floor.	Ae
00:06:45	**S:** diameter of this one is 3 meters, and the other is 1.5 meters. This much space is needed for 3 meters.	Ae
00:07:00	**S:** Yes, 2.5 meters. 3 items, 4, 5, these are small things.	Ae
00:07:15	**S:** Let me take a look. These are the doors that we are talking about.	Ae
00:07:30	**S:** A visual and textual presentation space is required at the entrance. If I take a look at here,	Ae
00:07:45	**S:** Fairly wide and empty space. Four windows and three doors.	Ae
00:08:00	**S:** It is standing like this. Like this. Three doors, two of them are closer.	Ae
00:08:15	**S:** At first, I thought it was better to enter from the door at the center.	Ae
00:08:30	**S:** How can it be? There is a small door beneath the stairs. Is there a door that opens through the stairs? **BP:** Yes.	
00:08:45	**S:** Ok. I got it. Actually, the entrance can be designed here. This space can also be used where the small depot is located	Ae. De
00:09:00	**S:** 9 items occupying a small place, located in a very wide space. What should be the design?	Ae
00:09:15	**S:** People can explore the objects that are suspended and large from the top; perhaps.	Dc
00:09:30	**S:** Let do it this way. Yes.	
00:09:45	**S:** The entrance will be here. Let is put it there	
00:10:00	**S:** There may be an entrance section, as I have told. Some people may be appointed here, occasionally	De, Ap
00:10:15	**S:** Can other things be exhibited here? How long will this permanent exhibition last? I think other things can be placed here? **BP:** That's up to you **S:** Yes they can be placed. And the space can be used in other different ways. In this case, there needs to be table here, which will be used occasionally.	Ap, De
00:10:30	**S:** Therefore, visitors enter from here, located somewhere around there. They don't have to see the information space, they are not obliged.	Ae.
00:10:45	**S:** Actually, they can enter from other doors. This means that permanent gallery becomes a part of the building.	Ae, Dc, Ap

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

00:11:00	**S:** This place is then becomes a space that is used for other things. May be there can be something that ascends. Like a door. While people pass through it, they see information about	Ap, De
00:11:15	**S:** the 9 permanent artworks. Then, when it is needed a portable table can also be used there. For the other things, the whole building can be used.	Ae
00:11:30	**S:** There were three suspended things.	Ae
00:11:45	**S:** This one is pretty large. The others are only tiny tiles.	Ae
00:12:00	**S:** I am not talking about ceramic tiles. A portable table is placed here when necessary,	
00:12:15	**S:** people enter from here, gets information. There is something here about these objects. The door. Here are the texts. Maybe located here,	De
00:12:30	**S:** text defining the objects, as small imprints. Three suspended objects, all three are approximately 170 centimeters.	De
00:12:45	**S:**	
00:13:00	**S:** The suspended things must be explored from all sides. Both from the right left below and even above. Then	De
00:13:15	**S:** these can be suspended in space and there can be a way to walk around. How can it be? As this place is large, a mezzanine will make it more enjoyable. May be from here…	Dc, De, Ae
00:13:30	**S:**	
00:13:45	**S:** There can be objects suspended between these gaps.	De
00:14:00	**S:** People will climb up to this place.	Ae
00:14:15	**S:** This way –itself- can appear as a ramp.	Ae
00:14:30	**S:** a place like this.	
00:14:45	**S:** there can be two ramps facing one another and, gaps.	De
00:15:00	**S:** may be in this form.	De
00:15:15	**S:** Will it be right to place these ramps descending and ascending towards right and left? That is to say, using the width, not the length of the building.	De, Dc
00:15:30	**S:** There can be something placed in the center.	De
00:15:45	**S:** Human. Like this.	Dr
00:16:00	**S:** the mezzanine floor will be reserved just for this artist as this space will also be used for other things. Again, other things can be used but,	Ap, Ae
00:16:15	**S:** We need to keep those tiny artworks as close as possible to each other so that they will attract attention. That is to say, it will be like this when we look from the opposite direction	Dc, Ae
00:16:30	**S:**	

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

00:16:45	**S:** 6 meters ceiling. 1/200 plan. In order to see how it looks like in elevation at scale 1/100.	Dp, Dr
00:17:00	**S:**	
00:17:15	**S:** The windows nearly reach up to the ceilings.	Ae
00:17:30	**S:**	
00:17:45	**S:** Now, the height of the ceiling was 6 meters. Windows? **B:** The height of the windows are 4 meters.	
00:18:00	**S:** This place is lower. I have just noticed. Whatever; like this.	Ae
00:18:15	**S:** we will see the walls in the section. OK I am drawing like this.	Dr
00:18:30	**S:** Let's look from this side. The mezzanine floor will be placed here.	
00:18:45	**S:** I mentioned two ramps of the mezzanine before. Let's check the length of this space: 17 meters, 16.5 meters something like that.	AE
00:19:00	**S:** Is it a good idea to make a ramp that goes up 3 meters at this small distance? Too steep. Then it is better to put stairs here.	Ae, De
00:19:15	**S:** But for an exhibition hall, it is more proper make a ramp so that the visitors will feel that they are walking on a single plane.	De
00:19:30	**S:** What can we do in this situation? A place like this. Is it a good idea to take the visitors with a ramp from the beginning of the room?	
00:19:45	**S:** For an exhibition space, it is good to be able to walk all around. May be people will	De
00:20:00	**S:** see the objects there, but at the same time, can there be other things?	
00:20:15	**S:** now I can put these aside. Because I am getting interested in the space.	Dp
00:20:30	**S:** Maybe I can think on this small plan.	DP
00:20:45	**S:** Usually, it is not preferred for the exhibited artworks like painting to receive direct sunlight.	Ae
00:21:00	**S:** But, if we think that this is a permanent exhibition space, they can be placed in front of the windows.	De
00:21:15	**S:** Now, exhibition of the ones that are suspended…These three…	Ae
00:21:30	**S:** If I make a mezzanine, there will be usable spaces around it. It is not possible to make a ramp in front of the door. Maybe going around it…	Ae, De
00:21:45	**S:** By this way, they will be able to see the all around the suspended works of sculpture	Ae
00:22:00	**S:** circulating up and all around. In this case why is there a need	Dc, Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	for small gaps? The center can be all open. How can it be?	
00:22:15	**S:** I will understand this subject better if I make a model.	Dp, Dr
00:22:30	**S:** A Beam, 6 meters high. I have to make a model of this room immediately. I need to see. Because it is not OK until you see it in 3d	Ds, Ae,
00:22:45	**S:** Usually, at this stage I make models. Now, again, I will try to cut and produce a small thing. (model)	Dr
00:23:00	**S:** Because I cannot decide when I cannot see clearly.	Ae
00:23:15	**S:** Yes. 3 meters	
00:23:30	**S:**	
00:23:45	**S:** I am cutting on this, to not to scratch the table.	
00:24:00	**S:** Are those modeling cardboards?	
00:24:15	**S:** I will make my model using these cardboards. The model will be better. 1/500 scale will be much better.	Dr
00:24:30	**S:** 4 meters	
00:24:45	**S:**	
00:25:00	**S:**	
00:25:15	**S:**	
00:25:30	**S:** Doing it in order to prevent scratching…	
00:25:45	**S:** In order to make a model…	
00:26:00	**S:** It is easier this way. There is no need for glue.	Ae, Dr
00:26:15	**S:** I will only stick the walls together. That is also enough for me. As the model is for interior design, I will make a model representing the walls, but not the ceiling.	Dr, Dp
00:26:30	**S:** Representing the entrance and the ceiling...	Dr
00:26:45	**S:** Now I will mark the doors.	Dp
00:27:00	**S:** Do we know the height of the doors? **B:** 2 meters and 50 centimeters.	
00:27:15	**S:** This means I will round it to 3 meters in this model.	
00:27:30	**S:** No, I will not. It will directly be 2 meters and 50 centimeters.	Dr
00:27:45	**S:** doors, 2 meters and 50 centimeters high.	
00:28:00	**S:** I also see needles here.	Dr
00:28:15	**S:** After forming the space, I can do the changes easily. You know, I always do it that way.	Ae
00:28:30	**S:**	
00:28:45	**S:**	
00:29:00	**S:**	

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

00:29:15	**S:**	
00:29:30	**S:**	
00:29:45	**S:** The cardboard is thick.2 millimeters. It may seem a little bit detailed, but as this is an interior design model, all the doors, windows are important, I wanted to do it more what-do-you-call-it (detailed)	Ae, Dr
00:30:00	**S:** The door must look like a door.	Dr
00:30:15	**S:**	
00:30:30	**S:** Let's open up these doors, like this.	Dr
00:30:45	**S:** I did not forget anything…? Hmm, they open inwards.	Ae
00:31:00	**S:** Yes, then, doors are at that side, and windows are at the other.	Ae
00:31:15	**S:** This thing will not hold up. That's why I am doing this thing. Making a model takes some time	Dr, Ae
00:31:30	**S:** I prefer to make a model after I decided for the ideas. When you make the model (and hold it) with your hands, you can see it better.	Ae
00:31:45	**S:** I don't and cannot feel this comfortable when I am drawing and modeling by a computer. I definitely prefer making physical models.	Ae
00:32:00	**S:** Also in the design studio, my design develops through (physical) models. I can say that models and section are complementary (representations).	Ae
00:32:15	**S:** Now it is taking a lot of time to make a model. I don't know if the time will be enough. (I make a) Model, and when I cannot get a result out of it, I draw a section.	Ae,
00:32:30	**S:** While working on the section, I need to make a model. Is this piece long enough for here? Yes.	Dp
00:32:45	**S:** My plans are ready.	Ae
00:33:00	**S:** If I need to cut from one of these.	
00:33:15	**S:**	
00:33:30	**S:** I need one. Let's how long is that: 16.6 centimeters	Ae
00:33:45	**S:**	
00:34:00	**S:** Will we be able to see the results of this experiment somewhere? I am curios about the results. **BP:** Yes. Let's talk about this later.	
00:34:15	**S:**	
00:34:30	**S:**	
00:34:45	**S:** Modeling is like labor intensive work	Ae
00:35:00	**S:** ..till you advance to a certain level. For instance, my vision is	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	limited until I complete this model	
00:35:15	**S:** I may think about different things: can it be like this or like that… But I don't appreciate them until I place these in a model.	Ae
00:35:30	**S:** For this moment, there are certain points that I am handling. Solid points.	Ae
00:35:45	**S:** But how is it really going to be applied? Or the other things will be related to it. At this moment, I decided to make a ramp, and with this ramp visitors will be able to go around…	Ae
00:36:00	**S:** … see these suspended artworks. Because this place is quite spacious and high. Boundlessly, if there are places which are only reserved for exhibition	Ae
00:36:15	**S:** … it seems that people will not enjoy it a lot… To be in an unlimited empty space. By doing this, I will be dividing the space. I mean going up by a ramp or accessing a mezzanine floor.	Ae, Dc, De
00:36:30	**S:** And by this way different exhibiting opportunities will be created.	Ae
00:36:45	**S:** I mean at his moment, I will stick to the idea of a higher circulation space which is accessed by a ramp or stairs.	Dp
00:37:00	**S:** After a while, the things that you have thought at the start begin to solidify.	Ae
00:37:15	**S:** There can be 1000 alternatives. The most import point is to select one and make deeper decisions.	Ae
00:37:30	**S:** Right now, I am thinking of a ramp to be here, and accessing a nice space by it.	De
00:37:45	**S:** But also a totally different alternative can be created without a ramp.	Ae
00:38:00	**S:** This is the point I started. I will develop the things based on this.	Ae
00:38:15	**S:**	
00:38:30	**S:** Shall I open this window a little bit?	
00:38:45	**S:**	
00:39:00	**S:** Now, I am opening the four windows on the longer side of the space. Right in front of here, the solid places.	De
00:39:15	**S:** The sculptures will be placed between the windows. A little bit further, people will be able to walk around. They will be able to see from the bottom. But not directly over it.	De, Ae
00:39:30	**S:** But they can nearly see it from the top. Besides all, some things can be hanged on these walls. (Talking about an special exhibition apparatus)	Ae, Ds, De
00:39:45	**S:** With certain building elements should be added here with	De

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	these circulation spaces.	
00:40:00	**S:** Because, the spaces that are outside of the exhibition space will be used for temporary things.	Ap
00:40:15	**S:** May be for a month or for a week. None of them should leave any marks on these walls. In order to do this ,	Ae, De
00:40:30	**S:** I have to think and do something with certain elements. Additions, portable pieces maybe. They can be kept at his depot. Or stay there continuously	De, Dc
00:40:45	**S:**	
00:41:00	**S:** Now, I am thinking about a special thing. I am trying to think on this. I am asking myself: “how can this design be like”. Should I think of something? What else?	Ae
00:41:15	**S:** For instance, I am thinking about the elements that I have talked about. How may they be like?	
00:41:30	**S:** Steel. There can be self supported pieces like the “çesan”s. They don’t need to be taken somewhere else when they are left alone.	Dm, Ds, De, Ae
00:41:45	**S:** There can be pieces of continuous walls in front of these walls. Will there be a need to close the windows?	Dc, De
00:42:00	**S:** I told before, artworks should no to be exposed to direct sunlight. There is enough light here.	Dl,
00:42:15	**S:** When you are attached to a normal thing	
00:42:30	**S:** I don’t like to be distracted.	
00:42:45	**S:** The design goes on even when you are outside.	
00:43:00	**S:** You always think about it, but the design does not develop until you get a pencil and a razor in your hand and start drafting and modeling.	Ae
00:43:15	**S:** Some of my friends tell that they can make decisions but I can’t	
00:43:30	**S:** really be sure how it is going to be. I need to model it manually and see. And also after this, more thoughts and ideas come up.	Dp
00:43:45	**S:** I think that I am going around inside the model. That is how it develops. I have to make a model as a starting point.	Dp, Dr
00:44:00	**S:** Is the height of the existing depot door 225 cm? **B:** No it is shorter, about 190 cm.	
00:44:15	**S:** Ok. Then this door will be under the mezzanine. Like this.	De
00:44:30	**S:** In this situation the mezzanine floor can extend up to here. Or a part of the ramp.	De
00:44:45	**S:** No the ramp cannot extend to here but mezzanine can.	De
00:45:00	**S:** I am thinking that I am walking inside. It is nice to think like	

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	this.	
00:45:15	**S:** I can think that is really exists.	
00:45:30	**S:** This glue has run out.	Ae
00:45:45	**S:**	
00:46:00	**S:**	
00:46:15	**S:** (Working with the glue, gluing things together)	
00:46:30	**S:**	
00:46:45	**S:**	
00:47:00	**BP:** What are you thinking?	
00:47:15	**S:** Yes if we continue from where left,	
00:47:30	**S:** I am gluing these..	
00:47:45	**S:**	
00:48:00	**S:** OK	
00:48:15	**S:** The doors will come together this way.	Dr
00:48:30	**S:**	
00:48:45	**S:** Here we have our place of concern	Ae
00:49:00	**S:** At this time, I drove a hole in this	
00:49:15	**S:** paper, I will use it.	Dr
00:49:30	**S:** here is the exhibition hall. Yes.	Ae
00:49:45	**S:** My windows are stretching out to the floors.	Ae
00:50:00	**S:** I am telling that our main entrance will be from here.	De
00:50:15	**S:** Besides it, there will be an info corner. When a visitor	De
00:50:30	**S:** enters the space… Now, let's take a look.	
00:50:45	**S:** when they enter this place, they will follow a certain root.	Dc
00:51:00	**S:** The most important thing in this exhibition hall is that the visitors will see the artworks on this pathway, but they won't notice that they are directed on purpose. I don't prefer them to go this way and then the other.	Ae, De
00:51:15	**S:** My purpose is to enable the visitors to see the artworks in a row and there will be no need to go back.	Dc, De
00:51:30	**S:** I don't understand the complex circulation orders in the malls. Even if it is complex, there should be a way or ways to go wherever you want. Considering all these facts,	Ae
00:51:45	**S:** I'll go over the walking path of a human being. I'll first try to understand the way. If the visitor enters from here,	Dp
00:52:00	**S:** How will be the circulation path downstairs? You know, I talked about the suspended artworks, there, downstairs. You can walk around these or something..	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

00:52:15	**S:** If we say that I entered the space and if there is a ramp going up…	Ae
00:52:30	**S:** from here. The cardboard is a though one I cannot push the needle in…. If we go up to place like this…	De, Ae
00:52:45	**S:** to the level of a mezzanine floor. But this is a short distance to go up. I we go up from here, walking all this distance and reaching a mezzanine …	Ae
00:53:00	**S:** Let's review it again: visitors enter from here; there will be an info point here.	
00:53:15	**S:** I don't still know how it can be. They will see a ramp as soon as they enter the space. Or, not immediately; I can be direct orient them towards up after visiting the exhibition in the entrance floor?	De
00:53:30	**S:** Of course they don't have to enter from this door. They can also use the other doors. Then I have said… it is different here	Ap
00:53:45	**S:** When temporary exhibitions are held, new stands can be constructed using the depot. There can be two people in charge on the entrance level. Goes around, comes around. If their place is here for the permanent exhibition.	De
00:54:00	**S:** The information space can be located somewhere else. May be at the entrance of another door. Creating a small entrance within the entrance. The visitors who came for another exhibition, after visiting it all	De
00:54:15	**S:** can get more information about the permanent exhibition and leave. Something like this. Let me make this thinner. (a part of the model)	Dr
00:54:30	**S:** I am looking around for a scissor.	
00:54:45	**S:** Something like this.	De
00:55:00	**S:** How much centimeters? This is 3 cm. Too high. A convenient height for a regular person to read is 2 meters. A height that he or she can pass under it but still a noticeable	Dr
00:55:15	**S:** height. If he or she stands a little bit further. Here, while creating an entrance for the door, the info corner can be located here. Here, the objects which are inside.	De
00:55:30	**S:** beneath those, short summaries (information about the art pieces) and here there can be information about this sculptor.	De
00:55:45	**S:** And even here, there can be brochures for take away, inside small boxes. We moved away from the architectural design, but it is ok.	De
00:56:00	**S:** for instance if I think that this is located here.	De
00:56:15	**S:** Ok.	
00:56:30	**S:** I am losing time with those kinds of things but there is	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	nothing to do about it.	
00:56:45	**S:** Normally, that's how I design. These types of small things. Sometimes while trying to get a more holistic view	Ae
00:57:00	**S:** if there are no satisfactory ideas, losing time with those things is a rescue point. Ok. This fit here.	Ae
00:57:15	**S:** Now, I entered here, There is an optional table here to be used when needed.	Ae
00:57:30	**S:** First of all, visitors will go around. How should they? Let's do something like this.	Dp
00:57:45	**S:** or there is need for walls that will orient them and that will carry the artworks.	De
00:58:00	**S:** then let's make these walls. This (modeling) cardboard is better for me.	Dr
00:58:15	**S:** Now, if a visitor walks to this point and goes up with a ramp in the center.	
00:58:30	**S:** this visitor will be in a controlling position. Is this distance long enough for the ramp? 16 meters?	
00:58:45	**S:** ok. Let's check it in a section drawing.	Ae
00:59:00	**S:** It will rise 3 meters in 16 meters.	Ae
00:59:15	**S:** It should not be too steep. 10. was the required slope 8%? Yes. There is an assumption like this.	De
00:59:30	**S:** It is not a rule but, 3 divided by 16, almost 1 over 5, one fifth.	Ae
00:59:45	**S:** Oh my god 20%. Then the ramp will go around a little bit.	Ae
01:00:00	**S:** Slowly, it will go around (rise) The only thing I know is that there will be a mezzanine here.	De
01:00:15	**S:** Let's first reflect this on the drawing.	Dp, Dr
01:00:30	**S:** Yes, I will make a correction like this.	Ae
01:00:45	**S:** What are the diameters of our artworks? 170, there was one with a diameter of 3meters, a big one	Ae
01:01:00	**S:** The other ones were something like 1 meter in diameter. If I try to find this.	Ae
01:01:15	**S:** This is the one with a diameter of 3 meters. 1.5 meters, the third one.	
01:01:30	**S:** Oh I was about to make a mistake. There are three suspended artworks and one that is exhibited on the floor - I totally forgot the one on the floor. And the others are paintings.	Ae
01:01:45	**S:** I always thought about ceramics. I have not analyzed it properly. Whatever, this will not change my thoughts on the exhibition.	Ae
01:02:00	**S:** An artwork with a diameter of 3 meters and one that will be exhibited on the floor. The things have changed a little bit	De

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:02:15	**S:** And the other one will be placed on the floor. Floor. The diameters of the sustained artworks are between 1 and 1.5 meters.	De
01:02:30	**S:** I have never thought about the one that will be placed on the floor. I was thinking that there are only three suspended artworks. What should be done right now?	Ae
01:02:45	**S:** a mezzanine, with three openings, artworks suspended through those. Other four paintings that will be exhibited while going up to the mezzanine with a ramp	De
01:03:00	**S:** while talking about a painting	
01:03:15	**S:** this will be hanged this will be too	De, Ds
01:03:30	**S:** No there four of them will be hanged. Three of them will be suspended, two will be placed besides them	De
01:03:45	**S:** two of them 2.5 and the other 3 meters.	De
01:04:00	**S:**	
01:04:15	**S:**	
01:04:30	**S:**	
01:04:45	**S:** Let's try it this way. hmm	Dp
01:05:00	**S:**	
01:05:15	**S:**	
01:05:30	**S:**	
01:05:45	**S:** there are decisions that are made while modeling. I have taken 6 design studio courses, and in all of them	
01:06:00	**S:** I started with a physical model. I need to control and see, to design something and then it goes on with a section.	Ae
01:06:15	**S:** I think more while I am modeling	
01:06:30	**S:** After you model, you don't return back. Everything is completed. If it extends towards the center, it will be nice. 5 centimeters.	
01:06:45	**S:** What happens when modeling? I certainly understand the space better.	
01:07:00	**S:** As I have told you can control it better. On the other hand it is nice to change and try the alternatives. Again, if I talk about what I am regularly doing	
01:07:15	**S:** I am continuously cutting. Usually, I use the model that I make as a working model. For instance if I need to make	
01:07:30	**S:** a decision in front of a 3D model, occasionally, I may not be able to make it. I just look and turn it around. No, it is not happening	
01:07:45	**S:** The physical model can be observed from different angles easily.	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:08:00	**S:** Now, if we think again how is it going be here? Like this… may be. These are the projections of the windows. There were three artworks to be suspended.	Ae
01:08:15	**S:** These three will be placed here like this.	De
01:08:30	**S:** Why a square shaped opening? If we think how they will be exhibited, a circular shape may provide symmetrical and equal approach to the artwork.	De, Dc
01:08:45	**S:** May be I could have more space. Perhaps, in this situation, the best is,	De
01:09:00	**S:** to make the circular one, without being lazy	Dp,
01:09:15	**S:** we will cut this a little bit.	Dr
01:09:30	**S:** Where are the columns? the mezzanine is exactly here, at this half	De
01:09:45	**S:** Really, you cannot make a draft model with thick cardboard	Ae
01:10:00	**S:** It is not suitable for this purpose.	Ae
01:10:15	**S:** Approximately there…	De
01:10:30	**S:** Sticking it together might have been easier but, it is practical for trying different floor levels.	Dr
01:10:45	**S:** Yes, that's it. Square or circle (openings)? I can add and remove those or I can make these ramps.. Because of this, it is nice to establish more than one points.	Dr, Dp
01:11:00	**S:**	
01:11:15	**S:** For instance, something like this.	De
01:11:30	**S:** If I have a mezzanine floor… Now, there will be the things that will be exhibited	
01:11:45	**S:** These are of course ceilings. These will be sustained with certain apparatus' from right here. Not from these walls of course. I am representing it like this because it is a model. Not built in.	Ds, Dr
01:12:00	**S:** Now here there are things that are standing like this.	
01:12:15	**S:** Where is that? It is sustained. Now this is a walking path for pedestrians. Sightseeing while walking.	Ae
01:12:30	**S:** The customer has 3 sculptures that are sustained, 2 standing on the floor. And 4 paintings that will be hung on the wall. The other two (floor) will stand between those. All will be in a row.	Ae, De
01:12:45	**S:** The people will walk around. Pictures. There are 4 of them. Nearly at the same size.	Ae
01:13:00	**S:** What can we do with them? May be, we can put them not at the side of the window, but hang them up to this wall over there. By this way, they will provide empty spaces for the ramp and me.	De, Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:13:15	**S:** Now, the visitor entered here. If they go up by walking around the ramp, if they see the sculptures that is hung there (as a whole)	Ae
01:13:30	**S:** And what about these sculptures? Won't they be seen from the top? May be it is more reasonable to put them at the entrance floor rather than the mezzanine.	De
01:13:45	**S:** These will be located downstairs. They will be located right at the projection of these two. At the same time, let's try the same thing (alternative) with a circular shape.	De
01:14:00	**S:**	
01:14:15	**S:**	
01:14:30	**S:** Now, this can be in two different ways:	Ae
01:14:45	**S:** In fact, when it is like this, the sustained objects will be highlighted contrasting with the space.	Dc, Ae
01:15:00	**S:**	
01:15:15	**S:** I think these are better like this. Instead of a square, large scale	Ae
01:15:30	**S:** large diameter created a better mezzanine space. People can see downstairs better. And equally, they can see all the space equally. Because of this I will select the circle opening (alternative)	Ae, De
01:15:45	**S:** There will be a sightseeing mood in the project. Hmm lets see.	Dc
01:16:00	**S:** Should they see it occasionally? Okay. How we will turn our attention to the ramp?	
01:16:15	**S:** What will be the different uses of the ramp? The objects in the space will be surrounded all around. The visitors will be able to see them from all angles.	
01:16:30	**S:** Nice sentences. (self critic)	Ae
01:16:45	**S:** If we start from here, if the visitor passes through here	Ae
01:17:00	**S:** from here and turns around there	Ae
01:17:15	**S:** A ramp that lies from end to end eventually climbs upstairs.	Ae
01:17:30	**S:** oops	
01:17:45	**S:** A ramp that climbs while going all around.	Ae
01:18:00	**S:** Ramp starts in the middle. On the floor there are two standing objects.	Ae
01:18:15	**S:** goes,	
01:18:30	**S:** At this point, it connects to the upper floor.	De
01:18:45	**S:** Yes. Here are the sustained ones. All of the paintings are side by side.	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:19:00	**S:** Because small paintings are stronger when exhibited together. Now lets think about what I left behind	De, Dp
01:19:15	**S:** for the temporary exhibition space. In fact in temporary exhibitions, the same hanging method can be used. Towards down the mezzanine floor. Moreover, while passing there with this ramp	De, Ds
01:19:30	**S:** they can slowly get higher. And again on the right and left, other exhibitions. Now, if I return back to the plan.	Dp
01:19:45	**S:** By this way… There was a ramp with a slope of 20 percent. Now, the slope is reduced.	Ae
01:20:00	**S:** In fact, these things define optimum situations, but we don’t have to stick to those rules.	Ae
01:20:15	**S:** Now, the difference between %8 and % 20 is so big that people don’t climb up that high even going up towards Barbaros boulevard. It will be hard heartedness.	Ae
01:20:30	**S:** I am satisfied with that.	Ae
01:20:45	**S:** I’ll get one more of this.1/100	Dp
01:21:00	**S:** OK. Now I’ll design the mezzanine floor.	Dp
01:21:15	**S:** Let’s see what came up	Ae
01:21:30	**S:**	
01:21:45	**S:**	
01:22:00	**S:** Let’s draw a section to see what I’ve done.	Dp, Dr
01:22:15	**S:** The color of this pen is my favorite. Yes how long did I say? There was a mezzanine floor right at the center of this wall. If we think that the ramp will be approximately at the center	Ae, Dr
01:22:30	**S:** and in an exhibition room, if we want to have ramps that people can go around easily, this ramp should be at least 1.5 to 2 meters wide. I mean if the exhibition gallery was larger.	De
01:22:45	**S:** I could talk about larger widths. But if we think about our space and its capacities in the context of the artworks,	Ae
01:23:00	**S:** 2 meters is too wide. It is wider than this table. This table is approximately 1 meter and 20 cm. wide. Let’s measure. 1,2,3,4 (measuring with her hands)	Ae
01:23:15	**S:** Exactly 1 meter and 20 cm. A ramp 1.5 m. wide is okay for me.	Ae, De
01:23:30	**S:** A ramp 1.5 m. wide is okay for me As it surrounds this place all around, this part has to be longer. Let’s see. 1.5 meters from this side, at least.	Ae,
01:23:45	**S:** 1.5 m from this side and 1.5 meters from somewhere around here?	De
01:24:00	**S:** This is the ground floor. 1.5 meters. It is not as narrow as I have tought.	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:24:15	**S:** Of course.	
01:24:30	**S:** If I think deeper about the occupants, a permanent exhibition in the school. A temporary one, can this be opened outside and to which extent?	
01:24:45	**S:** The exhibitions will not be bigger than the ones in our 102 gallery. This means that as the scope of space, as content may be more valuable.	Ap, De
01:25:00	**S:** There we only have the chance to hang them up or present them by hanging up to the Çesans. Here, I can present more space right now. They can be hung on the walls from the mezzanine.	De, Ds, Ae
01:25:15	**S:** The load bearing elements, metals, I will think about them,. Let's see how they will be. Is 1.5 m ramp too big for here?	Ds, Dm
01:25:30	**S:** It looks wide in this space. Yes, wide	Ae
01:25:45	**S:** If I compare with this table, and see how wide is 1.20 m, lets see	Ae
01:26:00	**S:** 1.5 m. from	
01:26:15	**S:** Because if the space is will be like this 1.5 meter is too big.	Ae
01:26:30	**S:** Yes really I will see how wide is 1.5 meters	Ae
01:26:45	**S:** (Measuring)	
01:27:00	**S:** Now, on the plan I saw that 1.5 meter is not as thin as in this space I have thought. I will return to my model and with 1.5 m. of ramp	Ae
01:27:15	**S:** I am trying to figure out what I can do. Of course here, a circle with a diameter of 1.5 meter.	Ae
01:27:30	**S:** I have the alternatives in my mind. Either I will lower 1.5 meters. And for this.	
01:27:45	**S:** I will assume that the number of users is low. I am thinking the different varieties of exhibitions, the number of people that it will serve and other related things.	Ae
01:28:00	**S:** I'll try something like 1.20 meters or I'll find a way to use the 1.5 m. ramps in a different way.	De
01:28:15	**S:** 9 meters in total. 1.5 meters to 9 meters. I think that the ramps will be opposite to each other	Ae, De
01:28:30	**S:** 1/3 will be a ramp. People will not be able to pass under the first ramp but they will be able to pass under the second	De, Ae
01:28:45	**S:** I'll be taking a width of 1.5 meters from the floor, right at the center.	De
01:29:00	**S:** I have to decide how will this ramp be and its qualities. Only like a bridge or a place where the art works are exhibited on?	De, Dc
01:29:15	**S:** Only a tool to improve the experience of place or a part of the exhibition space. A circulation system or a part of the space?	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:29:30	**S:** How can it be?	
01:29:45	**S:** I assume that people will use the ramp only for circulation, I mean placing the artworks on the ramps…	Ae
01:30:00	**S:** Will it be attractive? May be small printed texts about these objects can be placed on the ramps. On the way.	De
01:30:15	**S:** They will not be able to hold their heads up if this information is on the floor. No. these ramps will only be a circulation system.	Ae
01:30:30	**S:** I don't want people to look something or anything on the ramp. I want them to walk over the artworks, to analyze them from the top and sides,	
01:30:45	**S:** Then I can make this thinner. Apart from being proportionally too big in this space, a wide ramp transforms into the space, not a transportation tool.	De, Ae
01:31:00	**S:** If we take all these into account, I have decided to make this ramp narrower. Then 1.20	Ae, De
01:31:15	**S:** and sometimes I think about these numbers. 1.20 or 1.50. not 1.30. not 110.	Ae
01:31:30	**S:** These are habitual things I guess. 60. 60 is the distance that two people can pass through easily. 1.20. But if you	Ae
01:31:45	**S:** squeeze a little bit, you can pass through a place narrower than 30 cm s. ramp 1.20	Ae
01:32:00	**S:** Total space that it will occupy is 1.20 now.	Ae
01:32:15	**S:** This study that we are making is a summary of my approach to all projects.	Ae
01:32:30	**S:** I am making something to reach an end.	Ae
01:32:45	**S:** If I were to design allow, I would follow the same methods. Model, section, evaluation etc.	
01:33:00	**S:** Yes, from here	
01:33:15	**S:** till the center place.	
01:33:30	**S:** we already have said that there might be a desk here occasionally, and a ramp that starts just right across it.	Ae
01:33:45	**S:** Something approximately between 1.10 and 1.20.	
01:34:00	**S:** At his point I decided on the concepts and I want to develop the design based on these ideas and focused on concluding the design.	Dp, Ae
01:34:15	**S:** I don't think about the other alternatives. The things that I think right now sound rational right to me.	Dp, Ae
01:34:30	**S:** As a result, this design seems to satisfy the needs of an exhibition space.	Ae
01:34:45	**S:** Now if I calculate the total length that will be needed to	De

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	climb up to 3 meters.	
01:35:00	**S:** 13 m. 16. 12 plus 25 m. going up 3 meters in 25 meters	De
01:35:15	**S:** % 12. Oh. Anyways. That is also good. The thing that I have calculated is the min. height a visitor will not bump his or her head (clearance). 2 meters. At which point do I reach 2 meters?	De
01:35:30	**S:** 25 over 3 ,12, 16th meter. Where is my 16th meter? 12, 15 a person from here.	De
01:35:45	**S:** Can I use the bottom of this ramp? This is a nice situation. All the windows can be used.	De
01:36:00	**S:** Now, at this point, there will be the sculptures that will stand on the floor. These are the ones that will be suspended.	De
01:36:15	**S:** In fact, its legs touch the floor at a small point. Two 1.5 meters. I have decided that these two will be placed here.	Ae, De
01:36:30	**S:** Two sculptures. (Exhibited on the floor) and people have to go to this side of the ramp to see those.	Ae
01:36:45	**S:** No they don't have to. They can observe them while going up	Ae
01:37:00	**S:** Fortunately, I did this	Ae
01:37:15	**S:**	
01:37:30	**S:** If we turn our attention to the mezzanine floor. This is the mezzanine.	Dp
01:37:45	**S:** There are large open spaces over the mezzanine.	Ae
01:38:00	**S:** Are they too wide? Yes they are.	Ae
01:38:15	**S:** If we want the entrance floor to be observed from an opening, the diameter of that circle should be at least 3 meters. 2.5 or 3 m. So that it should work.	Ae
01:38:30	**S:** Let's see what we are doing. These are exactly 2.5 meters. Then we can draw circles that will cover the walls. Let's look	Ae, Dr
01:38:45	**S:**	
01:39:00	**S:** We forgot one thing. Of course.	Ae
01:39:15	**S:** We made a ramp there.	Ae
01:39:30	**S:**	
01:39:45	**S:** The real mezzanine stars here.	De
01:40:00	**S:** and up to here. To here, a little bit further, so that the sustained artworks can be exhibited without touching to the ramp.	Ae
01:40:15	**S:** Hıh. Now.	
01:40:30	**S:**	
01:40:45	**S:** Actually, the information place that I put in the entrance makes this place narrower. I can put this upstairs. I mean the	Ae, Ap, De

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

	place where the artworks are exhibited.	
01:41:00	**S:** A better place is available for that. Let's see. If we decide to make it pass through here,	Ae
01:41:15	**S:**	
01:41:30	**S:** If we think that the objects will be sustained right at the center of the ramp, they should be located at a "fair" place with respect to the lamp. At this line.	De
01:41:45	**S:** For this reason, I will place my openings according to this.	De
01:42:00	**S:** In fact, in a situation like this, I can break off the flooring. Here is	De
01:42:15	**S:** a real mezzanine sustained with rods. I go up from here, and come to here.	Ds
01:42:30	**S:** when the ramp is connected, you enter from here.	De
01:42:45	**S:**	
01:43:00	**S:** Let's see what I have here.	
01:43:15	**S:** a ramp 1.20 m wide, its position is completely decided.	Ae
01:43:30	**S:**	
01:43:45	**S:** from where? A little further from the first door.	Ae
01:44:00	**S:** Starting like this, at 25 meters.	De
01:44:15	**S:** Ascending.	Ae
01:44:30	**S:** A little high	Ae
01:44:45	**S:**	
01:45:00	**S:**	
01:45:15	**S:** A ramp that reaches up to 3 meters.	Ae
01:45:30	**S:**	
01:45:45	**S:**	
01:46:00	**S:**	
01:46:15	**S:**	
01:46:30	**S:** This is the ramp. In its final position.	Ae
01:46:45	**S:** If we leave this place empty,	De
01:47:00	**S:** How big is this?	
01:47:15	**S:** This much	Ae
01:47:30	**S:** It is not so good.	Ae
01:47:45	**S:**	
01:48:00	**S:** I decided to open these places completely. Because	De, Dc
01:48:15	**S:** if I remove a part of the mezzanine, there is a meaningless condition.	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:48:30	**S:** then the artworks will be suspended freely. Lets see.	Ae
01:48:45	**S:** up to here.	De
01:49:00	**S:** Are we getting close to the end? I thought I would stop.	
01:49:15	**S:** When you start thinking about something	
01:49:30	**S:** I want it to be concluded, not to be a subject only.	
01:49:45	**S:** In conclusion, I spend an effort, this way or that way. I want to see the result.	
01:50:00	**S:** This does not hold up because it is a model	Ae
01:50:15	**S:** Like this	Dr
01:50:30	**S:** This will stick to here (removes the needles)	Dr
01:50:45	**S:** I cannot hold them up, I am sticking those. Nice. I need to decide	Ae
01:51:00	**S:** whether this ramp allows enough clearance? Lets see.	
01:51:15	**S:** It passes through the upper floor from here. The highest point is here.	Ae
01:51:30	**S:** till where? 15 meters. In 15 meters how much will it ascend? 1/5 of 25.	Ae
01:51:45	**S:** 3/5 of 3 meters if it ascends to 1.8 meters.	Ae
01:52:00	**S:** then there is enough clearance with 2.20 m. Of course. If we think about the structural beams and etc. details. How will it be like?	Ds, De
01:52:15	**S:** this place is 5.5 meters, if we think that it is a mezzanine floor, like this, it will be suspended from these place from the ceiling.	Ds
01:52:30	**S:** Then 5m. is too thin for steel. I mean 25 cm thick beams can support this opening.	Ds, De
01:52:45	**S:** what is the total then? Approximately 1,95. I mean easily. OK this is good. Let’s take this from there.	Ae, De
01:53:00	**S:** Two sculptures are standing downstairs Three are suspended. 4 paintings are left undecided.	Ae
01:53:15	**S:** I thought about the location of these 4 paintings. Here. And at the end of this place there will be the textual information.	De
01:53:30	**S:** After seeing all sculptures and paintings, they will get information about this sculptor. Was there a special requirement for this? At the entrance, yes.	De, Ae
01:53:45	**S:** Ok then this will not go (pass) from here. It will be standing there.	Ae
01:54:00	**S:** There is a problem about this issue, I am so used to be the scenarist of the requirements, I am used to write the requirements myself.	Ae

Table A.2 : Protocols of Subject 11 (Conventional Design Condition) (Continued)

01:54:15	**S:** It can be located at the entrance but it is better at the "conclusion" I mean after they see everything	Ap, De, Dc
01:54:30	**S:** Of course the customer is important. But if my decision is absolute it should be like this I would try to be more convincing.	Ae
01:54:45	**S:** A place is required for the audio visual content to be exhibited. In my opinion it should be at the end. It is better after seeing all the artworks. Yes a space like this. People came from here.	Ae, De
01:55:00	**S:** Info space is located upstairs. The content will be organized ascending to the exhibition.	De
01:55:15	**S:** We entered. There is an info desk here. It is placed there on demand. Then we start going around. If it is needed to design this space, some objects will be put to be seen from the ramp.	Ae
01:55:30	**S:** placed completely spontaneously. It can be hanged from here depending on the exhibition.	De
01:55:45	**S:** In fact, the beams can break out of the mezzanine floor and provide opportunity to exhibit more sustained objects. (art works.)	De, Ds, Ae
01:56:00	**S:**	
01:56:15	**S:**	
01:56:30	**S:** I think I am done with this.	Ae
01:56:45	**S:**	
01:57:00	**S:**	
01:57:15	**S:**	
01:57:30	**S:**	
01:57:45	**S:**	

CURRICULUM VITAE

Candidate's full name: Burak Pak

Place and date of birth: Ankara, 1977

Permanent Address: Cumhuriyet Mah. Bilgic Sok. 14/5 34380 Sisli / Istanbul

Universities and
Colleges attended: 2000-2003 Istanbul Technical University, Institute of Science and Technology, M.Sc. Degree, Architectural Design Computing
1994-2000 Yildiz Technical University, Faculty of Architecture, B.Sc. Degree, Architectural Design
1983-1994 TED Ankara College

Publications (Selected):

▪ Pak, B, Ozener, O,Erdem, A, 2006 Utilizing customizable Generative Design Tools in Digital Design Studio: Xp-GEN experimental form generator, *International Journal of Architectural Computing,* Vol. 4 - no. 4, pp. 21-33

▪ Landreneau, E, Ozener, O, Pak, B, Akleman, E, And Keyser,J, 2006 Interactive Rule-Based Design -An experimental interface for conceptual design, Van Leeuwen, J.P. and H.J.P. Timmermans (eds.) *Innovations in Design & Decision Support Systems in Architecture and Urban Planning,* Dordrecht: Springer p.433-446

▪ Erdem, A., Pak, B., 2005 Information and Communication Technologies in Design Studio : Digital Design Experiments in ITU Faculty of Architecture, *A|Z Journal of the Faculty of Architecture,* Vol:2 No: 3-4

▪ Pak, B., 2005, Yeni Mimarlık: Mekanlaşmış Medya, *Mimarlık*, Issue 321 (January-February), The Official Publication of Chamber of Architects

▪ Pak, B., Ozener, O., 2004 Dijital Ortam ve Tasarım, *Portfolyo Magazine*, August 2004

▪ Pak, B., Ozener, O., Erdem, A., 2003, Xp-GEN. A randomized design tool for non-deterministic digital design methods in architecture and visual design, *Education of Computer Aided Architectural Design Conference 2003*, Vienna