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Computer-Based Sketching and the Productivity of the Conceptual Stage of Design

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Declaration

"I hereby declare that I am the sole author of this thesis; that the following thesis is entirely my own work; and that no part of this thesis has been submitted for another degree or qualification".

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This thesis is approved by the supervisors Professor John Lee and Professor Richard Coyne, Edinburgh School of Architecture and Landscape Architecture: Edinburgh College of Art.

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Prof. John Lee **Prof. Richard Coyne**

ABSTRACT

Many designers find computer-based tools are not as effective during the early stages of design as manual sketching. However, to abandon the computer in these conceptual stages denies designers the computer's capability to translate and supplement imaginative design thinking. Recent design studies address conceptual design. What is the impact of computer-based drawing and sketching on designers' cognition and productive reasoning?

This research focuses on the relationship between the characteristics of sketching using the drawing environment of the computer and the productivity of the conceptual design phase. I provide a theoretical framework that identifies and clarifies both sketching and productivity. Previous specialized studies are selective and sometimes only descriptive in defining this relationship. A review of these studies reveals a gap in our understanding of those aspects of sketching that relate to visualization, imagination and the generation of design ideas. The thesis addresses three objectives: (i) to build a comprehensive theoretical framework that on one hand defines the characteristics of sketching that might affect the generation of design ideas, and on the other hand defines the productivity of conceptual design and its indicators; (ii) to apply this framework in a practical study; and (iii) to extract implications for the relationship.

To address the problem of computer-based sketching, I indentify the continuity within the dynamic field of images usually generated while designers sketch as the most effective characteristic of the computer sketching process. I establish a measure of continuity defined by (i) the degree of ease in projecting design images, (ii) the degree of continuity of displaying images due to changing the status of the design objects and due to navigation around the objects, (iii) the degree of provision of a holistic view (i.e., the total view of the design objects on the computer screen). Then I define productivity within this framework in terms of the cognitive operations of dialogical reinterpretation. When sketching, designers seem to perform key operations such as interpreting, reframing and restructuring. I present the case that a process rich with these cognitive operations is *productive*. The study makes use of the fields of free hand sketching, literature, cognitive psychology and Gestalt theory. Four indicators emerge from this study: the occurrence of pattern discovery, conceptual reinterpretation, alternation of thinking, and restructuring.

I identify key variables that define the degree of continuity of the dynamic field of images which relate to designer's performance to verify their relationship with productivity. I study ten design participants who are given a design task that involves sketching with various CAD systems. The study involves 21 hours of recorded video analyzed using a method adapted from Goldschmidt's "linkography" tool for representing design protocols. I identify where patterns of relationships between variables exist, and where they do not apply. Not all the selected variables of continuity of the dynamic field of images, nor all the indicators of productivity in the conceptual design phase, support these patterns of relationships. This indicates that there is a special group of characteristics of sketching that maintain the pace of continuity within the dynamic field of images can improve the productivity in the conceptual phase.

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INTRODUCTION

This research deals with an important issue in architectural design: the use of the computer in the design process. Computers have been used in architectural design for a long time; the recent developments in this technology widen their role as essential design tools. In practice, the majority of professional architectural societies and students use computers as representation tools for their design works[1], this is the traditional use of CAD (Computer Aided Design) systems as drawing media.

As tools for representation, most architects use the computer drawing environment for drafting and presenting their projects in the final stages of the design process, rather than dealing with them as designing tools in the early stages. They claim that these tools are not useful or effective in the conceptual design phase[2]. However, the power of the computer sketching environment in visualizing what the human designer "can't do," and the possibility of using three dimensional modelling programs raises the question of the impact of this environment on cognitive design abilities and design thinking and reasoning. Consequently, the possibility of using the computer as a medium with which to think is an issue much debated recently in design studies, highlighting the issue of using this medium in the early stages of the design process.

The importance of this subject lies in the belief that knowing the impact of the computer on designers' cognitive abilities can develop the understanding of how designers' practices relate to their productivity, and that this knowledge can be used in the future to develop ways of increasing designers' productivity.

This issue has been addressed in recent design studies concerned with the use of computers and with the generation of design ideas at the conceptual phase. The studies revolve around what characteristics of computer sketching could improve or

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[1] See (Self, Dalke, & Evans, 2009). *Industrial Design tools and design practice an approach for understanding relationship between design tools and practice.* Paper presented at the IASDR 2009 – Rigor and relevance in design.

[2] See: (Lawson, 1997). *How Designers Think: The Design process Demystified*. Architectural press. (Lawson, 2004). *What designers know.* Elsevier. (Lawson & Loke, 1997). Computers, words and pictures. *Design studies, 18(2), 171-183.* (Bilda & Gero, 2005). *Do we need CAD during Conceptual Design?* Paper presented at the Computer Aided Architectural Design Future Proceeding of the 11th international CAAD Futures Conference Vienna, Austria.

hinder the effective use of computers in the conceptual design phase[3]. They differ in their defining, determining and explaining the impact of the drawing environment on cognitive operations that affect the designers' productive thinking. As for the characteristics of computer drawing that are involved in the idea-generation process, the design studies are either selective in that they focus on only certain characteristics of computer drawing and ignore others, or they are descriptive in the way they determine the influence on the designers' performance and cognitive abilities. On the other hand, these studies are capable of identifying the main cognitive operation involved in the process of idea-generation[4]; however, they are neither able to identify the correlated cognitive operations, processes and mechanisms that are strongly affected by the medium of drawing, nor are they able to assess the productivity of design thinking and reasoning at the conceptual phase, which is capable of recognizing the elements of strength or weakness in this process. They do not give a satisfactory applicable definition of productivity in the process of generating design ideas.

The absence of a comprehensive definition of the process of generating design ideas using the computer and the related processes, operations and mechanisms is the main motivation for conducting the current research.

These problems have been exploited in determining the research problem, the research aims and methodology. The research problem has been concerned with clarifying the relationships between some aspects related to the characteristics of the sketching process when using the computer, and the productivity of the conceptual design phase. The research aims to clarify these relationships and the methodology implies the achievement of three objectives.

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[3] See: (Dorta, 2008a) . Design Flow and Ideation. *International journal of architectural computing,* 6(3), 299-316. (Dorta, Lesage, & Perez, 2009). *Design tools and collaborative ideation.* Paper presented at the Joining Languages, Cultures and Visions: CAADFuture 2009. (Dorta, 2008b). The ideation gap: hybrid tools, design flow and practice. *Design studies, Vol 29 No.2* 121-141. (Abdelhameed, 2006). *How Does the Digital Environment Change What Architects Do in the initial Phases of the Design Process? Paper presented at the Communicating Space(S)* 24th eCAADe Conference Proceedings Volos (Greece).

[4] See: (Goel, 1995). *Sketches of thought.* Massachusetts Institute of Technology. (Stones & Cassidy, 2010). Seeing and discovering: how do student designers reinterpret sketches and digital marks during graphic design ideation? *Design studies, 31(5)*.(Stones & Cassidy, 2007),Comparing synthesis strategies of novice graphic designers using digital and traditional design tools. *Design Studies,* 28(1), 59-72.

- Building a comprehensive theoretical framework capable of identifying all the aspects of this relationship.
- Applying the theoretical framework in a practical study to verify the fundamental aspects of the relationship between the sketching process using the computer and the productivity of the conceptual design process.
- Extracting the relationships between the sketching process using the computer and the productivity of the conceptual design process.

Thesis overview

The thesis consists of seven chapters. While the first chapter examines the general problem area and the sections deal in sequence with specific issues related to the research problem, the remaining chapters deal with solving the research problem. Figure 0.1 illustrates the structure of this thesis.

Chapter one addresses the problem area: the use of the computer in architectural design. The chapter consists of two parts. The first part focuses on the use of the computer as a medium to think with and the related problem of generating design ideas in the conceptual design stage. Part two of the chapter reviews the empirical design studies; the review is focused on the discussion of two related issues. First, the cognitive operations necessary for generating design ideas: the studies identify two operations, interpretation and imagination. Second, the factors related to the characteristics of the computer drawings that affect the process of generating the design ideas.

These two issues are the two sides of the problem of using the computer in the conceptual design process. The relationship between them has been discussed in the light of the available studies. This discussion is in terms of the comprehension of the available knowledge, reliability and the easy application of the results. In discussing the aspects of this relationship, the studies focused on some characteristics of the computer sketching, neglecting others. The findings in some studies were the outcome of questionnaires, and the results were merely suggestions. Finally; the studies that focused on the cognitive operations were neither able to provide an applicable definition to the relative operations that are necessary for generating design ideas, nor were they able to define and evaluate the productivity of the conceptual design phase.

Accordingly, the study found that the theoretical framework is incomplete as it is not able to answer questions related to the operations of reinterpretation, imagination, and the occurrence of lateral transformation necessary for the generation of design ideas. It is not able to diagnose the problems related to these operations and to the overall productivity of the conceptual design phase, nor is it able to describe how the productivity might be affected by the characteristics of the medium (the computer drawing environment). In the light of this discussion the research problem has been determined. Then the stages of solving the research problem have been clarified. There are three stages: build a comprehensive theoretical framework; apply it in a case study; and then extract the implications of the relationship between the characteristics of computer sketching and the productivity of the conceptual design process.

Chapter two consists of two parts: the first part addresses the cognitive operations experienced while solving design problems and the specific operations and mechanisms of visual thinking. The operations include: reframing, restructuring and the reinterpretation. This part achieves the first stage of building the theoretical framework that defines the process of generating design ideas. The first section of this part reviews the definitions of design from a cognitive viewpoint. The second section identifies the cognitive operations and mechanisms of producing design ideas in the conceptual design phase. Then the third section addresses the visual thinking involved in the design process and defines the mechanisms of imagining and the role of memory and imagery in solving design ideas.

Part two addresses the cognitive operation of reinterpretation performed while sketching describing it as being dialogic. The first section identifies the role of the medium in generating design ideas: the drawing as a medium for generating design ideas, the role of sketching in providing an annex to the memory in the form of a dynamic field of images, and then the characteristics of the sketches that influence the generation of the ideas. The second section in this part clarifies the correlation between visual thinking and reinterpretation, and the related problem of fixation. By the end of this part, the second stage of building the theoretical framework has been partially achieved.

Chapter three completes building the second and third stages of the theoretical framework. In the first section, the drawing environment of the computer is scanned in the light of the characteristics of the sketching derived from hand sketching studies from chapter two. In the light of this scanning the characteristics of the sketching process using the computer, which might influence the generation of design ideas, are derived. These include: the degree of ambiguity of drawings which is defined as the ambiguity of the digital mark (the type of lines) and as the ambiguity of content of the drawings, the degree of continuity of dynamic field of images, which is defined by the degree of ease in projecting design images, the degree of continuity of displaying images due to changing the status of the design objects and due to the navigation around the objects, and finally the degree of provision of a holistic view. The power of computer in visualizing images is suggested to be the effective characteristic that supports the visual display of images by providing a dynamic field of images.

In the second section, the productivity of the conceptual design phase is defined within the frame of the experienced cognitive operations of dialogical reinterpretation and the related operations of reframing and restructuring, presenting the case that the process rich with these operations is productive. To identify the indicators of productivity, the study makes use of the field of literature, the specialized design studies of dialogue, and the productive thinking definition of “Gestalt theory”. The indicators are crystallized into four indicators: the occurrence of pattern discovery, the occurrence of conceptual reinterpretation, the occurrence of alternation of thinking, and the occurrence of restructuring. The first two are combined under the title “the degree of the occurrence of dialogical reinterpretation.” The second two are combined under the title “the degree of occurrence of a complete cycle of dialogical reinterpretation”.

By the end of this chapter a complete and comprehensive theoretical framework of the relationship between the characteristics of the sketching process using the computer and the productivity of the conceptual design process is introduced. Then the characteristics related to the designer’s performance are selected to verify their relationship with the productivity. Accordingly, the relationship between both the degree of continuity of displaying images and the degree of provision of a holistic view on the one hand, and the indicators of the productivity of the conceptual phase of design on the other, is selected as the specific research problem.

To test this relationship, preparation for the practical case study has been achieved in chapters four and five. Chapter four introduces the measurements of the variables of both the degree of continuity of the field of images and the degree of provision of a holistic view on one hand and the indicators of the productivity of the conceptual design phase on the other hand. The latter includes the development of a measuring tool- "Linkography." Chapter five fulfils the requirements for the practical study. In the first section, the general research hypotheses are displayed. Sections two and three display the independent variables (degree of continuity of the field of images and degree of provision of a holistic view) and dependent variables (the productivity of conceptual phase) respectively. In section four, the detailed hypotheses of the relationship are displayed. Section five determines the experiment setting including the choice of the participants, the software used, and the design task. Section six determines the measurement considerations and data collection. Finally, in section seven the circumstances of the analysis of the data are clarified.

Chapter six presents the implementation and results of the empirical case study. The first section presents the results of the independent variables. The second section displays the results of the dependent variable. Section three tests the detailed hypotheses by analyzing the relationships between every variable of the continuity of the field of images and all the indicators of productivity. The results of testing the hypotheses using fifteen cases confirm that there is a relationship between the continuity of dynamic field of images and the productivity of conceptual design stage. However, neither all the variables of the continuity of dynamic field of images, nor all the indicators of productivity have shown patterns of relationships. This indicates that not all of the ways that help in keeping the pace of continuity of dynamic field of images can improve the productivity in conceptual phase.

Chapter seven presents the discussion of the results and final conclusions. In the first section, the conclusions that relate to the theoretical framework are presented. Here, the discussion of the difference between the previous framework and the developed framework in this study is presented to clarify the contribution of the current study in defining a comprehensive theoretical framework for the relationship. In section two, the conclusions of the practical study are presented. These conclusions include the findings of the current study and their similarities and differences from the previous studies. It also presents general conclusions related to the results of measuring the variables of the dynamic field of images and also those related to the productivity indicators of the conceptual design phase. Section three presents the recommendations and suggestions for future research.

Figure 0.1: Structure of the thesis

1. The use of the computer in the process of architectural design

This chapter addresses the various roles that the computer can play in the architectural design process and demonstrates the advantages as well as the associated problems of each of these roles. The computer as a solution generator and the computer as a medium of representation are the two main roles, although these roles are very different. In practice, the majority of architects use the computer as a medium of representation in which other subsidiary roles can be categorized under two titles: the computer as drafting tool, and the computer as a medium to think with. This chapter consists of two parts: the first part displays the uses of the computer in the architectural design process, and sheds light on the problem area of this study: the computer as a medium to think with. The second part reviews the available specialized design studies on using the computer as a medium to think with. The review is followed by a discussion to determine the gaps in knowledge, and finally the research problem and aim are determined.

Part One - The problem area

1.1. The role of the computer in the architectural design process

In architectural design, architects use computers for various purposes during the different stages of the design process. While the majority of architects see the computer as a tool for presenting and finalizing their designs, some others see it as medium that can generate new designs and construct new forms in the early stages of design.

The theoretical studies have addressed the role of the computer in the architectural design process from different points of view. Lawson (Lawson, 2004) identifies few of these roles: the computer as “oracle” where the computer produces actual propositions, the computer as “draftsman” where the computer presents the design solution, the computer as “modeller” that generates forms, and the computer as a “critic” that integrates and optimizes design solutions. These roles can be categorized into two main roles taking into consideration the degree of the involvement of the computer in the design process: the computer as a solution generator and the computer as a medium of representation. The next two paragraphs address these two roles.

1.1.1. The computer as a solution generator

In this role the computer produces design propositions and is highly involved in the design process. To reveal the implications of this important role, a light requires to be shed on two issues: first, the theoretical design background and second, the application in design practice including the historical review of the use of the computer as a solution generator and the application of the recent artificial intelligence approaches.

- **The theoretical design background**

Fallman (Fallman, 2003) sees that the role of the computer as a solution generator follows the conservative definition of what design is. Relying on the philosophical base of rationalism, system theory and the theory of natural science, design is thought to solve problems following methodological steps that gradually progress from abstract requirements to sound resultant artefacts. This account assumes that there is a well-defined given problem of design where the designer has description of the desired requirements under certain constraints and has to find the solution within such circumstances. The early attempts to introduce design methods were a reflection of adopting the conservative view of design. Fallman sees that design methods in this tradition are generally normative; they include diagrams with the order of activities to follow and basic design principles to perform as guidelines. The methodologists describe design as a systematic process of controlled collection of information and well-defined objectives following logical principles and optimization techniques to reach a solution. All of this, according to Fallman, proposes that the rationality of designing can be externalized into guidelines in which the design skills of an experienced designer can be transferred to an inexperienced designer (Fallman, 2003, p. 226). In this sense, Jones (1970) who is one of the pioneers in design methods wrote:

"A second point of agreement between design methodologists is that the thinking that designers are accustomed to keep to themselves has now to be externalized so that the many people (including users), whose knowledge is relevant to designing at the system level, can put forward their ideas at an early stage and can share in the taking of critical decisions, An equally good reason for externalizing design thinking is to make possible design automation, i.e. the use of computers to speed up those parts of the design process for which the thinking is sufficiently well understood to be represented by a mathematical model or process."

(Jones, 1970, p. 61)

Jones suggested that the features of diagrams, matrices and different kinds of networks that the design methods literature is full of, are analogous to computers' use of diagrams and calculations.

This normative nature of the conservative's description of the design process suggests that there is appropriate structure for the design process and that it supports the desired clarity of design methods that the methodologists seek. The many kinds of developed design methods and the application of new techniques and procedures affirm the normative nature, which in turn reduces the creative role of the designer: the good designer, in conservative accounts, is the one who can best follow the prescription. This tradition in fact deals with the designer as an engineer or a natural scientist and the way of his thinking is described as a "glass box" (Fallman, 2003, p. 226).

After explaining the philosophical background behind using the computer as a solution generator, the next paragraph explains the application of this view in design practice.

- **The applications in design practice**

The conservative view that sees the computer as a solution generator has been applied in design practice in various ways. Lawson (1990) in his early review to the history of using the computer in architectural design sees that the early attempts to involve the computer effectively in the design process were achieved by dealing with the computer as a solution generator either partially or in total. The ability of the computer in manipulating and presenting the outcome of the text and graphic data into a written or drawn manner and the ability of the computer to repeat and manipulate the logical processes using programming techniques were seen as a powerful tool that could make inferences from the knowledge base (Lawson, 1990, p. 202). This powerful tool shortens the time and effort needed and thus, increases the productivity of the process.

The early use of software packages in architectural design helped in, for instance, arranging the layouts, find the best circulation solutions, and providing privacy constraints or daylight requirements. Later this role has been developed to deal with the computer as an evaluator of human ideas (Lawson, 1990, pp. 205-210). Many such software facilities have been added to the CAD system (Computer Aided Design) and help in raising the degree of the computer's involvement in the design process. The productivity of the process is improved by taking advantage of the computer's power in making fast calculations and manipulations, which shortens the time needed. However, these software packages dealing with the functional issues were neither being widely used in architectural design practice nor did they prove to produce better artefacts than those of the hand of the human being. Lawson attributes this failure to the nature of the design solutions that demand holistic integrated responses that cannot be divided into parts; architects, unlike the computer, do not produce separated series of optimized solutions (Lawson, 2004, p. 66).

Recently the use of artificial intelligence, which includes different approaches, deals with the computer as a solution generator. In these approaches, generative rules are used to express the architectural concepts where the evolutionary designs can be accelerated and examined (Lawson, 2004, p. 66). Kotnik (2010) sees that the computer, in these approaches, shapes the way in which designers move towards the question of design. He identifies three levels of "design computability", in which the distinction between the levels depends on the degree of the computer's involvement in the design process and also depends on, using Kotnik's own words, "the understanding and maturity in the exploitation of the computational nature of the digital tools". These levels are methods for generating new forms; namely: the representative methods, the parametric methods and the algorithmic methods. In the representative methods, in which a digital drawing tool is used, the involvement of the computer in the design process is low, thus they do not, according to Kotnik, represent the digital design. In the two latter methods (the parametric and the algorithmic), however, the computer is highly involved in the design process, thus representing methods of what is called "the digital design". In these two methods there is a computational relationship between the input and the output. In the parametric method, the function that defines the relationship is given as a spectrum of fixed possibilities that represent a continuous variation along the spectra, and the algorithmic level opens up this relationship using a formal description to this function. Here, a sequence of algebraic, analytic and geometric operations manipulate the data and transform them into architectural properties. In Oxman's terminology, the parametric method represents the formation models where a high level of digital interaction and control characterize the performance of digital phenomena, thus the formation models represent the edge between the digital and non digital designs. Similarly, the generative methods produce a high level of digital designs where the algorithmic models are the good examples of these methods (Kotnik, 2010, pp. 7-12).

- **Algorithmic and Parametric design in architectural practice**

In architectural design, the idea behind algorithmic design can be found in nature; the patterns of natural systems and patterns of behaviour of natural organizations. Designers learn from these patterns but do not mimic the natural forms but rather produce new systems of non-classical and non-static forms. Natural systems have the potential to transform from one condition of stability to another that ensures the fitness of these systems. It is a nonlinear process that promotes the emergence of new organizations by a deviation from a condition of stability, regularity and constancy. "..What emerges are not static forms but dynamic systems, expressions of a simple and rigorous recursive process," by these words Daniel Bosia described algorithmic architecture (Bosia, 2011, p. 61). In this approach, architects look for the deep structures and rules that organize natural systems and use them as algorithms. These seeds are mathematically coded into the computer to construct structures, spaces and to plan programs for buildings. The power of the computer enabled designers to repeat simple processes and rules in order to generate complex configurations of spaces and forms. Architects start from an arbitrary irrational point to allow new dynamic, structured and well organized systems to emerge. Wiscombe defines “the emergence” as a “universal way in which small parts of systems, driven by very simple behaviours, will tend towards coherent organizations with their own distinctly different behaviours” (Wiscobe, 2005, p. 2). Systems of woven, folded, and packed networks have formed the new building’s smooth surfaces, new 3D structural untraditional trusses and brought to light new flowing spaces (Bosia, 2011).

The idea of emergence has been taken further to generate what is called animate form. The power of the computer by using advanced software packages has taken parametric architecture to new levels. The AIA California Council defines parametric design:

“Parametric is a term used in a variety of disciplines from mathematics through to design. Literally it means working within parameters of a defined range. Within the field of contemporary design, it refers broadly to the utilization of parametric modelling software. In contrast to standard software packages based on datum geometric objects, parametric software links dimensions and parameters to geometry thereby allowing for the incremental adjustment of a part, thus effecting the whole assembly.”

(AIACC, 2012)

The parametric software packages provide effective tools to deal with further changing of the building’s parameters of program, site, environment, user, climate and setting. The emergence of a range of forms is the final outcome of this process. For example, Greg Lynn in his animate form project starts with initial prototype designs, which have been chosen for their flexibility and adaptability, to generate this range of forms (Brugellis & Brizzi, 2006). These prototypes are the “seeds” for the generation process and they are “internally-regulated” in the sense of having general flexible organization. To initiate the evolution process, which includes the transformation and mutation, external constraints affect the regularity of these prototypes. This leads to the emergence of an undecided outcome. Lynn’s embryological house is an example of this process. He started with generic diagrams (seeds) of the house, then the computer generated a range of solutions (mutations) which are in different stages of formation. Later, the designer will guide the growth of these mutations when new information (about the site, client, and lifestyle) will be added (Anderson, 2000).

Developing forms through equations rather than using drawings as prototypes is a shift line in contemporary parametric designs. It is a shift from figures to symbols, from geometry to algebra. The London-based practice IJP Corporation has developed a mathematical knowledge model to design novel structures (Legendre, 2011). In one of its developed projects F01(b), inversion is used as a transformational method by altering surfaces and basic geometries:

"..rather than recasting the static geometry favoured by the artist in a new technical idiom, deploying the analytic equations of inversion in F01(b) opens up the possibility of contemporary re-evaluation of his modus operandi itself"

(Legendre, 2011, p. 49)

Here, it is possible to invert the standard primitives such as planes, cones, or cylinders into non-standard surfaces, such as spheres, cycloids or cross-caps. The outcome does not need to be developed or rationalized.

1.1.2. The role of the computer as a presentation medium

In previous paragraph on contemporary digital design approaches, Kotnik's three level classification of digital design models has been presented; these are: the representative, the parametric, and the algorithmic models. This classification is due to the limitation to computational function (Kotnik, 2010). In this context, Kotnik referred to Rivka Oxman's proposition of classifying digital design into five models: CAD models, formation models, generative models, performance models, and integrated compound models. Her classification explores various relationships between the designer, the conceptual content, the design process applied, and the design object itself. Oxman argues that CAD models are of little effectiveness in design thinking since they are descriptive. Despite the fact that they utilize various kinds of software packages for rendering and geometrical modelling; in her point of view, they emulate the paper-based design methods (Kotnik, 2010, p. 12). They illustrate the "non-digital" designs in which the involvement of the computer in the design process is very low; in other words they show the representative digital methods. Using the CAD models on the representative level activates the geometric language. They enable the new geometric forms to be developed using unconventional architectural presentation; the ability of projection of non standard drawings and the use of NURBS[5] have helped in producing forms that otherwise cannot be produced (Kotnik, 2010, p. 7).

The use of the computer as a representative digital tool can be divided according to the design theoretical background into two categories: the computer as a draftsman and the computer as a medium to think with.

1.1.2.1. The computer as draftsman

The majority of architects use the computer in the final stage of the design process thinking of the computer as an electronic tool for rendering and presenting their designs. The use of various CAD software packages does not show the computer as a designing medium to think with, but rather as a rendering medium that is capable of visualizing the design artefacts.

- **The theoretical background**

Thinking of the computer as only a draftsman, using Lawson's term of the computer as a draftsman, gives the eminence to the designer over the computer and emphasizes the designer's creative role. The philosophical background might be regarded as romanticism. According to Fallman, romanticism asserts individuality and identity; it believes in the human's creative and imaginative abilities that stand against the "abstract reasoning" of rationalism in solving problems. Here, Romanticism suggests art to be the alternative model of design where issues of creativity and imagination are the central focus rather than the issues of methods and structures of rational thinking. The design process in this tradition is assumed to have a mysterious element, which does not have to be revealed, and the process is directed by the designer's values. It is obvious that the priority for this account is the produced artefact and its aesthetic values rather than the way of producing the artefact. This tradition in design theory is well known as the "black box" way of thinking (Fallman, 2003, pp. 226-227).

[5] **NURBS**, Non-Uniform Rational B-Splines, are mathematical representations of 3-D geometry that can accurately describe any shape from a simple 2D line, circle, arc, or curve to the most complex 3D organic free-form surface or solid. Because of their flexibility and accuracy, NURBS models can be used in any process from illustration and animation to manufacturing.
http://www.rhino3d.com/nurbs.htm

- **The application in design practice**

CAD advanced technology encouraged architects to produce unusual design forms. The role of CAD modelling is to produce complicated forms for ideas that have already been generated and given a rough shape by the designer. At this stage the CAD modelling is used to achieve unusual forms. For example, the use of NURBS to shape the outer skin of the physical models is a strategy used by Frank Gehry in designing the Guggenheim museum in Bilbao. His design firm uses Rhino modelling software to transform the skin of the physical massing models into curves from which the form of the building is generated. Rhino uses the 3D shell as a base to slice so that the functional floor plans can be developed to suit the generated form along with spreadsheets to develop the programmatic requirements. While Rhino is used primarily as a design exploration and development and presentation tool, CATIA and Auto CAD are used as the source of the data for the fabrication and construction of the building[6]. CATIA calculated and constructed the free forms, in which the final outcome was strikingly as the original sketch of Gehry. In this project the use of the computer remains at the representative level (Siamopoulos, 2012). The designer has already imagined the result; this is the critical point that distinguishes between the representative role and the generative role of the computer (the use of the computer in parametric and algorithmic design). In this latter, the outcome is an unexpected emergence of form or a range of forms.

1.1.2.2. The interactive role: the computer as a medium to think with

This account of using the computer in design process acknowledges the role of the designer and the computer as well. In this section we will present the research line of using the Computer Aided Sketching in early design stages, and then we will present the application in architectural design practice

- **The use of Computer Aided Sketching**

Recently, prototype computational systems have been developed to play an assistant role in solving design problems in the early design stages and can easily be connected

[6] AEC Bytes: Analysis, Research, and Review of AEC Technology. Technology at Work at Gehry Partners: A Case Study. AECbytes Feature (February 26, 2004). URL:http://www.aecbytes.com/feature/2004/Gehry_Study.html

with and read by any standard CAD system. The idea behind these systems and software packages is to use sketching as an interface to intelligent systems for design. They are simply translation systems that can construct a virtual 3D built visualization of objects and spaces from 2D diagrams and drawings to aid designers. Researchers in this field have applied this idea in many different ways and produced software packages as assistant interfaces. Ellen Yi-Luen Do has developed software that is capable of connecting designers' sketches with knowledge-based design tools, which include: 3D modelling programs, the Archie case library, the Great Buildings Collection, a visual analysis program, and a calculator. The software can activate certain intelligent tools since it can infer the intentions of designers from their drawings. While sketching and thinking, designers draw diagrams, symbols, and 3D drawings that could reflect their intentions in different design contexts. Designers may draw sectional diagrams of a sun and rays when thinking about lighting concerns (Do, 2005, p. 395). This system activates the assistant sketching tool by recognizing such symbols; the 3D modelling tool, for instance, can be activated when designers draw symbols representing a 3D drawing. These prototype systems serve as assistant tools to visualize 3D design spaces in very early design stages when designers think and analyze spaces using bubble diagrams and rough 2D sketches. The models can be read by CAD software or can merely be posted on the web for viewing and sharing with collaborators. In this context, researchers have taken a new line in sketching research. This line explores applications that enable collaborative work and also integrate design and analysis. Do & Gross have developed what they call a space-pen that enables collaboration within teamwork. Using this space-pen, designers are able to mark onto and into 3D model surfaces to add geometries and post the work as a drawing image on the web (Do & Gross, 2004, p. 216). The idea of using the space-pen is not new; Sutherland's sketchpad program [7] was based on his dissertation written in 1963. It focused on human-computer interaction to make the computer accessible to users such as artists and draughtsmen. In this very early attempt at using a sketchpad system, drawing was proposed as an interface for communication with the computer. Input, output and computation programs are the contents of this system,

[7] This technical report is based on a dissertation submitted January1963 by the author for the degree of Doctor of Philosophy to the Massachusetts Institute of Technology.

which uses light-pen as an input tool. It was able not only to position parts of drawing directly on the computer display but also to point to them and change them (Sutherland, 2003, pp. 3-9). Do & Gross developed the space-pen to work also as an interface to interact with intelligent systems that serve as a computational assistant in three dimensional design environments. It operates as an interface to interact with intelligent lighting programs, which makes it an effective interface in the domain of architectural lighting. Using space-pen lighting, designers can sketch on 3D models the desired lighting effects, which function as inputs. These inputs inform the lighting design intelligent assistant that reasons, calculates and helps designers in selecting and positioning lighting fixtures and lamps to produce the desired effects (Do & Gross, 2004, p. 217) .

- **Application in architectural design practice**

In architectural design practice the interactive role of the computer can often be seen in generating new design forms. Some early works of the expert architect Peter Eisenman could be regarded as being to some extent in this direction. He uses the computer drawings to explore building form possibilities where the simple CAD functions of copy, transformation and rotation are used. These functions repeat the computer-generated drawings which become the algorithm for generating series of alternative drawings (Kwon, 2003, pp. 1-2). Eisenman breaks down the convention of drawings by using various algorithmic strategies intentionally suggesting that the related computer role in this process is to do things that the human mind can conceptualize but not visualize (Herbert, 1993, p. 67). The strategies used shift the graphic process to bring "uncertainty" and produce unpredictable forms and events:

> "..as Eisenman does in the Waxner centre at Ohio state University [...], produces uncertain, unpredictable events in the hurly-burly of the design task. The collisions between coordinate systems inevitably generate not only unpredictable forms and spaces but unpredictable impact on the program, site-related, and technological elements."
>
> (Herbert, 1993, p. 67)

The computer helps in going through these strategies where the apparent systematic and certain algorithmic processes are broken by keeping the presence of the human designer who selects the particular geometries and specific programs. The strategies plan intentionally for unexpected events and ideas thus encouraging the reflective skills of the designer.

However, the majority of architects neither introduce intentional strategies nor do they plan for stimulating the uncertainty in the computer drawings' attempts to establish a more effective role of engagement in the design process. They instead work with the computer as merely a presentation tool using the basic drawing conventions of hand drawings. Therefore several theoretical design studies raise the question of the impact of the traditional kind of use of the computer drawings and its power of visualization on the cognitive design abilities to establish such a reflective relationship with computer drawings; a kind of spontaneous reflection rather than planned. It is the relationship with the computer as a partner, a medium for drawing with magnificent power that can be exploited in developing the cognitive designing abilities; in other words, the possibility of dealing with the computer as a medium with which to think.

Instead of exploring design methods or design strategies, the context of design cognitive studies is concerned with modelling design reasoning and bringing to light cognitive design strategies. One basic query of these studies is how to increase the productivity of the design process. The importance of such studies lies in the belief that knowing the ways of design reasoning and knowing the strategies used in generating and evaluating design solutions can contribute to the establishment of a basic knowledge of the properties of design creativity (Runco & Pritzker, 1999, p. 533). Researchers in this account study the design activities and actions while solving design problems, collecting data from observations of real design practice attempting to describe the various design strategies and ways of thinking. Fallman believes that the background of this attitude is the pragmatic definition of design where the engagement in the design situation and the specific circumstance of that situation are the basic elements of this definition. Instead of the scientific model of rationalism and the artistic model of romanticism, pragmatism introduces the hermeneutic process of interpretation as the alternative model in defining design where "...knowing in action is the main element of knowledge and as such providing the key for understanding design." The designer is described as self-organized with constructive and reflective skills with regard to the design situation in hand. The designer in this account is the one who can act with the situation of the real-life world, and in this way the pragmatism sheds light on the interconnected roles, practices and technologies involved in design practice (Fallman, 2003, p. 227).

The notion of interwoven roles of multiple partners in the design situation that contribute to the design process highlights the question of the role of the computer in the design process as a medium to think with and the expected influence of its presented drawings on the designer's cognition. The majority of design theorists share the thought that these machines are effective and useful but only in the later stages of the design process. They raise the thought that CAD system are useless in the early stages where the essence of the design concept is built; CAD, in their view, not only lacks the ability to enhance the way that designers think or conceptualize their ideas but also it may have a negative impact if compared with freehand drawings. In this sense Kalay wrote "..CAD technology was undeniably useful, and it had made design work more efficient, but it had not opened up new domains to architectural imagination.." (Kalay, 2004, p. xi), and Pallasma queried the mental and sensuous impacts of computers on designing work, saying that:

> "At the same time that we acknowledge the benefits of the computer and associated digital technologies, we need to identify the ways in which they differ from previous instruments of design. We must consider the limitations and problems that they may pose, for instance, in the mental and sensuous aspects of the work of the architect. The computer undoubtedly expedites most aspects of architectural production decisively and in addition to being a tool of precise and rapid drawing, it has been put to good use in analysis, testing and visual prototyping prior to building construction. Furthermore, the computer is used to directly generate artistic, architectural and urban forms."
>
> (Pallasmaa, 2009, p. 95)

It is obvious that Pallasma refers to the power of the computer in drawing as a presentation and rendering tool rather than a designing tool, therefore he finds the computer useful in the final stages; he believes that the early stages of the design process are essential in forming and establishing the architectural essence of the building so that the fully computerized design process in this stage is problematic.

Lawson enumerated many difficulties in using CAD as a tool for sketching in the early stages of design. He characterized two related problems:

- first is the precision of the digital mark; the symbolic representation of the vectoring CAD systems does not work well with the internal mental symbolic representation used by designers. In other words, these digital marks do not give feedback to the designer in a way leads the project forward.
- second is the multi-step process of sketching by CAD. In the early stages designers need the experimental study drawings, fabulous drawings and proposition drawings. The symbolic representation and the vector system of CAD demand a multi-step process for sketching:

> "..So I come to work at a computer and in addition to advancing my own thinking, I must stop and work out how to make each on the screen. This is usually a multi- step process [....] This is no longer a conversation; it is a halting clumsy process that more closely resembles the assembly of a sentence in a foreign language with the aid of a dictionary."
>
> (Lawson, 2004, p. 70)

These systems have, from his point of view, strengthened designers' cognitive abilities in storing and reproducing the design information. This can improve the productivity of the design process by reducing the manpower and time requirements where the complexity of the drawing, the degree of the repetition and symmetry in the features of drawing can determine the degree of improvement in the productivity (Narayan, Rao, & Sarcar, 2008, p. 17). However, this cannot improve or support the creative thought that is needed in early design stages. Therefore these advantages can only support the final stages of the design process.

Lawson pointed also to the results of two pieces of empirical research that compare designing by hand drawing versus computer drawing. He referred to Goel's study (Goel, 1995) who found that sketching with the computer creates versions of the same ideas. The other study is the study of Bilda (Bilda & Demirkan, 2003) who found that the cognitive operations are less experienced with digital drawings than with hand drawings.

It is obvious that the traditional use of the computer as a medium for drawings to think with is open to question. Issues around experienced thinking, the effect on imagination and the experienced cognitive activities, the advantages of using the computer over other media, are all in question.

1.2. The computer as a medium to think with and the productivity of the design process

The previous paragraph clarifies that the use of the computer in the conceptual phase is in question. Many research projects have been carried out to establish the impact of computer as a medium for sketching on the cognitive activities of designing, attempting to examine the deficiencies of computers in comparison with other media such as hand sketching.

The investigation of the effect of using the computer on the design process requires experienced design practice and patterns of thinking while sketching to be assessed. The point that has to be explained here is the link between assessing the effectiveness of using a medium and assessing the design practice. Goldschmidt has written about the assessment of the design process. Her thoughts on the evaluation of the design process are going to be used to display the connection between assessing the medium and assessing the process.

- **How to evaluate the medium of sketching**

The cognitive design studies correlate between the properties of the medium of designing and the resultant product. To evaluate the effectiveness of any medium or device as a design tool, they either evaluate the experienced design thinking, or evaluate the quality and the quantity of the (outcome) product. This latter is a product oriented assessment of the design process by evaluating the properties of the artefact. The problem with this kind of evaluation, according to Goldschmidt (1992), is that it is content (product) oriented and focuses on the decision making instead of focusing on the kind of thinking behind taking decisions. Goldschmidt sees that the focus on decision making does not give a clear picture about the design thinking; decision making is not synonymous with design thinking, rather it is the outcome of it. She finds that decision making was the focus of not only the early research in design methods but also in later research when these methods became computerized. She argues that although research in computerized methods considers the computer-designer partnership, decision making is still the focus of this partnership. Goldschmidt believes that the evaluation of the design process demands the evaluation of the experienced reasoning behind the decision making. This can be achieved only by investigating the pattern of thinking; her focus is on the designers' patterns of thinking while solving problems. These patterns are not related to what designers already know (the background knowledge) rather they are related to the knowledge that is built and improved while designing. It is a kind of "inner design routine" of cognitive activities which occur while designing (Goldschmidt, 1992, pp. 70-71).

- **Why the assessment of the process is needed?**

Goldschmidt proposes that evaluating the design process demands evaluating the pattern of thinking that leads to a better product, or happy results in her term (Goldschmidt, 1992, p. 71). A better product means several things at different stages of design process; in the conceptual phase the generation of a greater number of varied ideas is what defines the "good product". The comparison between the patterns of thinking is needed in order to know the behaviour that leads to a "better product".

The study of the pattern of thinking while generating design ideas can tell about the effect of following certain patterns of design behaviour in using the medium on the designing practice. Consequently, this can help not only in assessing the role of the medium but also can give a clearer picture about the strengths and /or the weaknesses of using that medium.

- **Assessing the process through assessing the productivity of the process**

Because design problems are described as ill-structured problems, Goldschmidt argues that productive thinking is essential to solve design problems adequately (Goldschmidt, 1995, p. 194). Thus the evaluation of the design process through investigating the pattern of thinking evaluates the productivity of the process. Productivity could be defined within the context of cost and efficiency and it could also be defined within the context of performance:

"The term productivity brings to mind issues of cost effectiveness and profitability. But it is also related to performance, motivation, efficiency, effectiveness, production, competitiveness, quality etc."

(Goldschmidt, 1995, p. 194)

Because this current study is concerned with the conceptual design process the definition of productivity of the process should have to be within the frame of cognitive activities and the process of generating design ideas.

To sum up, the productive thinking and the productive design process are correlated to the kind of experienced thinking that can be affected by the properties of design media. It is this space of knowledge that the current research is going to focus on. This requires examination of the use of the computer as a medium for drawing to think with in the early design stages and the productivity of the process. In these design stages the cognitive activities are highly demanded and the goal is directed to generate alternatives of ideas and design proposals. Accordingly the research needs first to explore the available knowledge by reviewing the previous specialized design studies in this field to determine the gap in knowledge.

1.3. Part One- Summary

This part addressed the use of the computer in the design process. The aspects of discussion evolved around the use of computer in the early design stages for generating design ideas, and the use of it as a medium for representing the design product in the final stages. This discussion can be summarized in these points:

- The current research highlights this area of knowledge that forms the problem area of this study: the use of the computer as a medium to think with.

  There are two issues related to this area:

  First- the claim that the computer is not a useful tool in the conceptual design process: the majority of architects do not find the computer a useful tool of sketching in early design stages.

  Second- the power of computer in drawing and its influence on cognitive design activities and designers’ imaginations are in question; the theoretical design studies questioned the effect of its use on the imagination and on the cognitive activities necessary for the generation of ideas.

- To study the effect of the computer on the cognitive activities requires dealing with the issue of assessing the process of using the computer as a medium for sketching in the conceptual phase. Design studies evaluate the effectiveness of the computer by evaluating the out-come in qualitative and quantitative terms. On the other hand, other specialized studies in design process and human-computer interaction believe in assessing the pattern of thinking while solving design problems (knowing in action). Since this can give a clearer picture of the characteristics of the cognitive activities and operations, it can lead to a better understanding of the design process.

- In order to assess the effectiveness of using the computer in the conceptual design phase, the process has to be evaluated through evaluating the pattern of thinking and the related cognitive design activities. This latter is defined as the productivity of the process.
- The current research of this study follows the attitudes that focus on the design thinking and the experienced cognitive activities necessary for generating design ideas in the conceptual design phase.

Part Two – Research problem

Part one raises the problem of using the computer in the conceptual phase. The computer is seen as being not supportive for generating design ideas and alternatives. The experienced thinking, the designing behaviour and acts are in question. Part two displays the problems of using the computer as a medium to "think with" and the related issues in early design stages.

1.4. The use of the computer as a sketching medium to think with: literature review of empirical design studies

This section reviews the empirical design studies that deal with the computer as a sketching medium for generating design ideas. The aim is to explore the problems of using the computer in the conceptual phase of design that have been addressed by previous specialized design studies. In this context the design studies can be categorized into three groups:

- the studies on using the computer and cognitive operations focus on two directions: the ambiguity of the drawings and reinterpretation, and the visualization and cognitive operation.
- the studies on using the computer and the quality of the product.
- the studies that discuss the possibility of using the computer in the conceptual stage and characterize the associated problems.

In the following, the three groups will be reviewed.

1.4.1. The computer and the cognitive operations

The studies that address the effect of using the computer on the designing cognitive operations focused either on the relationship between the ambiguity and the related design cognitive operation of reinterpretation (Goel, 1995, pp. 453-455); (Stones & Cassidy, 2010), or they focus on the computer's power of visualization and its effect on imagination (Hanna & Barber, 2001); (Won, 2001); (Oh, Stuerzlinger, & Danahy, 2005); (Niblock & Hanna 2008); (Bilda & Demirkan, 2003); (Hanna & Barber, 2006); (Hanna, 2012); (Zhu, Dorta, & De Paoli, 2007).

1.4.1.1. Goel's Study 1995

This study is concerned with the various symbolic systems that designers use to represent their works. Goel argues that every design stage requires a distinct symbolic system that facilitates specific cognitive processes required in that phase. He divides the design process into four phases: problem structuring, preliminary design, refinement, and detail specification. He believes that the preliminary phase, which is the conceptual phase, demands a dense and ambiguous symbolic system that facilitates lateral transformation. This leads to the creation of various ideas. He considers the transformation of ideas to be one of the major sources for creating new ideas from old ones through using the graphical language of drawings. He believes that there is no idea completely new, as it must have either some kind of direct connection to previous ideas, or an indirect connection through the associations. He defines the lateral transformation as the transformation that is opposite to "..a more detailed version of the same drawing, totally unrelated drawing, or an identical drawing" (Goel, 1995, p.210). Goel conducted an empirical study to examine the impact of the non-symbolic graphical language of paper-based sketching, in comparison to the symbolic graphical language of the computer, on the kind of experienced transformations and the generated ideas. Thus his study established the empirical base not only for freehand sketching but also for digital drawing. He noticed that there are two things that distinguish the hand sketching from digital drawing (Goel, 1995, p. 200):

- while the generated idea from freehand sketching is followed immediately with a number of variant ideas that expand the problem space, the initial generated idea from the MacDraw (the software that was used for the experiment) is fixed to one idea and all the work that comes after goes vertically to develop the details.
- when using paper and pencil the exploration within the problem area and the transformations of the ideas were documented on the paper. In comparison, working with MacDraw gave the feeling that everything was happening

internally rather than externally, and then after, the work has been presented using the symbolic system of digital graphics.

Goel concludes that the exploration and transformational operations are not supported by the symbolic system of computer's external marks. Thus the symbolic system does not support the creative thinking by hindering the lateral transformation of the ideas. He attributed it to the precision of the digital mark that prevents the moving from one idea to another. However, he noticed that subjects were able to generate ideas and drawings by using MacDraw; they did not face great difficulty in tackling the task. The actual problem was within the frame of being able to generate variant ideas and the accompanying need for transformational operations. He developed a scale of a semantic and syntactic level to measure the degree of difference between the previous and present designs. He compared the completed drawings with the initial ones and considered them as alternative solutions. The differences in the properties of these completed drawings compared with the previous drawings are used for the comparison to decide whether the drawing is a new generated idea or a new version of the previous idea (Goel, 1995, p. 211). Goel considered the cognitive operation of interpreting the drawings as the measure tool for the relative ambiguity of the drawings. He found that the number of the reinterpreted ideas (at the semantic level) by using the computer was few in comparison to using the hand drawings.

Here, it has to be clear that the aim of Goel's empirical study was to show that the system of freehand drawing is more ambiguous thus the associated references within the drawing is expected to be more dense, and in this way it would be supportive for the reinterpretation. The multiple readings, according to Goel's definition, indicate the occurrence of the reinterpretation where a subject assigns one meaning to a drawing and subsequently assigns a different meaning to the same drawing (Goel, 1995, p.211). Therefore the chosen method for evaluation, the developed scale of measurement and the simple software highly facilitated the goal. This study in its approach and findings opened the way for other studies considering further aspects related to the effective use of digital media.

1.4.1.2. Stones & Cassidy's Study 2010

This study updated Goel's study, though the aim was different. The main aim was to explore the factors affecting the reinterpretation and the influence of using different designing tools (paper based sketching versus computer drawings). Reinterpretation is considered in this study as the significant operation for new unexpected ideas that would not determinately lead to better ideas but rather can generate design alternatives (Stones & Cassidy, 2010, p. 441). The relation between the level of ambiguity that the design tool can provide and the frequent occurrence of reinterpretations was examined. As in Goel's study, this study highlighted the problem of the digital mark of having almost a finished appearance, which reduces the level of ambiguity. The claim of this study was that the chosen setting of Goel's study was arranged to be a highly unambiguous symbolic system, thus the experiment was conducted within highly restricted conditions of disabling the freehand tool and the work was carried out within the limited grid structure (Stones & Cassidy, 2010, p. 444). Stones & Cassidy conducted their experiment with novice students in graphical design to answer the main questions of whether reinterpretation can take place in digital design or not, identify the processes that lead to it, and explore what might support the reinterpretation in digital designing (Stones & Cassidy, 2010, p. 445). To achieve the purpose of the experiment, the study suggested two ways to indicate the occurrence of the reinterpretation: when a new object is seen in the solution, and when the new object leads to a new solution (Stones & Cassidy, 2010, p. 449).

The remarkable findings of this study can be presented under two aspects:

- The possibility of interpreting the digital mark

  The digital mark has been reinterpreted; the students were able to see new figures in digital drawings. However the reinterpretations have not been exploited in order to generate new solutions. Students were able to express what they could see through verbal phrases rather than showing them through drawings. The conclusion was that "we cannot claim that digital marks couldn't be seen as something else" (Stones & Cassidy, 2010, p.455); Stones and Cassidy consider this finding is remarkably different to Goel's.

- The related issues that may give better understanding to the nature of the reinterpretation in the digital environment (Stones & Cassidy, 2010, p.453-455).

    - Reinterpretation is a result of not only a visual imagery when looking at images but also comes from the verbal thoughts due to the active looking and interaction with the images.
    - When using the digital drawings, students were looking for the accuracy of the drawing and to what extent it looked like their mental image.
    - Instead of looking for potential new shapes and figures in their drawings, students were looking for precision in the shapes they had intended to draw. Some students used ready-made shapes rather than self-generated, to reassure the accuracy of the objects.

1.4.1.3. Hanna & Barber's Study 2001

This study dealt with the changed attitudes of the novice students when using the computer as the only design medium. The attitudes towards sketching, model making and time required for decision making were assessed before and after using the computer to examine the difference in the students' design attitudes. The findings revealed significant points related to the use of the computer and its impact on the design process and the related issues of creativity, intuition and design cognition. The CAD's abilities in visualization (the options provided for three dimensional modelling) and their effect on some aspects of the design process gave a better understanding of how to improve and enhance students' skills in using the digital environment. The impact on design cognition was described in accordance with its relation with decision making. Attitudes towards decision making included (Hanna & Barber, 2001, p. 29):

- quick generation of three dimensional views of design makes it possible to shift quickly and frequently from 2D to 3D view and this in turn is very helpful in improving the students' cognitive abilities and design conceptualization.

- quick design decision is due to the availability of some CAD's elements such as: space diagrams, layers, dimensioning, area calculations and distance inquiry. In describing their attitudes after using CAD, students found themselves spending more time in thinking than in sketching in comparison to the traditional way of using paper and pencil where time is divided between sketching and thinking. The study found that this improved students' attitudes towards decision making. Another finding was that when students become involved in managing the problems using the computer they apprehend the problems and find quick solutions. One of the participants regarded this quick decision making to 3D visualization for designing in computer. The researchers argued that arriving at quick solutions enhanced students' attitudes towards using intuition in solving design problems (Hanna & Barber, 2001, p. 171)

The study also showed an impact on the quality of the generated objects; the quick and easy making of 3D digital models revealed that CAD can replace physical models. Boolean operations enabled the students to create complex objects from primitive solids. The process was described as quicker, easier and more intelligent than paper-based models. Also the Boolean operations of union/subtraction of architectural form in CAD helped the student to generate new hybrid design forms and configurations very quickly and easily thus enhancing the creativity. The study also showed some other points that influenced the whole process rather than the conceptual phase[8]. The availability of large visual libraries for building elements improved the students' skills of constructing and learning architectural vocabularies (Hanna & Barber, 2001, p. 273).

1.4.1.4. Won's study 2001

This study is concerned with the cognitive operations and designers' behaviour using the computer as a visual thinking medium for generating ideas in early design stages. Won points to the effectiveness of traditional sketching in generating the ideas. He refers to the previous studies that classified the visual thinking of traditional sketching

[8] See also: (Porter & Hanna, 2007), where the authors show how media helped the design process.

into three design behaviours: seeing, imagining and drawing, and the performed design processes into arguments and moves (Won, 2001, pp. 319-320). The aim of the study was to explore the cognitive operations performed while sketching using computer aided design and to reveal the distinct difference in design cognitive behaviour between using the computer and the traditional way of sketching. Won assumed that the visual abilities of feedback from computers could influence the frequency of the cycle of seeing-imagining-drawing. The study was carried out by recording and analysing the behaviour of only two industrial designers solving a design task using both the traditional sketching and computer software of Pro-Engineering. The results show three things (Won, 2001, p. 324):

- first, the cognitive behaviour of imagining takes a longer time and occurs frequently while using the computer. Won attributed it to the computer's ability of immediate visualization. The intensive visualization can support seeing the drawings as something else:

  > "Among the movements of drawing, the designer will gaze at the figural properties of sketches on the monitor, and he/she will easily see the representation as some kind of image for the intensive visualization of the computer."
  >
  > (Won, 2001, p.324)

- second, the shift from part to whole is more frequent while using the computer.
- third, the number of the generated concepts using the computer is less than that when using traditional sketching.

These results suggest that visualization can support the imagination of the designers by helping them to see more images; however it does not prove that it can produce new ideas.

1.4.1.5. Bilda & Demirkan's Study 2003

The study is concerned with the effect of using different media tools on the cognitive activities that take place while sketching. It compares the difference between using the traditional hand sketching and using the computer's drawing environment. The comparison depends on a coding system for the designer's cognitive behaviour while solving design problems that could give some insight on designers' reasoning. The encoding system is divided into two groups of design cognitive activities (Bilda & Demirkan, 2003, p. 30):

- the goal oriented segment coding that considers the designing purposes behind deigns' actions, such as defining and creating design spaces.
- the content oriented action coding that includes the physical, perceptual, functional and conceptual design actions.

Investigating the effect of the media on the frequent occurrence of the primitive design cognitive processes in the conceptual stage was the main concern of this study using the coding scheme. The study finds that digital media has no advantages over the traditional. The hand drawings are better in supporting the perception of design visual- spatial features, the design organizational relations, and the production of design proposals and alternatives.

The study also investigated the specific cognitive actions related to the imagery arguing that digital visual thinking might be different in nature from traditional sketching. The study built this argument in reference to Madrazo's claim that digital visual representation can improve the understanding of forms, and it also relied on Marx's view that intensive visualization and immediate feedback can help in imagining (Bilda & Demirkan, 2003, p. 28). Marx claimed that the simulated 3D environment permits designers to foresee their work features and properties, and that working in three dimensional environments allows designers to be less dependent on their own imagination and think within greater degree of imagery (Marx, 2000, p. 20). The study also pointed to the findings of Bilda 's unpublished work (2001); it implied that the capability of viewing objects in 3D provides the designer with an immediate tool to check the attributes, features, and organizational relationships and feed back to the mind with the required information to answer questions and evaluate the qualities of the created space. The frequent exposure to the intensive images may improve the designer's imagery while searching for alternatives and design proposals since the designers had to do many conceptual evaluations in early design stage. However, the empirical study showed that the participants did not frequently check the features or the spatial organization of the designing space when they were actively sketching.

The study assumed that either the designer had the ability to imagine the 3D by looking at 2D so there was no need to visualize the space, or it might be regarded that the designer needed ambiguity while sketching to influence the imagery. The study suggests that designers may not need excessive exposure to images while experiencing the interactive imagery. Thus the digital visual thinking could be similar in its nature to the paper-based visual thinking. The study also reports a general finding that designers employ more cognitive processes using freehand sketching in comparison to digital sketching (Bilda & Demirkan, 2003, p. 46).

1.4.1.6. Oh, Stuerzlinger & Danaky's Study 2005

The aim of this study was to show how a computer could support design thinking. The study assessed the 3D modelling software SESAME (Sketch, Extrude, Sculpt, and Manipulate Easily) through the evaluation of designing behaviour such as the rapid creation/modification, or the use of emergent unexpected shapes and the tolerance of the ambiguity. The empirical case study revealed some important points related to the designing behaviour; it has been noticed that the participants, while solving an urban design task, frequently compared the forms of their buildings with the surrounding area to test the scale of the new structures, check their impact on the landscape from different viewpoints and check the overall view from eye-level. In this context, the study referred to the benefit of using the computer's facility of real time changing the views when looking at the designed objects. The study suggested that changing the view to look at the sketching from another point can help in considering different aspects of the problem, whereas the fixed view point of 2D sketching may limit the problem to a single viewpoint (Oh et al., 2005, p. 7).

In order to show the different tendencies of using the computer, the study compared the design behaviour in two situations; the use of paper-based versus the computer-based sketching. There were two ways to carry out the sessions, either to start with a computer session and then the paper and pencil session or vice versa. It has been noticed that subjects who used the computer first to solve the task, then solved the task again with paper and pencil, dealt with the computer positively as a medium for generating ideas, whereas the subjects who started with paper and pencil used the computer for presenting the ideas generated in the paper-based session. It has also been observed that subjects using the digital medium followed the same steps and acts of designing with paper; they started with 2D then moved to 3D considering first the overall idea then moving to the specific details. This led the study to suggest that the computer can support various levels of design abstraction. Finally, the emergence of unexpected shapes were observed in some cases and led to creative design explorations.

1.4.1.7. Niblock & Hanna's study 2008

The study investigates the difference in behaviour between two designers (one novice and one expert) to explore the effect of using the computer on cognitive actions. The study assumes that there are factors related to design behaviour that can have an influence on the process exhibited by the two designers. To interpret the designers' verbalization while doing the task, the study used a simplified coding scheme to analyze design protocols. The coding scheme deals with design information (context, user, function requirement, form and structure), and design process (problem analysis, solution generation, evaluation and design strategy). The study also analyzed the pattern of distribution of these design cognitive activities throughout the process of solving the task.

The study revealed that the novice performed more evaluation activities and regarded this as related to the inexperience of the novice. The results show no significant difference in the number of fragments of problem analysis and problem strategies performed by both. The expert used these fragments to contribute to solution activities. One of the significant differences was shown in the process of management: the novice performed more design strategies resulting in complex management of controlling large number of cognitive actions. However, this attempt is considered successful when evaluating the quality of the solution; the novice was able to produce a complex design (Niblock & Hanna, 2008, p. 696).

In analyzing the design approach of the two designers, the study revealed differences in reflections on using the computer. The expert used the computer as a visualization tool. His strategy includes generating a conceptual solution using hand sketching then visualizing and adjusting design solutions using the computer, and finally choosing one final solution later. One the other hand the novice used the computer as the only design tool; he used it as a strategy to manage design complexity. His strategy includes creating one solution and he then spent time adjusting it (Niblock & Hanna, 2008, p. 697).

Although the expert, unlike the novice, shows a more efficient and well structured process, the novice was also capable of generating a complex design. The quality of the solution was less than that of the expert's but it still shows aspects of complex design equivalence to that of expert. The study attributed this to the high number of design strategies performed while solving the task, suggesting that sketching using free-modelling of Rhino could be a possible reason for supporting novices in managing the design process of complex objects.

1.4.2. The computer and the quality of the product

The following studies assess the effectiveness of the design by using the computer through assessing the generated product.

1.4.2.1. Hanna & Barber's study 2006, and Hanna's study 2012

The study of Hanna and Barber (2006) highlights questions related to the creativity of the design and the impact of using CAAD (Computer Aided Architectural Design) on the cognitive processes of receiving, processing and manipulating design information. It assumes that there is a connection between the use of CAAD as a cognitive medium and the quantitative and qualitative issues of the generated forms, which in turn can support the creativity.

The focus of this study is on the developed 3D modelling package of CAAD that enabled the visualization, slicing and Boolean operations and the relevant increased cognitive information and perception which might affect the creativity in terms of the quality and quantity of the generated designs. The case study was conducted with novice students who had to solve an architectural task. The completed projects were evaluated by the researchers, who also used the results of a questionnaire for assessing the whole process.

As for the quantitative criterion, the study finds that the slicing and sectioning potential of CAAD and the easy and quick regeneration of layouts had a positive influence on the fluency of ideation and helped in examining general layouts. The intensive use of CAAD appeared to affect the students' involvement in the design task and helped in the fluency of generated layouts.

As for the qualitative criterion, the study found that the abilities of CAAD in manipulating and deforming objects and the immediate change influenced the novelty and uniqueness of the forms; they helped in generating more complex forms (Hanna& Barber, 2006, p.105). The capabilities of CAAD in 3D modelling helped in creating free forms; the modelling power supported the quality of the product by changing the attitudes towards having more complex, non-linear and asymmetric forms (Hanna & Barber, 2006, p. 108). This study came up with the conclusion that all of the above abilities of CAAD and its power in visualization have affected the creative cognition. Visualization can help in creating the combinations and structures of visual patterns necessary for the creation process:

"It appears that having a creative cognitive is an important precursor to generate pre-inventive structure, strategies and elaborate them to produce a useful object (design). The power of visualization in CAAD could help to assemble and synthesise visual patterns-one can call the DNA of geometry."

(Hanna & Barber, 2006, p. 110)

Finally, the capability of CAAD to test materials and lighting conditions and the possibility of getting more information through the quick access to the internet have a general influence on the analytical stage of the design process; however, the study found that there is no correlation between providing more information and the overall creativity (the fluency and the quality of the product) (Hanna & Barber, 2006, p. 106).

Recently, Hanna has examined students' attitudes towards creativity raising the question of the impact of long term exposure to CAD (Hanna, 2012). The new study verified two hypotheses related to the difference between intensive and occasional users of CAD, and the difference in attitudes towards design creativity among students who use CAD intensively. Questionnaires and semi-structured interviews along with monitoring students' behaviour were used for three years to observe students attitudes towards creativity dimensions. Creativity has been defined in terms of fluency of ideation (the number of ideas), flexibility (variety of ideas), and complexity of design product. Hanna clarifies that design ideas are "not considered to be equal to design solutions. A design idea is any strategic decision or a design move that has contributed significantly or led toward finding a solution to the design problem" (Hanna, 2012, p. 230)The study also identified two factors that influence ideation: CAD as an ideation factor, and design maturity (the time spent in designing can develop design skills and in turn produce a large volume of design ideas). In general, the study found that extensive exposure to CAD correlated positively with ideation fluency and flexibility, and that creative decision making was somehow improved. However, the ideation fluency can be improved through means other than CAD, that is by the interaction effect of design maturity. CAD's positive effect on ideation fluency and its importance in generating ideation fluency can be reduced when more time spent on developing design ideas; students can improve their ability to producing more ideas through spending longer time for design maturity. The study also found that using CAD as a parametric/generative tool develops attitudes towards producing complex geometries; however, fixation on using curved and complex forms can be encouraged (Hanna, 2012, pp. 231-232).

1.4.2.2. Zhu, Dorta & De Paoli 's study 2007

This study consists of two parts; the first part addresses the problems of using current CAAD in professional design and clarifies what is needed from CAAD tools during the conceptual design phase. The second part addresses the effect of using CAAD on the quality of the product. The latter will be presented here as it deals directly with the influence of the CAAD tool on the product. The aim of the study was to see whether the quality of the design became better by using digital media in comparison to traditional sketching. There were two criteria to assess the quality: the degree of complexity and adaptation; they evaluated the involved geometrical elements and the viability of the project respectively. The study found that there were no remarkable differences in the results between the finished projects using the digital and the traditional sketching. This led the researchers to conclude that the digital design does not achieve a significant improvement on traditional sketching (Zhu et al., 2007, pp. 35-37).

1.4.3. The possibility of using the computer in the conceptual design phase and the related problems

In additional to the above two categories of studies, there is a third group of empirical studies that outlines some aspects pertaining to the possibility of using the computer in the conceptual stage. One of them answers the question of whether the computer is ever considered as a conceptual tool (Jonson, 2005), the other explores the problems and characterizes the aspects that prevent the designers from using it as a conceptual tool (Zhu et al., 2007).

1.4.3.1. Jonson's Study 2005

Jonson's study (2005) aimed at shedding light on the various conceptual tools used in educational and professional practice of design in different domains: fashion, architecture, graphic, product and general design.

To achieve this goal an empirical case study was held within a normal condition of everyday practice rather than under the restrictions of lab-like conditions. For every domain, a different task was prepared to be solved within one day and the participants were free to use their own tools. They reported their use of different conceptual tools: words, sketches, models, and computers. The study found that designers used a range of tools in generating ideas including the computer; all the designers used the computer except the fashion designer. It also showed that words rather than sketches were the most frequent tool used in the conceptual stage. Moreover, the computer was also reported as a tool for the "Aha" moment, or the insight moment of breakthrough to generating the idea; it was reported that the computer captured three "Aha" moments, which is equal to the number captured by sketching. From these findings a new view emerged of the computer, which is different from the old view that the computer is an inappropriate tool for conceptualization. Jonson suggested that the computer may encourage new patterns, relationships, or spread aesthetic values rather than hindering the design creativity (Jonson, 2005, p. 662). Although this study suggests that the computer could be used, it implied that this use could be within a range of other tools rather than using it alone. This study is useful in revealing some points about the use of these conceptual tools; however it does not show the pattern of using them, which can help in describing the way or the position the computer can take within other tools in solving design tasks.

1.4.3.2. Zhu, Dorta & De Paole ‘s Study 2007

Zhu and Dorta conducted interviews with professional architects to gain a better understanding of using CAAD tools in the conceptual phase. They determined four hampering factors for using the current CAAD tools in conceptual design, which are (Zhu et al., 2007, pp. 33-34):

- the inability to sustain a global view for the whole design: designers put emphasis on their own part and ignore the whole development of the design.
- the inability to cope with the way of design thinking that demands some ambiguity, current CAAD does not accommodate with the required brevity of the drawings in the early stages. While CAAD needs precise information, designers have vague ideas with little information.
- the inability to support the immediate transformation of the idea which could be regarded as the result of the complexity of interface. Designers have to follow special orders to deal with it.
- the architects tend to concentrate on the screen during working time rather than communicating their ideas with others.

The first three factors are of great importance to the current study as they have a direct effect on thinking and imagery during the sketching. The study highlighted another related point that is the need for a multi-task tool in the conceptual stage. Designers do prefer to use one tool rather than combination of tools to complete the multi-functional required jobs to solve a design task. CAAD packages in their current environment are designed to focus on fulfilling one task only, therefore designers prefer to use the traditional sketching, which can fulfil the variant required tasks (Zhu et al., 2007, p. 41).

1.4.4. Discussion

This section will discuss the above empirical studies in order to: first, extract the aspects of the available knowledge about the relationship between the characteristics of using the computer as a medium for sketching and the process of generating the ideas. Second, discuss these aspects to define the gap in knowledge about this relationship.

1.4.4.1. Extract the aspects of the relationship

The empirical design studies defined some aspects of the relationship between the computer as a medium to think with and the generation of the design ideas. On the one hand, they identified the reinterpretation and the related process of imagining as the cognitive operations involved in the generation of the design ideas. On the other hand, they identified the following characteristics of the computer drawings, which either proved to influence the generation process or were expected to have an influence on this process:

- the certainty of the digital mark hinders the reinterpretation.
- the capability of visualization: the computer's power of making immediate 3D images of the drawings may improve the imagination. However; the empirical study of Bilda and Demirkan 2003 shows that designers do not use the facility of visualization very frequently. This suggests that this argument is highly correlated to the designers' performances and their habits in sketching while using the computer.
- the complex interface of the computer's screen might hamper the transformation of the conceptualized idea.
- the current CAD system might encourage the focus to be on part of the work rather than support the maintenance of a "global" view that is the "holistic view" of the work.

1.4.4.2. The discussion of the aspects

The aim of Goel's study was to show that the ambiguity of the non-symbolic system can well support the lateral transformation; therefore the experiment was conducted under very controlled conditions to assure that the difference between the compared cases (non-symbolic system/the traditional sketching versus the symbolic system/digital sketching) was very marked. Goel considered the occurrence of the reinterpretation as the measure tool for the relative ambiguity of the drawings. Under the very controlled situation of the experiment, the relatively less occurrence of lateral transformations and reinterpretation, in comparison to hand drawing, could be related directly to the less ambiguous digital marks.

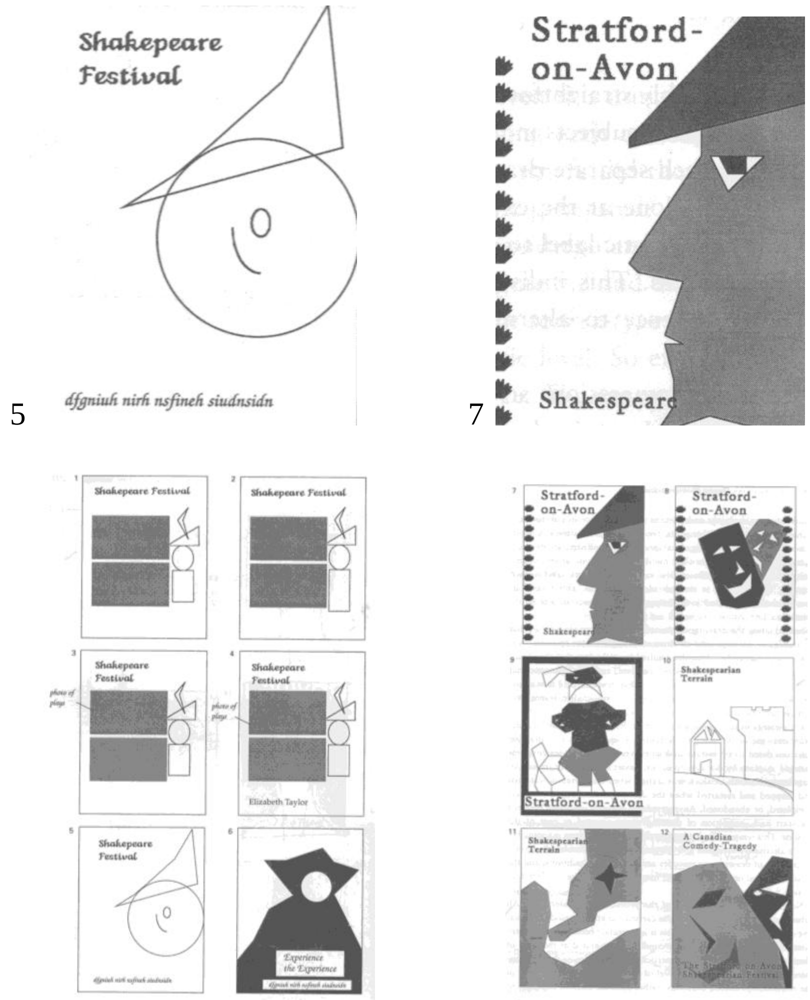

Figure: 1.1 Output of a design session on MacDraw, from a Shakespeare Festival poster task.

Reference: (Goel, 1995, pp.4-5)

It has to be mentioned here that the results of Goel's study showed that the participants using the MAC had reinterpreted the digital mark; one of the examples is shown in figure 1.1 where "the Shakespearean actor in drawing 5 was reinterpreted as Shakespeare in drawing 7" (Goel, 1995, p.211). Moreover, the coding scheme of Goel's experiment discounted "any episodes/alternative solutions that did not result in marks on paper" (Goel, 1995, p. 201), which means that the verbal reinterpretations were not included in the results. Goel used reinterpretation as an indicator to the degree of ambiguity of the drawing. His findings showed that the digital marks are remarkably less ambiguous than the hand drawings, which means that the digital mark is less reinterpreted in comparison to hand drawings. Stones and Cassidy saw that in real design practice, designers do not use the computer under such restrictions and controlled situation of Goel's experiment and they also pointed out that the software used for implementation was old and simple. In their study, they found that the participants were able to interpret the digital mark verbally rather than literally.

Stones and Cassidy noticed that in some cases students preferred to use the available readymade objects rather than constructing their own digital shapes. Although the used digital marks and the readymade objects for the graphical task "lacked" the degree of ambiguity needed, students were able to reinterpret the drawings verbally (give multiple readings and meanings). This means that whatever the case is, students can see the digital marks as something else. However these new interpretations were not adopted to create lateral new alternatives. This suggests that there are factors other than the ambiguity affecting the occurrence of reinterpretation and the lateral transformation. This claim can be supported by Goel's observation about the designing behaviour with the computer. He noticed that working with MacDraw gives the feeling that the work was done internally and the computer was used only to present it, whereas in the traditional sketching everything was done and seen on the paper. This suggests that the problem is not in the digital mark itself but rather it is in the process of constructing the digital objects. In this sense, Zhu, Dorta & Paoli in their study characterized some essential problems of using the computer in the conceptual stage. They highlighted the point that the current CAD environment is unable to respond immediately and transform the conceptual idea (into digital marks).

This deficiency can be viewed in two ways: it is either the problem of the input device technology (the mouse) that does not allow the designer to reflect immediately or to be in direct touch with the materials, or it is due to the fact that constructing the digital objects is a multi-step process (using Lawson's term), which has to be done within a few steps following special options and commands. The former suggestion could be supported by Hanna and Barber's findings in their questionnaire where the novice students did not prefer to use the computer in the conceptual stage, blaming the mouse

(Hanna & Barber, 2001, p. 269). The latter suggestion is implied in this citation from Zhu, Dorta & Paoli's study:

"Comparing to the traditional ways of freehand drawing, the CAAD tools hold the immediacy of the transformation of idea, [.......], which implies that freehand drawing is a more efficient medium to directly transform ideas into paper illustration than the current CAD. This problem could be partially caused by the complexity of interface, which does require certain rules to follow so as to cope with it."

(Zhu et al., 2007, p. 33)

They also directed attention to another very important fact that can give another explanation for this deficiency; it is the problem of the precision of the information required to construct digital objects in a conceptual stage of design where the designer has no precise definition to his idea:

"Current software packages tend to demand a very precise input of information before they can carry on the task to the next step. Nevertheless, most of the time during the early design phase, as having been disclosed in the earlier paragraphs, the ideas generated by the architect contain certain levels of uncertainty and vague impressions, which can hardly be precisely and quantitatively described."

(Zhu et al., 2007, p. 33)

The above problems represent the obstacles that may hinder the adoption of the reinterpreted ideas and give them a physical existence (result in marks on screen).

A further examination of the studies that have been reviewed reveals a group of studies that focus on the positive factors that may encourage the cognitive operations necessary for creating the ideas. They address the relationship between the cognitive operations and the visualization and highlight an issue in point, which has to be discussed. The two empirical studies of Hanna & Barber (2001 and 2006) arrive at the view that visualization has a positive impact on the cognition and ideation. In the first study, the questionnaire revealed that some novice students have found that their abilities in decision making were improved by making the quick shift from 2D to 3D and the quick and easy generation of new hybrid forms. In the second study, students found that the CAAD abilities of quick manipulation and regeneration of designs have influenced the fluency and novelty of their designs. This led to the suggestion that visualization may help in creating the combinations and the structures of visual patterns necessary for the creation process thus enhance the creativity. The practical study of Hanna (2012) has provided valuable evidence of the positive effect of using CAD on ideation in the long term. The intensive use of CAD over a long period (three years) improved the fluency and flexibility of design ideation. Students were able to give more strategic decisions and suggestions that might contribute to emerging design ideas and solutions. This suggests that the design cognition of students shows long-term improvement following use of CAD. Students' cognition preference is also found to be affected by intensive use of CAD; students prefer to use complex curved forms. This suggests that CAD can in long term build new attitudes, preferences and abilities.

Won found that the computer's visualization supported the imagination more than freehand drawing through encouraging the frequent move from part to whole and the frequent occurrence of the moving from "seeing things as" to "seeing that" arguments. However, this frequency didn't give advantages to the computer over the traditional hand sketching in proposing more ideas. In spite of the importance of these findings, the reliability of these results is restricted as the sample was limited to two cases only.

Bilda & Demirkan, however, in their experiment with the novice students of interior design to analyze designers' most frequent actions while using the software, noticed that these students did not make a frequent check to the features of their objects or the space's organization while they were actively sketching. It was expected that the high level of exposure to rich graphical images in 3D views can support the design decision making about the characteristics of the spaces in early stages of design. The reason for this is thought to be either the designers' need for ambiguity rather than the excessive display of images to encourage the interactive imagery, or designers' ability in imagining the 3D by looking at the 2D, thus they do not need to visualize their objects frequently. The study also suggested that the latter reason could be very much related to the designers' habits; they used the software in a manner similar to their traditional sketching, taking into considerations that these designers are novices. In comparison, Oh, Stuerzlinger & Danahy's findings are in contrast to those of Bilda & Demirkan. In their observation of the Masters students, they found that the participants checked their designs frequently in the initial period of investigating the problem, comparing them with the surrounding built environment, and navigating the different views at eye level. It seems that Bilda & Demirkan's comment that the participants in their study were novices and the sketching habits might affect their use of the computer is quite reasonable and can give a partial explanation to the difference in the results between the two studies. Going further into comparing the settings of the two experiments also suggests that the nature of the task may play a high role in designing behaviour. The wide scope of the urban design problem versus the narrow scale of the interior design task may give another explanation to the differences in the findings of these two studies.

To sum up, some aspects of theoretical framework of the relationship between the use of the computer and the productivity of the design process in the conceptual phase have been extracted from the available empirical design studies. The discussion of these aspects highlighted several issues, which can be summarized in these points:

- the discussion of the previous studies revealed that there are three main factors affecting the process of producing design ideas using the computer in early stages:
    - the characteristics of design sketching process using the computer
    - the designers' backgrounds and skills in using the software
    - the kind of designing tasks
- the previous studies have focused on some aspects of characteristics of sketching using the computer and shed light on their relationship with the process of generating ideas.
- the characteristics of sketching using the computer can be categorized into two groups: the first group can hinder the process of generating the design ideas, the second group can support the generation of ideas. These are:
    - the technical problems of using the traditional device of the mouse and the complicated interface of the CAD system are suggested to be negative factors that might hinder the effectiveness of generating design ideas.

- the power of visualization is suggested to be the factor that might improve the process of generating design ideas.

- the reinterpretation, which is related to imagination, is the cognitive operation that is responsible for generating design ideas.

1.5. Research problem and objectives

The highlighted issues of discussing the specialized design empirical studies present some problems in knowledge. These problems can be considered in two aspects.

- Firstly, the partial view in identifying the possible factors that could affect the productivity of the conceptual design process by using the computer. Previous studies explain the results in the light of specific factors regardless the possibility of the influence of other factors. For example, the studies of reinterpretation have regarded the problems around the lateral transformation issue to one factor - the degree of ambiguity- regardless of other possible affecting factors such as the technical factors of designing the sketching software or the human factors of designing habits in using the software.
- Secondly, the studies vary in the degree of precision of their results. For example, the studies that focused on the possible obstacles that prevent the effective use of the computer in the conceptual phase and also the possible positive potentials for this use in enhancing imagery provide a rich informational base. However, the aspects of these possibilities have not been tested under controlled situations; they are merely suggestions depending on questionnaires. The studies also vary in the specific setting and the specific coding scheme of every case study. This caused in some situations different views in interpreting the experiments' findings. For example, while Goel in his coding discounted verbal reinterpretation, Stones & Cassidy counted it which led them to think that their findings were different from Goel's.
- Finally, the studies are varied in the criteria of evaluating the process. While some of them focused on the qualitative and quantitative aspects of the product, others focused on the richness of performed cognitive operations. However, the latter studies were not able to provide an applicable definition to

the relative operations. Although these studies were concerned with the cognitive operation of reinterpretation, they were not able to explain the related problems regarded the occurrence of this operation. These demands require studying the pattern of thinking and the operations related to decision making; this is what Goldschmidt calls the study of the productivity of the process (Goldschmidt, 1992). Because productivity is concerned with examining the pattern of thinking, it is capable of giving a precise and comprehensive description to the experienced operations relative to the generation of design ideas. Thus it is able to diagnose the related problems of lateral transformations necessary for generating new alternative ideas. Accordingly, productivity has to be well-defined to suit the purposes of the current study.

It is obvious that the current theoretical framework is incomplete and thus cannot answer or give sufficient answers to these questions.

Question one- If reinterpretation is taking place in digital design, then why does it not lead to a lateral transformation? Are there any other factors affecting the reinterpretation and leading to lateral transformation? Are there factors other than the suggested factors; the technical problems; the focus on the parts rather than the holistic work; and the low degree of ambiguity in the design drawings, which could affect the process? In other words; what are the other factors related to the drawing environment of the computer and affecting positively the process of generating ideas. This question leads to the second question.

Question two- Can frequent exposure to 3D visualization improve the imagery and thus improve the conceptual process? What are the mechanisms of the process of imagination and the related operations of reinterpretation that can be affected by visualization?

The available design studies suggested a few things with regard to visualization. Firstly, intensive use of CAD has improved designers' ability to give more suggestions and strategic decisions that can lead towards finding design solutions (Hanna, 2012). Secondly, visualization may have an influence on seeing more things in drawings (Won, 2001). Thirdly, the computer's power in regenerating the structures of drawings and constructing complex objects can improve imagination (Hanna & Barber, 2001). Finally, the intensive exposure to the visualized 3D design spaces does not take place while testing the work of interior design students (Bilda & Demirkans, 2003). In the light of the latter finding, the current study sees that the matter in question should be the effect of visualization on imagination rather than focussing on whether the intensive exposure to the visualized designs occurred or not. That is because the intensive use of visualization in the conceptual phase can be influenced by other factors related to the designing habits of the user (skills and background), the kind of the CAD system software, the nature of the task and the design field, e.g. architectural design, industrial design, interior design. In the light of the available framework and the related problems, the research problem of the current study has been determined as: The available knowledge about the relationships between some aspects of the sketching process by using the computer and the productivity of the conceptual phase of design are unclear. The research aims to clarify these relationships. In order to achieve this aim and give a better understanding to the nature of the relationship between the characteristics of the design environment that the computer provides and the process of generating design ideas in the conceptual phase, three objectives have been defined as follows.

A) Build a comprehensive theoretical framework aiming at:

- first, exploring the cognitive activities and the related operations involved in the process of generating design ideas. This will identify the role of interpretation in the generating of design ideas and the related involved operations that can affect the occurrence of lateral transformation.
- second, exploring the role of the medium in the process of generating design ideas. This will identify the most effective factors related to the medium (in general) that can influence the process of generating design ideas.
- third, identify the characteristics of sketching using the visual environment of the computer that might affect the generation of design ideas, and then define the productivity of the conceptual phase of design within the frame of the idea-generation process.

To achieve the first stage the current study is going to make use of the available studies in the field of design cognition and cognitive psychology since the available specialized design studies are limited in this context.

In order to achieve the second stage of the framework, the current study is going to make use of the available studies of hand sketching as a medium for generating design ideas to extract the fundamental properties of the traditional hand sketching process that affect the generation of design ideas.

Finally, to achieve the third stage, two steps are needed:

- the drawing environment of the computer will be scanned in the light of the extracted properties of the hand sketching in stage two.
- the literature of productive thinking and the field of "literature" will be used in identifying the indicators of the productivity of the conceptual design phase.

B) Apply the theoretical framework in a practical study to verify the fundamental aspects of the relationship between the sketching process using the computer and the productivity of the conceptual design process.

C) Extract the relationship.

1.6. Part Two- Summary

- This part reviewed the literatures of the use of the computer in the conceptual design phase. The review has been discussed under two aspects.
    - Firstly, there are two cognitive operations necessary for generating design ideas: the interpretation and imagination.
    - Secondly, the characteristics of the computer's drawings that affect the process of generating the design ideas.
- The discussion of these two aspects revealed that there is a gap in knowledge about the relationship between the characteristics of sketching by using the computer and the productivity of the conceptual design process.
- This gap has been exploited to define the research problem. The aim and the objectives of the study have been determined.

2. The design process and the generation of the ideas

In this chapter, the first and second stages of building the theoretical framework of the relationship between the characteristics of the sketching process using the computer as a medium and the process of generating design ideas will be achieved. This chapter consists of two parts. The first part addresses the definition of the design process and the cognitive operations involved in generating the design ideas. The aim of this part is to introduce the cognitive processes of generating the ideas and the cognitive operations deriving from the visual thinking. The second part focuses on the effective role of the medium in generating design ideas and examines the operation of reinterpretation inherent in visual thinking.

Part one-The process of generating design ideas

2.1. Designing from the cognitive viewpoint

According to Visser (Visser, 2010), there are three approaches in analyzing design from the cognitive viewpoint:

- The classical approach to design as problem solving
- The situated approach to design as reflective practice
- The representational approach to design as construction of representations

The first approach represents the viewpoint of Herbert Simon who defines design activity as: “Design is inherently computational - a matter of computing the implications of initial assumptions and combinations of them. Simon 1968” (Visser, 2010, p. 9). He sees the sciences of designing as “sciences in their own right”. He distinguishes them from the natural sciences by describing them as the sciences of the artificial; design is human-made rather than being natural. The sciences of the artificial according to Simon include a wide range of disciplines such as Engineering sciences, computer sciences, Architecture, painting, the human and social sciences. They create the artificial world that dominates modern life. Using engineering design as a reference, Simon describes the creation process of artificial things as a systematic process that models the artefacts to attain certain goals and purposes. By this way he sees the phenomenon of creation as a systematic information approach. This is also known as the rational approach or the classical approach to solving the problems (Visser, 2010, pp. 11-13).

This view describes design as a problem oriented process where the problem is well known and solving it directs and stirs the process. Since it is a systematic approach, it could be applied to solve well-defined and simple problems (Visser, 2006, p. 58). Design problems are more complicated and classified as ill-defined problems where structuring and formulating the problem are substantial activities rather than " accepting the problem as given" (Cross, 2001, p. 3). William Mitchell identified some characteristics of the ill-defined problems; these problems are problems where:

"No complete or definitive formulation is given [...] No applicable model is provided [...] the formulation which is achieved is not rigorous [...] The formulation doesn't remain stable [...] The formulation may embody conflicts and inconsistencies which must be resolved during the course of the design process [...] The problem-solver does not have all pertinent information available for consideration as any one time."

(Mitchell, 1977, pp. 60-61)

This description clarifies that the borders of the possible solutions of these problems are blurred and indistinct, and there are no clear criteria for their solutions (Mitchell, 1977, p. 60). In this context, Cross points to Lawson's description of the difference between scientists and designers in solving problems, which, in Lawson's view, is a matter of the difference between the well-defined problem and ill-defined problem. While the scientist adopts the problem-focusing strategy where his job is to discover the structure of the problem, the designer has to adopt the solution-focusing strategy to proceed through generating a sequence of solutions until reaching an acceptable one (Cross, 2001, p. 5). The designer, unlike the scientist, suggests how the world might be, rather than describing it, therefore design is much more a matter of finding problems rather than solving them (Lawson, 2006, pp. 114-118). This futurist job of the designer explains why design problems are ill-defined, and why the systematic approach might not be appropriate to solve design problems.

On the other hand, the other two aspects of design, the situated aspect and the representational, are more likely to define a design problem as an ill-defined problem and designing activity is solution oriented. In the following paragraphs the scope of these views will be explored and examined in order to arrive at the cognitive activities and operations that are involved in producing design ideas.

2.1.1. The situated approach of designing as a reflective practice

In this approach, the designer formulates the problem, then structures and solves it in subsequent actions, using Visser's own words the designer "acts and takes actions as the object of reflection in his subsequent actions." (Visser, 2010, p. 9). This approach represents the viewpoint of Donald Schon, whose model of reflection in action defines design activity as a pattern of reflected actions in which these actions construct the dimensions of the problem space rather than dealing with the problem "as given". Visser (2010) pointed to Schon's writing in his book (1983) "The reflective practitioner: How professionals think in action" where he affirms the process of setting the problem over the process of problem solving. He sees that when problem solving orients the design process, the designer has to choose, decide and solve within the available means that best match the defined ends; here the problem setting is ignored. In comparison, problem setting can "define the decision to be made, the ends to be achieved, the means which may be chosen"; problems do not present themselves to the designer; instead, the designer has to construct them from the materials of the situation. Schon describes these materials as "puzzling, troubling, and uncertain". By setting the problem, the designer names the part of the problem that will be attended and frames the context of the problem (Schon, 1983, pp. 39-40). His model for designing consists of naming, framing, moving and evaluating. While naming and framing the problem are central domains of the conceptual stage, moving is essential in transforming the situation (Visser, 2010, pp. 23-24).

Framing the situation means that the designer gives a tentative solution to guide his work, however he has to keep the work open to inquiry. And the move that has been achieved through this framing could make an unintended change which gives the situation a new meaning. In this way the situation "talks back" and when being "heard", the designer reflects again and reframes the situation (Schon, 1983, pp. 129-134). Snodgrass and Coyne describe the structure of this conversation by expressing it in this way:

"the principle is that you work simultaneously from the unit and from the total and then go in cycles-back and forth…Schon says, is a 'what if' to be adopted in order to discover its consequences, and can always be broken open later."

(Snodgrass & Coyne, 2006, p. 45)

The above "what if" keeps the dialogues open since it allows the designer to experience the confusion and the uncertainty of the situation. In every reflection the designer criticizes and tests his prior understanding; the design proceeds and the designer gets better understanding of his problem. The reflection of the designer on the situation might focus on his prior appreciations, the adopted strategies and implied theories, or the frame of the problem (Schon, 1983, p. 62). It is a kind of judgment to the prior shape that he gives to the situation using the same factors that shape it (Snodgrass & Coyne, 2006, p. 47). It is a test of his prior understanding in the light of the new understanding as the circle proceeds.The move and the transformation of the design come in a form of reflective actions which could be seen as dialogues. The potential for this reflection is the designers' own understanding that interprets the situation and causes its transformation.

2.1.2. The representational approach of design

Visser proposes that design is a construction of representations. This expression "representation" is widely used in cognitive studies. Richardson defines it as:

"... A representation is a spatial or temporal configuration of symbols which is conventionally regarded as standing in a certain relationship to something else. Representations are created, used, and interpreted by human beings in order to think or to communicate more easily about concepts and ideas which would otherwise be less tractable."

(Richardson, 1980, p. 37)

Visser focuses on defining design as the activity of specifying an artefact that fulfils requirements and satisfies goals and needs. The specification of the artefact consists of constructing representations of the artefact in which the requirements and goals stir the construction till these representations become precise and sound and specify- explicitly and completely- the implementation of the artefact product (Visser, 2006, p. 116). In this sense, representations are the specification of the artefacts; they are also the artefacts themselves in term of being entities created by people. They can be presented in many forms; in designing the internal mental representations (mental images) and the external representations (the drawings) play an essential role in producing design ideas. In this context Visser clarifies that the importance of these representations lies not only in their ability to keep track of ideas, in adding new understanding and offering a possibility of seeing things differently, but also in their essential function of creating ideas by interpreting the representations (Visser, 2006, p. 120). These functions show that designers by constructing representations can reuse them for producing more ideas; they can use them initially to think with to produce ideas and also reuse the constructed representations in producing further new ideas based on the interpretation.

Visser clarifies that the construction of representation consists of generation, transformation, and evaluation activities. This construction is iterative, in which many intermediate representations are generated, transformed, and then evaluated (Visser, 2006, p. 116). Thus both generation and transformation are the activities involved in creating ideas. As for the generation, Visser believes that the new representations are never generated from nothing pointing to Goel who considers every new generation and transformation as a type of transformation, thus the generation of representation is also a kind of transformation. That is because the "main source" of new representation is the memory of the designer; the requirements of the design project; and other external factors, which will be interpreted by the designer (Visser, 2006, p. 193). As for transformation, Visser considers activities such as interpretations, associations, exploration, restructuring, combining and others play a role in producing different types of transformations. She clarifies that in the initial design stage designers need activities other than the algorithmic activities of analyzing the requirements; they do need the reinterpretation, association, brainstorming and exploration necessary for transforming designs' representations. She also distinguishes between two kinds of transformations, namely lateral and vertical, referring to Goel's definitions of both:

> "Even if Goel (1995,p.119) states that lateral transformations lead to "slightly different" versions, we consider that both transformations into different versions (through modifying) and into alternative representations (through revolutionizing) constitute "lateral" transformations. Goel's (195,p119) vertical transformations (which, in his terms, introduce "details") cover what we call both "detailing" and "concretizing."
>
> (Visser, 2006, p. 194)

2.2. The conceptual design phase and the generation of ideas

The above two models, the situated and representative models, answer two different questions related to solving design problems and producing ideas. While Visser's model answers the question of how to formulate design problems, by constructing representations where many intermediate representations take place until a final one is reached, Schon's model answers the question of what to deal with while formulating and structuring the problem. As for the former, Cross (2001) gives more details for describing the problem solving behaviour and how designers formulate problems: he clarifies that design problems are often loosely defined by the client and the related data and constraints are often not clear. In solving design problems, designers often formulate their problems by jumping to a solution, which is an early conjecture. Designers define problems in relation to ideas for solutions or part of solutions (Cross, 2001, pp. 3-4). They often generate what Cross called a "design element", which in Visser's terminology constructs the initial representation, and then determine the qualities of design. Accordingly, this jump to an early solution is the means for defining the ill-defined problem, and exploring the space of the problem, which in turn includes the construction of many "intermediate representations" before reaching a final one. As for the latter point, that is the things to deal with while formulating and structuring the problem, Cross refers to Schon's reflective practice where the designer is not limited to the problem as given, and instead, designers have to name and frame the problem in accordance with that unique situation. While naming implies selecting the part or the features of the problem to be dealt with, framing implies identifying areas of solution (Cross, 2001, p. 6). Framing in this context becomes, as Cross sees it, the guide for the subsequent moves. Cross refers to Lloyd and Scott's findings

(1995)[9], in defining the role of framing: they find that when architects work on problems, they now and then make strong statements describing how they see their problems, and these statements become the frame (the guide and the primary generator) for setting the problem dimensions and the solution goals (Cross, 2001, p. 6). However, designers often change the goals, constraints and reframe the problem as they proceed in designing. That is because their understanding of the problem develops and their definition to the solution proceeds; this is what Akin[10] finds in the protocol studies of architects (Cross, 2001, p. 4) . This healthy behaviour prevents the block or fixation on the early frames and solutions. The reframing causes the transformation in the design situation. While naming and framing give birth to the ideas, or the generation of ideas in Visser's model, moving or "transforming" is essential for generating more ideas. To avoid the possible fixation that might caused by the early jump to solutions or representations, designers have to explore the problem space again and reframe the problem in accordance with the new understanding of the situation (Cross, 2001). Visser identifies interpretations and associations (among other operations) as a means to transform the situation and to restructure the problem and give it another frame.

To sum up

- There are two sequential stages for solving design problems; first, re-structuring the ill-structured problem by defining and formulating the problem, and then solving the resulting well-structured problem. The former represents the conceptual design stage where designers review the design requirements and often redefine the design space to formulate what Bilda calls a "tentative solution", which is a proposal based on one or more concepts (Bilda & Gero, 2005).
- The framing and structuring of the design problem are substantial cognitive activities that dominate the design conceptual phase. Visser pointed to Herbert A. Simon's claim that much effort is spent in formulating the problem in

[9] See (Lloyd & Scott, 1995): Lloyd, P. & Scott, P. (1995). Difference in Similarity: Interpreting the architectural design process. *Planning and Design, 22*, 382-406.
[10] See (Akin, 1978): Akin, Omer (1978). *How do Architects Design? Artificial intelligence and pattern recognition in computer aided design*, J. C. Latombe (ed), IFIP/North Holland.

comparison to the time and effort spent in solving it. She remarked that structuring the problem is the essential characteristic of the conceptual stage (Visser, 2006). Framing and reframing and structuring and restructuring have to take place several times when producing ideas. While reframing is defined as the selection of the features of the solution to be the theme of the idea that is responsible for transforming the design situation, restructuring is to put the components of the problem within that selected frame.

- Reframing and then restructuring the design problem are essential for avoiding the possible fixation on an early jump to a tentative solution.

After defining the cognitive activities performed in producing design ideas and identifying reframing and restructuring as the distinct dominant operations of producing ideas in the conceptual design stage, the question here is how to achieve them?.

2.2.1. The cognitive activities: the operations and mechanisms of producing design ideas

Researchers in cognitive studies and psychological cognition believe that restructuring is due to the discovery of hidden patterns in the problem. It could be achieved through the mechanism of imagination, which perception and visual thinking are essential for achieving it. The geneplore model introduced by Finke, Ward and Smith (Finke, 1996), is inherent in creative cognitive thinking. This model, which consists of two words: generation and exploration, describes the aspects of visual creative thinking and the role of imagination.

Finke explains the creative cognitive activities performed in constructing mental images through visual thinking. Initially, mental images (mental representations in Visser's term are vague images or ideas in the designer's mind) (Visser, 2006, p. xviii)), could be synthesized through combining and superimposing features which been retrieved from the memory. In this context, this kind of thinking is assumed to be a form of visual thinking but not in the sense of "seeing". Psychological cognitive studies distinguish between the internal mental imagery and external imagery through a visual medium. Bilda refers to evidence, found by the psychologists Kosslyn (1980) and Psylyshn (1984), that this thinking is visual in a sense of resembling perceptual mechanism (Bilda & Gero, 2005). In the generation–exploration cycle, the generative process implies the discovery of hidden structures; Finke calls them the pre-inventive structures. The discovery is followed by giving functions to the pre-inventive structures. While the generative process includes the discovery of the hidden patterns, the exploratory process implies giving the pre-inventive structures and forms possible functions by examining these structures and interpreting them (Finke, 1996, pp. 382-383). The cycle of generation–exploration is iterative, in which further modification or replacement to the resultant forms can take place resulting in expansion of the concept (Finke, 1996, pp. 385-386).

The notion of expanding the concept through interpretation and the iterative cycles is consistent with Visser's construction model of generating and transforming representations mentioned earlier in this section. Activities of generation and transformation can be found in the two models under different names. Although the generation activity has been explained in Finke's model as a kind of discovery of the structures, the pre-inventive structures are the results of mental transformational operations through combinations and superimpositions, which are, according to Visser (2006), the tools of interpretations. The second point is that both models consider the interpretation of the represented structures as the activity involved in reusing the generated idea to generate another idea. Thirdly, the generation and the transformation are iterative activities and represent a repeated cycle. Finally, in the two models the representations could be constructed mentally or externally through a visual medium.

Accordingly, these studies suggest that the discovery of structures and patterns while constructing the representation lead to the reframing of the problem. The interpretation of the constructed representations is the process involved in the discovery of the hidden structure and patterns of the problem.

2.3. Visual Thinking and the mechanisms of generating the ideas

This study is concerned with the operations involved in producing ideas, the factors affecting the production of the ideas and how to increase the productivity through activating the positive role of these factors. The mechanism of imaging that is involved in achieving these operations is a very crucial element of this study. This section will deal first with the visual thinking and imagery, focusing on the memory and its role as the first medium involved in constructing the mental representations or images, and then the following paragraphs will proceed to describe the visual medium of producing the external representations focusing on sketching and its role in producing architectural design ideas.

2.3.1 Visual Thinking and Perception

While the word 'visual' refers to one of the perceptual senses, that is vision, thinking implies the processing and manipulation of information to solve problems. The mind, according to Arnheim, in order to deal with the world, has to carry out two fundamental functions: collect information and process it (Arnheim, 1970, p. 1). The materials of thought have to be provided to the mind in some fashion so that they can be manipulated. Arnheim (1970) argues that because of perception's ability to gather information in some sort of "concepts", the mind can deal with that information as accepted materials for thought, and the mind has nothing to deal with if the senses turn off. His argument came in reflection on the opposite thought of dealing with perception as a system of recording information as given or seen rather than a kind of thinking. In his studies (1970 & 1980), he displays the history of the debate around considering perception as inferior to thinking. In the fields of philosophy, psychology and cognition, perception has been considered for a long time as a system of receiving rather than manipulating information, e.g., Descartes considers imagining as a passive activity of receiving images. The mind has to shape the received images using the mind's higher faculty and active effort (Arnheim, 1980, p. 489).

Arnheim claims that his argument extends the meaning of cognition to include all mental operations engaged in the receiving, storing and processing of information: sensory perception, memory, thinking, learning. He asserts that the cognitive mental processes of thinking are not superior to perception; instead, they are essential components of perception itself (Arnheim, 1970, p. 13). He also separates between seeing and perceiving; while seeing implies the mechanical passive projection of the object on the eye's "retina", perceiving implies the active concern of the mind where the perception is not a complete recording of what is seen. He attributes a distinct difference between the optical image of the retina and the corresponding percept to the fundamental traits pertaining to the intelligence of perception in forming mental images. The mental image is not a "replica" of the physical object; rather it is the abstraction of it seized by grasping its essential feature and organizing it to the simplest pattern compatible with it (Arnheim, 1970, p. 27). In this way Arnheim shows that perception is a response to the shape rather than an image being merely recorded, it is a true visual thinking since it implies the imagining process. The question here is: what is imagery?

2.3.2. Imagery, Memory and Solving Problems

It is obvious that visual thinking implies the process of imagining by performing some related operations of processing and manipulating the images. Generally, the fields of knowledge, which are concerned with imagery, provide several definitions and bring light to different sides of the phenomenon. Firstly, in language, the Oxford dictionary defines imagery as "language that produces pictures in the minds of people reading or listening"[11], whereas the free online dictionary gives a more specific description to the language used; "it is a vivid or figurative language to present objects, actions, or ideas"[12], it also defines imagery in terms of its product; "A set of mental pictures or images". Secondly, in psychology, the psychological glossary[13] defines it:

"Imagery: Imagery is simply the formation of any mental pictures. This simple process has great benefit when it comes to memory. By using imagery, we can enhance the processing of information into the memory system. For example, trying to remember a phone number by repeating it in your head is a common method, but what might enhance your processing of the information might be to use imagery - maybe visualize the numbers being written on a chalk board. This allows you to create a mental picture of the numbers that may be processed more completely."

This definition focuses on the role of imagery in enhancing the memory system by creating mental images of the information. Thirdly, in visual learning, imagery is defined in terms of visualisation, which means "to form and manipulate a mental image", which is essential in problem solving and spatial reasoning to tackle and cope with abstract images by using concrete means. As a process, visualisation

[11] WWW document. URL http://oxforddictionaries.com/definition/english/imagery?q=imagery
[12] WWW document. URL http://dictionary.reference.com/browse/imagery?s=t
[13] WWW document. URL http://www.alleydog.com/glossary/definition.php?term=Imagery

demands the formation of images, mentally or using paper and pencil, that can be used to investigate and discover ideas and concepts (McLoughlin & Krakowski, 2001, p. 127). From the above general definitions, three points become clear.

- As a process, imagery is to form and manipulate the images (mentally or physically)
- The purpose of imagery is to help in constructing and enhancing the memory by using figurative language
- Imagery contributes to solving problems

As for the first point, forming the mental images, according to Arnheim, includes the process of capturing the visual images of the world and interpreting them into more abstract and generic patterns. The simplicity and generic qualities of the percept makes it good material for thought since dealing with a pattern means that there is no one individual unique shape for the percept. Arnheim clarifies this fact by saying:

"Strictly speaking, no percept ever refers to a unique, individual shape but rather to the kind of pattern of which the percept consists. There may be only one object to fit that pattern or there may be innumerable ones."

(Arnheim, 1970, p. 27)

As for the second point related to memory, there is a point in view which states that the traces of mental images in memory and the captured shapes of the visual images are also generic since the mental images are generic. Arnheim shows that there are two contradictory tendencies that play different roles in the process of tracing; while one of them acts towards making the images simple by capturing the generic structural features but not the complete details of the object, the other acts towards sharpening the distinctive features of that pattern (Arnheim, 1970, pp. 83-84). This point highlights the fact that the traces in the memory have to be altered by time. This fact is crucial in explaining the development of new traces and therefore it needs further explanation. It has to be clear that there are two kinds of memory working together with visual perception in forming the altered traces: the long term memory and the short term or working memory. The long term memory is like storage for the world images built throughout the lifetime and becomes active when there is no direct object available; like closing one's eyes and evoking images. In the case of direct seeing of the objects, the short term memory becomes active as the eye moves from one fixation of vision (the area of view that has been focused) to the other retaining visual information about what is being seen (Ware, 2005, p. 31). However the retained information does not register the entire detail of the scene.

Arnheim shows that working with the same object several times alters its traces in memory and brings a new one (Arnheim, 1970, p. 81). Here the memory becomes not mere a store of the mental images but rather a dynamic store that works together with perception in producing new structures.

The above two points- constructing the mental images and the role of memory in forming and manipulating mental images- are essential in explaining how imagery is used to solve problems, which is the third point in defining the imagery process. Visual perception is often described as having a purpose. In this sense Colin Ware draws attention to the fact that at any given moment in time people see what they are attempting to achieve; they see what they need, for example, when we are in a crowd and looking for a path we can see the openings (Ware, 2005, p. 27). Here the short term memory is activated to work with perception in capturing the openings. In perceiving the world around us, the eye tracks a particular area to become central and isolated; which is, in Arnheim's own words, "taking up one thing at a time and distinguishing the primary objective from its surroundings." The emergence of this centre of attention is purposeful, it can either meet the needs of the observer or this centre shows up against the surroundings (Arnheim, 1970, p.24). When the eye's central attention is fixed on some area, the emergence of such a new stimulus within the field of vision can cause tension. In other words, the captured outer structure is eccentric to the centre of attention of the given order. Solving this tension requires a move in visual orientation or the centre of attention to allow the two centres to coincide, the eyeball has to move and fix it, and this is the normal response of the eye to adapt the inner order to the outer.

Ware (2008) sees the information captured by frequent eye movements as sequences of visual "queries" seeking for the useful information for the task on hand. The pattern processing machinery (the imagery) shows up the most relevant pattern, from what is seen, to the task on hand. Ware believes that the fractures and parts of the captured visual information become meaningful because of the built visual memories that people have. Although memories are not fully detailed, they can supply "frameworks" for setting eye movements and the correspondent actions (Ware, 2008, p. 21).Then how can this help in solving problems?

Arnheim believes that solving problems can occur visually in a similar way. He sees that thinking starts when a given order of the problem has to be modified to fit the requirements of the task. Capturing an outer order different from the given structure of the problem can solve the problem by shifting the orientation without changing the perceptual pattern. It is a kind of restructuring that is needed in solving problems (Arnheim, 1970, p.24). In this way, Arnheim sees that imaging is capable of solving the problems and he refers to Shepard's finding of the rotated position of the object to support his view. The psychologist Roger N. Shepard found that when solving problems and when a different view is needed, the spatial position of an object can be rotated by the imagination (Arnheim, 1980, p. 490). Arnheim used the cube puzzle example to show how imagination can work in solving problems. The task has to be solved without illustration.

The task is:

> "Imagine a large cube made up of twenty-seven smaller cubes, that is, three layers of nine cubes each. Imagine further that the entire outer surface of the large cube is painted red and ask yourself how many of the smaller cubes will be red on three sides, two sides, one side, or no side at all."
>
> (Arnheim, 1980, p.490)

Arnheim shows that if one is going to imagine the cube as described in the task, there will be nothing more than a cubic mass of three blocks consisting of small cubes. But if the visual conception is changed to a cube that consists of a centrically symmetrical structure of small cubes the situation will definitely look different. Arnheim shows that the new imagery provides the viewer with a well arranged image capable of mapping out and appraising the small cubes and solving the problem (Arnheim, 1980, p.491). The real change occurs when the mental image is changed from the cube of three layered blocks to a cube of centrically structured small cubes; this latter image becomes meaningful to the viewer.

Part Two- Sketching and Reinterpretation

2.4. The need for externalization and the role of the medium in generating the design ideas

So far in this chapter, memory is dealt with as a medium involved in storing the constructed mental images and representations. Not all of the cognitive operations required while constructing design representations could be performed mentally (through retrieving the mental images and modifying them). Researchers in cognitive psychology find that some cognitive operations could be performed much more easily while drawing; research projects conducted in mental discovery confirm the active role of external visual representations in pattern discovery. Finke sees that the capacity of imagery in discovering “emergent structures” is not sufficient. He points out to Reed (Reed, 1974) who showed that discovery of patterns through detecting the hidden structures could be made much easier by looking at the patterns rather than using the internal mental imagery alone (Finke, 1996, p. 383). Other researchers identify the specific mental imagery processes that subjects cannot conduct mentally. Verstijnen focuses on two processes; the combination and the restructuring of the forms. His experiments focus on the ability of subjects to distinguish new forms through combining and overlapping figures revealing that subjects are capable of combining figures mentally, but they cannot restructure them without using sketching. He ascribes this to the limitation in imagery (Verstijnen, Hennessey, Leeuwen, Hamel, & Goldschmidt, 1998) remarking to the Chambers and Reisberg[14] argument of the limitation of mental discovery in comparison to visual perception (Verstijnen et al., 1998, p. 523).

Moreover Herbert sees that the difficulty in a totally mental thinking process while solving design problems is attributed to the fact that the cognitive visual system can only hold a limited amount of visual-based information at any one time. Referring to George Miller’s observation that the immediate memory can carry only seven items at one time, Herbert shows that the limited capacity of the immediate memory (short

[14] See (Chambers & Reisberg, 1985), Chambers, D. and Reisberg, D. “Can mental images be ambiguous?” *Journal of Experimental Psychology: Human perception and performance 11*, 1985, pp.317-328

term memory) makes it possible to take only basic judgments of several things at the same time (Herbert, 1993, p. 102), therefore the mental imagery is not sufficient to help in solving design problems.

It has been mentioned earlier in this study that design problems are described as ill-defined problems. In order to be solved, elementary preparations from the initial stages have to be made to define a chosen part of the problem and to give it a frame. The mental images, using the working memory, can't supply the mind with all the immediately required information to achieve these processes. Consequently it becomes necessary to depend on the drawings as "a memory annexe" to help in the processes of catching information, saving, interpreting it where the design evolves (Herbert, 1993, p. 102).

2.4.1. Drawings as the medium of generating the design ideas

In order to achieve the goal of this chapter of examining the role of the computer as the medium of drawing, the process of producing design ideas using the computer should be presented. It has been mentioned earlier that the theoretical studies that describe the process of producing ideas using the computer are limited, this study, therefore, is going to make use of the literature on freehand sketching, which describes the effective role of the medium in producing design ideas. This will help in examining the factors that have an influence on the effectiveness of the process of producing the ideas. In the following section the role of drawing will be examined to extract the crucial characteristics that influence the process of producing design ideas.

The previous paragraph shows that the process of imagery deals with the transformational information between the external world, the eye and the mind. Similarly, thinking via drawings is a transformational process of visual information between the world of the drawings, the eye and the mind "the mind eye," and the hand. Initially, drawings are usually used by designers to achieve two different functions:

- to present their ideas and communicate them to the others
- to construct their ideas in which drawings are used as a medium with which to think

The second function is going to be explored because the production of ideas is the main concern of this study. The role of drawing as a medium will be presented through its effect on the construction of design ideas.

2.4.2. Sketching and the dynamic field of display

Goldschmidt (1994) believes that the purpose of sketching in early stages is to pick up some "meaningful clues". The meaningful clues here are "the patterns" in Arnheim's term, which have meanings in the designer's memory. Picking up these clues can help in building the design concept. Goldschmidt's view coincides with Arnheim in his description of the imagery. She uses the term 'clues' to describe the captured fragments and the searching for the relevant pattern that restructure the problem in Arnheim's description. The clues, she explains, can trigger something in the mind that is meaningful and may solve the problem. Without these clues the associated meanings may never be retrieved and brought to mind. For example, to remember someone's name, it may be useful to know that the name starts with letter "A"; this letter cannot be a clue unless the name is well known to us in the first place (Goldschmidt, 1994, p. 163). She believes that picking up these clues is related to the imagery and sees imagery as a process of interpreting the straight vision. The designer interprets what he sees, meaning that he is reading more than what has been seen. When sketching, designers add marks and lines which create new relationships among the designing materials and elements and new configurations could be picked up as clues; it is a reading of the mark in accordance with the context or in accordance to the other elements. Therefore she sees sketching as "an interactive imagery":

> "Imagery makes it possible to see certain selections of dots, lines and marks as something meaningful. Seeing something as something else (which is not there physically) is the essence of imagery, and since in this case imagining is brought about through sketching, we call this process interactive imagery."
>
> (Goldschmidt, 1994, p. 164)

Goldschmidt shows that the importance of the sketches lies in the fact that they are the only source for retrieving the images when designing. The interactive imagery differs from the normal imagery in that the images are not retrieved from the memory but from the previous images perceived only from the sketches (Goldschmidt, 1994, p. 165).

It has to be clear that picking up the clues and interpreting them are the essence of producing design ideas. They take place through cognitive operations between "the mind eye", the hand and the drawings. Herbert sees that in order to be effective, this cognitive system has to maintain a quick run through the cognitive cycles, which in its turn demands a rapid change for the images (in the "memory annexe"/the drawings). So, to be effective the drawings should not be mere "static storage" but rather a dynamic change of images. The mind works within the last few images or recent works seen; the perception and visual thinking deal with the visual materials on hand as the only source for imagery. This suggests that visual thinking is a specific kind of situated thinking. In order to change the pattern of thinking the images have to be changed frequently, otherwise the thinking can be fixed to the same pattern. Therefore Herbert sees that the dynamic change of images can help in keeping up the rapid pace of capturing and reinterpreting the images; it can help in finding new design aspects (Herbert, 1993, p. 102). It is the rapid transformations that create a dynamic field of changing displays and up-date the mental images. It is obvious that the sketches, as Goldschmidt argues, do not register the mental images but rather create them through the repeated cycles of interpretation. Goldschmidt describes how the process carries on during the sketching:

> In a series of rapid sketches the designer transforms images in a cyclic manner: each sketch generates images in the mind, and these images inform a continued search for greater coherence that leads the designer to transform the previous image by adding, deleting, modifying or replacing certain parts.
>
> (Goldschmidt, 1994, p. 164)

Herbert points out that the up-dating occurs within a cyclical manner of step-by-step production of transformed mental images by reading the changed part or the mark added to the drawing in accordance with the context, which is crucial for reinterpreting the drawings (Herbert, 1993, p. 80).

Drawing on the above description by Goldschmidt, the process of creating the dynamic display can be described in further detail by considering the role of the context; in every sketch the designer adds a mark and interprets according to the other elements in the context (functional, spatial, or conceptual); that is the process of generating the mental image, and then the added mark acquires the context and the other marks within it, which opens the way for further interpretations and leads the designer to change and transform his drawings by manipulating and modifying some parts; that is the potential for drawing another sketch.

2.4.3. The characteristics of the sketches that influence the generation of the ideas

After defining the purpose and the distinctive characteristics of the sketching as a process of doing displays and exploring how interpretation takes place in this process, the specific characteristics of the sketches that allow the interpretation to take place have to be identified.

It is obvious that the continuity of reinterpretation and the series of visual display are highly attributed to the “rapid transformation” of the drawings. Many design studies see that since sketches are kind of rough, brief and abstract drawings, they can facilitate this purpose effectively.

Goel (1995), in his investigations about the symbolic system of sketching, sees that paper based sketching is correlated with the preliminary design phase because of the ambiguous symbolic representations of the sketches. He describes sketches as a dense ordering of symbols that does not exclude the possibilities and helps in transforming one symbol into another:

“The dense ordering of reference or content classes in the symbol system of sketching insures that possibilities are not excluded and helps to transform one idea into another.”

(Goel, 1995, p. 192)

He shows that this provides the ambiguity and assures the indefinite meanings of the symbol, which in turn helps in deferment of the crystallization of the idea and contributes to reinterpretation of the drawings.

While rough fuzzy lines of the sketches can support the required ambiguity of drawings in the conceptual phase, the brief and abstract drawings (without full details) can support the required speed for transformations. Goldschmidt describes sketches as economical tools, which are necessary for achieving creativity. They can keep up the rapid pace of transformation not only because of the abstractness of the content, which consumes the time needed for drawing, but also because of the easy achievement of the transformation. Designers usually use transparent tracing paper for freehand sketching, in order to superimpose one layer over other and trace the outlines of the drawing from the prior sketch. They then modify or manipulate the selected part. Goldschmidt sees that the layering technique provides an easy method of transformation (Goldschmidt, 1994, p. 165). Layering can also provide a suitable work place capable of keeping the flow of thoughts. In describing how Alvar Aalto works while sketching using a roller of tracing paper and pulling out strips, Pallasmaa points to the fluidity of the ideas which are "train-like" in Aalto's mind while he moves from the whole to parts, thinking in plans and sections and jumping to some details of furniture, a light fitting or writing some notes (Pallasmaa, 2009, pp. 75-76). This flexible work place helps in controlling the total information for the project in one place and keeps in touch with design materials.

To sum up

- Sketching provides an environment of visual display that increases the ability of seeing new configurations and capturing new clues.
- The effectiveness of the sketches is regarded as being related to specific characteristics that can be divided into two categories:
    - the ambiguity of the drawing, which pertains to the graphical qualities of the lines produced by paper-based sketching. Designers can find more clues in the rough and fuzzy lines of sketches and interpret them. In other words, increasing the ambiguity increases the chances of multiple readings for the same image.
    - the flexibility of the sketching process by which the rapid and easy change can be achieved. The focus point here is to increase the number of changed images in order to increase the chances for discovering new patterns and clues. Moreover, flexibility also contributes to the fluidity of the thoughts. This is due to the attributes of the sketching process: the abstractness of the drawings, and the characteristics of the work place and tools that provide access to the whole work and an easy and fast way to make changes.

The above two characteristics of sketching have an essential role in supplying the mind with more clues. This represents one part of the process of generating new ideas, in which the clues have to be captured and reinterpreted as something else. Reinterpretation is a new reading for the design elements either on their own or in accordance with the other elements. In the following, the experienced reinterpretation while sketching will be examined to present its role in producing design ideas and related problems.

2.5. Examining the reinterpretation while sketching

Earlier in this chapter, interpretation has been defined as a focused cognitive operation involved in producing ideas. This section will first explore the distinct characteristics of the process of reinterpreting the drawings. Second, it will investigate the reinterpretation's role into the discovery of the "clues" or the new patterns that are essential in producing the ideas, and finally will focus on the qualities of those produced ideas. This latter step is necessary to shed light on the relationship between sketching and producing the design ideas to explore the related problems.

2.5.1. The dialogical reinterpretation while sketching

The notion of designing as a reflection in action to design materials introduced by Schon has been presented earlier in this study. Schon & Wiggins (1992) go further in explaining the kinds of seeing and the companioned "dialogical interpretations" that the designer experienced while drawing through Schon's notion of designing as "a reflection in conversation" to the design materials. On the other hand Goldschmidt describes the dialectic reasoning and the interpretations that take place while sketching. This section examines the types of reinterpretations experienced through this "dialogue" with the drawing.

- Schon's dialogical model and the unintentional discovery

The situated model of Donald Schon could be examined carefully to extract how the designer interprets his drawings through establishing a dialogue with the design materials. Schon describes architectural design as a kind of reflection in conversation with the materials conducted in the medium of drawing. His model of seeing-moving- seeing informs the dialogical nature of this reflection where designing "is an interaction of making and seeing doing and discovering” (Schon & Wiggins, 1992, p. 135). The designer discovers a pattern in the drawing (this is the first seeing), then after the designer draws, modifies, manipulates or adds something in accordance with what has been seen, which changes the configuration of the drawing (this is the move), then the drawing talks back in relation to this move where the designer judges and evaluates the move (this is the second seeing). This model describes the cognitive activities of visual thinking as a dialogue in a form of action and a reflection to that action where the designer constructs the design situation and acquires it. The dialogue starts when the designer discovers a feature or a pattern of relationships in the content of the drawing and interprets it. By discovery, Schon means the unintentional finding of new issues in the drawing; the designer adds a mark to the drawing for a specific intended purpose and then s/he finds that this mark can serve another purpose. The unintended new issue could be discovered through seeing a formal pattern or feature that is the spatial figure or the “Gestalt” form (the Gestalt form is to see a shape like a face in the clouds or see the L shape as a chair, as an example). The unintended new issue could be also a pattern of relationship such as a functional relationship or spatial relationship of the design elements through reading these elements in relation to each other, to the context or to the spatial organization. Schon describes two levels of readings the design drawings that lead to the discovery of the two types of patterns:

> “…seeing of marks on a page as a spatial figure….[she]sees the three L shape as a figure, seeing them Ls rather than as steps or as incomplete rectangles…..At a second level, she sees the Ls’ arranged in a coherent layout….to see how the L-shaped array groups grades one to two, creates an inside/outside, and so on.”
>
> (Schon & Wiggins, 1992, p. 146)

It is a kind of interpreting the drawings by reading them from different levels. Schon calls these levels “the domains”. Then the unintentional discovery of new issue reframes the problem and generates a new idea by changing the configurations of the design drawing; it is a transformation from a physical figural form to another new one. This transformation is the move in Schon’s model:

"What is meant by a move is just such a change in configuration….this move of hers can be seen in two ways: first, as an accomplished transformation, a shift from one drawn configuration to another, second, as the act of drawing by which the transformation is made"

(Schon, 1992, p. 5)

This model consists of iterative operations of transformations through interpreting the new marks added to the drawings. The most important point of this model is that the discovery of the pattern is unintentional; it is, in Schon's words, "unintended consequences and qualities" to the previous move (Schon & Wiggins, 1992, p. 141).

- Goldschmidt's dialectical model of figure – concept

Goldschmidt defines designing within visual thinking framework as:

"Designing entails generating, transforming, and refining images of different aspects of that still non-existent artefact and making representations of it which enable communication and examination of the ideas involved, the purpose of designing is to produce visual representations of the designed entity, in which its construction could be enabled through the completion and coherence of these representations."

(Goldschmidt, 1991, p. 125)

In this definition Goldschmidt considers that the construction of representations while sketching is dealing with the specifications of the artefact, which are in her terms "the different aspects of the artefact". This process goes through a process of transformation and refinement of the representations that have been produced.

Goldschmidt is concerned with the kind of reasoning employed while making these representations through sketching. In this aspect, she argues that the mental images are the result of both pictorial and descriptive information. While pictorial information deals with particular properties that give things particular features, the descriptive information deals with the generic qualities and rules without giving things specific features. There are two kinds of arguments contributing to the construction of representations, namely; "seeing as" and "seeing that". Goldschmidt defines them as follows: "the designer is "seeing as" when he or she is using figural, or "Gestalt" argumentation while sketch-thinking. In comparison, when "seeing that", the designer advances non-figural arguments pertaining to the entity that is being designed" (Goldschmidt, 1991, p. 131).

She believes that physical representations under construction exploit these two modalities otherwise it is unlikely to achieve a result by translating the particular qualities to generic only. When sketching, these operations are repeated back and forth into a number of cycles that could help in achieving a good fit between the components of the created entity through a sequence of transformations (Goldschmidt, 1991, pp. 138-139).

2.5.2. Interpretation in visual thinking and the problem of fixation

Fixation could occur when solving any kind of problem including design problems; it can affect the process of remembering things and generating innovative designs. The fixation on the initial ideas, thoughts and solutions is the usual kind of fixation, it can occur also when designers use previous design examples or physical prototypes to overcome the limited cognitive capacity (Youmans, 2011, p. 117).

Finke sees that prior knowledge is often involved in structuring the creative imagination. He referred to his work (Finke, 1995) and to other studies on imagination; (Ward, 1994); and (Smith, Ward, & Schumacher, 1993). In his study (1995) subjects were asked to imagine an alien creature or create a new design for a toy. The results emerge with findings that there are tendencies toward creating new structures according to familiar forms, typical features of familiar categories or recently seen examples (Finke, 1996, p. 389). The tendency towards a fixation on recent examples or ideas could happen unconsciously, because the storage system of human memory is associative:

> "Humans' associative memory systems store information, via associative networks of interconnected concepts, in ways that make recently-activated concepts more likely to be retrieved"
>
> (Youmans, 2011, p. 117)

Accordingly, it is easy to understand the fixation on initial ideas or features that might occur in reinterpreting the drawing. In this sense, Van der Lugt is concerned with how to get variant ideas by sketching. He classifies the activities in the creative problem solving stage of idea-finding into two phases: the divergent phase that focuses on idea production and convergent phase of idea evaluation. In his study, Van der Lugt developed the divergent phase, by using Finke, Ward and Smith model of creativity "the Geneplore", into a cycle of generative and interpretative operations.

Van der Lugt (2003) found that sketching encourages the repeated cycle of generation-interpretation when used as a medium for what he calls a sketch-storming technique. The importance of his findings can be summed up in two points:

- Interpretation helps in producing interconnected ideas, which means that interpretation, is conducive to ideas with a low degree of variety. This is due to the process of producing ideas when sketching by reflecting on what has been already drawn and then interpreting it. In other words, the earlier idea is interpreted to produce the next idea. In order to be effective designers have to "find clues or directions" for generating further ideas rather than developing the early ideas (Van der Lugt, 2003, p. 279)
- The creativity of the sketching process lies in the interpretation phase of the generation-interpretation cycle. Designers reflect immediately on their drawings and interpret them, this is essential in visual thinking while sketching. Accordingly, the prolongation of the divergent phase by delaying the "total" evaluation for the generated combinations seems to be impossible. Instead, the loop of generation-interpretation-evaluation takes place several times while sketching. This suggests that the designer constructs combinations or design representations and evaluates them immediately. The notion of producing several combinations and design representations then selecting one of them does not describe the real situation of producing ideas while drawing (Van der Lugt, 2003, p. 279).

These findings reveal that although interpretation can help in producing ideas, it also could cause fixation on one idea. The immediate reflection on what the designer sees in the drawings and how he interprets it is the distinct property of visual thinking while drawing. The discussion of the cognitive operations and producing ideas, in this section and previous sections, reveals that the problem of fixation on one idea can be caused by performing a cognitive operation: the early framing of design problems and the interpretation of design drawing while visual thinking. These two operations can play a dual role. The early jump to a tentative solution to framing the problem is an essential step in the generation of design ideas; however, this early jump might cause a fixation on the early frame. To solve this problem, researchers recommend reframing the problem. Similarly, interpreting the drawings is essential for generating design ideas while sketching; however, reinterpretation can produce interconnected ideas causing some kind of fixation and attachment to the early idea.

2.6. Chapter Summary

The first objective of this thesis is to build the theoretical framework about the relationship between the characteristics of the sketching process using the computer as a medium and the process of generating design ideas. This chapter contributed in achieving the first stage and part of the second stage of building this theoretical framework. The chapter consisted of two parts; the following are the conclusions of the two parts:

- Section 2.2 has presented Finke's cognitive creative model and its development by Van der Lugt in section 2.5 to explain the process of producing ideas. This model consists of two phases: first, the divergent phase that is the generation and interpretation of ideas. The second is the convergent phase that is the evaluation of ideas. Visser introduces her model of generation, transformation, and evaluation. These models show that the processes of generation and transformation through interpretation are the main cognitive activities that are involved in producing ideas. They form an iterative cycle that produces combinations of representations. The two processes (generation and transformation) could be either mental or external processes. When dealing with the process mentally, that is to think visually; the imagery process consists of capturing visual images from the visual environment around us to build a long term memory by constructing mental traces of what is seen. These mental traces are abstract and generic patterns. When solving a task by visual thinking, the eye seeks for a pattern that fulfils the requirements of the task in hand. It seems that the emergence of such a pattern needs to evoke one of the memory's mental "traces", which becomes visible and sharper by altering some parts of it -without losing the percept- to fit with the new requirements of the task in hand. Altering the pattern becomes necessary since the invoked mental trace is a pattern that can take any related shape. This altering causes a shift in the structure of the given problem by capturing an outer different structure. When dealing with external presentations, that is, dealing with visual thinking while drawing, instead of invoking mental traces from the memory, the sketches become the memory ‘annexe’ and provide the designer with visible images. Here, interpretation of design drawings and visual thinking are coherent. Interpretation is essential in generating design ideas where the transformation process implies the reinterpretation of the initial representation at different levels to construct what Visser calls intermediate representations. To construct these representations, according to Schon, Goel, Visser, and Cross, the designer suggests something that defines part of the problem then this part frames and formulates the design problem and structures the whole design situation. When sketching, the process of framing can become iterative as the designer adds a mark to the drawing and reads the situation from a point of view relative to the change caused by the new mark; the designer looks at the drawing from another domain. Then this domain becomes the new generator and reframes the whole situation. This is what Schon calls the reframing and restructuring of the design problem.

- The second part focused on visual thinking and how imagining takes place through sketching. The available knowledge turns around one big issue; that is, capturing more clues and interpreting them.

The related hand sketching studies provide the framework with information moving in two directions:

1. The characteristics of the sketching process that can provide more clues

The sketching process consists of integrated system of operations between the “mind’s eye”, the hand and the drawings. The effectiveness of the system can be supported by two characteristics:

- The ambiguity of the drawings can supply the drawing with more clues, which may trigger something that has a meaning in the mind and contribute to generating new ideas.

- The flexibility of the sketching process keeps the pace of rapid and frequent change of the images:
  - It can keep the dynamic display of the images, which can in turn increase the possibility of seeing more clues by updating the mind with necessary new information.
  - It provides easy access to the work and easy modification to the drawings by the process of layering using tracing paper.

2. The interpretation and capturing of the clues

   The available studies provide the framework with information in three directions.

   - Capturing the clues by reading the drawings from another domain can cause the transformation of the design ideas. This is the mechanism of transforming the design idea through the interpretation; Schon focused on reading the drawings from a domain other than the intended one.
   - The content that the transformational interpretation deals with. Goldschmidt identified the two modalities of 'seeing as' and 'seeing that' to take place; reading the drawings as figures and reading them as basic rules. These readings imply:
     - reading the content of the mark: as geometric shapes and forms, as "Gestalt" forms, and as functional contents.
     - reading the mark in relation to the context and the other elements.

     It has to be clear that reading these marks depends on the ability of the designer in capturing clues, the designer's experience and background.
   - The quality of the generated ideas

     Van der Lugt introduced the coherent problem of reinterpretation that is the generation of interconnected ideas. Dialogical interpretation while sketching may produce interconnected ideas with less variety. The discovery of new patterns and clues can solve the problem and lead to lateral transformation. Keeping the pace of change in images is suggested to be the key issue in discovering new clues and patterns.

3. The use of the computer and the productivity of the conceptual design phase

This chapter achieves the final stages of building the theoretical framework of the relationship between using the computer and the productivity of the conceptual stage of design. This requires two things:

- to represent the characteristics of the computer involved in the generation process
- to identify the indicators of the productivity of conceptual stage of design

Drawing on the conclusions of chapter two, the final stage of the theoretical framework will be presented.

3.1. The characteristics of the sketching process using the computer

The majority of design studies believe that traditional hand drawings are the most effective medium for generating ideas. The previous chapter showed that the visual field of the dynamic display of drawings provided by the sketching process is the key issue of the idea-generation process using hand sketching as the medium. Accordingly, any tool or medium that can provide such an environment of dynamic display is supposed to be effective and helpful, as long as it can support the availability of more clues. The dynamic display of images updates the information and allows the designer to find clues and new issues in the drawings. The efficiency of this process depends on two factors:

- the ambiguity of the drawing, which allows more readings and provides the potential to find more clues.

- the rapid pace of the change in the images which causes the dynamic field of images, in which the easy creation of the objects, the easy change and manipulation and finally the easy access to the drawing materials are the fundamental factors of keeping this pace.

These two factors are the key issues that support the discovery of new patterns in the process of thinking using hand sketching. They facilitate the lateral transformation of ideas and thus support the generation of more variant ideas. In this section, the characteristics of the sketching process using the computer will be displayed in the light of these two factors. The aim is to extract the possible inherent potential of the characteristics of sketching using the computer that might affect the generation of design ideas.

In chapter one, the empirical studies of using the computer as a medium in the conceptual design phase have been reviewed. The specific characteristics of the current CAD system that can affect the process of producing the design ideas have been detected. These are:

- the low degree of the ambiguity of the graphical digital mark itself reduces the possibility of the multiple readings in comparison to the hand drawings (Goel, 1995; Stones & Cassidy 2010).
- the complex interface of the computer may hamper the instant transformation of the conceptual idea on the computer screen (Zhu, Dorta & De Paoli, 2007); it is a "multi step" process where designers have to follow special drawing orders and commands.
- as the designer is not in direct contact with his materials, working within the environment of the current CAD system does not support keeping "a global view" of the whole work (Zhu, Dorta & De Paoli, 2007).
- the capability of visualization, the computer's power of making immediate 3D images of the drawings, may improve the imagination (Bilda & Demirkan 2003; Won 2001; Hanna &Barber 2001; Marx 2000).

While some of the above characteristics (the low degree of the ambiguity of the digital mark and the complex interface) have been presented as barriers against using the computer in the conceptual phase, it has been suggested that the power of visualization plays a positive role in improving the designers' imagination.

Aspects of these characteristics will be discussed more widely, and each one of them is going to be scanned in the light of the framework of the effective process of hand sketching. In the discussion of every aspect, two steps will be taken:

- present the characteristics of the hand sketching that influence the idea-generation process.
- present the computer drawing facilities and characteristics that can play the same role as in hand sketching.

At this point, it has to be clear that the effective process of sketching using paper and pencil is not determinately similar to that of the computer since the two are very different. That means a positive point in the sketching process could be achieved in different ways in each of them. Accordingly, the following paragraphs are attempts to extract these different ways of achieving the same aim in these two different worlds.

3.1.1. Ambiguity and the characteristics of the computer's drawing

The empirical studies reviewed in chapter one found that the digital mark, which is supposed to be lacking in the required degree of ambiguity, can be interpreted (Stones & Cassidy, 2010), (Goel, 1995). Although this reinterpretation did not lead to new design proposals, the digital mark can be seen as something else.

These studies defined the graphical ambiguity in terms of the degree of the irregularity and the imprecision of the produced drawing lines. However, other studies suggest that the ambiguity of the computer could be seen from a view other than the ambiguity of the lines. Herbert (1993) sees that the computer's techniques and options of a dynamic rather than a static representation can provide various kinds of ambiguity beyond the potentials of paper and pencil. For example, the zooming options, dynamic overlay, and the unorthodox views or impossible projections can produce ambiguous images (Herbert, 1993, p. 121). This can enrich the field of vision with images that cannot be displayed with the static means of paper and pencil. He also considers the medium that is capable of producing irregular or uneven figures and shapes is a medium of a graphical ambiguity. In this sense he gives ambiguity another dimension, suggesting that the computer's power of representation can set up various irregular overlays of shapes, lines and spaces (Herbert, 1993, p. 120). Coyne, Park & Wiszniewsky (2000) looked at the ambiguity of the computer's drawing environment in terms of its "surrealistic" images, suggesting that the computer can produce strange images. Drawing on Breton's surrealistic view of getting the unfamiliar from familiar[15], drawing by computers can produce unfamiliar views of familiar objects and forms. One of the examples was from some observations of students' work where the computer changed the scale of the drawings accidentally while the student was trying to insert a "chair" in a three dimensional modelling of a "cafe". The building disappeared because of the over zooming scale of the chair. This gave a strange appearance and also a strange feeling toward the whole situation (Coyne, Park, & Wiszniewski, 2000, p. 58). In this context, McLachlan & Coyne suggested that the computer's accidental moves can enrich the design conceptualization by creating "spatial configurations", which otherwise remain hidden (McLachlan & Coyne, 2001, p. 98).

These views give another dimension to the ambiguity of the computer; it is the ambiguity of the images and the overall appearance of the content of the drawings rather than the quality of the lines that matters. It could be achieved only through the power of visualization and the dynamic display of the objects when using the computer.

3.1.2. Flexibility of the sketching process and the characteristics of the computer

The complex interface of the CAAD system has been presented as a barrier that may hinder the immediate transformation of the conceptual idea. This transformation demands a flexible and easy creation process for the design objects and the drawings on the computer's screen. It also demands an easy way to modify and manipulate the drawings.

[15] See (Finkelstein, 1979). Finkelstein, Haim N. 1979. *Surrealism and crisis of the object*. Haim N. Finkelstein.

It has been mentioned earlier that the power of visual thinking by hand sketching lies in the ability of the medium to keep the pace of displaying the changing images to create a dynamic field of images. Therefore, sketching by using the computer should be flexible enough to support, first, the representation of the idea on the computer's screen, and second the manipulation and modification of the drawing. The sketching tool should also support the holistic view of the design work by supporting the accessibility to design materials. The discussion of these aspects is as follows.

First- the representation of the conceptual idea on the screen

It is suggested that the complex interface of CAD controls and conditions the transformation of the idea. The designer has to follow steps to construct design digital objects, which might hinder the speed needed for the immediate response. This problem could be considered as an input technical problem. It could be regarded as pertaining to the input device (the mouse) or to the built-in strategy of the software for constructing the objects. The designer has to follow a step-by-step strategy in order to construct the design objects and elements.

However, it could be said that the impact of the technical problem could be reduced, if the user is highly skilled in using the software. It is a matter of convention and experience; people who use the software intensively in their work can have their own fast strategies for building the most complicated forms.

It is also suggested that the complex interface of CAD may cause another problem; the CAD cannot cope with the vague idea in the conceptual phase. It can also be related to the technical requirements of the input process and the built-in strategy of the software for creating and constructing the objects and design elements. In the conceptual phase brevity in executing the drawings is needed, not only to facilitate the required speed of the change in images, but also to cope with the vague information about the ideas that the designers have at this stage. The construction of design objects using the computer demands precise information about the size, shape and the scale of the objects that represent the idea.

However, it could be said that this problem may face the designer even during hand sketching; designers work within approximate rough sizes, shapes and scales of the objects to solve this problem. It has to be said that the current 3D modelling potential of CAD systems is more flexible in coping with this problem. Some of the currently available CAD systems such as 3D Max, Maya, Sketchup, Rhino, among others, are considered to be more flexible in constructing rough 3D modelling than, for example, Auto-CAD or Archi-CAD, which demand more precise information. The built-in strategies for constructing the objects using the 3D CAD systems enable the designer to start from the rough 3D modelling, then precise 2D plans, sections and elevations could be projected immediately. Again, this also depends on the designer's experience, skill and his/her own strategy for using that software.

To express the conceptual ideas, designers draw plans, sections or 3D forms that represent their ideas. Designers, to some degree, are keen to express their ideas using three dimensional forms. In this sense, the power of visualizing rough objects in 3D modelling CAD systems can be considered as an effective means to facilitate these requirements in early design stages. These systems can provide the designer with free tools to shape, carve and sculpt the objects and create more free forms. The immediate techniques of morphing and sculpting, for example, the pull and push techniques, can improve the speed that is required for the construction of the most complicated forms.

Second- the manipulation and modification of the created objects

Once the design objects and elements are drawn on the screen of the computer, it is very easy to maintain the rapid change of the images of the drawings. Here, it has to be clear that thinking with hand drawings differs from thinking with digital sketching in an essential point. The modification of the hand drawings can be achieved by overlaying strips of tracing layers which demands redrawing the design contents every time; it is a kind of recreation of the objects. In comparison, changing the computer's drawings takes place on the same drawing: designers do not have to regenerate the objects. The dynamic representation for the same modified objects keeps the pace of the continuous display of the design images through the step-by-step production process. These two terms- step-by-step production and the dynamic representation- have to be explained.

In describing the process of creating the dynamic displays using the hand drawings, it is obvious that the manipulation and modification of the drawing are essential in keeping the pace of the dynamic display. The step-by-step changes to the drawings, which are called the "incremental refinements", can allow the designers to find more clues in their drawings. Manipulating and modifying the drawing may facilitate the discovery of clues by keeping the representation of the new modified images. Herbert (1993) asserts the role of the incremental refinement in providing new "issues".

Drawing on this description it could be said that keeping the pace of continuous display of the images when carrying out the incremental refinement can be seen in many aspects of the CAD system. It is either due to the step by step changes in the drawing and the immediate feedback, or it is due to the "dynamic representation" of the same digital object. This term "dynamic representation" is firstly used by Herbert to refer to "a dynamic and deliberately fuzzed replay of a series of incremental refinements" (Herbert, 1993, p. 121). This term is going to be used in this study to refer to the continuous display of the images of the digital objects, in which a whole or partial change in the characteristics of the objects takes place. In other words, the dynamic representation refers to the unsteady display of images by moving from one state to another of the "same" digital objects without making any change to the content of the objects. Accordingly, the aspects of the continuous display of the images are either due to the change in the contents of the objects or due to the dynamic representation. These include:

- the change of the object's status, which is classified into two categories.
    - The change of the forms of the digital objects themselves; this can be achieved by the common step-by-step development of the work. The current 3D modelling CAD systems are exclusively designed to support the processes of manipulation and modification (add, subtract, copy, cut, twist, etc). While the strips of tracing paper are the flexible tools that allow these processes in hand drawings, the CAD system provides the designer with several options and commands, which enable direct, immediate change. This immediate feedback can keep the pace of change in the drawing.

It is obvious from the description of this characteristic that the kind of change is not due to the dynamic representation but rather it is regarded as changing the content of the objects and the step by step development of the forms.

- The change of the appearance of the digital objects. The CAD system is capable of changing the images of the digital objects by moving from one appearance to another. For example, the change from solid to mesh state (which can give the objects a transparency); the change from 2D (plan, section, elevation) to 3D (axonometric and perspective); the change from the interior to exterior view. These kinds of changes can help not only in finding the clues by encouraging "Gestalt" readings of the drawings (Gestalt as a word means configuration, that is to see features in a drawing, more explanation will be given later in this chapter), but also facilitate the flow of thoughts by providing "better understanding of the building form and spaces" as Hanna & Barber assumed. They also suggested that these moves can be considered as a kind of "3D shaded walkthrough", which can be closer to "a kinaesthetic experience of walking through the building" (Hanna & Barber, 2001, p. 265).

• the change of the position of the object by changing the viewer's position to look at the drawing from another point of view. This change includes:

  - the change due to the "turning" around the object; it is the change of the position of the viewer which causes the change in the position of the captured images of the designed objects. It also can occur by moving and turning the objects themselves. The current CAD system allows this kind of change in images by an easy movement of the mouse. This can provide more "Gestalt" readings of the objects and may provide better understanding of the whole building form and spaces by checking the appearances.

- the change due to zooming by focusing either on the part or the whole object; this is the move from the part to the whole and vice versa (whole-part, part-whole). It can facilitate the move from the whole designed objects to their parts. The move from part to the whole and the whole to the whole can be achieved by the zoom onto the designed objects from varying distances. Although the zooming itself cannot give detailed information, this kind of move facilitates the understanding of the parts of the building's spaces within the whole design proposal. It can be mixed with walking and turning around the drawings.

These two factors (changing due to turning around the drawn objects and the change due to zooming) could be put under the title "change due to navigation". These changes are concerned with the dichotomy of "part-whole". The need to move from whole to parts reveals in some of its aspects the nature of the design process in solving design problems, which demands, in Coyne's view, an understanding of the "whole and parts of a design at once" of which design is the process of breaking the problem into parts (Coyne et al., 2000, p. 8).

Third- Accessibility to the design materials and drawings

This issue can be explained by focusing into two directions.

The first, the rapid access to drawings and making the immediate change to the drawings is what hand drawing can provide through the use of layers of tracing papers. The easy access to design drawings can support the fluency of thought and improve visual thinking by conserving the time required for achieving the changes. The key issue here is to be in direct touch with the drawings, the drawings are accessible.

In comparison, designers cannot be in direct touch with their digital drawings. However, the computer provides some facilities that can improve the situation. Constructing, developing and refining the digital drawings can be achieved on the same drawing rather than generating copies, and the feedback comes immediately. This can save thinking time as the computer suggests the new look of the forms. This process has one defect, which is that it may cause the loss of some previous drawings and thoughts. However, the power of the computer in saving design images can solve this problem. The computer provides an effective storage for the designer's drawings and thoughts, and can be easily accessed.

The second, access to the design drawings at any given moment can be achieved easily. Once the 3D modelling is constructed, it is very easy to get the plans, sections, elevations, which can be displayed individually or together on one screen. Here, the layout arrangement of the screen interface is the factor affecting the speed of the accessibility to all design drawings; the flexible arrangement can increase the opportunity to have an overall view of the whole work. Current CAD systems allow the concurrent display (real time display) of design objects from different views (plan, section, elevation, and perspective) in one screen. Moreover, any change in one of the drawings can be seen immediately in the other drawings. It also allows the layering and scrolling of these different views, which may improve the overall view rather than the partial views of the design.

In this context, the questionnaire of the study by Zhu, Dorta & De Paoli (2007) to the professional designers led to the suggestion that working with the computer may hinder the "global" view and focus on only part of the design work. This problem may be regarded as emanating from the degree of accessibility to the design materials, or it may be regarded as a common problem of thinking with drawings in general. As for the former, it demonstrates the need to grasp the whole work and the parts. Lawson noticed that most professional designers prefer to work on small size paper. Designers keep control on their projects by keeping all of the drawings in their sight. That is because of the limited capacity of the short term memory (Lawson, 2004, p. 57). The matter in point here is the degree to which the designing tool can support the display of the all design drawings.

As for the latter, Lawson refers to several "drawing traps" into which the designer falls; one of them is the "image trap" where the designer designs the drawing rather than the goal object. Instead of designing the information that stands behind the drawings or the object that the drawing represents, it ends up designing the drawing itself. Lawson also sees the danger of the drawings lies in the conventions related to that kind of drawing; it may constrain the designer's vision of the problem. That is because different kinds of drawings can lead to different design problems. Moreover, the drawings can only represent part of the features of the design objects; the characteristics of that kind of drawing might weaken or strengthen some features over others (Lawson, 2004, pp. 57-58). All of these views suggest that drawings in general might lead the designer to focus on the parts of the design work that the drawings represent.

From the above, it is obvious that this characteristic of the easy and rapid access to design drawings focuses on the ability to provide a holistic view of the work. Gathering the drawings that express the idea into one screen facilitates understanding and supports the fluency of thought.

To sum up

In the light of the studies of hand drawings, the extracted characteristics of the sketching process have been used to deduce the characteristics of the sketching process using the computer, which are involved in the process of producing design ideas. The available studies on computer use are used to support these attempts of deducing the sketching characteristics of the computer as factors affecting the generation of design ideas.

These attempts have led to new views of some aspects of the distinctive characteristics of the sketching process using the computer. These are:

- the visualization is given new dimensions; it is not the mere move from 2D to 3D of the designed spaces or simply giving them some features and appearances. The power of the computer to allow immediate visualization strengthens its ability to dynamically present and display variant design images of the designed objects. This can help not only in updating the short term memory with new variant images and thus new clues, but it also suggests a new view of the issue of ambiguity. The possible accidents occurring in the dynamic representation and unordinary projections may result in strange images that could trigger some ideas.

- the navigation around the designed objects (or turning of the objects themselves) and changing their status by changing their appearance are an inherent possibility in the dynamic representation. They can support the intensive exposure to the visualized spaces and get immediate feedback. These two factors enlarge the scope of visualization; they bring to light new aspects of the possibilities of changing the images and updating the visual memory. Navigation around designed objects is a distinctive facility that distinguishes the drawing environment of the computer, which cannot be found in paper and pencil drawings. It could be said that navigation is a specific feature of visualization in the conceptual stage of the digital environment.
- the change in the images due to the change in the content of the drawings and the form of the designed objects is the result of implementing design ideas and suggestions, whereas the change in status due to the change in appearance and the change in the position due to navigation often occur as attempts to search for new patterns of relationships among the design elements and components, or to check the appearance of the forms and spaces after being created or manipulated. This has been pointed out by Bilda and Demirkan in their study as intensive exposure to the visualized spaces (Bilda & Demirkan, 2003); it implies a kind of evaluation and judgment.
- the seeing-moving-seeing model of Schon's dialogue can be explained within this perspective of the different kinds of changes of images while drawing by using the computer. While the first "seeing" is the discovery of a new pattern or suggesting a new issue, the "moving" represents the implementation of the discovered pattern or idea where the change in the image takes place due to the change in the form.. The second "seeing" in the modality is the checking of the appearance of the created forms and spaces, the evaluation of these appearances and the searching for new clues. The two "seeings" are the moments of thinking and contemplating. The difference between hand sketching and sketching by computer in these two "Seeings" lies in the fact that the dynamic representation of the computer drawings takes place and can

support both the search for new patterns and the evaluation of these patterns by adding a further dimension to the process of displaying that is the dynamic display. In comparison, the traditional paper sketches are static representations and lack this power of dynamic representation. The power of hand sketching depends only on keeping the pace of changing the content of the drawings, whereas in using the computer, the suggestion here is that the power of digital sketching depends on keeping the pace of changing the content by keeping the pace of the dynamic display due to both changing the appearance and position.

This dynamic display can improve the design thinking by increasing the chances of seeing more clues in the drawings. The designer may suggest more things, take more actions and decisions, and make more modifications and manipulations because of this additional seeing. In other words, the additional seeing of dynamic display does not only support the direct search for new patterns and issues but also it contributes indirectly to providing more chances for the creation of these patterns. It might encourage more "moving" or the step-by-step development of the design drawings thus increasing the chances of finding new clues and issues.

Looking at the subject from this last perspective suggests that more navigation and more changes in appearance can encourage more moves and actions thus causing more changes in the content of the drawings to take place. So the whole story here is about dynamic representation, it is the mechanism that can encourage the step-by-step development or the incremental refinement. This may keep the rapid and frequent change in the contents of the drawings and thus increases the possibility of discovering new patterns.

- there are two kinds of navigation: the first one is the active navigation that takes place during the second "Seeing" of the "Seeing-Moving-Seeing", the second one is the "background navigation" that takes place during the "Moving", in which the implementation of the idea takes place.

- the diagram below is drawn to illustrate these three kinds of changes in images, and followed by explanation of the role of each kind of change, Figure 3.1.

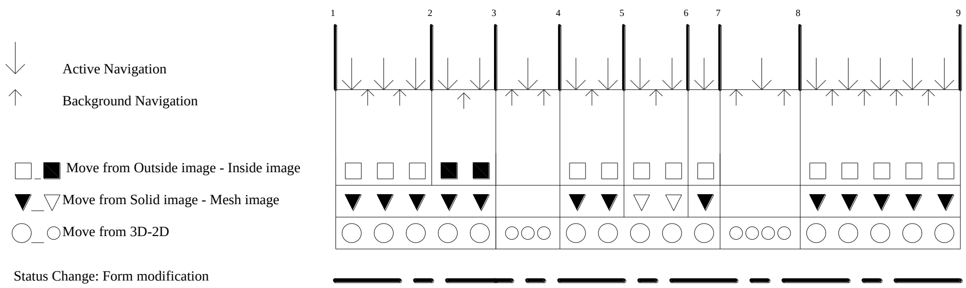

Figure 3.1: Diagram of kinds of changes in the computer's displayed images

This diagram shows the kinds of changes in the displayed images of the designed objects that take place in sketching by using the computer. Starting from the base, the change in the form (the dotted line) is the common step-by-step change that takes place while modifying and manipulating the forms. Then the change in the status due to the change in the appearance (the move from outside images to inside images, the move from solid state of the designed objects to mesh state, and the move from two dimensional drawings to three dimensional drawings 2D-3D) comes second. And finally, the change in the position of the drawn images due to the navigation around the objects is illustrated at the top. The numbers (1-9) illustrate the number of times that the change in status takes place. This is sensitive to any kind of the above changes.

It has been mentioned earlier that the change in the form takes place as a step-by-step change when the designer deals with the forms to implement his/her ideas and decisions, in comparison with the change in the position and appearance take place when searching for new clues or checking and evaluate the appearance of the forms and spaces; they represent the period of contemplation.

Accordingly, the changes due to (the appearance & the navigation) could be described as additional changes, which are regarded as arising from the power of the computer in dynamic presentation and immediate visualization. So the upper part of the diagram is specific to the power of the computer as the medium of sketching. The other media (hand sketching and physical models) do not have this power. Although the physical model can provide the active navigation, it provides neither the background navigation nor the change in appearance. Therefore this study is concerned with these two kinds of change to bring light to their extraordinary role and how they work.

It is obvious from the diagram that these two kinds of changes can take place at the same time/simultaneously, which means that the navigation can take place while the objects, for instance, are in solid or mesh state, and also they could be seen from inside or outside. The importance of this point could be explained by explaining the effective role of changing the appearance of the images. The expected role of changing the appearance in increasing the visual cognition can be explained in two ways:

- from the designing point of view and dealing with the content of the drawings, the designer uses the various displayed views (the section, the plan and then changes the view to 3D modelling) in order to solve some problems or implement an idea that can be expressed well by using only the section or only the 3D modelling. Designers may also choose to change the state of the objects to wireframes (mesh) to be more transparent and capable of providing images from the inside and the outside of the objects at the same time. Then they may return to the solid state to check the materials and the overall appearance. The same thing could be said in choosing to work with the interior space or the exterior space.

  The cognition may be improved by this frequent change of the appearance where navigation can take place in all of the various states of the appearances.

- from the visual cognition point of view and dealing with the “Gestalt” images of the geometrical drawings, the studies of perceptual and visual thinking affirm the effect of the sudden change in images (by moving from one image to another, different image) on cognition and perception. The vision is selective therefore organisms are more sensitive and interested in the change in the environmental setting. The field of vision that has irregular factors, e.g., changes in shape, size, colour is more effective in capturing the human attention. Therefore the mobile features in a steady environment or a changing rhythm of mobility in a mobile environment are better in capturing the attention. It is a matter of adaptation that hinders the attention by time. Cognitive psychologists assert that the repeated stimulus stops the reaction; the immobile objects as well as the mobile objects that repeat actions over and over persistently lack the change (Arnheim, 1970, p. 19). Thus varying the images can help in capturing the attention towards new patterns and clues, and may improve the imagination.

Accordingly, the repeated navigation around the same objects several times may not achieve the desired results because of this adaptation. Although the change in images takes place due to navigation, the change may be more effective if frequent sudden change in appearance takes place, which causes the change in the rhythm of change.

- the factor of the provision of the holistic view to the work has been defined through the use of different ways of presenting and displaying design drawings (plan, section, elevation, isometric, among others). This factor is not specific to the conceptual stage; it could be also an important factor in other stages of the design process. However, in the conceptual process designers need to present their ideas in different ways of graphical representation, for instance some ideas need to be expressed through the section rather than the isometric. Designers also need to test the practicality of their ideas, in order to solve some problems that should be presented in plans, sections, elevations, and 3D drawings. Consequently, designers need to be in touch with all of the design materials in order to have a holistic view of the work.
- the characteristics of the sketching process using the computer, which might affect the generation of design ideas, have been deduced. They include:

1. the ambiguity of the drawings, which is due to:
   - types of the lines
   - the content of the images (snapshots), it indicates the degree of strangeness of the images and the content of the drawings.
2. the continuity of the dynamic field of images, which depends on:
   - the flexibility of forming images
     - The ease in projecting design images, which indicates the flexibility of constructing shapes and forms on the computer's screen.
     - The continuity of displaying images, which is due to the change in the object's status (the appearance) and the change in the object's position (the navigation).
   - The provision of a holistic view of the work, which indicates the accessibility to the design drawings, thus indicating the exposure to various parts of the work.

3.2. Productivity of conceptual design phase

To introduce the final stage of the theoretical framework of the relationship between the characteristics of the sketching process using the computer and the efficiency of the conceptual phase of design, the indicators of the productivity have to be identified.

Earlier in this thesis, the term productivity has been discussed. In chapter one, section 1.2, the theoretical studies refer to the effective use of any medium or device as a design tool either by evaluating its effect on the thinking and design behaviour, or evaluating the quality and the quantity of the product (design proposals and ideas). Since this study is concerned with the kind of cognitive operations that could be affected by the characteristics of the computer, it is quite logical to analyze the thinking that has been performed and to examine the process rather than the product.

The design literatures (Goldschmidt, 1991), (Kan & Gero, 2005a), (Van der Lugt, 2000) refer to the efficiency of the design process as the productivity of the process.

Goldschmidt sees that evaluating the process deals with evaluating the reasoning and the kind of thinking that lead to the productive process.

In the next section the definition of design productivity will be reviewed in some specific design studies that introduce measurements for the design productivity. This will be followed by a discussion of the suitability of using them to fulfil the purposes of the present study.

3.2.1. Evaluation of the productivity of design process in previous design studies

Goldschmidt claims that we can evaluate the effectiveness of the design process, if we evaluate the design reasoning. She identifies one of the characteristics of reasoning, which is that the cognitive system is economy minded (Goldschmidt, 2003, p. 53). She sees that the design reasoning achieves design proposals through moves; the move is "an act of reasoning that presents a coherent proposition pertaining to an entity that being designed" (Goldschmidt, 1992, p. 72). She also defines it as " a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" (Goldschmidt, 1995, p. 195).Thus the design process is a series of moves and linkages and the effective reasoning should achieve proposals with little waste in moves (Goldschmidt, 1992). The waste in moves is defined as those moves with no linkages to other moves or with a small number of links. The validity of this claim relies on the fact that designers build on their previous decisions; they minimize the waste by linking the moves they generate to previous moves in order to ensure that the best possible fit is achieved between the emerging design and criteria for its evaluation (Goldschmidt, 2003, p.53).

On these bases she developed a quantitative way for measuring the effectiveness of reasoning. Effective design reasoning should achieve a high proportion of interlinked moves. She considers the high ratio of links as an indicator of a fruitful process of design reasoning. The productivity of the design process could be assessed through calculating the ratio of links to the moves, which is called the link index (L.I) (Goldschmidt, 2003, p. 56). To investigate this, Goldschmidt developed a system of representation which can record design moves and the links among them known as the linkography.

Kan and Gero developed Goldschmidt's way of measuring, arguing that the degree of interconnection of the movements should be within limits. The fully saturated linkages between moves do not provide an opportunity for the generation of different information. The basis of this argument is the information theory of Shannon: "the amount of information carried by a message or symbol is based on the probability of its outcome. If there is only one possible outcome, then there is no additional information because the outcome is known" (Kan & Gero, 2005b, p. 52). In this case all acts and moves are directed toward achieving that outcome and there is no space for the generation of different outcomes. Using Shannon's entropy equations, Kan and Gero[16] developed the entropy scale, which is a measurement for the potential to develop ideas. By using the linkography and the entropy scale the opportunity for producing surprise or a different outcome can be predicted.

On the other hand, Van der Lugt (Van der Lugt, 2000) developed the likography and Goldschmidt index in another direction. He was concerned with the characteristics of the design creative process. He developed the linkography to trace the generated ideas for determining the relationship between the characteristics of the connecting links and the quality of the outcome. Therefore he was concerned not only with the density of connections but also the quality of the links. He defined the links as kinds of transformation processes between the ideas they connect and categorized the links into three groups: the supplementary links which provide a small change between the earlier idea and the current idea; modification links which provide structural change; and Tangential links where no direct function of an earlier idea presents in the current idea (Van der Lugt, 2002, p. 46).

Since his study is concerned with using a creative technique for producing design ideas, which is called brainsketching, he adjusts the linkography to be applicable for the purposes of this technique. His empirical study outlined the fundamental

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[16] See also (Kan & Gero, 2005b) Entropy measurement of linkography in protocol studies of designing. In JS Gero and N Bonnardel (eds), Studying Designers '05, 2005 Key Centre of Design and Cognition, University of Sydney, pp 229-245, (Kan, Bilda, & Gero, 2006) Comparing entropy measure of idea links in design protocols. In J. Gero (ed), Design computing and cognition '06 (pp.265-284) , (Cai, Do, & Zimring, 2010). Extended linkography and distance sources in creative design evaluation: an empirical study of the dual effects of inspiration sources in creative design. *Design studies, 31*(2).

characteristics that define the creative process. He found that the integrated process is the process that has a high density of links where subjects build on each other's ideas using the technique of brainsketching, it also has a low density of links with someone's own ideas, and a balanced number of link type (Van der Lugt, 2002).

3.2.1.1. Discussion

The focus of these definitions was:

- Goldschmidt's definition works within the economical framework of the design process.
- Gero's development of the definition focuses on the process that provides more opportunities to generate different new information.
- Van der Lugt's definition is within the frame of the creative process.

These definitions give a base from which to start assessing the effectiveness of the design process. However, Goldschmidt's definition is specific as it concerned with the economy of reasoning. Moreover, it deals with the whole design process; it is not specific to the conceptual phase. As the goal of the present study is to determine the effect of the medium on producing ideas within the conceptual phase, the definition of productivity and the suggested scale should be more sensitive to all the circumstances that belong to the process of producing the ideas in which the medium plays an effective role. Gero's development gives more specific determinants than Goldschmidt's; it is still within the frame of the whole design process; it still focuses on the quantity rather than the quality or the kind of linkages. Finally, Van der Lugt's scale is within the conceptual design phase; however, it is developed to be suitable for using specific creative techniques, brainstorming and brainsketching, in creating ideas. The use of these techniques affects the nature of the conceptual phase as they focus on creating ideas by building on each other's ideas within a group meeting. Moreover, by using these techniques the conceptual phase becomes more clearly divided into the divergent phase of creating ideas and convergent phase of selecting one of these ideas. This division is not clear in creating ideas by someone's own attempts using the drawings without using these techniques. As a result the definition of the productivity within such a creative process is definitely different; it has to be suitable to such situations.

It is obvious that the three definitions cannot be used for achieving the purposes of the present study. Accordingly, in the following sections the definition of the productivity and its indicators in the conceptual design process will be identified to be more suitable for this study.

3.2.2. The indicators of productivity in the conceptual design process

The aim of this section is to reach a sufficient definition for the productivity that is capable of describing the indicators of the efficient design process in the conceptual phase rather than in the whole process. As the research problem of this study is to determine the relationship between the use of the computer as a medium for drawing and the productivity of the design process, the definition has to pay attention to the effect of the medium in general on producing design ideas, in other words, the definition has to be within the framework of producing design ideas using an external medium of representation.

Accordingly, this study is going to define the productivity of the design process in the conceptual stage through defining the cognitive operations and activities in which the medium plays an essential role. The related cognitive operations, inferred from the sketching studies in chapter two, will be exploited in defining the indicators of this productivity. This study presents the case that a process rich with these operations is productive. The existence of these specific operations during the sketching increases the likelihood of producing ideas. In chapter two, the cognitive operations have been extracted, these include: reframing, restructuring and reinterpretation. Framing is defined as the selection of features of a solution, to be the theme of an idea, which transforms the design situation. Putting the components of the problem within a selected frame is the definition of structuring a problem. Framing-reframing and structuring-restructuring have to take place several times when producing ideas to avoid fixation on early design ideas.

Reinterpretation expands the concept and the space of the design idea through performing the iterative activities of generation-transformation. Schon's reflective model and Goldschmidt's dialectic model show that the interpretation is iterative and reflexive in a dialogical manner. Under such circumstances, the cycles of what this study is going to call "the dialogical reinterpretation" become the generators for more ideas as the problem is always under construction and reconstruction: it is open ended. The reinterpretation could occur at different levels of this construction process.

However, during the sketching, reinterpretation could have a dual role. Van der Lugt clarified that reinterpretation can help in producing interconnected ideas, therefore the fixation on the initial idea could occur. Moreover, the flow of ideas during the dialogical cycle of generation-transformation might support vertical thinking in another way (that is to solve secondary problems within a main idea) rather than horizontal thinking (that is to give alternative main ideas and design proposals). These two kinds of thinking will be explained later in this chapter within the section on restructuring. Accordingly the definition of productivity through the occurrence of specific cognitive operations implies:

- the occurrence of the dialogical reinterpretation in the conceptual design phase is supposed to be an indicator for productivity achieved by solving the fixation on the initial idea and keeping the fluency of variant ideas.
- the occurrence of a complete cycle of dialogical reinterpretation. This is a completely effective performance of the dialogical reinterpretation. This is supposed to be an indicator for productivity achieved by solving the problem of moving vertically due to solving secondary problems.
- the operations of reframing and restructuring have to take place to solve these two problems of fixation.

Consequently, there are two main indicators for the productivity of the conceptual phase through the dialogical reinterpretation: the occurrence of dialogical reinterpretation and the occurrence of a complete cycle of dialogical reinterpretation.

To display these two indicators we first need to give a description of the types of dialogical reinterpretation that are experienced during sketching.

3.2.2.1. Types of the dialogical reinterpretation

To give a description of the types of the dialogical reinterpretation, two substantial qualities are going to be exploited in attempting to define them.

- The first is the characteristics of the dialogue since the process of reinterpreting the drawings is described as being dialogic.
- The second is the properties of the interpretation that plays a fundamental role in the transformation process between the physical representations (the drawings) and the mental representations (the visual mental image).

As for the former, the dialogical design models present the cognitive operations as reflective iterative reactions. In this sense, studies of the hermeneutic circle of understanding present the dialogue as a tool to reach a new understanding. Snodgrass and Coyne (2006), in their description of the nature of the established dialogue between the reader and the "written text", clarify that the structure of asking and answering a question is hermeneutic only when the question represents a case of preliminary seeing; the prior understanding of the reader/interpreter supplies the meaning of the text. The reader gets involved in a dialogue with the text, which means that there is a fusion of horizons of meanings that enables the reader to question the text. The study also clarifies that the openness to the text provides the "true conversation" and reveals the text itself (referring to Gadamer's description of the "genuine dialogue"; that is the dialogue for obtaining understanding). The dialogue with the text comes in a form of give and take; "to-and –fro" that proceeds in cycles to finally reach understanding. Saying that the text is asking or answering a question is an analogical use of the term to explain the case of involvement and that the communication has been achieved (Snodgrass & Coyne, 2006, pp. 42-43).

These descriptions are important to this study since the text could be "written" or "visual". They highlight four fundamental points:

- the pre-understanding of the reader formulates and directs the dialogue

- the dialogue proceeds and continues when the designer gets involved with the situation. The continuity of the structure of asking and answering indicates this involvement until understanding is reached.
- the openness to the text supports the continuity and reveals the latent dimensions of the text that leads to new understanding.
- thinking dialogically does not only mean being repetitive and reflective, but also being directed toward new understanding.

As for the properties of the reinterpretation process, Gestalt theory can provide the basis of the thinking style experienced in the reinterpretation as it concentrates on organizations and processes of perception and stresses the importance of the context of thought (Lawson, 2006, p. 134). Gestalt as a word means the "configuration", and being a psychological school of perception it is concerned with "pattern seeking" in human behaviour and organizations. The Gestalt perceptual principles and laws of visual thinking provide the base that explains the spatial organizations and the "tendency to group things" in a scientific way, therefore designers are interested in Gestalt visual principles (Graham, 2008, pp. 1-2). It is useful to exploit them in design not only to explain the structure of a visual image but also to discover its hidden pattern, which could be a structure that represents a figural form or a structure of inner relationships.

In the next paragraph, the levels and types of the dialogical reinterpretation will be explored by focusing on the design dialogical models.

3.2.2.2. Types of dialogical reinterpretation from the visual dialogical models

Earlier in this study, the dialogical models of Schon and Goldschmidt explain interpretation which is experienced while sketching. This section will go further to identify the different types of dialogical reinterpretation, answering questions about what to deal with as a content to be interpreted and how to reinterpret.

In Schon's dialogical model, the designer reframes the problem in accordance with a pattern discovered in the drawings. The discovery occurs by interpreting the drawing's entity (as a formal configuration or as content) through looking at it from a domain different to that intended while producing the drawing. The discovery takes place only when the designer reads more than simply what is being seen; this is the imagining process where receiving and thinking is taking place. The "unintentional discovery" represents one possible form among other forms of the "dialogical reinterpretation", which can fulfil various functions at different levels of the generation – transformation cycle while constructing the design representations. Here, a point has to be explained: it is the relationship between interpretation and transformation. The cycle of generation – transformation is the cycle of constructing design representations, and the transformation in these cases is the tool to achieve what is being interpreted.

In this sense**,** Goldschmidt in her dialectic model confirms the substantial role of reinterpretation in transforming design information from generic qualities: the conceptual descriptive qualities of the constructed representations, such as the linearity of the building, to specific qualities: the figural pictorial qualities of the representations such as the rectangular shape of the building.

While the figural quality of reasoning is to give a specific quality to the mental visual image, the conceptual quality of reasoning is to extract a generic rule from a given drawing. To explain the difference between the figural and the conceptual, Goldschmidt used an example from a recorded design protocol of a designer while drawing: the designer sees some parts of the walls in his drawings as being open by making them glazed walls. Then he sees that this opening can achieve the prolongation of the axis in the site (Goldschmidt, 1991, p. 138). It is obvious from this example that the specific figure of the open wall represents the figural argument and the prolongation of the axis is the extracted rule or the conceptual argument inferred by reading "the opening" in relation to the other elements in the context; the prolongation is the result of reading the opening in relation to other elements of the site. Goldschmidt argues that mental images are the result of interactive figural and conceptual images; construction of mental images implies "non-pictorial" and pictorial information. When sketching the transformation of pictorial /figural – descriptive /conceptual becomes alternative and there is no fixed pattern for this alternation.

Drawing on this understanding, the alternation can be imagined in these various possible ways:

- Figural representation- Conceptual representation
- Figural representation-Figural representation
- Conceptual representation-Conceptual representation
- Conceptual representation-Figural representation

Each of the above possibilities of dialogical reinterpretation (Figural – Conceptual, Figural – Figural, Conceptual – Conceptual, and Conceptual – Figural) represents a distinct kind of reinterpretation. Each requires transformational operations different from the other kinds and plays a different role in the crystallization and production of the idea. Accordingly, the existence of these types in the design process could indicate the occurrence of the dialogical reinterpretation at different levels and could represent the indicators of the productivity. The first two possibilities (Figural – Conceptual and Figural – Figural) could be presented under the title "pattern discovery", represent Schon's notion of the "pattern discovery". The Conceptual – Conceptual transformation could be presented under the title "conceptual reinterpretation". And the last one, Conceptual – Figural transformation, can be presented under the title "figural physical reinterpretation". While the first two represent the first seeing in the model of seeing-moving-seeing, the latter (figural physical reinterpretation) represents the "moving", that is the reinterpretation while doing, in which the mental image can have a specific form through drawing.

The total cycle of this transformational model can be developed in more detail taking into account the role of sketching in transforming the mental visual image into physical visual image. While sketching, the transformation from the mental visual images to physical visual images and vice versa takes place several times through the transformation of visual image from mind to paper and from paper to mind. Mental image, according to Visser (2006), is a vague idea or image that the designer has in mind. Chapter two clarifies that mental image in addition to being vague is also abstract. The transformation from mind to paper gives the mental image a particular appearance; this appearance in Goldschmidt's term is pictorial /figural. So, since drawings have specific properties of shape, orientation and size they are pictorial/ figural:

"Sketches are obviously pictorial, for they refer to shape and orientation, and often to approximate size even if they maintain a varying degree of abstractness."

(Goldschmidt, 1991, p. 131)

It is obvious from this description that the transformation of the image from mind to paper is a transformation to a state of figural physical image. Taking this fact into account, the cycles of dialogical reinterpretation can be imagined as in figure 3.2. The processes of transformation are hypothetical and the "steps" are not sequential, not linear and do not follow a specific order, rather they are continuous alternative cycles of mentally and physically making figural combinations and conceptual descriptions of representations. Figure 3.2 illustrates four possible cycles of alternations of figural and conceptual representations:

Figural physical – Conceptual mental

Conceptual mental – Figural physical

Figural physical – Figural mental

Figural Mental – Figural Physical

The Conceptual – Conceptual transformation does not appear in the diagram as it represents the case of using the same idea for a second time. This will be explained later in paragraph 3.2.2.3.2.

The process starts by discovering a pattern from a particular physical drawing, which represents the Figural physical – Conceptual mental transformation. This can happen by reading it in relation to the context to extract a generic quality and rule. In this way a visual mental image is constructed.

The next transformation occurs through sketching where the Conceptual mental-Figural physical transformation gives the constructed mental image a physical existence.

Then a pattern discovery could take place again through sketching. This transformation is a Figural physical – Figural mental transformation achieved by reading the design drawings in accordance with one of the Gestalt visual principles such as figure/ground, proximity, closure, similarity, and continuation. Consequently, a new visual image is constructed.

Then this mental image is transformed from mind to paper through sketching in order to give it a specific physical appearance. This is the figural mental - figural physical transformation.

In the following, these types of dialogical reinterpretation are going to be used in defining the indicators of the productivity of the conceptual design phase.

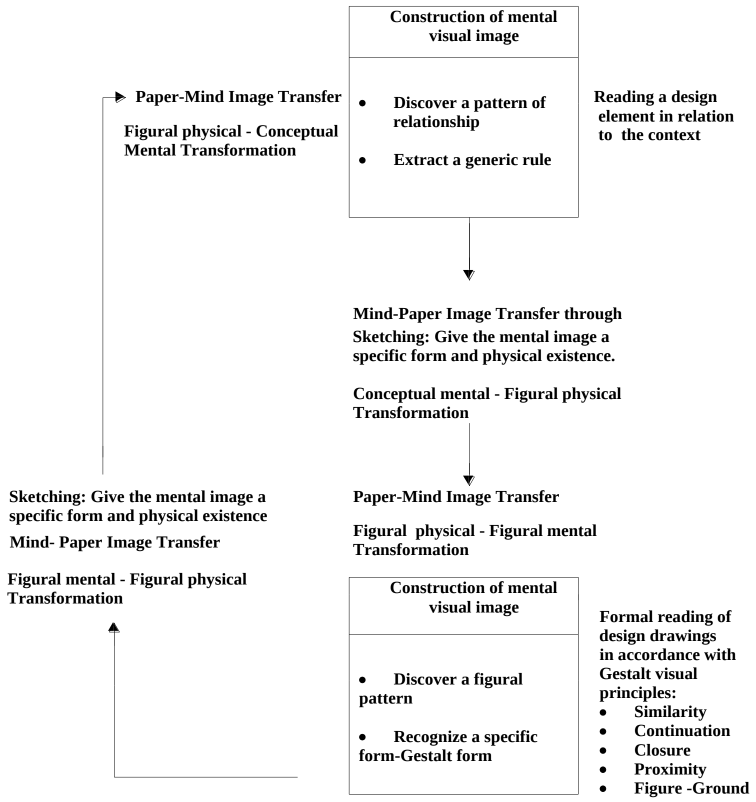


Figure 3.2: The hypothetical cycle of the transformational model of producing design ideas through sketching

3.2.2.3. The first indicator: The occurrence of the dialogical reinterpretation

The occurrence of dialogical reinterpretation can be defined in two ways:

- the occurrence of pattern discovery

- the occurrence of conceptual reinterpretation

In the following, a description will be given for each indicator using the properties of the dialogue and the reinterpretation within the Gestalt framework that has been described earlier in this chapter.

3.2.2.3.1. The occurrence of Pattern Discovery

Pattern discovery indicates the occurrence of the dialogue with the drawings by recognizing certain characteristics of physical figures and interpreting them by reading them from a domain other than their own. This can happen as a kind of appreciation the designer feels toward achieving his intention in a previous move and he starts to explain his drawing in another way by recognizing new patterns of relationships or forms. Following Gestalt theory, this pattern could refer to a unified structure, configuration, or layout which has the distinct properties of the whole, and is not simply the sum of the parts (Graham, 2008, p. 1). This pattern could be either a figural pattern or a pattern of relationships. The figural pattern is the Gestalt figure of seeing lines on a page as a spatial pattern (Schon & Wiggins, 1992, p. 145). It is a formal configuration that follows certain Gestalt formal grouping principles, such as figure/ground, proximity, closure, similarity, and continuation. For example, seeing the arrangement of the six classroom units, in Schon’s example (Schon & Wiggins, 1992), as a set of three large L shapes rather than six squares can help in describing the Gestalt figure. In this study we consider the figural pattern as related to formal properties of design drawings. The figural pattern can be a configuration that has a certain reference shape; this is what we call the “Gestalt form”, like seeing the L shape as a step. It also can be a configuration that has more than one reference or no certain shape; this is what we call the “formal pattern”, like describing something as being organic. The latter is more abstract than the former.

On the other hand, the pattern of the relationships is defined as the reading of a physical element in relation to other elements in the context of the drawing to induce the generic conceptual qualities or rules. While the discovery of figural pattern (Gestalt form and formal pattern) represents the figural (physical) – figural (mental) reinterpretation, the discovery of pattern of relationship represents the figural (physical) – conceptual (mental) reinterpretation. Both of them (figural pattern and conceptual pattern) are vague abstract mental visual representations extracted from a figural physical representation.

3.2.2.3.2. Conceptual reinterpretation

This indicates the continuity of the dialogue within the same frame or the primary generator. This continuity would reflect the involvement in the dialogue.

There are two possibilities for the conceptual – conceptual transformations:

1. the direct conceptual – conceptual transformation: this is the case of conceptual mental – conceptual mental transformation. Here, the designer reuses a previous idea that he thought of before but never implemented on paper.
2. the indirect conceptual – conceptual transformation: this is the case of conceptual mental – figural physical through sketching – conceptual mental. Here, the designer reuses a previous idea that he has implemented on paper.

The conceptual reinterpretation is the case when the designer reuses the idea but in another way. Although the literatures of visual thinking do not give a sufficient description to this mental visual transformation, the connection between the transformed ideas is supposed to be in some way a kind of association. The second conceptual representation is related to the first in some way but it is supposed to be different.

This working with the ideas mentally suggests that the reinterpretation of the content of the same frame does not deal with the physical elements and components but rather deals with "generic qualities" (using Goldschmidt's term) and the generic organizational relationships and rules of the previous idea such as the openness, the out-in relationship, the continuity. To reach an applicable definition for the conceptual transformations through the dialogical reinterpretation three gaps have to be filled:

1. why the conceptual reinterpretation occurs
2. when it occurs

3. how the reuse of the old ideas can create new ideas through the dialogical reinterpretation.

To answer the above questions this study is going to make use of the available literature of visual thinking, reinterpretation, Gestalt theory and the specific dialogical studies.

1. Consideration of why the designer reuses the old ideas to create new ideas

This occurs when designers either like the contents of the idea they have been dealing with and want to go further into some aspects of the concept itself, or they failed to achieve the idea and start a second attempt at achieving it in another way. In such cases the response in a form of an idea is the reflective dialogical reaction to these situations.

Herbert describes the case where the designer fails to achieve the idea while sketching. He refers to the role of the incremental refinements in the occurrence of the major reorganizations while sketching. Incremental refinements might lead to happy discoveries; however they might also lead to dead ends and negative results rather than developing the situation (Herbert, 1993, pp. 80-81). In the latter case the reinterpretation is demanded by major reorganization, in which the designer selects a new issue. The new issue could be something external to the situation or it could be an issue related to the old idea, in which the connection is a kind of association. As the current study is concerned with visual thinking and the connection between ideas, the latter situation where the chosen issue is related to the old idea is going to be in focus, assuming that the designer mostly will return to some issues in his previous drawings as a starting point for the new idea. Unlike the idea that comes from the unintentional discovery of a pattern, the idea of conceptual reinterpretation is intentionally selected.

2. Consideration of when the conceptual reinterpretation takes place

Murty (2006) highlights the Gestalt concept of incubation and its role in what he calls the cold discoveries (the discoveries that occur while the problem is put aside, that is when the designer stops working) to differentiate them from ‘hot’ discoveries (the discoveries that occur while active working on the problem is taking place). In describing the cold discoveries, he highlights two different points of view about the consciousness of the designer while making these cold discoveries: the first one is the Gestalt view that the cold discoveries occur in a period when the designer completely stops thinking about the problem after failing to solve it and the discovery is supposed to be unconscious. The second one is the opposite view of Kaplan & Davidson[17], which is that cold discoveries could occur while the designer is actively working and the incubation could be affected by means of conscious processing. Murty in his study finds that "incubation" is an uncontrolled mental experience describing it as a "latent preparation" that differs in how and where it occurs from person to person:

"Latent preparation or its outcomes, in the form of interruptive thoughts, apparently takes place at any time and during different states of consciousness and attentiveness. It appears to be, at different times, unplanned, unintentional, undirected, unnoticed, or unconscious, in combinations, not necessarily all at once. It is clearly not only an unconscious process."

(Murty, 2006, p. 2)

This suggests that the latent preparation is more general and incubation is only one of its components. Designers experience a range of components of mental insightfulness and therefore the conventional view of unconsciousness is not adequate to describe this range.

What matters for this study is the suggestion of the possibility of the existence of this range of mental latent preparation at any time. The mental conceptual reinterpretation could be one form of the latent operations that can take place when the designer returns to a previous idea after failure in achieving it, and tries to give it another description.

3. Consideration of the creation process

This paragraph highlights these issues: The creation of ideas, the conceptual reinterpretation and the continuity of the dialogue.

The visual design studies and the specific studies concerned with reinterpretation have not given a sufficient description for the case of conceptual reinterpretation and its relation with the creation of new ideas from old ideas, whether the conceptual

[17] See (Kaplan & Davidson, 1989), Hatching a theory of incubation effects. Carnegie-Mellon University Technical Report.

reinterpretation occurs directly, conceptual-conceptual transformation or indirectly, conceptual-figural-conceptual transformation.

Therefore this study is going to explore other dimensions of the conceptual reinterpretation by focusing on its definition as an indicator of the continuity of the dialogue. Earlier in this section, this study referred to the Snodgrass & Coyne study (2006) that showed the importance of getting involved in a dialogue with the text to support the continuity through the structure of question-answer. The notions of acquiring the text to reveal its latent dimensions and the openness to the text to achieve new understanding have to be explained in the light of the continuity of the dialogue cycle. The role of the dialogue has to be emphasized in defining the conceptual reinterpretation since dialogue plays a fundamental role in creating new understanding from old. What matters to the present study is how to get the "new understanding" through the continuity of the dialogue. The role of the openness to the text has to be explained within the frame of continuous dialogue to reveal the creation process from the old idea. This will help in explaining the conceptual reinterpretation and its relation with obtaining new ideas using issues from old ideas.

This study is going to make use of other fields, namely the philosophical dialogical study of Bakhtin, which can describe the situation of the openness to the other and the continuity of the dialogue, and their role in generating the new. Also Bakhtin's notion of polyphonic dialogue in literature can provide knowledge pertaining to the creation of the new from the old.

The validity of using this field to enlarge the understanding about the conceptual reinterpretations lies in two points.

- The Bakhtinian dialogical model of creativity explores the process of creation by focusing on the process of the authoring of the novels. Both cases; the authoring of a novel and the creation of design ideas, deal with the processes of composing a text.
- The process of authoring a novel in Bakhtin's model seeks the continuity of events which occur to the same characters through activating the role of the

dialogue in creating a new series of events. This can provide the techniques used to create the new from the old.

In the following, Bakhtin's polyphonic[18] model will be displayed in some detail and then will be followed by a discussion to extract the points that can help in defining the conceptual reinterpretation and creating the new.

Polyphonic Work: Bakhtin's Creative Model

For Bakhtin, to compose a text is to create by the interaction of multiple voices. In his discussion of the polyphonic novel, Bakhtin sees that the author is involved in a dialogue with his characters that are independent (Morson & Emerson, 1990). In the polyphonic work the voices of the others can be heard; there is no priority for the author on his characters.

Bakhtin explains the polyphonic work as being the opposite of the monologue where the voice of the author is being heard as the only voice.

He introduces two terms in his explanation of the creation process in the polyphonic work. The first one is the surplus of vision, and the second one is the transgradient. Both of these terms refer to the position that the author takes in the creation process. They help in clarifying the moments of creation and the role of the dialogue with the "imagined other", that is the hero in the world of novel. The following paragraphs will attempt to explain these terms and the creation process.

- Polyphony, Surplus and Transgradient

The polyphonic work that Bakhtin wrote about is part of the world of the novel. He discussed the work of Dostoevsky and found that his novels are polyphonic works. In the polyphonic work, the author creates a world of many points of view that engage in a dialogue, and he himself is part of it (Morson & Emerson, 1990, p. 239). His characters are independent, they have their own views. Although he is the author who

[18] See (Holquist & Liapunov, 1990). *Art and Answerability Early Philosophical Essays by M.M. Bakhtin*. The university of Texas., (Holquist, 2002). *Dialogism: Bakhtin and his world*. London: Routledge . (Shepherd, 1998). *The context of Bakhtin: philosophy, authorship, aesthetics*. Routledge., (Shepherd, 1989). *Bakhtin and the reader*. In K.H.a.D. Shepherd (Ed), Bakhtin and cultural theory. Manchester University press., (Haynes, 2008). *Bakhtin and visual arts*. Cambridge University Press.

creates these characters, he seeks to establish a genuine dialogue with them. He can imagine their responses but never merges completely with them. This is what Bakhtin calls the “transgradience”, that is the situation of being inside and outside the character/the other (Clark & Holiquist, 1984, p. 78). The moment of living in the world of the character or the moment of “empathizing” enables the author to perceive the other’s own feelings and to experience his suffering or his pain. By putting myself in the other’s position I can see the world from his/her eyes, see things I cannot see from my own position and this is what Bakhtin means by the surplus of vision. This moment of surplus is followed by the moment of objectification, that is, the returning to my own world (space and time), my own unique place in existence. By experiencing these two moments the author has the two consciousnesses which are kept in dialogue (Clark & Holiquist, 1984).

Bakhtin uses the term transgradient to refer to the existence of two consciousnesses. The polyphonic author uses this transgradient to keep the fluency of the dialogue between him and his characters. He designs his work expecting a genuine surprise as a product of these dialogues; he never plans for it from the beginning (Morson & Emerson, 1990, p. 247).

The role of the author has been changed radically in this model, s/he does not know the outcome of the dialogue, s/he cannot decide in advance what will happen; s/he may sketch out various possibilities:

> “The author understands characters in each present moment by imagining future [….] anticipation is not a plan for the future, it is a dotted line drawn and redrawn as the creative process proceeds.”
>
> (Morson & Emerson, 1990, p. 247)

The author uses his own creative techniques to induce the unexpected reactions of his characters which might lead to surprise, so the polyphonic work is designed to expect the surprise and make it visible. For example, Dostoevsky tests his characters’ ideas in radically different frameworks. These voices/ideas react and respond in a different way as they find themselves in different environments and circumstances (Morson & Emerson, 1990, p. 258).

In the polyphonic work the author creates the characters only by addressing them; they are not finalized. There are no prepared dialogues or shaped dialogues beforehand, rather they occur in the time of the present where the creation is taking place. Dostoevsky was able to induce the new by provoking the carrier of the idea (the character) to produce the new. Some of the potentials of the ideas come through the depiction of the changed conditions and certain situations of the characters. In this way the author is planning for future events but does not know the outcome; he cannot decide in advance what will happen. He can anticipate and expect the surprise to take place; anticipation, however, is not a plan but rather a dotted line (Morson & Emerson, 1990, pp. 246-247).

Discussion

Three points can be highlighted from this model:

- the notions of transgradient and surplus of visions refer to the position of the author while creating, which enables him to look at the situation from another point of view.
- the Bakhtinian dialogue displays what can be called "the planned discovery" to distinguish it from the unintentional discovery of the pattern discovery. The surprise that the author seeks by establishing a dialogue with his characters is not unintentional; rather it is expected to occur as the author provides the situation with the possible potentials. However, the author is unable to predict the content of the surprise or the idea since the content is the outcome of the real-time dialogue within certain circumstances of the situation.
- the potential for evoking the new ideas includes some techniques used by the author such as changing the context, the environment and the certain conditions of the carrier of the idea.

The above three points are helpful in describing the process of creating the new ideas within the same conceptual components by exploring the potentials of these components. The process of the planned discovery can describe the fruitful conceptual transformation.

Two mechanisms allow the conceptual reinterpretation to take place:

- looking at the situation in another way
- changing the environment and the context of the old idea.

These two points are crucial for achieving the planned discovery. To project them on the process of generating design ideas using the computer, it could be said that both of them are techniques. The first point is related to medium where the change of objects status and position can achieve it. As for the second point, changing the context of the problem is a technique to manipulate the old frame of the problem in order to create the new within the same frame.

After defining the two indicators of the occurrence of dialogical reinterpretation, the next paragraphs will display the indicators of the occurrence of a complete cycle of dialogical reinterpretation: the occurrence of alternation of thinking and the occurrence of restructuring.

3.2.2.4. The second indicator: the occurrence of a complete cycle of dialogical reinterpretation

The theoretical literatures of productive thinking discuss two styles of thinking that should be experienced in the conceptual stage in order to be more productive. These are: the divergent and convergent styles of thinking. The occurrence of the dialogical reinterpretation is not enough as the dialogical cycle of reinterpretation may not be completed; the designer may suggest an idea (discovers a pattern or wants to reuse an idea) but does not implement it on paper. To be more productive the effective performance of the two styles of thinking has to take place. Accordingly, the occurrence of two operations, the alternation of thinking and the restructuring can indicate the complete effectiveness of the dialogical reinterpretation.

3.2.2.4.1. The occurrence of alternation of thinking

Broadbent (1973) was concerned with the processes of design thinking. He referred to Paul Valery’s thought that describes design as two personalities in dialogue, one of them makes up combinations and the other chooses. He considered the former is creative with a divergent way of thinking and the latter to be critical with a convergent way of thinking (Broadbent, 1973, p. 175). De Bono differentiates between the two styles of thinking and clarifies that both of them are necessary in order to be more effective. While in vertical thinking the information is used to move through the process and reach the solution by making use of the content of the information, in thinking horizontally the information is used for re-patterning, but not for the sake of the information itself. The matter here is not to say which one of these ways of thinking is more effective, but the point is to use both of them effectively (De Bono, 1970, p. 43).

In different stages of design, designers need to be more divergent or more convergent. In the conceptual stage divergent thinking is needed more than convergent. As mentioned earlier, the deferment of judgment and evaluation is recommended in conceptual design stage to allow the prolongation of the divergent phase. However, early evaluation cannot be avoided while drawing, as designers interpret what they see and give their judgements. Consequently, the style of thinking in the conceptual stage becomes a mixed thinking of the two styles, the divergent and the convergent, in which the designer experiences a sequence of alternations between both styles several times over.

Broadbent's suggestion that productive thinking needs a structure of alternations between both divergent and convergent thinking adds another dimension to the definition that is the effective timing of alternations or shifts from convergent to divergent and vice versa. Broadbent suggests that the structuring of dialogue between the two personalities of the designer's thinking could help in knowing when and in what form to present the generated combinations. He claims that being within a divergent mode can produce combinations but can also result in some "slapdash" ideas:

"Divergers, as we saw, can cope with ambiguous situation, with incomplete instructions; they will tend to throw up more and more elaborate ideas when it comes to making combinations, but they will tend to be rather slapdash."

(Broadbent, 1973, p. 175)

It can be understood that the issue of timing the alternation in the conceptual stage is to give more chances for the birth of ideas and then for investigation of the practicality of this generation; it is useless to suggest ideas without testing their practicality; suggesting an idea has to be followed by attempts at making them real by choosing and testing some of their aspects. To be productive, divergent thinking has to be stopped at some level by selecting or choosing, that is to narrow the range of possibilities. Similarly, convergent thinking has to be stopped at some level and the attempts have to be started to look at the problem in a different way and widening the scope by giving different suggestions. This description is typical for the conceptual design stage that demands more suggestions and more ideas with acceptable levels of application.

This suggestion of Broadbent can be explained using the hypothetical scheme of the dialogical reinterpretation. The dialogical reinterpretation includes different types of representation of the idea; it could be a visual mental or a physical representation. The physical representation is one of the two possibilities for expressing the mental visual idea. The other possibility is to express the idea verbally. The difference between the two kinds of expressions is that the physical representation is more specific as the designer selects specific forms and shapes for representing the idea. By doing this the designer becomes a convergent thinker. However, he can perform divergent thinking within the selected form by reinterpreting it.

There are three cycles in the hypothetical scheme, Figure 3.2, that describe this kind of reinterpretation, these are:

- Figural mental – Figural physical
- Conceptual – Figural physical
- Conceptual – Conceptual – Figural physical

The figural physical reinterpretation (it is a mental – physical transformation) indicates the completeness of the dialogical cycle by applying the discovered patterns or the selected conceptual qualities. It is to give the visual mental representations (figural or conceptual) a physical existence. As mentioned earlier, the mental visual image is vague and abstract; it doesn't have a clear form. Performing the mental – physical reinterpretation gives a specific, clear and exact form to the mental image where the size, shape and scale are decided. In this way the thinking becomes more convergent.

Accordingly, in performing the cycles of the dialogical reinterpretation, pattern discovery and conceptual reinterpretation are supposed to represent the divergent phase that is to generate the ideas, whereas the physical figural reinterpretation is supposed to represent the convergent phase that chooses some aspects of them. The alternation takes place through the two cycles of transformation:

- when the designer moves from either the pattern discovery or the conceptual reinterpretation to the physical figural reinterpretation. These moves represent the convergent moves where the completeness of dialogical cycle of reinterpretation is achieved.
- when the designer moves from the physical reinterpretation to the pattern discovery or to the conceptual reinterpretation. These moves represent the divergent moves where the designer starts a new cycle of the dialogical reinterpretation.

3.2.2.4.2. The occurrence of restructuring

The occurrence of the dialogical reinterpretation is capable of indicating both the quantity and the quality issues, that is the fluency of the ideas and the variety (through the change of domain and the use of techniques to change the context) of the produced ideas. However, it does not guarantee the avoidance of thinking about the problem in parts rather than as a whole. The designer can perform the variant types of dialogical reinterpretation but within the parts of the problem. For example, the designer might see one design component of the drawing as something else, or he might recognize a pattern of functional relationship related to part of the spatial composition. In architectural design, there is one main idea and several secondary ideas that support the main. For instance, the main idea could deal with the building and its relation with the site; however, the designer has to support the application of the main idea with secondary ideas solving problems connected to the issues of functionality, formality, and interior spaces among others.

There is another dimension of the productivity pertaining to the complete effectiveness of the cycle of dialogical reinterpretation in producing design alternatives, which is to move laterally (to suggest another main idea) rather than vertically. Moving vertically could be explained within two dimensions:

- not seeking to replace the previous idea (the suggested new main idea is a revised version of the previous main idea). Guilford describes this kind of rigidity in thought as a reverse situation of "spontaneous flexibility". For example, in the brick uses test, the high score of flexibility is the number of kinds of uses, not the total number of uses (Guilford, 1961, p. 13). In architectural design, this fixation can happen when the designer focuses on one idea that deals with pattern of relationship, then uses this pattern more than one time and gives it different forms.
- continuing to work within the details of the main idea , that is to develop the main idea by supporting it with secondary ideas that solve relative problems of the site for example, the function or form.

The occurrence of the dialogical reinterpretation within the condition of looking at the problem from another point of view (change the domain or change the context of the idea) can indicate the avoidance of the former; however, it cannot avoid the latter. The flow of variant ideas might support solving the detailed problems or secondary problems for achieving one dominant idea rather than making combinations of several alternative ideas. The dominant idea might deal with the problem at different degrees of comprehensiveness (De Bono, 1970, p. 111). Designers may suggest many secondary ideas, which work on the details, to support the dominant idea and solve aspects of it at different levels, rather than going beyond it.

The complete cycle of dialogical reinterpretation will be discussed within the dimension of the lateral thinking of the conceptual phase of designing. To give a full explanation of this indicator, the available studies of productive thinking will be used. Wertheimer in his study of productive thinking (1959) introduces restructuring as the essential operation for thinking productively.

3.2.2.4.3. Wertheimer's productive thinking

The Gestalt theory is one of the schools that explain thinking and how to solve problems. Max Wertheimer, who is one of the founders of Gestalt psychology, introduces the idea of productive thinking based on Gestalt theory. The central content of productive thinking is to restructure the problem in accordance with a new view that explains the situation in a more adequate structure and grasps the structural relationship of its components (Wertheimer, 1959, pp. 239-240).Wertheimer sees that the inadequate view of the situation stops the subject from grasping the "true structure" to solve the gap within the problem set. The subject might lose the extensive view of the problem as he is busy with the details and parts of the problem rather than the whole. The good structure for Wertheimer is the structure where parts are determined within the structure of the whole. He describes it as a structure with a dynamic nature:

"Often two mutually related directions are present in the process, one which proceeds from some parts toward the whole, and another, which goes from whole-qualities to the parts."

(Wertheimer, 1959, p. 242)

So far in this study, the operations of reframing, restructuring and reformulating the problem have been displayed as essential cognitive operations for producing design ideas. They are the tools for reinterpreting and transforming the design situation. While reframing the problem refers to renaming the problem and identifying areas of solutions, reformulating the problem, according to Murty, is a Gestalt concept that refers to the reinterpretation of the situation by a cognitive act, which is called "the insight" and described as the act of restructuring the problem (Murty & Purcell, 2003, p. 2). Restructuring the problem implies:

- finding an adequate pattern of the inner relationship of the problem in which the "adequate pattern" is defined as the pattern that belongs to the whole rather than the parts.
- structuring the designer's acts in accordance with the discovered pattern and the desire to achieve it.

Reaching an adequate structure or adequate understanding of the situation requires looking at the problem in another way and reinterpreting it. Designers can use their past experience in discovering an adequate structure. Murty (2006) points to the Gestalt concept of solving the problem using analogy, that is, to use a past solved problem in solving a new problem (Schon (1987) calls it "doing as"). Murty points to Mayer's citation to Wertheimer who affirms the importance of the nature of past experience and the fitting of its structure to the present situation which allow the successful analogy. What matters to Wertheimer is "what to recall" and "how to apply". These questions play a role in the correctness of the "insight" to the present situation and the fitness of the past experience. The emergence of the new use of the analogy could take place by abstracting the structure of a specific problem, by using the principle of that specific problem or by noticing the shared underlying structure for the past and present problems (Murty, 2006, p. 42).

The other source for finding an adequate structure is the unintentional discovery through visual thinking. The sudden reorganization of visual information, or what Murty calls visual insight, can lead to pattern discovery. Visual insight or visual restructuring is to experience looking at the problem "literally" in a new way. The sudden appearance and never being reproduced from prior information are considered to be the essential features of this insight (Murty, 2006, p. 41).

How to work with restructuring or how to direct this process is a question in point. Arnheim answers it by pointing to the role of the target concept in directing the restructuring; the tension between the present image (before discovering the pattern) and the image of the goal situation (the discovered pattern) restructures the problem and provides the direction of proceeding through the process (Arnheim, 1962, p. 8).

3.2.2.4.4. Restructuring and the dialogical reinterpretation

As mentioned above, the target concept is the discovered adequate structure of the problem. Wertheimer describes the structure as being adequate to refer to its fitness to the whole situation in which the parts are determined within the whole. To apply this concept using the types of dialogical reinterpretation, two conditions have to be considered: the first one is to look at the problem from another point of view in order to grasp its structure; the second is to look at the whole rather than the part. It is obvious that restructuring is a subset of the three indicators: pattern discovery, conceptual reinterpretation and alternation of thinking. In achieving restructuring, designers perform reinterpretation at these levels:

- discovering a new pattern that belongs to the whole structure of the problem and reframing the problem (pattern discovery), or reusing a previous idea that belongs to the whole problem and changing its context (conceptual reinterpretation). Since restructuring includes dealing with a pattern that belongs to the whole structure of the problem, it can indicate the birth of a main idea.
- transforming the resultant constructed mental image (the main idea) from mind to paper by giving it a specific appearance. This is the figural physical reinterpretation (alternation of thinking). This application of the idea should deal with the entire design object rather than with parts to produce a new design proposal on paper. By achieving this last point, restructuring takes place.

3.2.2.5. The productivity of the conceptual phase of design

The definition of productivity of the conceptual phase of design considers the process that is rich with operations of dialogical reinterpretation to be productive. The dialogical reinterpretation operates at different levels. Each level represents a different stage in the production of design ideas and proposals. Each level indicates the occurrence of specific cognitive operations that render fixation less likely. Thus the levels of dialogical reinterpretation and their specific cognitive operations are indicators of productivity. These include: pattern discovery, conceptual reinterpretation, alternation of thinking, and restructuring.

The occurrence of pattern discovery and the occurrence of conceptual reinterpretation are correlated with the condition of looking at the problem from another point of view. As for the former, looking at the problem from another domain achieves the condition of looking at the problem from another point of view. This is the reframing process. As for the latter, using the technique of changing the context of the reused idea achieves this condition. These two conditions provide the means to avoid producing a second version of the initial idea. Accordingly the occurrence of pattern discovery and the occurrence of conceptual reinterpretation can indicate the productivity of the conceptual design process.

Since pattern discovery and conceptual reinterpretation are responsible for generating design ideas by constructing mental visual images from existing drawings, their occurrence represents the divergent style of thinking of the dialogical cycle. On the other hand, figural physical reinterpretation is responsible for giving a specific appearance and physical existence to the design idea generated by these processes. Therefore, figural physical reinterpretation represents the convergent style of thinking.

The alternation of the two styles of thinking can enrich the conceptual process by:

- ensuring the completion of the dialogical cycle through the occurrence of physical figural reinterpretation.
- establishing new cycles of dialogue through the occurrence of pattern discovery and conceptual reinterpretation.

The creation of a continuous sequence of alternations of the two styles of thinking establishes new cycles and completes them over time. Accordingly, the alternation of thinking represents an indicator of the occurrence of a complete cycle of dialogical reinterpretation. Finally, the occurrence of restructuring represents another indicator of the occurrence of a complete cycle of dialogical reinterpretation. Restructuring as a cognitive operation includes suggesting an idea that deals with whole structure of the problem and tackling the parts within this whole. It indicates the birth of a new, alternative design proposal as it includes transforming the constructed image from the designer's mind to paper and applying it on the whole design objects.

3.3. The relationship between the computer sketching and the productivity of the conceptual design phase

In this chapter the theoretical framework of the relationship between the characteristics of the sketching using the computer and the productivity of the conceptual design process has been built and presented in its final stage, table 3.1. The table shows the indicators of the productivity of the conceptual stage arranged in horizontal rows and the characteristics of the sketching arranged in the vertical columns. We expect that the degree to which the characteristics of sketching are used can affect the productivity by affecting the degree of occurrence of every indicator. Accordingly, in table 3.1, the word degree has been added to the characteristics of sketching and also to the indicators of the productivity. The intersections of the rows and columns show the relationships between the characteristics of the sketching and productivity. The empty boxes refer to unknown and untested relationships.

By achieving this stage the first objective of this study has been fulfilled. The table 3.1 of the theoretical framework shows that the only approved relationship is the relationship between the ambiguity due to the type of the lines and two indicators of the productivity: the degree of occurrence of dialogical reinterpretation: the occurrence of pattern discovery; and the degree of occurrence of a complete cycle of dialogical reinterpretation: the occurrence of restructuring. The rest of the relationships have not yet been tested.

In the following paragraph there is a discussion of each of the remaining relationships in order to choose the most important relationships that have to be examined in this study through an empirical study:

- the relationships between the first factor of ambiguity that is related to the type of the lines from one side and the two indicators of productivity on the other side; the occurrence of conceptual reinterpretation and the occurrence of alternation of thinking have not been tested yet. However, the previous studies have proved that reinterpretation not only has taken place in digital design but also has produced design alternative proposals.
- the occurrence of the second factor of the ambiguity (the ambiguity due to the content of the image/ the strangeness of the image) depends on accidents that lead to strange images, which means that it is not a common situation, therefore this study is not going to explore its relationship with productivity.
- the degree of ease in projecting design images is a technical factor that depends on the design of the software. The scope of its relationship with productivity lies outside of the field of this study therefore this relationship is not going to be examined. In general, the factors that affect productivity are classified into two groups; the technical factors that related to the design of the

software (the degree of ambiguity due to type of the lines and the degree of ease in projecting design images), and the factors that relate to the visual environment of the software where the performance of the designer contributes to its existence (the degree of ambiguity due to the content of the image, the degree of continuity of displaying images and the degree of provision of a holistic view). This study is going to focus on the second group as it could be enhanced by improving the performance of the designer.

- the degree of continuity of displaying images, which is one of the indicators of the degree of flexibility of forming the images, has been defined through two variables: The display due to change of status (change the appearance), and the display due to the change in the position (navigation around the objects). This study finds that changing the appearance and navigation, which are called also the dynamic representation, are essential variables in the sketching process using the computer. They are distinct characteristics related to the sketching process of using the computer, which distinguish it from the hand sketching. These attributes are the properties that distinguish the use of the computer as a medium of sketching therefore the relationship between them and the productivity of the design conceptual process is going to be examined.
- the relationship between the degree of the provision of a holistic view and productivity has not been verified, therefore this study is going to explore this relationship in an empirical case study.

Table 3.1: The theoretical framework of the relationship between the characteristics of the sketching using the computer and the productivity of the conceptual design phase.

			Characteristics of Sketching Using the Computer					
			Degree of Ambiguity of Drawings		Degree of Continuity of Dynamic Field of Images			
					Degree of Flexibility of Forming Design Images			
						Degree of Continuity of Displaying Images		
			Ambiguity Due to the Type of Lines	Ambiguity Due to the Content of the Image	Degree of Ease in Projecting design images	Continuity of Display Due to changing the Object's Status - Appearance	Continuity of Display Due to changing the Object's Position - Navigation	Degree of provision of a holistic view
Indicators of the Productivity of the Conceptual Design Phase	**Degree of Occurrence of Dialogical Reinterpretation**	**Occurrence of Pattern Discovery**	⊕					
		Occurrence of Conceptual Reinterpretation						
	Degree of Occurrence of a Complete Cycle of Dialogical Reinterpretation	**Occurrence of the alternation of thinking**						
		Occurrence of Restructuring	⊕					

Note: ⊕ Positive relationship

3.4. Chapter Summary

This chapter has focused on clarifying the vocabularies of the theoretical framework that have been extracted from the hand sketching studies, visual thinking studies, cognitive psychology, literature, design studies and the Gestalt based theory of productivity.

- The characteristics of sketching using the computer include two main factors: the ambiguity of the drawings, and the degree of continuity of the dynamic field of images. The first includes two characteristics: the ambiguity due to the type of lines of the drawings, the ambiguity due to the content of the images of the designed images.

  The second includes four characteristics; one of them, is regarded as a technical issue of designing the software, is the degree of ease in presenting design images; the others, which are regarded as related to the performance of the designer, include: first- the degree of continuity of displaying images due to changing the status of the designed objects (appearance), second- the degree of continuity of displaying images due to changing the position of the objects (navigation), third- the degree of provision of holistic views of the design work.

The study has found that the degree of continuity of the images being displayed due to changing the status and changing the position are particular to sketching using the computer.

- There are four indicators of productivity through the dialogical reinterpretation in which the occurrence of every one of them is an indicator to the productivity of conceptual process. These are: the occurrence of pattern discovery, the occurrence of conceptual reinterpretation, the occurrence of alternation of thinking, and the occurrence of restructuring.

By identifying the vocabularies of the theoretical framework the study has achieved the first objective towards achieving the aim of this research.

4. The measurements of the variables

This chapter addresses the measurements of the variables of both sketching characteristics of using the computer and the indicators of productivity. This contributes to achieving the second objective of this study, that is, to test the relationship between the characteristics of sketching using the computer and the productivity of the conceptual design phase in the applied case study.

The following sections are going to: first, introduce the measurements of the three chosen variables of the characteristics of sketching. Secondly, introduce the measurements of the productivity variables. Third, describe the methods of measurement and data collection of the productivity variables.

4.1. The measurements of sketching variables: the degree of continuity of the dynamic field of images

In the previous chapter, the characteristics of the sketching process using the computer, which may affect the generation of design ideas, have been deduced. The degree of continuity of the dynamic field of images has been identified as the most distinctive characteristic of sketching. It includes two factors: first; the degree of flexibility in forming design images. This factor is defined by a technical factor that is the degree of ease in projecting design drawings onto the screen, and another factor that is regarded as being related to the performance of the designer: the degree of continuity of displaying design images. The second is the degree of provision of the holistic view. This factor is also regarded as being related to the performance of the designer and his techniques in using various displaying views. In the previous chapter the variables that are related to the designer's performance have been chosen to test their relationship with the productivity.

Because this study is dealing with the sketching as a process, it has to be clear that the computer's sketching variables can be measured through measuring the frequency of the use of the computer's facilities and drawing tools. The use of these drawing tools is regarded as related to the designers' techniques in using them. Thus there is no fixed range of limits for the values of these variables.

Collecting the data on the use of the software's tools demands a video recording made while designers are working in order to facilitate the collection of these measurements.

In the following paragraphs, the measurements of the above two factors and the related chosen variables will be determined.

4.1.1. The degree of the flexibility of forming the images

This variable can be measured through measuring these two variables: the degree of ease in projecting the design images, and the degree of the continuity of displaying images. In the previous chapter, the degree of the continuity of displaying images has been chosen to test its relationship with the productivity.

4.1.1.1. The degree of the continuity of displaying images

The continuous display of the images is due to two kinds of changes: the change in the object's status (due to the change in appearance); the change in object's position (due to navigation around the designed objects).

The measurement of these two variables will be determined.

First, the continuity of displaying images due to the change in the object's status (change the appearance)

The change in appearance indicates the complete change in the way of representing the drawings of the same designed objects. This change can be achieved through the move from two dimensional drawings (2D plan, section, elevation) to three dimensional drawings (3D state), or the move from the outside view of the designed objects to inside views, or from the mesh wireframe state of the designed objects to solid state, and vice versa. Accordingly, the measurement of this variable can be achieved by counting the number of times there is a move from one state to the other of each kind of the three kinds of moves.

Second, the continuity of displaying images due to the change in the object's position (navigation around the objects)

The designer can change the position of the object by changing the angle of the view of the observer. Moving the mouse or the object itself to the right or left, up or down changes the angle of the view and thus changes the resultant image of the design objects. It facilitates walking around and through the design objects. Accordingly, the measurement of this variable can be achieved by counting:

- the number of moves from whole to whole (W-W): these moves indicate the change of images due to the navigation around all of the design objects or moving the objects themselves, when the angle is changed within 45° vertically or horizontally 45° is sufficient to give another new look at the designed object. So the change of images is due to the change in viewpoint rather than the change in the content (elements) of the snapshot.
- the number of moves from whole to part (W-P) and vice versa; where the change is due to the change in the angle of the view accompanied by the change in the distance from the designed objects. When the navigation from different distances (navigation+ zooming) is taken place, it indicates the change in view and the partial change of the contents. This is the alternation of focus from the whole objects to focus on parts of them and vice versa.
- the number of moves from part to the same part (P-SP); where the change is due to the angle of the view rather than the content. These moves indicate the change due to the navigation around the parts of objects when the angle of view is changed 45° vertically or horizontally.
- the number of moves from part to another different part (P-AP) and vice versa; where the change is due to the change of view and the change of focus within the same view.

This variable is going to be calculated into two ways: to calculate the total number of every type of the above moves separately, and then to calculate the total number of all types together. By using this latter way the scale will be more sensitive to the sequence of the designer's thinking while moving between these types.

The considerations of this measurement:

This factor of "Navigation", which is the (Turning around+ Zooming), can take place intentionally, and also unintentionally. The former represents the case when the designer moves the mouse in different directions just to watch the drawing from different points; it is the active navigation where thinking, imagining and evaluations are supposed to be taking place. As for the latter, it is the case where designers move around and among the designed objects to draw or manipulate their drawings. The purpose of the move is not to watch the object but rather to realize the intended object. However, these moves imply a kind of background navigation that can subconsciously update the memory with images.

Accordingly, this variable has to be measured twice; in the active state and in background state as follows:

- calculate the active navigation only: the number of times of navigation has been used only when the designer stops working with the objects and starts to watch his drawings.
- calculate the active navigation with the background navigation: the number of times of active navigation plus the number of times of moving around the objects while working.

4.1.1.2. The degree of provision of a holistic view

To provide a holistic view of the work, it is either by the concurrent display of all the drawings on the computer's screen, or by frequent visits to various types of displaying views (looking at the design in 2D/3D, from inside/from outside). Since navigation and changing the appearance of the objects can provide the designer with tools for looking at the drawings from a different view, they support the holistic view of the whole design work. The second way of providing a holistic view (the frequent visiting of various types of displaying views) also includes all the types of views that navigation and changing the appearance can provide.

Accordingly, this variable is going to be measured in three ways:

- the first is to count the number of times the four ports on the screen for displaying views are used. The screen of the current 3D modelling software system can display the drawing in four viewing ports of the screen by dividing the screen into four quarters that display plan, section, perspective, and elevation.
- the second is to measure the number of types of displayed views that have been used. This includes the types that the navigation around the objects can provide and the types that changing the appearance can provide. Accordingly, the number of the used types could have a value from 1-10, these are: the four types of navigation (part to same part, part to another part, part to whole, and whole to whole) and the types of views of changing the appearance (plan, section, elevation; which represent the 2D status, and the outside 3D modelling, inside 3D modelling, and the mesh view of the object).
- the third is to measure the total number of times of using these types of displaying views. This can be achieved by the summation of the total number of times of using the "navigation" types plus the total number of times of using all the types of changing the appearance.

The third one is sensitive to the number of times these types are used; however, it does not consider the distribution among these types, which is the rate of using each type. Since this point is not essential in achieving the holistic view of the work, counting the total number can satisfy the purposes of this study.

To sum up

The measurement of the sketching variables has been defined. To achieve these measurements the data have to be collected while the designers work. This demands a video recording for all the activities of the design drawings.

4.2. Measurement of productivity variables

In general, every variable of the productivity could be measured by counting the number of times of occurrence of that variable. High numbers indicate high productivity.

The indicators of the productivity have been derived in the previous chapter, and the circumstances of every indicator have been clarified. In the following, the measurement of every variable of these indicators will be introduced and then followed by the description of the developed tool for these measurements and data collection.

4.2.1. Measurements

There are four main indicators of the productivity, which are categorized under two titles: the occurrence of the dialogical reinterpretation and the occurrence of a complete cycle of dialogical reinterpretation. Accordingly, the measurement of the productivity depends on the degree of the occurrence of dialogical reinterpretation and the degree of the occurrence of a complete cycle of dialogical reinterpretation.

In the following the measurement of each one will be determined.

4.2.1.1. The degree of occurrence of dialogical reinterpretation

The degree of the occurrence of the dialogical reinterpretation depends on the occurrence of two operations: the pattern discovery and the conceptual reinterpretation.

First Variable- The occurrence of pattern discovery:

The occurrence of pattern discovery indicates the starting of a dialogical cycle between the designer and the drawings. The measurement of this variable can be achieved by counting the number of the discovered patterns; these patterns could be formal figural patterns (Gestalt form, formal pattern) or patterns of relationships (functional and spatial organizations).

When the designer takes an action to achieve an idea and then recognizes another different idea, it is the unintentional discovery of a pattern. This definition can help in achieving the measurement of this variable.

There are two steps that have to be taken to insure that the suggestion is a pattern discovery. These are:

1. to determine the type of the recognized pattern, which could be figural or conceptual (the functional or spatial organizational relationships). While the discovery of figural pattern represents the figural physical – figural mental transformation, the conceptual pattern represents the (figural physical – conceptual) transformation.

2. to check the un-intentionality of the suggested idea:

- by comparing the domain of the suggested idea (discovered pattern) with the domain of the idea of the drawing that has been interpreted; they should be different. The domain can have these values: formal, functional, structural, spatial organization, environmental, among others. In general, the suggestions are ideas within frames related to the problems being discussed by the designer. They take place either for the first time, which means that this frame is being highlighted for the first time, or they occur for a second or third time within the same frame. The pattern discovery deals with the suggestions that occur for the first time. The ideas of the first cycle are usually the ideas that frame or reframe the problem.

- by ensuring that there is no connection between the suggested idea and the previous ideas, which could be a direct connection or an indirect connection through associations.

Second variable- The occurrence of conceptual reinterpretation

This variable indicates the continuity of the dialogical reinterpretation by transforming a previous idea at conceptual level and using it for more than one time in different ways, which indicates the conceptual – conceptual transformation. This can be measured by:

1. counting the number of the connected ideas. To explore the occurrence of the conceptual – conceptual reinterpretation, the transformation process has to be examined. This includes three steps:

- to investigate the connection of the suggested idea with previous ideas
- to investigate the type of connection of the idea with previous ideas: that is to examine the parts of the idea that have been transformed. These parts could be related to the design elements and components of the idea or to the design organizational relationships (formal, spatial or functional relationships).
- to investigate the technique used for the transformation that is changing the context of the idea. This could be achieved through changing the type of the context of the previous ideas to another type, that is to examine the focus part of the idea (the domain), which could have the following values: functional, formal, structural, environmental, among others.

If the designer repeats from the previous idea elements or design relationships without changing the context, a new version of the previous idea will be generated. Therefore, the occurrence of the conceptual reinterpretation is conditional on the change of the context from one type to another.

2. calculating the length of the series of the conceptual reinterpretation: this indicates the degree of the involvement in the dialogue. This can be measured by calculating the number of the ideas of the conceptual reinterpretation that repeated the same issue and have changed the context.

4.2.1.2. The degree of the occurrence of a complete cycle of dialogical reinterpretation

This includes two variables: the occurrence of alternation of thinking and the occurrence of restructuring.

Third Variable- The occurrence of alternation of thinking

This variable is defined through the alternation of the dialogue between the two styles of thinking, “the divergent” and the “convergent”. The divergent way of thinking is most often required in the conceptual stage; however, the alternation of thinking between the two styles represents the more productive way of thinking according to Broadbent. It is expected that the frequent alternation in thinking from one style to the other indicates that the designer does not only suggest ideas but also attempts to apply them and continues this cycle several times, in which the modality of "seeing-doing-then seeing" keeps repeating all through the process.

Consequently, there are two indicators for the occurrence of the alternation of thinking:

A. the occurrence of the figural physical reinterpretation

The measurement of this variable depends on measuring the alternations within every dialogical cycle, which ensures its completeness. A completed cycle can be achieved when the generated idea acquires a physical existence on the computer screen. It represents the cases of the mental conceptual – physical figural transformation and the mental figural – physical figural transformation. While, the mental conceptual and the mental figural are the divergent operations, the physical figural reinterpretation is the convergent operation. That is because the mental image is a vague image constructed in the mind and still does not have an exact shape or form. We consider the construction of a mental image as a divergent operation as the image still has no exact shape or form.

It is obvious that this variable is a subset of the two variables: pattern discovery and the conceptual reinterpretation. However, this scale is sensitive to the drawn ideas only, it abandons the suggestions that the designer thinks in this way without applying them. The measurement of this variable is to count the number of the ideas (pattern discovery and conceptual reinterpretation) that have been implemented and given a physical existence.

B. the effectiveness of the rhythm of alternation over the time

Examination of the rhythm of alternation over the timeline is sensitive to the timing of the alternation, which demands a method of presenting the above divergent and convergent operations chronologically. This requires examining the operations and determining their types (divergent or convergent), then presenting them chronologically to show the rhythm of sequence. The rhythm can show areas of similarity in the type of thinking and the areas of shift from one type to the other. What matters to this study are the areas of shifts; the number of these shifts rather than the time spent in each of type of thinking. Measuring the length of period of time spent while experiencing the divergent or convergent thinking reflects the nature of the process. This can show the stages of constructing and developing design ideas inside the conceptual process. This study is not focusing on describing the stages themselves; instead, it is focusing on the occurrence of these stages by experiencing the two types of thinking. Accordingly, counting the number of shifts from divergent to convergent and vice versa on the chronological line measures the alternation of thinking thus measures the degree of occurrence of these stages.

It is obvious that the sequences of divergent-convergent-divergent or convergent-divergent-convergent can achieve the highest values of shifts as they make two alternations in a process consisting of three cognitive design acts. That is because the other possible sequences of divergent-divergent-convergent or convergent-convergent-divergent can obtain the value of only one alternation. The high number of shifts represents the high degree of alternation of thinking and thus a high degree of productivity.

To sum up, this variable could be measured through two indicators:

- the occurrence of figural physical reinterpretation, this indicates the completeness of the dialogical cycle, which could be measured by counting the number of shifts from divergent to convergent thinking.
- the effectiveness of the rhythm of alternation of thinking, which could be measured by counting the number of shifts in thinking from divergent to convergent and from convergent to divergent thinking.

Fourth Variable- The of occurrence of restructuring

This variable indicates the occurrence of lateral thinking by confirming the shift of thinking from parts of the problem to the whole. This variable is a subset of the previous variables. Its scale is sensitive to the suggestions that have three properties: first; achieve the reframing (by changing the domain or changing the context of the problem within the same frame); second, the suggestions that have a physical existence and finally been applied to the whole building. It could be measured by counting the number of physical figural reinterpretations that have been applied to the whole building, which ensures the generation of lateral rather than vertical ideas. To explore the occurrence of this shift from part to the whole, two steps have to be taken:

- the resultant drawings have to be examined to check whether the idea is applied on parts of the building (part of the building elements, part of the site, and so on) or on the whole building and masses.
- the transformation of the suggested idea to be the main idea should be examined by investigating the moves which follow next. If they imply steps toward modifying, managing and adjusting the various parts of the problem within the context of the suggested idea, then the restructuring has occurred.

To sum up

The measurement of every variable has been determined (Table 4.1). However the achievement of these measurements demands the tracing of the designers' movements and the developments of the ideas. The measurement of the first variable (pattern discovery) and the second variable (conceptual reinterpretation) cannot be achieved without tracing the connection of the suggested idea with previous ideas to decide the intentionality of these ideas. The measurement of the second indicator of the third variable (alternation of thinking) cannot be achieved without examining the sequence of the occurrence of the suggested ideas chronologically, which demands a tracing of this sequence by presenting all of the suggested ideas on the timeline. And finally, the measurement of the fourth variable (restructuring) cannot be achieved except by examining the transformation of the suggested idea to be the main idea, which demands the examination of the connection with the moves which occur next.

A useful graphical tool has been introduced by Goldschmidt called "Linkography" can help in achieving these measurements. In the following a description for the data collection will be given then followed by linkography and its development to suit the measurement of the productivity variables.

Table 4.1: Measurement of the productivity of the conceptual design process

Indicators of the Productivity of the Conceptual Design phase through the Dialogical Reinterpretation					
Degree of Occurrence of Dialogical Reinterpretation			Degree of Occurrence of a Complete Cycle of Dialogical Reinterpretation		
Occurrence of Pattern Discovery	Occurrence of Conceptual Reinterpretation		Occurrence of the Alternation of Thinking		Occurrence of Restructuring
			Occurrence of Figural Physical Reinterpretation	Effectiveness of the Rhythm of alternation over the time	
Number of the Discovered Patterns	Number of the Connected Ideas	Length of the Dialogical Series	Number of Shifts from Divergent to Convergent Thinking	Number of Shifts over the Time Line	Number of Ideas that have been Applied on Whole Building (No. of shifts from part to whole)

4.3. Productivity variables: Methods of measurements

The following paragraphs will describe the way of collecting the data of the productivity variables.

4.3.1. Protocol analysis and data collection

As this study is concerned with the process, the data collection can be achieved by observing and analyzing the actions and moves taken by the designer while working. Watching the designers and coding their behaviour is called protocol analysis.

Ericsson and Simon claim that the closest reflection of cognitive processes is verbal reports. There are two types of verbal reports (Ericsson & Simon, 1984, p. 16), these are:

- the concurrent think aloud or talk aloud reports “where the cognitive processes, described as successive states of heeded information, are verbalized directly.”
- the retrospective reports where “A durable (if partial) memory trace is laid down of the information heeded successively while completing a task.”

The introduced measurements of the indicators of the productivity through the dialogical reinterpretation are sensitive to any thought and idea that can be suggested by the designer whether they are applied and drawn or they are merely suggestions.

Collecting such data demands a recording for these mental thoughts, which cannot be captured without concurrently thinking aloud. Retrospective reports cannot help in this case as designers may forget their instantaneous thoughts or may interpret the completed drawings when they see them again and might give another picture.

For these reasons and for achieving the purposes of this study, the ‘think aloud’ protocol is chosen. However, some may say that thinking aloud can affect the performance and can modify the cognitive process. Ericsson and Simon have conducted a series of empirical studies and found that the effect or absence of effect depends on the level of verbalization and the characteristics of the verbalization instructions (Ericsson & Simon, 1984, p. 106). They found that in the case of the vocalization of covert “articulatory” or “oral encoding”, in which no efforts of intermediate processing are needed to communicate the thoughts, there is no change in the structure of the thought process. Also, in the case of giving description or explanation of the thought content, more time is needed but this doesn’t change the structure of thought (Ericsson & Simon, 1984, p. 78). Accordingly, the vocalization of covert “articulatory” is chosen as method for collecting the data and achieving the purposes of this current study.

4.3.2. Linkography

Through the dialogical reinterpretation designers give their suggestions, thoughts and ideas. This study defines the indicators of the productivity through the dialogical reinterpretation where specific operations take place. These operations have to be explored and examined over the designing process in order to collect the required data for measuring the productivity. This requires a presentation tool that allows the tracing of the ideas, examining their developments and their connections with other ideas. It should also provide a means to identify the operations that contribute in generating these ideas. Tracing the ideas and the operations can be achieved by examining the drawings in progress and the verbal sentences from the design protocol analysis which give a picture about what the designer thinks in specific moments. The drawings in progress and the verbal sentences are the two sources for the design protocol.

To record the designing reports, analyze them and represent the data graphically, Goldschmidt has introduced the "linkography" as a graphical tool whose main purpose is to assess the productivity of the process. This tool provides an analytical technique attempting at connecting the design process and the content of the design protocol of acts and designing behaviour. In this sense, design protocols are basically the collection of design procedures which imply the designers' thoughts and suggestions.

Goldschmidt presented this tool to facilitate her own definition of productivity. Researchers (Van der Lugt 2003, Kan & Gero 2004) have extended its use to serve the specific purposes of their studies. Linkography is capable of tracing the design ideas and their connections; therefore it can facilitate the purposes of the current study. However, the linkography introduced by Goldschmidt does not serve this current study; it has to be developed to illustrate the operations of the dialogical reinterpretation, in order to provide a flexible tool for presentation. In the following, a general description of Goldschmidt's linkography will be given first and then followed by a description of the developed linkography.

4.3.2.1. General Description of Goldschmidt's Linkography

Goldschmidt decomposed the design process by analysing the design protocol into its smallest unit, which she calls the move. She defines it as "an act of reasoning that presents a coherent proposition pertaining to an entity that is being designed" (Goldschmidt, 1992). She also defined it as " a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move" (Goldschmidt, 1995, p. 195). The design protocol can be represented by a set of these moves and the connecting links between them. She depends on logic and an expert's judgment, which should consider the verbalized words and the sketch itself, in order to derive the moves and to determine the connection between them (Goldschmidt, 1992, pp. 72-73).

To draw the linkography, Goldschmidt described it as follows.

"The linkography is a simple graphical notation in which the sequence of moves is shown on a straight line and the links are nodes at the intersections of diagonal network lines connecting two related moves." (Goldschmidt, 1992, p. 74).

The drawing of the linkography of four moves is shown below:

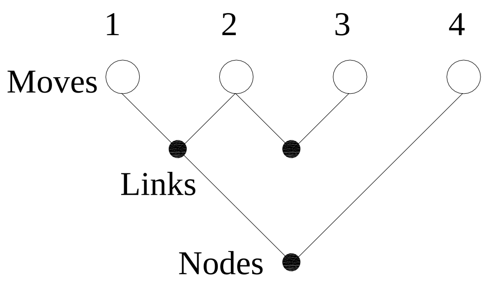


Figure 4.1: Linkography of four moves

Goldschmidt was concerned with the pattern of the distribution of these links and the number of the links; she had noticed that the links are unevenly distributed thus can reflect the nature of the performance of the process. There are two kinds of links: the *forelinks* (link M2-M3) and *backlinks* (Goldschmidt, 1995, p. 195); in the case of move 2, link 2-1 in Figure 4.1 represents a backlink and link 2-3 represents a forelink.

4.3.2.2. The Developed Linkography

While Goldschmidt focused on the number and the distribution of links, the focus of this study is on special kinds of links that represent the transformation of ideas through the dialogical reinterpretation. Thus the development will focus on exploring these links.

For the purposes of this study, Goldschmidt's definitions of moves will be adopted, in which the moves can be made verbally or literally. Their content can be a design decision, a design act, or both of these. The rule that controls the derivation of these moves is that the decision or act or group of acts should make a noticeable difference in the situation, and this will be recognized in the drawings. The verbal sentences that contain design decisions and ideas are also considered to be moves as they report the designer's thoughts, and thus report the thinking progress. The number of acts does not reflect the degree of change in the situation or the change in the resultant drawing.

While sometimes one action can achieve a remarkable change, at other times a group of acts cannot reach the same change. Below are some examples of one student's protocol that belongs to this study (sentences within square brackets [] are the student's own words, while the rest is the researcher's own notes):

M1 [First I'm going to use the service area as anchor] ***(verbal move)***

M2 [Then the celebration hall is going to be an organic shape] ***(verbal move)***

M3 [First is to start with a primary solid, scale, what I want just to address the corner property and gives it a prominence]... [The service area, the parking to be located back, pedestrian entrance at the front]. ***(decision and action move)***

M4 Draw a quick pedestrian entrance. [Thinking as an axis point here], looking at the object in four ports (a bird's eye view):[the parking at the back, roughly somewhere. Do not know how big is the service area so give it rough guide just to work with] (draw the site). ***(action move)***

The first and second moves are "verbal moves" where the designer suggested ideas verbally (the recorded video also confirmed that they are only verbal suggestions), the third is a "decision and action move" where the designer started to take some decisions and implement his ideas, and the fourth move is an "action move" where he implemented and drew the design elements.

To give a description of the linkography for this study, Figure 4.2 shows the developed linkography. The linkography is divided into two parallel parts; the first upper part illustrates the moves and the links in Goldschmidt linkography, the moves are coded with the letter M and have been given numbers. This part also shows all kinds of the suggestions and ideas. The designers' own ideas are coded with the letter D and the ideas that emerged through the dialogue between the designer and the computer are coded with letters D-Comp. The links network is drawn with thin lines and the links that trace the connections among the ideas of D-Comp are drawn in thick lines. The second, lower part is introduced to measure the variables, to determine the kinds of links and the kinds of moves. It consists of three lines, the first illustrates the measurement of the first, second and third variables; the pattern discovery, the conceptual reinterpretation and the first way of measuring the alternation of thinking, that is the physical figural reinterpretation. On this line all the coded ideas in the first part have been classified and given values of unintentional ideas (coded Unint.) or intentional ideas (coded Int.) referring to the occurrence of pattern discovery and conceptual reinterpretation respectively. The moves that achieve the transformation of the ideas into figural physical states are marked and coded with letters (ap) referring to the word application.

The second line illustrates the moves that deal with the whole building and that deal with parts of the building, which can help in measuring the fourth variable, “the restructuring”. It also illustrates the moves that transform the suggested idea to become the main idea.

The third line illustrates two kinds of information. The first one is pertaining to the kinds of moves by classifying them into two categories: the construction group of moves and the development group of moves, which can help in determining the second way of measuring “the alternation in thinking”: the effectiveness of rhythm of alternation. The construction moves are the moves that achieve and establish the primary building of all the components of the idea including the secondary suggestions that achieve the task’s basic requirements within the construction of that main idea. Therefore these moves represent the divergent way of thinking and are named the construction web. The second category is comprised of the development moves, which are the refinement moves that develop the idea vertically by giving more details. Therefore they represent the convergent way of thinking and are named the development web. Although the construction web represents the divergent style of thinking and the development web represents the convergent style, the issue here, to some extent, is relative. The construction web suggests new forms and shapes that can represent the idea. This suggestion of specific shapes to represent the idea can be explained as a kind of convergent way of thinking since it implies a kind of choice and selection. However, it is a divergent way of thinking in comparison to the development web, which deals with the details of the shapes and forms that have already existed, thus there are no new suggestions related to the construction of a new main idea. The length of these webs (construction webs and development webs), which could be measured by the number of moves in the web, represents the time spent in each type of thinking; however, this latter is not the focus of this research.

The second kind of information is pertaining to the sequence of the alternation; the divergent-convergent is coded div-con and vice versa.

To show the way it is used for measurement, below is an example taken from one of the protocols of this study. Part of the transcript of the protocol (moves 24-38) is used, and the developed linkography Fig. 4.2 shows the moves from 1-38 to illustrate the previous connections with the selected part of the example.

The transcript (sentences within square brackets [] are the student's own words, while the rest is the researcher's own notes, M = Move):

M24 [What we can do, this side entry has now changed, it will be some kind of garden, a kind of outdoor stage. OK this area becomes a kind of landscape area]. (the designer looks at the whole drawing from top). ***(verbal idea)***

M25 The designer creates a landscape area or sitting area, fixing it in place -the volumes are in mesh situation. [We can add some random shapes which can represent some art work, it doesn't really matter]. ***(action move)***

[Let's think about the main view]. Looking at the whole design from inside and outside: [Checking the shadow, the light. Do some tests, we can see the entry, the skylight, the frame, the car parking. Save that. Starting the second idea]

M26 [The wall still there, the entrance should be shifted. It is ok, the parking over there, what we going to do.........., the parking covers two square here, so we can give that different material, give it green colour]. ***(decision and action move)***

M27 [What we want to do is to keep that entrance, it is going to be the same colour, see the symmetry. so in terms of axis....we want to keep this open area], manage the surfaces of the site by turning the platform of the drawings and modify them from beneath:[turn off the grid, this is the wall, this is the road], again fixing everything from beneath. ***(action & decision move)***

M28 [Thinking in the outdoor celebration...Keep in the axis becomes the heart of celebration]. ***(verbal move/idea)***

M29 [It is bounded by this box here, the surface area... of the given block site....is locked off here, we can now move it out], (he is managing it from beneath), [so we have boundaries, roads, we are going to give them colour. The service area will be kept in the back, create a cube, so as to be a boundary...] ..***(action move to implement the idea)***

M30 [We want to give this semi yard a kind of shape but we can try a different form of generation (different from the first idea), we can use curves, so what we want to do first of all is, we can sweep..] ***(verbal idea/secondary suggestion)***

M31 [we can create...curve, flowing curve a kind of music notation, we just have a curve shape, a floating surface] (roof). ***(action move implementing the idea)***

M32 [Thinking where is the anchor again...], the service area, create the cube. ***(secondary idea & action)***

M33 [make it taller...a taller tower]. ***(action move)***

M34 [a kind of a hanging point...it is a hanging tower] ***(verbal idea secondary)***

M35 [we can slot it..start to cut it up...we got a free standing..]***(action move/modify)***

M36 [we need something to hold it up so, I'm going to create something to hold it up, go back to top view, put it..] ***(decision & action move)***

M37 [I'm going to spread it up]. ***(decision and action move)***

M38 [It is a double space, a kind of observatory]. ***(verbal idea/secondary)***

The moves are marked on the line of the first upper part of the linkography. While the moves 28, 30, 34, and 38 represent the dialogue between the designer and the computer's drawings, move 26 is a suggestion from the designer. The transcript of the protocol is used to classify these types of moves, the designer's acts watched on the video tape and the interview and the report of the designer are all used for this classification.

To decide the intentionality of these dialogues, the connection with previous ideas is checked:

In Move 24, the designer moved the main entrance and pedestrian axis and started a new reading: he read it as an open landscape area, then he saw it as an outdoor celebration (outdoor stage). This idea has no connection with previous ideas, therefore it is unintentional. The new reading changed the domain from spatial organization of the site to a functional domain of celebration. Thus it is a pattern discovery.

In Move 28: there is a connection between this move and move 24. The designer used the idea of move 24 "the outdoor celebration" for the second time, so it has been chosen intentionally. It is obvious that the context is changed by suggesting the axis is the heart of the outdoor celebration, thus the spatial context of the outdoor celebration is changed from garden to axis.

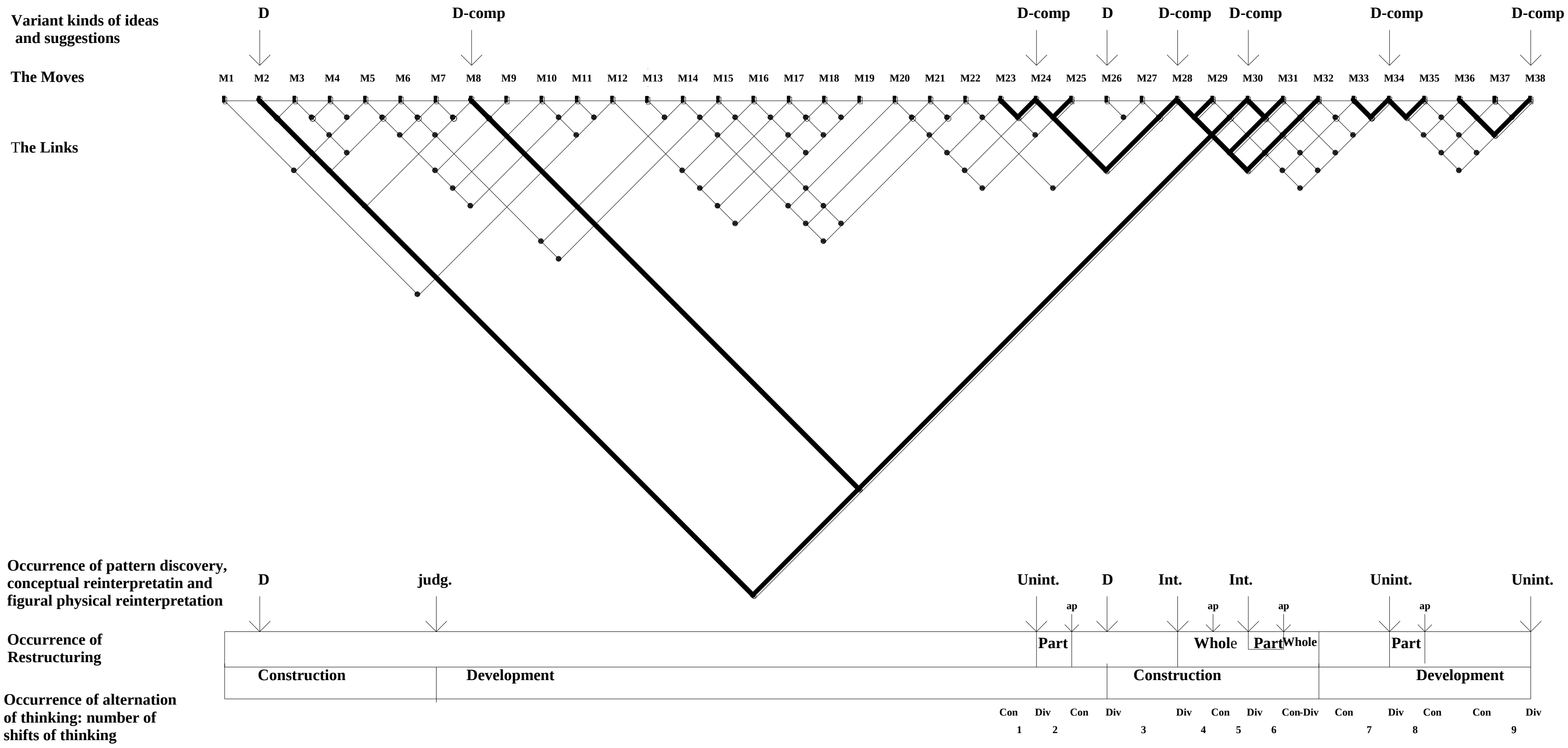


Figure 4.2: The Developed Linkography

In Move 30: there are two connections with previous ideas (moves 2 and 8); in these moves the designer failed to morph the geometric form into organic form. In move 30 he chose the same idea of organic form and changed his strategy to achieve it, instead of morphing the geometry to become organic, he used curved elements to represent the organic forms. So it is chosen intentionally.

In Move 34: there is no connection with previous ideas. The designer modified the height of the anchor (service cube), it became a tall building, and he saw it as a "hanging tower", so the designer has changed the domain from functional and structural domain to formal domain.

In Move 38: there is no connection with previous ideas. The designer wanted to hold the top of the tower so he created a small cube as a structural supporter. He saw the tower as an observatory. The designer here has changed the domain from a structural to a functional domain. Accordingly, this move is a pattern discovery.

To achieve the first way of measuring the third variable (the completeness of the cycle and the occurrence of the physical figural reinterpretation), the moves in the transcript have been classified as verbal ideas, action moves, decision moves. The moves after each idea have been checked according to this classification to determine the moves that contribute to implementing these ideas (the action moves). The thick forelink line in the upper part of the linkography ensures the application process. These moves have been marked with letters (ap) at the first line in the lower part to refer to the application process. Counting the number of these moves achieves the measurement of this variable.

These moves have been checked once again to investigate the wholeness of the application. To achieve this, the video tape has been watched, and then the moves which follow next were analyzed to determine whether these moves have any kind of connection to support that idea. These connections have been drawn within thick lines at the first part of the linkography. They are also marked on the second lower part with words (part, whole). For example the idea of "the axis is the heart of celebration" (move 28) has a forelink with next moves, even the suggested idea of using the curve in move 30 is supporting the idea of celebration as the designer described it “ a flowing curve a kind of music notation”. Therefore the second line shows the “whole” along moves 28-32. Accordingly, the re-structuring is taking place. Other ideas (30, 32, 34, and38) are applied to parts.

As for the second way of measuring the third variable (the rhythm of alternation of thinking), the webs of the selected part of the protocol have been marked on the third line; moves 26-32 are considered the construction web as they achieve the construction of the suggested idea and manipulate other basic requirements of the task within this idea. Moves 33-38 are considered the development web as they deal with the details of the constructed components. The alternation of divergent and convergent modes is shown under the third line. The data of the first line in this part of the linkography are used together with the data on the line that shows the types of webs to achieve this measurement. The moves marked with (Unint, Int, or D) are considered to be divergent moves. The moves marked with (ap) are considered the convergent moves. When counting the number of shifts due to the alternations, only the alternations that are related to the dialogical reinterpretation (Unint & Int) are included, and those related to the designer’s suggestions (D; depending on the designer’s background knowledge) are excluded.

4.4. Chapter Summary

This chapter addressed the measurements of the variables related to the characteristics of sketching using the computer (the degree of continuity of the dynamic field of images), and the variables related to the indicators of productivity through dialogical reinterpretation. It also described the methods and tools used in measuring the productivity variables. Protocol analysis and data collection have been presented. To achieve the purposes of this study, “think aloud” protocol has been chosen. Linkography, as a tool for presenting data, has been developed to suit the requirements of measuring the variables that indicate the productivity of the conceptual design through dialogical reinterpretation.

5. Research Design

This research is concerned with studying the relationship between the characteristics of the drawings using the computer on one hand and the productivity of the design process through dialogical reinterpretation with the drawings on the other. In chapter two and three the theoretical framework has been built, and the variables of the characteristics of the sketching process using the computer and the indicators of the productivity have been defined. Then the variables of the sketching process that are related to the performance of the designer have been determined and chosen to be in focus in this study to test the hypotheses of their relationship with the all variables of the productivity. These are: the degree of continuity of displaying images due to changing the object's status and due to changing the object's position, and the degree of the provision of the holistic view. In the last chapter, the focus was on determining the measurements of these chosen variables and also the productivity variables.

In this chapter, the necessary information for research design is going to be outlined. This is crucial for conducting the practical study and testing the hypotheses. Accordingly, the following sections are going to: first; determine the hypotheses, the independent and dependent variables, and the indicators of their measurement. Then the setting of the experiment is going to be determined by determining the kinds of the 3D modelling software that will be used, the design task and the participants in the experiment. Finally, the circumstances of collecting and analyzing the data are going to be determined.

5.1. The relationship between the characteristics of sketching using the computer and the productivity of the conceptual design process

This relationship is hypothetical in most of its points. The test of this relationship can be achieved through testing the hypotheses related to the detailed parts of both of the chosen variables of the characteristic of sketching using the computer and the variables of the productivity.

5.1.1. General Research Hypothesis

The research hypothesis is pertaining to all of the detailed relationships between the characteristics of sketching using the computer and the indicators of the productivity of the conceptual design stage, table (5.1). The research assumes that these relationships exist. In general, the hypotheses are pertaining to the degree of the existence of the characteristics of the sketching to the relative increase in the productivity.

Three variables of the degree of the continuity of the dynamic field of images have been chosen to test their relationship with the productivity. These are: the degree of displaying variant images due to changing the object’s status (the appearance) and due to changing the object’s position (the navigation), and the degree of provision of a holistic view. The hypotheses are around these relationships.

In order to formulate the detailed hypotheses, a full description for the independent and dependent variables will be given.

5.2. The Independent variable: The degree of the continuity of the dynamic field of images

The indicators of this variable and the measurements have been determined in chapter four. In the following a brief description will be given for the two variables chosen to test their relationship with productivity.

5.2.1. The degree of continuity of displaying images

The environment of the 3D modelling software packages provides the designer with the ability to change the object's status by changing the appearance, and the ability to change the object's position by navigating around and inside the designed objects. These two abilities are considered to be the tools for displaying variant images. The measurements are as follows.

1. The measurements of the change in the object's status due to the change of the appearance are achieved by counting the number of the following kinds of moves.
    - Moves from 3D to 2D that is the looking at the objects in perspective or isometric and then move to plan, section or elevation, and vice versa.
    - Moves from solid state to mesh state, when the designer switches from solid to a more transparent situation and vice versa.
    - Moves from inside to outside, when the designer looks at the object from interior then moves to the exterior and vice versa.
2. The changes in images due to the navigation; the measurements are achieved by counting the number of the following kinds of moves.
    - Moves from whole to whole by turning around the object left and right or up and down.
    - Moves from part of the object to the whole and vice versa by zooming in and out.
    - Moves from part to the same part by looking at the same part from another angle of view.
    - Moves from part to another different part of the designed object.

Table 5.1: Hypotheses of the relationship between the variables of sketching using the computer and the indicators of productivity

			Characteristics of Sketching Using the Computer					
			Degree of Ambiguity of the Drawings		Degree of Continuity of the Dynamic Field of Images			
					Degree of Flexibility of Forming Design Images			Degree of provision of a holistic view
						Degree of Continuity of Displaying Images		
			Ambiguity Due to the Type of Lines	Ambiguity Due to the Content of the Image	Degree of Ease in Projecting design images	Display Due to changing the Object's Status (Appearance	Display Due to changing the Object's Position (Navigation)	
Indicators of the Productivity of the Conceptual Design Phase	Degree of Occurrence of Dialogical Reinterpretation	Occurrence of Pattern Discovery	⊕	⊕	⊕	⊕	⊕	⊕
		Occurrence of Conceptual Reinterpretation	⊕	⊕	⊕	⊕	⊕	⊕
	Degree of Occurrence of a Complete Cycle of Dialogical Reinterpretation	Occurrence of the alternation of thinking	⊕	⊕	⊕	⊕	⊕	⊕
		Occurrence of Restructuring	⊕	⊕	⊕	⊕	⊕	⊕

Note: ⊕ **Positive Relationship, Shaded columns: hypotheses to be tested.**

The measurements will be taken twice, once for the active navigation and once for the background navigation.

5.2.2. The degree of provision of a holistic view

This variable is measured by measuring three indicators:

- the first is to count the number of times the four ports screen is viewed.
- the second is to measure the number of types of displaying views that have been used, which could have a value from 1-10. These are: the four types of navigation (part to same part, part to another part, part to whole, and whole to whole) and the types of views of changing the appearance (plan, section, elevation; which represent the 2D status, and the outside 3D modelling, inside 3D modelling, and the mesh status of the object).
- the third is to measure the total number of times of using these displaying views.

5.3. The Dependent Variable: The productivity of the conceptual design process

Four variables have been identified to indicate the productivity of the conceptual design stage through the dialogical reinterpretation. The measurements of these variables have been determined. In the following, there is a brief description of these variables and their measurements.

5.3.1. The Degree of the occurrence of dialogical reinterpretation

This variable includes two indicators: the occurrence of pattern discovery, and the occurrence of conceptual reinterpretation.

5.3.1.1. The occurrence of pattern discovery

The measurement of this variable is achieved by counting the number of the discovered patterns. To ensure the occurrence of this variable, the following points have to be checked.

1. The un-intentionality of the idea: to decide whether the suggestion is a discovery suggestion, which is due to dialogue with the computer drawings, or it is due to the designer's own values. The intentions can be checked in the following ways.

   - Review the recorded videos and meetings with the participants and the written reports. The focus should be on the sentences being used by the designer; sentences such as: "I want to do; I think public places are important; and my idea is..", indicate that these suggestions represent the designer's desires and values but not suggestions due to the dialogue with the drawings. Sentences that express the impression or reaction to what the designer is seeing, for example: "this is amazing; wow it is more than I can imagine; aha it seems very interesting", such sentences indicate that the dialogue with the drawing is taking place.

   - Check the linkography to check the connections and links of that suggestion with the other previous main ideas. If there are no links with previous main ideas, then the suggestion is classified as a pattern discovery. The connection with the ideas on the linkography is decided by checking the verbal sentences of the designer and also by comparing the main issue of the suggestion with that of the previous idea.

2. The domain of the idea has to be compared with the domain of the previous effective move that leads to the idea. The definition of the effective move is the move that suggests something or implements an action that produces the drawings; these drawings are then interpreted by the designer. This effective move could be just before the idea or long before it. It also could be one effective move or more than one move.

   If the two domains are different, then the suggested idea is a pattern discovery and the reframing is taking place.

5.3.1.2. The occurrence of conceptual reinterpretation

The measurement of this variable is achieved through measuring two variables.

- Counting the number of the ideas that are connected with previous ideas; this indicates the intentionality of using the idea for the second time. The intentionality of using the issues of the previous ideas can be achieved by checking the linkages with previous ideas on the linkography. This link is decided through checking the verbal sentences of the designer; for example, Sentences like "I like the idea of the slope in the previous option... I'm going to use the slopes in my second option" or "in previous option we used the strip grid .... now I'd like to use these strips in another way", these sentences confirm the intentionality of using the same issue of the previous idea. Then the transformation of the idea has to be examined by investigating the technique used to change the context.
- Measure the length of the series of transformation, which can be achieved by counting the number of times the same idea is used; that is to calculate the number of the ideas of the conceptual reinterpretation that repeated the same issue and have changed the context.

5.3.2. The degree of occurrence of a complete cycle of dialogical reinterpretation

The second indicator can be measured in two ways: the occurrence of alternation of thinking and the occurrence of restructuring.

5.3.2.1. The occurrence of alternation of thinking

The measurement can be achieved through measuring two variables; the occurrence of figural physical reinterpretation and the effectiveness of the rhythm of alternation of thinking; this can be achieved in the following ways.

- Examining the completeness of the dialogical reinterpretation's cycle due to the occurrence of figural physical reinterpretation. The measurement of this variable is to count the number of the ideas (pattern discovery and conceptual reinterpretation) that have been implemented and then given a physical existence. This can be achieved on the linkography by counting the number of moves on the second part of the developed linkography, they are marked with letters “ap” which means “application”.

- Examining the rhythm of alternation over the timeline. Then the number of moves from divergent to convergent and vice versa has to be counted on the chronological line of the linkography.

5.3.2.2. The occurrence of restructuring

This could be measured by counting the number of the figural physical reinterpretations that have been applied to the whole building. This can be achieved by simply counting the number of the “whole” marks on the linkography.

5.4. The detailed hypotheses

The research assumes that the relationships are exist and are positive for the following variables.

First- The degree of continuity of displaying images due to changing the appearance of the objects: the increase in the number of times of changing the images due to changing the object’s status (change the appearance from 2D to 3D, from inside to outside, and from solid to mesh) leads to the increase in productivity.

Second- The degree of continuity of displaying images due to changing the position of the objects (the navigation): the increase in the number of times of the images change due to changing the object’s position (the navigation from whole-whole, whole-part, part-same part, part-another part) leads to the increase in productivity.

Third- The degree of provision of a holistic view: the increase in the degree of the provision of a holistic view leads to the increase in the productivity. This includes: the increase in the number of times of using the four ports screen; the increase in the number of types of displaying views; and the increase in the total number of times of using these displaying views.

5.5. The experiment setting

This section presents the experiment setting and the design task.

5.5.1. The experiment: the choice of the participants and the 3D software used

Since the occurrence of the independent variables depends on the performance of the users, it is impossible to choose in advance the sample that provides the minimum and maximum values. There is no fixed range to the limits of the occurrence of these variables. Accordingly, the choice of the modelling programs depends on the availability of the facilities of the dynamic display.

In order to get more generalized results, more than one kind of 3D program should be used. The most common programs used by the students in their projects have been chosen for this experiment. The programs have been classified into groups.

Group (A) - the 3D Max: this program is used by architects for achieving more free organic forms; it is very flexible in forming 3D objects.

Group (B) - the Sketchup: it is straightforward to use in forming 3D orthogonal forms. It has less ability in forming free forms. However, the abilities of push and pull make the forming and modifying more flexible, and finally this program is the most common used program among the students.

Group (C) - the Auto-Cad: this program is more precise than the others and shares them most of the basic modelling requirements. However, it differs in the built-in strategy of constructing the objects, the design of the interface layout and the sketching environment.

All of the above programs are capable of providing the facilities of dynamic representation; they are capable of changing the status by changing the appearance (solid-mesh, in-out, and 2D-3D); capable of changing the images by the use of navigation; and finally, they can present the design work in plan, section, elevation and perspective. However, the concurrent display for design objects from different views (plan, section, elevation, perspective) in one screen can only be achieved by using the 3D Max. This variable, therefore, is going to be checked within the group of the 3D Maxs.

The choice of the participants depends on the degree of their skills in using these modelling programs; they should share similar skills and experiences, they also should have the same educational background. Ten post-graduate master students (in Architecture) have been chosen to participate in this study; two of them are in the MSc Digital Media programme, two participants are in MSc City programme and the rest are in the MA programme. Some of the participants have taken parts in the experiment twice in order to get cases of more controlled situations, raising the total number of cases to fifteen.

The number of the participants in every group should not be less than three so that the comparison can take place; in an ideal situation one of the participants in the group will achieve the maximum number of sketching variables, another achieves the minimum and the third is in the middle.

The participants are divided into four groups and everyone is given a coded letter. These are as follows.

Group (A): three participants use the 3D Max (P, N, E1)

Group (B): five participants use the Sketchup (R1, S, M1, A, T)

Group (C): two participants use the Auto-CAD (Mk1, K) and one participant uses the MicroStation E2.

Then a fourth group (D) has been added. This group consists of the participants who have taken part in the experiment for the second time solving another different, but almost similar task.

Group (D): one participant uses the Maya (MK2), and two participants use the Sketchup (R2, M2).

Here, two points have to be clarified:

1. It is obvious that all the participants in Group (A) and (B) use the same program; however, in Group (C) they use two different programs; the Auto-CAD and the MicroStation. Although Auto-CAD is the most common

program for architectural drawings, it seems that few students have high skills in using it. Only two students volunteer to work with Auto-CAD. To complete the required number of Group C to three participants, a volunteer using the MicroStation has been added to complete the group. Since the two programs are almost the same but with some differences, which are not essential for this study, the reliability of the results is not affected.

The possibility of the comparison between the participants of Group (C) is going to be discussed in more detail. The essential fact for this study is that the drawing environment for the two programs is significantly similar. This is because the selected independent variables of the sketching are strongly related to the environment of drawing, thus the criteria of the possibility of comparing between the users using different programs are focusing on the similarities in the built-in strategy of constructing the design objects and the similarities in what the designer sees in this environment, how to use this environment of drawing and what this environment can provide. As for these two programs, both are used by architects to produce more precise drawings for engineering purposes, working drawings, and final full presentation. They also have the same built-in strategy in constructing the design objects; the user has to start from the components of the plan giving full details, then extrude the whole object in 3D. Secondly, the commands are almost the same with some differences in language and the way of using these commands. The review of the manual of "MicroStation for Auto-CAD users"[19] shows the differences in some commands like (Line Command, Direct Distant, Shortcuts and Alias Commands, View ports, Object Snap among others); all of these differences are minor. Finally, the review also shows many similarities in the user interface so that the users of AutoCAD can easily learn MicroStation.

For these reasons the participant E2 has been added to group (C) in spite of the fact that this participant is using different software.

[19] See "Microsoft for AutoCAD users: learn to be more productive than ever before" presented by Jeanne Aarhus, Nabraska User Group, Spring 2005
URL http://www.dor.state.ne.us/NEUG/pdf/12%20uSTN%20for%20AutoCAD%20Users.pdf

2. As for the participant E1 in group (A) and participant E2 in group (C), he is the same participant using different software and solving two different but almost similar tasks so that the comparison can take place. Accordingly, the participants who have attended the experiment twice can be classified into two categories: two of them used the same software twice (R and M with Sketchup), and the other two used two different programs (Mk: AutoCad and Maya, E: 3D Max and Microstation).

5.5.2. Design Task

The experiment includes solving a design task followed by a short meeting with each designer. Two design tasks have been prepared as there are four participants have to join the experiment twice. While groups (A) and (B) have to solve Task 1, groups (C) and (D) have to solve Task 2. All the participants of group (D) have to solve Task 2 except participant MK2 who is using the Maya to solve Task 1.

Task 1

Multi-purpose Hall in a Park
This M.P. Hall could be used for meetings, celebrations and social purposes. It should have two functional zonings: Lobby and public celebration area (sitting and stage area), the service area (kitchen and store).
Its total area is between 250-300 m^2.
Site Plan

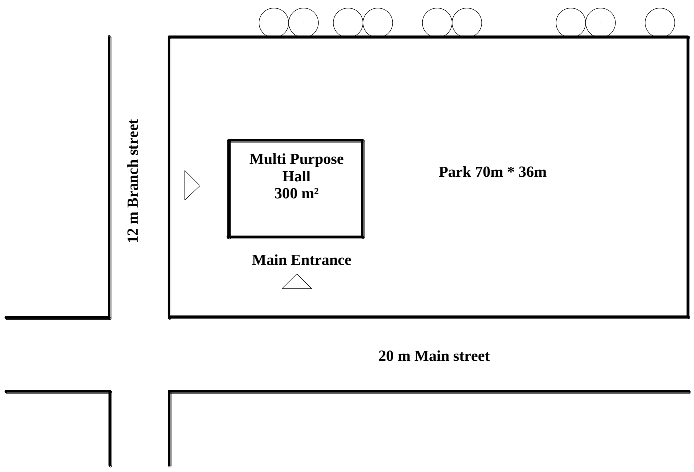


Figure 5.1: Task 1, Site Plan

Instructions

- You have to give at least 3 different ideas by using only the computer.
- You have to outline general solutions to the relationship between the service area50m^2 and the sitting area 200-250m^2.

- You are not allowed to use pen and paper.
- Please report your acts by speaking loudly
- You have to save your drawings every 20 minutes in separated files and name each.

Task 2

Gallery of Art

This Gallery could be used for displaying Art works (paintings and sculptures). It contains these functional zones:

- Entrance and lobby (30 m^2)
- The display zone, which includes:
    1. Permanent display hall (150 m^2)
    2. Temporary display hall (90 m^2)
    3. Outdoor display yard (60 m^2)
- The stores (60 m^2)

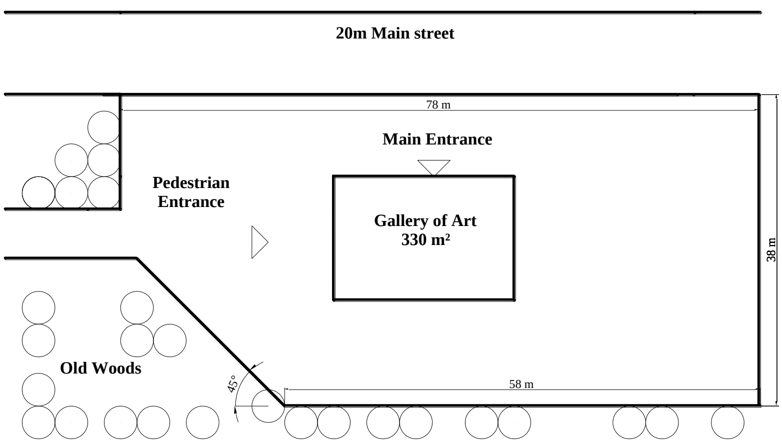


Figure 5.2: Task 2, Site Plan

Instructions

- You have to give at least 3 different ideas by using only the computer.
- Try to give general functional solutions for the relation between the display zone and the storage zone.
- You are not allowed to use pen and paper.
- Please speak loudly to record your thoughts.
- You have to save your drawings every 20 minutes in separated files and name each.

The function of the two tasks is simple so that they can achieve the purpose of this study in concentrating on ideation rather than the development stage of designing. Participants have been asked to give at least 3 ideas within one hour and a half. The task, the time and the requirements have been examined and revised with three volunteers (two PhD students and one undergraduate student) before setting up the case study. The task and instructions have been revised several times while doing the pilot study. The volunteers were asked to give ideas as many ideas as they can in one hour. The three participants gave only one idea in detail. Therefore the instructions and requirements have been changed to require them to give at least three general ideas in one hour and a half. This is expected to encourage them to exploit their previous suggestion in generating new ideas and continue the dialogue with their drawings. The participants were not allowed to use pen and paper so that the ideas and suggestions can be related to the dialogues and to the computer's drawing. And finally, the participants were asked to talk loudly to record their thoughts as they occurred.

The experiment with every participant has been recorded using a video camera, then after finishing the experiment a video recorded interview has been held with every participant to describe their ideas. A report giving a short description of the ideas is the final requirement that the participant has to write at home.

5.6. Measurement Considerations and Data Collection

In this section the measurement considerations of every variable of the independent and dependent variables are going to be presented. Then the circumstances of data collection are going to be clarified.

5.6.1. The independent variables

To verify the effect on the productivity of each of the chosen independent variables that are related to the medium, the other factors that affect the productivity have to be controlled. These other factors are the kind of design task, the software and the individual skills of the participants.

As for controlling the effect of the kind of the design task, the comparison will take place, separately in each group. As the participants of every group are solving the same task, this ensures the control on this factor (design task) as well as the factor of the software in use.

As for the skills of the participants, the participants who have been chosen have almost the same background and have almost the same level of skills in using the 3D software in order to lessen possible differences. However, the skills of designing cannot be at the same level for all of the participants even if they have the same background. The full control of this point lies on the fact that the measurements of the productivity depends on the dialogical reinterpretation of the drawings only. Any idea or suggestion coming from the designer him/herself is not included in the measurements. Moreover, this study is going to make use of the differences in the participants' habits when using the software and their abilities in initializing a dialogue with the drawings. Finally, to ensure the full control on this point, some of the participants will join in the experiment twice. Although the task has to be changed to another task, the second task is prepared to be at the same level of difficulty and the participant has to achieve similar requirements.

Furthermore, to verify the effect of each of the chosen variables of the characteristics of the sketching using the computer on the productivity under a controlled situation, the independent variables have to be separated from each other. However, the built-in strategy of constructing objects using the 3D modelling software does not allow such a separation, as has been clarified in chapter three, section 3.1, Figure 3.1, and also solving an architectural design task demands the use of all of the variables together. For example, the participant cannot construct an object using only the whole to whole navigation without using the other options such as; part to part; part to whole. In order to achieve any kind of design task the designer has to use all of them. The designer also cannot work with the 3D modelling without using the 2D drawings. The ideal situation of control cannot be achieved. Thus designing a separate experiment for each independent variable is not only impractical but also it cannot be achieved in real life since some variables are essential and cannot be switched off. Moreover, the productivity depends largely on working under normal design situations; setting the experiment under many restrictions and rules may affect the designing abilities of the participants and thus affect the reliability of the results.

Therefore the validity of the results depends on the fact that the existence of the independent variables is related to the difference of the performance of the participants in using these software options. Therefore the existence of a pattern of differences in the use of these variables that coincides with the pattern of the difference in the productivity among the participants, is going to indicate a kind of relationship between the two.

A description of some considerations of the circumstances of the calculation of each variable follows.

- The total number of navigation moves related to each variable/kind of navigation (whole-whole, part-whole, part-same part, and part-another part) is going to be calculated separately, and then the total number of navigation moves due to all of the variables is going to be calculated through the summation of the number of times all the types of navigation are used. This can achieve the goals of this study as it is designed to discover the relationship between navigation and productivity and answer the basic question, could a design process that is rich in navigation give more alternatives?
- The question of this study is about the possibility of increasing the alternations of designs in the conceptual stage by increasing the changes of image due to the navigation, change the appearance, and the provision of the holistic views. These alternations come in a form of ideas and suggestions. It is not right to consider only the number of changes in images just before the suggestion has taken place (between the move of current suggestion and the previous move) and exclude the others. That is because the suggestions do not come only from what the designer has just seen, which could be true for some cases (such as finding the Gestalt figure), for most of the other cases (conceptual pattern, conceptual reinterpretation, the physical reinterpretation and the restructuring) the idea comes from the accumulation of many previous images. The incubation stage of the idea has to be considered, which comes before giving a suggestion. Accordingly, the accumulation of many images contributes to the generation of this idea and not only the images seen just before. As there are no limits to the incubation period, the calculations include the total number of changes in images over all the whole process for each variable.

5.6.1.1. Data Collection

The recorded tape for every participant has been watched separately by the researcher. The data have been collected by pausing the tape whenever there is a change in the image. The changing images have been classified into the categories of whole to whole, whole to part, part to same part, part to another part. The data of changing the status have been also collected: 2D to 3D, solid to mesh, and inside to outside. And finally, the data of the degree of provision of a holistic view have been collected and calculated.

To achieve the reliability of this method of data collection; the researcher watched every tape more once (2-3 times) and checked if there were any difference in the decisions of categorizing these changes or in counting the number of each. To unify these decisions the researcher has put forward some basic rules for these decisions. These rules have been used for the entire practice of the participants. Some of these rules:

- if the designer turns around the object and goes left or right, within an angle not less than 45°, this will be reported as one change in image. If the angle is more than that, for example 90°, this will be reported as two changes in the image. So every turn within 45° is reported as a change Figure 5.3.

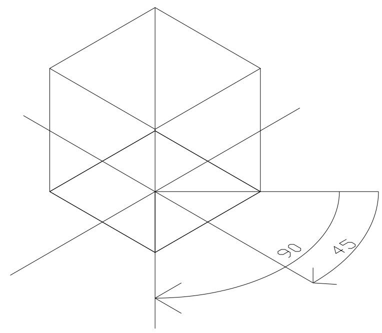


Figure 5.3: Change the design image by turning around the object, the 45° angle indicates a change in image

- if the designer moves slightly right or left keeping the same image with slight difference (less than 45°), this move will not be recorded.

- zooming out or in, keeping the same whole image of the object will not be recorded as a change, while "zooming in" from a whole image to part of it or vice versa will be recorded.
- zooming from whole to part followed by a zoom out of this part will be recorded as the image having been changed twice.

The researcher has applied these rules when collecting the data for every participant. The recorded tapes of each participant have been watched twice. Whenever there was a difference in counting, the tape has been watched for a third time. For example, in counting the total number of the displayed images for every independent variable (the degree of continuity of display images: the display due to changing object's position (navigation) and the display due to changing the appearance, and the provision of a holistic view), the counting has been repeated twice for every participant. In some cases there were differences in the results of counting the total number of navigations in the second count compared with the first count. The differences were within a range of 5-8 times; these cases are: P, N, MK2, R1, and R2. Although the range of difference is noticeable, the difference is quite acceptable when compared with the total number of navigations for these cases 345-235. The data for these five cases have been recollected and the counting has taken place for a third time. It is believed that the reason behind this difference is that these participants were very active in using the navigation tool; in some cases participants turned around the object and returned to the first position and repeated the same moves again and again without taking any action except they changed the vertical or horizontal angle of vision a little (to nearly 45°). This small change in the angle of vision has been calculated sometimes and neglected at other times.

5.6.2. The dependent variable-Data Collection

The video recorded tapes have been watched for every participant to prepare a written transcription of the protocol. In general, most of the time the participants were active in describing their thoughts and actions. However, this is not always the case as some times the participants prefer to keep silent and work; in such cases the experimenter has described their actions. In some of these cases the experimenter has also reviewed the written reports and watched the recorded interviews to check some points related to the description of ideas in order to help in recording these silent periods of a designer's actions and reflections.

Then, the written text has been transformed to moves for every participant, Appendix A, and the linkography has been drawn for every case, Appendix B. Finally, the measurements of the variables of the productivity have been achieved through using the written texts and the linkography. The tables of the calculations have been prepared for the four variables: The pattern discovery, the conceptual reinterpretation, the alternation of thinking, and the restructuring.

5.7. Data Analysis

The differences between the participants for every independent variable, which has been chosen for the test, have been calculated. Then these differences have been represented on symbolic lines; they work as indicator lines for the differences. On the other hand, the differences between the participants for every variable of the productivity's indicators have been calculated and represented on the symbolic lines of difference.

To analyze the relationships between the independent variables (changing the images due to changing the status; changing the images due to the navigation; and the provision of holistic view) on one hand and the productivity variables on the other hand, the comparisons have been achieved between the two variables using the indicator lines of differences. These symbolic lines of differences show the sequence of participants from high to low. The existence of the relationship and the strength of this relationship can be obtained by observing the degree of the harmony of this sequence on the indicator lines of difference of both the independent variables and the productivity variables. The direction of the relationship (positive or negative) could be obtained by observing the nature of this sequence.

As the sample is small in number the statistical methods have not been used in determining these relationships. In such cases the correlation coefficient will be highly affected by the extremes rather than by the general pattern of the measurements of these variables.

6. Practical study –Results

In this chapter, the results of the practical study are going to be displayed and then the data will be analyzed to test the research hypotheses with the goal of establishing general indicators that help in enhancing designers' performance in conceptual design stage while using the 3D modelling software.

To achieve these purposes, the sections of this chapter will do the following:

- present the results of differences among the 15 cases for the three independent variables that indicate the degree of the continuity of the dynamic field of images: the change in the object's position due to the navigation; the change in the object's status due to the change in appearance; and the degree of the provision of the holistic view.
- present the differences among the 15 cases for every variable of the productivity variables (the dependent variables): the degree of occurrence of pattern discovery; the degree of occurrence of conceptual reinterpretation; the degree of occurrence of alternation of thinking; and the degree of occurrence of the restructuring.
- test the related hypotheses through analyzing the relationships between the independent and dependent variables.

Accordingly, this chapter consists of three sections. Section 6.1 presents the results of measuring the three independent variables. The paragraphs of this section deal with the collection of the data of every variable. This was obtained by watching the videos of the participating groups (A, B, C, and D), arranging tables for the variables' measurements, ranking the participants of each group according to the results of the measurements, and finally searching for suitable samples that could best present the difference in the values of every variable; in other words, the samples that displayed a sufficient difference in the values. This search has successfully provided suitable samples for all the independent variables except the following: the move from part to whole- active navigation, and the two measures of the provision of the holistic view variable (these are: the number of times of using the four displaying ports, and the number of types used for displaying the images).

The second section 6.2 presents the results of measuring the indicators of the four dependent variables. The paragraphs of this section have been arranged to present the measurement of every variable. Each paragraph presents the measurements of one of the dependent variables and shows the ranking of the participants in every group from high to low indicating the difference in the values of that variable. Paragraph 6.2.1 presents the measurement of pattern discovery and tables have been arranged to search for the occurrence of reframing; then to calculate the number of times of the occurrence of pattern discovery. The final calculation has excluded the ideas that are regarded as related to computer accidents. Paragraph 6.2.2 presents the measurement of the two indicators of conceptual reinterpretation: the number of the connected ideas and length of series. Tables have been arranged for every group to check the occurrence of changing the context of the reused ideas, which insures the occurrence of conceptual reinterpretation. Paragraph 6.2.3 presents measurements of two indicators of alternation of thinking: the occurrence of figural physical reinterpretation and the number of times of shift in thinking. Tables have been arranged to present the results of calculating these two indicators. To achieve these calculations the linkography of the protocol of every participant has been checked. Paragraph 6.2.4 presents the measurement of restructuring. Tables have been arranged for these measurements. To check the occurrence of restructuring the linkographies of the protocols have been checked searching for the moves that indicate the application of the idea on the whole rather than on the part of design objects.

The paragraphs of section 6.3 present the results of testing the relationship between every independent variable (the continuity of the dynamic field of images) and the dependent variables of productivity. Paragraph 6.3.1 describes how to verify the accuracy of the hypotheses by using the symbolic line of difference, which is used to compare between the sequences of the independent and dependent variables that are under consideration. Paragraphs 6.3.2, 6.3.3, and 6.3.4 illustrate the figures of testing the hypotheses using the symbolic line of difference, with a discussion of every case to reach a final decision about the existence or non existence of these relationships. Finally, paragraph 6.3.5 gives a summary of the results.

In the following, a detailed description of every section will be given.

6.1. The independent variable: the degree of continuity of the dynamic field of images

Before going through the results in tables (6.1, 6.2, and 6.3), a general description of some circumstances of collecting the data and the performance of the participants in using the drawing environment of the computer are going to be given.

- Tables have been arranged to show the results of measurements for the three independent variables. In general, the results of the three variables show differences in the values among the participants, in which the high numbers indicate the high values and the low numbers indicate the low values. As there are no high or low limits for the values of the independent variables, the groups of participants (A, B, or C, and the individual cases of D) that show cases with adequate differences in the values are the only recommended groups that are going to be in focus when testing the relationships. That is because in a situation of small samples like this, the samples should be selected very carefully to provide the high, middle, and low values of the independent variable and the difference between these three values should be adequate to fulfil the minimum requirements of the testing purposes. Otherwise the results cannot represent the results of the population or bring insight to the performance of the whole population. In such small groups that consist of only 3-5 cases, the high and low values are critical, and the scattering of the in-between values around the mean plays a crucial role in the testing results, especially in the situation of the sample of 5 cases. In small samples, the normal distribution cannot be checked statistically so that the scattering around the mean should be checked especially in the case of group (B), which consists of five participants.

The adequate difference means that the group provides one case of high value, a second case of low value, and a third which is almost in the middle, and the differences among the three should be noticeable. The lower value, in the situation of this case study, does not always mean zero value or near to zero, rather it is relatively low in comparison to the other values, except the independent variables that have possible fixed values where the minimum and maximum values are fixed and known. This study has only one variable of possible minimum and maximum values that is the "number of the types used" when measuring the degree of provision of holistic view. The possible values of this variable are within a range of 1-10, so the minimum value should be 1. Since there are no limits for the possible values for the rest of independent variables, the difference between high and low values is not restricted to a fixed number ,but rather it depends on the difference between the higher and lower values of that variable for that group. The minimum acceptable difference between the higher and lower extents in each group depends on the main stream of the data; the highest and lowest values of all of the data in that group. For example, table (6.1) shows the values of the data of the independent variable of active and background navigation (Whole-Whole) for groups (A) and (B): these values are higher than that of the active and background navigation for the group (C). Therefore the minimum acceptable difference in groups (A) and (B) is higher than that of (C). The reason for this difference could be regarded as the distinct difference in the drawing environment of the software used. Similarly, the minimum acceptable difference for the data of the independent variable (whole-whole) of group (A) is higher than that of the first three independent variables in the same group.

As for the cases that achieve adequate high and low values and the third value of the in-between, these cases are going to be examined once more to check whether the in- between values (especially in the case of group B) are close to the middle or if they are highly polarized to either the high or low values. While the former situation is going to be used as a case in the sample for testing the relationship, the latter is going to be excluded since it does not have a clear value to represent the in-between.

- In the following there are general observations about the use of some drawing tools used by the participants.
    - Participant N is the only participant who used the four ports of view (plan, section, elevation and perspective) for displaying the drawings. The change in the plan or section can be seen immediately in the 3D port of views.
    - Participant Mk2 who used the program Maya, used the camera effectively not only in walking through the 3D spaces but also in achieving the requirements of his idea by using the camera track route to be the circulation route inside the building. This participant also exploited the power of Maya in giving a high quality of reflection of the materials, which is considered essential in supporting his idea.
    - Participant P used the tool of the 3D layering to be effective in achieving his idea.
    - Most of the participants used the shadow to check the spatial composition of spaces and blocks; they also used the human figure to indicate the scale.
    - In some of the cases, the designer used unfamiliar points of view to look at the drawings such as the ant's eye views (participants P, Mk2 and R1); however, none of them paid attention to the resultant strange images of the objects being drawing.

The following paragraphs are going to present the results of the three independent variables.

6.1.1. Variable: Degree of Continuity of displaying images due to changing the position-Navigation

Table (6.1) shows the results of measurements of each type of navigation for the four groups (A), (B), (C), and (D). There are two kinds of measurements for every variable of the navigation. The first one is the active navigation that occurs when the designer only moves and turns around the drawings watching and contemplating the design objects. The second one is the active and the background navigation where the designer moves and turns around the objects while drawing and manipulating those objects. The results show that most of the navigation for the variables (P-S.P: the move from part to the same part of the drawing), (P-A.P: the move from part to another part of the drawing), and (P-W: the move from part to the whole of the drawing), is considered as background navigation, rather than being an active navigation. The results also show that the percentage of the occurrence of (W-W: the move from whole to whole) active navigation to the occurrence of W-W active and background navigation is 50% or more for almost all of the cases. This shows that designers prefer to have a whole view of their drawings while thinking and tend to turn around their whole drawings several times.

The following is a presentation for the results of every variable:

- First- Active Navigation, this includes:

Part-Same Part: The sequence of the participants in the four groups is as follows:

Group (A): N>E1>P respectively, with an adequate difference between the values of the three participants.

Group (B): A> R1>T>S>M1 respectively; however, the values are polarized on the high and low limits only, there are no middle values.

Group (C): MK1>K>E2 Respectively with an adequate difference in the values between the three participants.

Table 6.1: Results of measurements- Navigation

Group	Participants	Software	The Independent Variable: Degree of Continuity of Displaying Images due to Changing the Position-Navigation								
			Active Navigation				Active & Background Navigation				
			P-S.P	P-A.P	P-W	W-W	P-S.P	P-A.P	P-W	W - W	Total
A	P	3D Max	7	12	14	127	76	28	60	181	345
	N	3D Max	33	22	25	111	55	32	37	150	274
	E1	3D Max	18	1	25	66	36	9	46	102	193
B	R1	Sketchup	9	3	21	141	20	7	46	181	254
	S	Sketchup	1	0	4	81	33	2	22	135	190
	M1	Sketchup	0	0	7	92	40	5	20	130	195
	A	Sketchup	10	1	20	88	30	2	45	118	195
	T	Sketchup	3	1	3	49	13	17	41	71	142
C	MK1	ACad	17	5	8	64	43	16	62	107	228
	K	ACad	6	0	10	38	15	6	39	51	111
	E2	Micro Station	0	0	1	12	35	20	25	16	96
D	MK2	Maya	50	6	12	80	94	33	55	130	312
	R2	Sketchup	18	1	26	97	32	13	41	149	235
	M2	Sketchup	1	5	9	61	17	12	30	92	151

Group (D): The results of the sequence of the participants who sat for the experiment twice:

> Mk2>Mk1 with an adequate difference, E1>E2 with an adequate difference, R2>R1 with an adequate difference, M2>M1; however the difference between the two cases is not adequate.

Accordingly, the groups that are in focus for testing are: (A), (C), and (D) with cases Mk, E, and R, where the difference between the cases is adequate for comparison purpose.

- Part – Another part: the sequence of the participants in the four groups is as follows:

Group (A): N>P>E1 respectively, with an adequate difference in the values between the three participants.

Group (B): R1>A, T>S, M1; however, the rate of using this tool is very low and there is no adequate difference in the values between the five participants; all the values are polarized in one extreme.

Group (C): MK1>K, E2; however, the rate of using of this tool is very low and the difference between the values is not sufficient.

Group (D): The results of the sequence of the participants who undertook the experiment on two occasions: E1>E2 the difference is not adequate, Mk2>Mk1 the difference is not adequate, R1>R2 the difference is not adequate, M2>M1 the difference is not adequate.

Accordingly, group (A) will be in focus for the test purposes.

- Whole – Part: The sequence of the participants in the four groups is as follows:

Group (A): N, E1>P, The difference is not sufficiently adequate and the values are polarized in the two extremes (minimum and maximum) with no middle value.

Group (B): R1>A>M1>S>T, the difference between the two extremes is significance; however there is no adequate middle value.

Group (C): K>Mk1>E2, the difference between the two extremes is only 9, which is relatively low in comparison to the values of the other variables in the group, and the difference between the middle value and the high extent is not adequate either .

Group (D): The results of the sequence of the participants who performed the experiment twice: E1>E2 with an adequate difference, Mk2>Mk1 the difference is not adequate, R2>R1 the difference is not adequate, M2>M1 the difference is not adequate.

Accordingly, there are no groups in focus for the purposes of the test. As for the cases in group (D), only the case of E is in focus. Accordingly this hypothesis pertaining to the relationship of this variable and productivity is not going to be tested.

- Whole – Whole, the sequence of the participants in the four groups is as follows:

Group (A): P>N>E1 with an adequate difference in the values between the three participants

Group (B): R1>S>M1>A>T with an adequate difference in the values between the participants who achieve the high and low extents, the cases of (S, M1, and A) represent a middle group of almost polarized values that has achieved an adequate difference from the two extents (high and low).

Group (C): MK1>K>E2 with an adequate difference in the values between the three participants.

Group (D): The results of the sequence of the participants who performed the experiment twice: E1>E2 with an adequate difference, MK2>MK1 with an adequate difference, R1>R2 with an adequate difference, and M1>M2 with an adequate difference.

Accordingly, all the groups will be highly focused for the purposes of the test.

Second- Active and Background Navigation, this includes:

- Part-Same Part: The sequence of the participants in the four groups is as follows:

Group (A): N>E1>P respectively, with an adequate difference in the values between the three participants.

Group (B): M1> S>A>R1>T respectively, with an adequate difference in the values between the high and low extremes and the middle group.

Group (C): MK1>E2>K Respectively with an adequate difference in the values between the three participants.

Group (D): The results of the sequence of the participants who performed the experiment twice: Mk2>Mk1 with an adequate difference, E1>E2; however the difference between the two cases is not adequate, R2>R1 with an adequate difference, M1>M2 with an adequate difference.

Accordingly, all the groups will be in focus for the purposes of the test.

- Part-Another part: the sequence of the participants in the four groups is as follows:

Group (A): N>P>E1 respectively with an adequate difference in the values between the three participants.

Group (B): T>R1>M1>S, A respectively with an adequate difference in the values between the three participants.

Group (C): E2>MK1>K respectively with an adequate difference.

Group (D): The results of the sequence of the participants who performed the experiment twice: Mk2>Mk1 with an adequate difference, E2>E1 with an adequate difference, R2>R1 there is no adequate difference, M1>M2 there is no adequate difference.

Accordingly, the groups that will be in focus for the purposes of test are: (A), (B), (C) and (D) with cases MK and E.

- Whole – Part: The sequence of the participants in the four groups is as follows:

Group (A): P>E1>N respectively with an adequate difference in the values between the three participants.

Group (B): R1>A>T>S>M1respectively, the difference in the values between the two high and low extents is significance; however there is no middle value as the values are polarized either to the high or to the low extents.

Group (C): Mk1>K>E2 respectively, with an adequate difference in values between the three participants.

Group (D): The results of the sequence of the participants who performed the experiment twice: E1>E2 with an adequate difference, Mk1>Mk2 the difference is adequate, R1>R2 the difference is not adequate, M2>M1 the difference is adequate.

Accordingly, the groups that will be in focus for the test purposes are: (A), (C), (D) with cases E, MK, and M.

- Whole – Whole, the sequence of the participants in the four groups is as follows:

Group (A): P>N>E1 with an adequate difference in the values between the three participants

Group (B): R1>S>M1>A>T with an adequate difference in the values between the participants who achieve the high and low extremes, the cases of (S, M1, and A) represent a middle group of almost polarized values that has achieved an adequate difference from the two extents (high and low).

Group (C): MK1>K>E2 with an adequate difference in the values between the three participants.

Group (D): The results of the sequence of the participants who sat for the experiment two times: E1>E2 with an adequate difference, MK2>MK1 with an adequate difference, R1>R2 with an adequate difference, and M1>M2 with an adequate difference.

Accordingly, all the groups will be highly focused for the purposes of the test.

- Total navigation, the sequence of the participants in the four groups is as follows:

Group (A): P>N>E1 with an adequate difference in the values between the three participants

Group (B): R1>S>M1>A>T with an adequate difference in the values between the participants who achieve the high and low extremes, the cases of (S, M1, and A) represent a middle group of almost polarized values that has achieved an adequate difference from the two extents (high and low).

Group (C): MK1>K>E2 with an adequate difference in the values between the three participants.

Group (D): The results of the sequence of the participants who performed the experiment twice: E1>E2 with an adequate difference, MK2>MK1 with an adequate difference, R1>R2 with an adequate difference, and M1>M2 with an adequate difference.

Accordingly, all the groups will be in focus for the purposes of the test.

6.1.2. Variable: Degree of Continuity of displaying images due to changing the object's status- Changing the Appearance

Table (6.2) shows the results of measurements of all variables of changing the appearance for the four groups (A), (B), (C), and (D).

The table shows the results of measuring the three variables: the move from inside to outside of the objects and vice versa, the move from two dimensional drawings to three dimensional drawing and vice versa, and the move from solid to mesh state and vice versa. In general, the results show low values for the three variables in comparison to the results of the display due to the navigation. In several cases, especially the change from mesh to solid, the values of these variables are (zero) or near zero, which reflect the fact that these variables are optional rather than being

Table 6.2: Results of measurements- Changing the appearance

Group	Participants	Software	The Independent Variable: Continuity of Displaying Images Due to Changing the Status-Changing the Appearance			
			Number of In-Out Moves	Number of 2D-3D Moves	Number of Mesh-Solid Moves	Total Change in Appearance
A	P	3D Max	0	2	18	20
	N	3D Max	0	40	15	55
	E1	3D Max	2	99	17	118
B	R1	Sketchup	14	2	13	29
	S	Sketchup	0	29	0	29
	M1	Sketchup	2	6	0	8
	A	Sketchup	0	5	0	5
	T	Sketchup	47	2	0	49
C	MK1	ACad	20	29	12	61
	K	ACad	4	34	28	66
	E2	Micro station	8	40	7	55
D	MK2	Maya	16	21	20	57
	R2	Sketchup	0	2	0	2
	M2	Sketchup	5	17	0	23

essential to drawings and to solving design problems. The task could be done while the object is either in solid state or in mesh, either in 2D or 3D. It is also noticed that in the conceptual design stage the purpose of switching to 2D, mesh or to the interior view is to implement a command rather than to watch the object from another view.

As for the variable “the move from 2D to 3D”, table (6.2) shows a relative rise in the figures of this variable in comparison to the other variables; however there are few cases of low usage of this tool. The following is a presentation for the results of every variable:

- The move from In-Out, the sequence of the participants of the four groups is as follows:

Group (A): E1>P, N; however, the rate of using the tool is very low and there are no adequate differences in the values between the three participants.

Group (B): T>R1>M1>S respectively with an adequate difference in the values between the participants.

Group (C): Mk1>E2>K respectively with an adequate difference in the values between the three participants.

Group (D): E2>E1, Mk1>Mk2, R1>R2 with an adequate difference in the values, M2>M1; the difference is not adequate.

Accordingly, the groups that will be in focus for the test purposes are: (B), (C), and (D) with cases E, MK, and R.

- The move from 2D-3D, the sequence of the participants in each of the four groups is as follows:

Group (A): E1>N>P respectively with an adequate difference in the values between the participants. In this context, the calculation of the number of moves from 2D to 3D for the participant (N, group (A)) takes place also when the concurrence display by using the 4 ports of view is taking place.

Group (B): S>M1>A>R1, T respectively with an adequate difference between the high and low extents. The in between values are polarized to the lower extent.

Group (C): E2>K>MK1 respectively with an adequate difference in the values between the participants.

Group (D): E1>E2, R1>R2, M2>M1 with an adequate difference between the participants, Mk1>Mk2 the difference is not adequate.

Accordingly, the Groups that will be in focus for the purposes of the test are: (A), (C), and (D) with the cases E, R, and M.

- The move from Mesh-Solid, the sequence of the participants in each of the four groups is as follows:

Group (A): P>E1>N respectively, however the difference in the values is not adequate.

Group (B): R1>S, M1, A, T respectively, however there is no in between value, the values are polarized to the low extent.

Group (C): K>MK1>E2 respectively with an adequate difference between the two extents, there is an acceptable difference between the in between value and the lower extent.

Group (D): E1>E2, MK2>Mk1, R1>R2, with an adequate difference in the values, M1=M2.

Accordingly, the groups that will be in focus for testing purposes are: (C), and (D) with the cases E, MK, and R.

- Total display of images, as for the total display of images due to change the appearance, the results show a difference in the values of every group. The following is a presentation to these results:

Group (A): E1>N>P respectively with an adequate difference in the values between the three participants.

Group (B): T>R1, S>M1>A respectively with an adequate difference in the values between the participants except the cases M1 and A, the difference is not adequate.

Group (C): K>MK1>E2 respectively, the difference between the high and low extremes is 11, which is relatively acceptable in comparison to the values of the other variables in this group.

Group (D): E1>E2, R1>R2, M2>M1, the difference is adequate. MK1>MK2; however the difference is not adequate.

Accordingly, all the groups are in focus for the testing purposes. As for the cases of group (D), all of them are in focus except the case of MK.

6.1.3. Variable: Degree of provision of a holistic view

Table (6.3) shows the results of measurements of all variables of the provision of holistic view for the four groups (A, B, C, and D).

Table 6.3: Results of measurements- The provision of a holistic view

Group	Participants	Software	The Independent Variable: Degree of Provision of a Holistic View								
			Number of Times of Using the 4viewing Ports Together	The Number of the used Types For Displaying Images							Number of times of using the types (the total navigation+ the total change in appearance)
				Plan (2D)	Section (2D)	Elevation (2D)	Inside (3D)	Outside (3D)	The Mesh status	The number of the used Types	
A	P	3D Max	0	●	-	-	-	●	●	3+4	365
	N	3D Max	65	●	●	●	-	●	●	5+4	329
	E1	3D Max	0	●	-	●	●	●	●	5+4	311
B	R1	Sketchup	Not available	●	-	-	●	●	●	4+4	283
	S	Sketchup	Not available	●	-	-	-	●	-	2+4	219
	M1	Sketchup	Not available	●	●	-	●	●	-	4+4	203
	A	Sketchup	Not available	●	-	-		●	-	2+4	200
	T	Sketchup	Not available	●	-	-	●	●	-	3+4	191
C	MK1	ACad	Not available	●	-	-	●	●	●	4+4	289
	K	ACad	Not available	●	-	●	●	●	●	4+4	177
	E2	Micro station	Not available	●	-	-	●	●	●	4+4	151
D	MK2	Maya	Not available	●	-	-	●	●	●	4+4	369
	R2	Sketchup	Not available	●	-	-	-	●	-	2+4	237
	M2	Sketchup	Not available	●	●	-	●	●	-	4+4	173

Note:● being used, ─ never used

The table shows the results of measuring the three variables: the number of times of using the four view ports, the number of the types used for displaying images, and the number of times of using the types. As for the first one, Group (A) does not provide the three required cases of high, low and in between values. While participant N used this facility, the other two participants did not use it. Since this group is the only test group for this variable, the test of the relationship between this variable and the productivity cannot be conducted. As for the second variable, the measurement includes the number of the used types of navigation and the number of the used types of changing the appearance. It has been mentioned earlier that the four types of navigation are essential for achieving the design work; therefore these types are being used by all of the participants. Consequently, the comparison between the participants for this second variable depends on the difference in their use of the different types of changing the appearance, which are: plan, section, elevation, outside 3D modelling, inside 3D modelling, and the mesh view of the object. Accordingly, the results of this variable are written with +4 that refer to the four types of variables of navigation (P-S.P, P-A.P, P-W, and W-W).

In general the results show low use of the various types; all of the participants solved the task using the plan/top view and the outside 3D displaying view. Here we have to clarify that some cases, especially the cases of using Sketchup, use the top view and work with it as a plan of one line. It is also noticed that in most of the cases the use of the plan or top view is restricted at the beginning of the process when designers start drawing their ideas; once they use the 3D they continue working with it without the need to return to the plan. However, there are few cases in which the use of the plan is quite frequent especially the cases of group (C). In this latter group, the built-in strategies of constructing the objects for AutoCAD and Micro-Station depend on 2D to extrude the 3D therefore they use the plan quite often.

The results of the other types of displaying views (sections and elevations), the rates of using them are relatively low; most of the participants do not use these facilities. However the participants look at their works from the interior quite frequently.

The results of the number of the used types for the groups (A), and (C) show that each group doesn't provide the three required cases of high, low, and the in-between. Group (B) also could not provide the three required cases; all of the values are polarized around the middle 8, 6, 8, 6, 7 of the possible range of 1-10. As for group (D), only one case achieved a difference in the values, that is R1>R2. Therefore the relationship between the number of the used types and productivity is not going to be tested.

As for the third variable: the number of times of using the types (total navigation+ total change in appearance), the results show adequate differences in the values of this variable for the four groups (A), (B), (C), and (D).

In the following is a presentation of the results:

Group (A): P>N>E1 respectively, with an adequate difference in the values between the three participants.

Group (B): R1>S>M1>A>T respectively, with an adequate difference in the values between the high and low extremes, as for the cases of the in-between, the mean of the values is 237 so that the values should be around that number. The actual values are 219, 203, 200 for the participants S, M1 and A respectively. It is obvious that these values (especially M1 and A) are polarized to the lower extent rather than being scattered around the middle value.

Group (C): Mk1>K>E2 respectively with an adequate difference in the values between the three participants.

Group (D): E1>E2, MK2>MK1, R1>R2, and M1>M2, the difference between the cases is adequate.

Accordingly, all the groups are recommended for the purposes of the test.

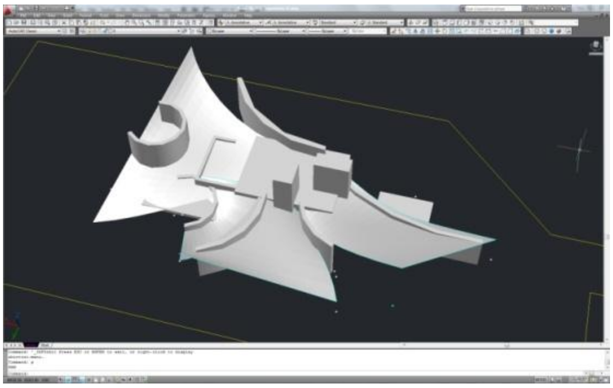
6.2. The dependent variable: Productivity of conceptual design phase through dialogical reinterpretation-Results

Before going through these sections, a general description for the circumstances of the experiments and some observations are going to be given:

1. First of all, all of the participants were able to give three drawn ideas within the given time (one hour and a half) except participant MK1 using the AutoCAD. However, the two ideas of this participant were the most completed ideas among all the other participants' ideas with a high level of presentation; this can explain the reason for giving only two ideas, Figure 6.1. The participant is professional in use of AutoCAD; he was able to draw complicated forms using curved shapes. There are also three other cases that have to be mentioned here: the case of participant N, the case of participant E1 and that of participant T, See appendix C. Participant N drew three proposals where the second proposal was a transformation of the first proposal. The transformation was a result of implementing a new suggested idea where the participant copied the drawings of the previous proposal (he used the same setting of his previous idea), then he modified them to implement the new idea. Similarly, participant T used a copy of drawings of his second proposal to implement a new suggested idea. Participant E1 gave three proposals; however, the second and third proposals were transformations of proposal one.
2. The sources of the ideas have been checked through reviewing the design protocols, transcripts of these protocols, the participants' descriptions of their ideas in the interviews that followed the experiments and the written reports they wrote at home; however, not all of them have returned these reports. The sources of the ideas are varied, while some of them came from the designers depending on their previous experience, others are triggered to their minds while experiencing the dialogical reinterpretation. However, the ideas which are in consideration are those triggered while establishing a dialogue. In this context, it has to be clear that the productivity that this study is concerned with is the productivity due to the dialogical reinterpretation only. Consequently, the result of calculating the productivity of the participant MK1, for example,

is higher than the productivity of the other participants in group (C), though he only gave two drawn ideas and each of the two other participants gave three ideas. That is because of the sources of some ideas are the designers' background rather than dialogical reinterpretation, or sometimes the given idea is a new version of the previous. It has to be clear also that the reason of focusing on the dialogical reinterpretation is related to the objective of this study; which is to find the effect of the medium (the computer) on the productivity through the dialogue. This also explains the reason behind asking the participants to give at least three different ideas. It was an attempt to encourage the designer to establish a dialogue with his work rather than to test his own ability in giving more than one idea.

First idea



Second idea

Figure 6.1: Pictures for the first and second drawn ideas, participant MK1

3. It was mentioned earlier in the previous chapter that the individual differences of the participants have been minimized by choosing participants of shared

architectural background. However the individual differences in skills of design and the skills of using the software cannot be avoided. The following is a description for the skills being observed while watching the video records for every participant: The participants of Group (A) who use 3D Max showed a relatively high level of design abilities and skills in using the software. Participants P and N were keen to give creative ideas and solutions. While participant P has skills in initializing dialogues with his drawings and tolerance to cope with new problems, participant N has the desire to discuss new issues related to the problem. Participant E1 showed the ability of starting from a simple idea and developing it to be more complicated. However, he showed fewer abilities in establishing a dialogue with his drawings. As for group (B), participant R1 showed abilities in initializing dialogues with his drawings and tolerance in discovering new issues. While participants R1, S, and M1 showed abilities to start from simple ideas and develop them into more complicated concepts, participant A started from philosophical concepts related to the functional problem or to the site and urban problems. Although participant T worked sometimes within concepts to solve the task, the physical forms that present his ideas were simpler than the others. However his ideas are within the level of the other participants.

As for group (C), Participant MK1 has the desire to challenge new concepts and discover new issues; his experience with AutoCAD makes it possible to achieve complicated forms. The three ideas of participant K are of philosophical conceptual base; he showed ability in implementing these ideas using simple geometric forms. Finally, participant E2 undertook the experiment for the second time using Micro-Station. His three proposals are of one main idea (one pattern) with three versions: that is the use of separated basic geometric forms connected with almost linear axis, see Appendix C. The source of this idea is the designer's own values and thoughts. He failed to establish a dialogue with his drawings and spent most of the time implementing the details of these proposals. As for group (D), all of the participants of this group undertook the experiment a second time. The period between the first and second time was 4-5 months, which is a sufficiently long period to forget everything about the first experiment and start something else. Participant E2, however, undertook the experiment for the second time after two weeks only.

Participant MK2 showed ability in initializing a dialogue with his drawings, his good experience with Maya allowed him to challenge new ideas; he changed his strategies of constructing his forms quite often to reach better solutions to the drawing's problems. Both R2 and M2 used Sketchup the second time they took the task. They showed the same skills and tolerance for initializing dialogues with their work.

To sum up, these distinctive differences are expected and they are essential for achieving the purposes of this study. It is expected that their different habits in using the software programs will allow the different results of the independent variables.

4. The linkography of each participant has been drawn, and is shown in Appendix B. For some of the linkographs, marks of arrows labelled with the word "judgment" shown on the first line have been used in the developed part of the linkography. These represent the moves where the designers start evaluating their previous moves and give their judgments; they are the second "seeing" of the Schon's model of "Seeing-Moving-Seeing". It has been noticed that these moves are the motives for either starting new and different ideas when the given comments express cases of dislike, or continue the dialogue when the comments express appreciation. Below are some examples of these moves from the participants' protocols, see appendix A (sentences within square brackets [] are the student's own words, while the rest is the researcher's own notes):

    a. Participant R1: M9 turn the view looking at the facade of the main road: [so I think volumetrically if we look at this corner, it is very strong, very blocky]. M11 look at the whole composition: [it is quite diagrammatic and simple].

b. Participant S: M13 [this (hall volume) becomes too massive].

c. Participant A: M7 [It is one height volume, which may be need some change to a transition zone between the entrance and the hall,...] reduce the height of the corner part:[So I've got almost all the elements towards the actual junction, which lead them to be a little bit disconnected from the park].

d. Participant MK2: M8 [Ok just follow the computer]. He said in his report "I had planned to mould the shape into an organic one but the results from dividing the cube did not go as planned. I just followed the computer at that stage."

e. Participant N: M10 Create the roof, modify it to fit:[How one more big concrete structure could become a roof... rather than more free].

The following paragraphs are going to present the results of the dependent variables. Table (6.4), shows the final results of measuring the indicators of the productivity variables for the groups (A), (B), (C), and (D).

6.2.1. Variable: The Occurrence of Pattern discovery

The first column in table (6.4) shows the final results of this variable. In order to measure this variable a few steps have to be conducted. Appendix B shows the linkograpy of every participant; the linkages between every suggested idea and the previous ideas have been checked to decide whether the discovered pattern is intentional or un-intentional. The line of the upper part of the linkography is used for tracing the forelinks and back links of the involved moves. The bolt lines show the confirmed linkages with other ideas. The lower part shows the results of tracing these ideas and marks them with (Unint.), which means un-intentional.

To meet the other required measuring conditions of this variable, tables (6.5, 6.6, 6.7, and 6.8) for the four groups (A), (B), (C), and (D) respectively are arranged to show the way of dealing with the data that presents the occurrence of the reframing process. The second column of these tables shows the moves that lead to the forming of the discovered patterns. The third and forth columns show the transformation process from the figural physical element (third column) to conceptual mental and figural mental (formal pattern and Gestalt form) ideas and suggestions that are defined as the discovered patterns (fourth column).

The moves in the second and fourth columns have been taken from the written transcripts of every participant, Appendix A. The fifth column in the tables shows the occurrence of the reframing by comparing the domains of the moves in the second column with the domains of the moves of the discovered patterns in the fourth column. If there is a change in the domain, then reframing is taking place.

The shaded rows present the cases of the computer's accidents where the designer makes a move then the computer gives something else by accident (the word 'accident' here is related to the performance of the designer when trying to move something or implementing an option). The "discovered" patterns are the computer's suggestion; however, these ideas have been excluded when calculating the final results of this variable "the degree of occurrence of pattern discovery" in table (6.4). The cause of the accidental move is the accident itself; the generated idea is the direct outcome of the accident but not from the possible effect of the continuity of the dynamic field of images, which may affect what the designer sees and trigger something in the mind. It is obvious that these accidental moves of the computer are not a real "pattern discovery" since the designer is not experiencing a complete dialogue with the drawings by reading the drawings in different way "interpreting them" then applying the new reading of the new discovered pattern; instead, the computer is taking this role. The computer suggests and applies this suggestion, the designer experiences a partial dialogue by evaluating and judging this move, then may appreciate it and simply work with it. In other words, it is the direct contribution of the computer but not through dialogical reinterpretation; it happens by doing but not by seeing. Finally, it has been noticed that most of the discovered patterns come after a period of contemplation; designers make moves that change something in the drawings, then afterwards they spend a period of time contemplating these drawings by navigating around the drawings, looking at this change in plan or section, or even taking further actions.

Table 6.4: Results of measurements of the indicators of productivity

Group	participants	Software	Productivity Through the Dialogical Reinterpretation					
			Degree of Occurrence of the Dialogical Reinterpretation			Degree of Occurrence of a Complete Cycle of Dialogical Reinterpretation		
			Occurrence of Pattern Discovery	Occurrence of Conceptual Reinterpretation		Occurrence of Alternation of Thinking		Occurrence of Restructuring
						Occurrence of figural physical reinterpretation	Effectiveness of rhythm of alternation	
			Number of the Discovered Patterns	Number of the Connected Ideas	Length of Dialogical Series	Number of Shifts from Divergent to Convergent Thinking	Number of Shifts over the Time Line	Number of ideas that have been applied on whole building (No. of shifts from part to whole)
A	P	3D Max	4	3	1 – 2	7	10	3
	N	3D Max	3	2	1 – 2	5	9	3
	E1	3D Max	2	1	1	3	6	0
B	R1	Sketchup	6	3	1	8	16	3
	S	Sketchup	2	2	1 – 2	4	7	2
	M1	Sketchup	2	2	1	4	8	2
	A	Sketchup	2	2	1 – 2	3	6	1
	T	Sketchup	1	0	0	1	2	0
C	MK1	AutoCAD	3	2	1	4	8	2
	K	AutoCAD	1	1	1	2	4	2
	E2	Micro Station	0	0	0	0	0	0
D	MK2	Maya	6	2	1 – 2	7	13	3
	R2	Sketchup	4	2	1	6	12	2
	M2	Sketchup	1	1	1 – 2	1	2	1

Table 6.5: The occurrence of reframing-Group (A)

Participants	Previous effective move	Figural physical – Conceptual & Figural physical – Figural mental transformations		Occurrence of pattern discovery
		The physical element that is in focus	The discovered pattern	Reframing by changing the domain
P	M10 Create public outdoor spaces towards the park; create an opening in the surrounding wall.	Public outdoor spaces	M11 This seems simple but promising public space, um.. it becomes accessible to the park (physical axes to the park)	Functional – Spatial organization
	M19 Pull the site layer towards the building, the layer covers the whole building (computer accident)	Site layer	M20 wow it is better you can see from the park the building becomes the park, it is a park	Spatial organization – Formal & Functional context
	M21 ummm.. this part doesn't need to be high, push it down (the building becomes part of the park)...Modify the site layer which covers parts of the building	Site layer	M22 The hall is about 10meters high, it is interesting to see it this high so I will keep it.. AND I WILL TRY TO LIFT THIS CARPET (See the whole site as a carpet)	Geometric functional layer – Formal more organic layer
	M30 Cut part of the upper layer to create a balcony, the computer adds a third layer (computer accident)	The third layer	M31 This provides a direct axis to the upper balcony	Building's functional requirements – Site spatial arrangement
	M49 push- in the front facade, return to previous... I'm trying to create something like an entrance, push the facade in place underneath the site platform, create something to be the entrance. (The entrance of the BLOB is sang into the platform)	The sang corner entrance	M50 The building corner looks like a sculpture	Functional – Formal
	M83 the problem is that this big unused area underneath, so I have to put it on the ground, fix its relation with the ramp, sided wall and roof, A gap is created between the hall and the facade wall by moving down the elevated hall.	The gap and the detached wall	M84 The wall could shape the building's interior spaces as well as the exterior spaces	Formal& Structural – Spatial organization (in-out)
N	M34 V I think I can split this.. I was thinking about this one big surface, I'm thinking I can do this but in separated triangles (Split the roof triangular forms).	The triangular element	M38 The roof shapes the interior: I think this could be more fluid, this could provide an interesting space for the interior, Manage the joints between the connected triangles; change the height of the points of the triangles	Exterior form – interior form
	M39 Modify the triangular forms, manipulate the height	3D units	M40 Triangular units can provide the functional organization of the space	Formal – Spatial & Functional organization
	M39 Manipulate the 3D triangular units to be functional	3D units	M49 The units provide the continuity with the site: the building is a landscape	Functional – Formal &Spatial organization
	M51 ..changing the size of the triangular volumes, (while trying to fix the edges, a gap is left between the two by accident)	Gaps	M52 It might look less fluid less dynamic, im.. looking internally..these edges of triangles do not touch each other so we can use the gap for interesting lighting	Formal – Environmental
E1	M11 Looking at the whole composition; create a box to create the entrance opening, modify it and fix it in place, create the opening, the pedestrian route is from here.. I need more free passage underneath the stair case	Inner space under the stair	M12 Provide free inner passage for the public flow	Functional requirements- Spatial arrangement
	M25 Modify the side columns which filter the light	The columns size	M26 these columns become much more thicker, this gives the rest of the building a sort of identity.	Environmental function – Symbolic function

Note: Shaded rows in this and following tables not included in final calculation

Table 6.6: The occurrence of reframing-Group (B)

Participants	Previous effective move	Figural physical – Conceptual & Figural physical – Figural mental transformations		Occurrence of pattern discovery
		The physical element that is in focus	The discovered pattern	Reframing by changing the domain
R1	M4 Create a pedestrian route and entrance for people	Pedestrian entrance and route	M7 Give a human scale for the building	Functional - Formal
	M14 Cover part of pedestrian route	Covered route	M15 Create a kind of out-door enclosure for pedestrian	Environmental – Spatial enclosure
	M23 Carve the volume of the ground floor to create an inner passage	Semi shaded central space	M28 The building looks like a table	Functional – Formal
	M34 Modify the accessibility from the building to the park	The inner axis to the park	M35 Exaggerate the visual connection with the park	Spatial – Visual Organization
	M49 The hall is attached with one arm of U shape service area	U shaped block	M50 Seeing the building as a spiral	Functional - Formal
	M55 Create a space to buffer the design from the street	The space between the buffer and the hall (the in-between space)	M56 This creates a third function where people can meet before entering the hall	Environmental – Functional
S	M8 I'm going to pull this space (the service volume) to create a service corridor. Draw line on the ground from the entrance to define the end of the hall block. The line extends toward the park.	Connecting axis	M9 looking at the drawing, .. I want keep this axis (from the side entrance through the courtyard) draw it and colour it. It became the main axis for the whole composition.	Building function – Spatial arrangement of the site plan
	M22 The top of the hall is a garden	Roof garden	M23 The roof of the units could become part of the L.S	A Local Building Function – The Entire Site L.S (the scale: building landscape – the site landscape)
	M25 Give one of the slope units a transparency to connect with the site	Transparent surfaces	M26 The continuity between blocks by merging the interiors	Visual – Spatial organization Outside – Inside
	M37 Check the position of the volume with the edge of the site to create a kind of connection	The volume's edge and site edge	M38 Just follow the division lines connecting the building with the site edge (computer accident)	Spatial – Spatial & Functional
M1	M10 Take the glazed box a bit out to increase the outdoor views	Attached glass boxes	M11 Sticky out windows	Visual Function – Formal
	M26 Separate the two halls and the central part	Physical disconnection	M27 Visual connection between the two halls	Functional arrangement – Visual Environment
	M29 Play with the form of the roof, push and pull the flat roof (computer accident)*	Flat roof	M30 Steep inclined roof of the two halls	Formal – Formal **
	M39 Divide the roof surface into equal units, push and pull (computer accident)	Roof shape	M40 More organic 3D divisions for the volumes	Functional – Formal
A	M20 I'm going to locate the hall and service volume within the strip grid and create an orthogonal concrete grid here	The orthogonal grid	M21I'm thinking in this area, it could be a kind of football area and recreation	Spatial organizational grid – Functional grid
	M30 Checking the service and structural elements that stand in the park	Strips of structural elements	M47The site as an industrial area	Functional – Formal
T	M25 Change the height of the roof, it becomes a flat floating roof	The gap between the floating roof and the structure	M26Visual continuity with the site	Functional – Visual organization

Note: * computer accident, ** Domain's transformation is failed

Table 6.7: The occurrence of reframing-Group (C)

participants	Previous effective move	Figural physical – Conceptual & Figural physical – Figural mental transformations		Occurrence of pattern discovery
		The physical element that is in focus	The discovered pattern	Reframing by changing the domains
MK1	M11The enclosed corridor is connected with outdoor exhibition	The indoor corridor	M12 Thinking in the corridor as a kind of colonnade extends horizontally	Functional – Formal & Functional
	M47 Create various curved elements for the plan: free curves, cylindrical curve	The cylindrical tall element/ the verticality of the cylinder	M50 Seeing the cylinder as an anchor for the composition (focal point)	Functional – Formal & Spatial
	M75Create a square roof instead of the curve to suit the composition.	Square roof/flatness of the roof	M76 The roof as a garden	Formal – Functional
K	M11 I'm doing very quick test, trying to separate the volumes, move the park glazed volume and separate it from the building block.	The outdoor open space	M12 V We have open space here, it is a kind of physical barrier, suddenly we have the idea of indoor- outdoor, one continuous void approaches the site	Formal – Functional & Spatial organization
E2	-	-	-	-

6.2.1.1. Results Presentation: The occurrence of pattern discovery

The first column in the table (6.4) shows the final results of every participant. The results of the measurement show differences in the value of the variable among the participants in groups (A), (B), (C), and (D). The high numbers indicate high values of the variable and the low numbers indicates low values.

To present this difference, the results of the participants in every group are sequenced from high to low as follows:

Group (A): P> N>E1 respectively.

Group (B): R1>S, M1, A>T respectively, the difference is noticeable between the high and low extremes, the three participants S, M1 and A share the same values and together form the middle group.

Group (C): MK1>K>E2 respectively.

Group (D): E1>E2, MK2>MK1, R1>R2, M1>M2.

Table 6.8: the occurrence of reframing-Group (D)

Participants	Previous effective move	Figural physical – Conceptual & Figural physical – Figural mental transformations		Occurrence of pattern discovery
		The physical element that is in focus	The discovered pattern	Reframing by changing the domains
MK2	M24 Move the main entrance from the branch street to the main street	The left side outdoor space / functional properties	M24 The absence of the axis suggests an outdoor celebration stage and landscape garden	Function/Circulation – Functional/Celebration
	M33 Modify the anchor (service cubic volume) , becomes a tall building	The tall tower/the vertical element	M34 The service volume as an anchor, a kind of hanging tower	Functional & structural – Formal
	M36 Create a box at the top to hold up the hanging tower	The top of the tower	M38 The tower as an observatory (functional)	Structural – Functional
	M33 Modify the anchor (service cubic volume) , becomes a tall building	The tall tower/the vertical element	M49 The tower as a chimney (formal properties of the chimney)	Structural – Formal
	M62 The inclined group of assembled boxes should be suspended.	The suspended boxes/ the hanging properties of being floated	M63 The building as a suspended roof volume (essential formal properties)	Structural – Formal & functional
	M70 The area under the roof/building is a playing area	The suspended building and the under ground/ the relation between the two elements	M72 The building as a shelter (essential formal properties)	Functional – Formal
	M83The random cuts created by computer instead of the regular subdivisions that were intended to do for doorways from one cub to other. (computer accident)	The random divisions	M84 Provide a random fragmentation for the interior spaces	Functional cuts – Formal & Functional cuts
R2	M32 Put the entrance at the middle of the building connecting the two elevated halls	An open space defined by elevated halls and entrance	M39 The display yard is a kind of in – out space approaches the site	Functional – Spatial
	M49 This gap is dark, push and pull to widen the space	An open wide space	M50 This space has the potential to be a nice court yard surrounded by the volumes	Environmental – Spatial
	M56 Manipulate the connection edge with the storage by creating an opening in the solid	The created opening	M57 The accessibility to the courtyard through the hall block	Formal – Functional
	M60 Break out the opening into smaller openings with different sizes and shapes to passing through	Deep openings punctuating the block	M64The use of the openings for displaying and they could bring the balance with the massive hall	Functional – Functional & Formal
M2	M17 While raising the display hall up the computer get it down. (computer accident)	Underground level	M18 It might be a kick point to have the outdoor area to be raised and the indoor area lower than the outdoor area	Formal – Functional
	M38 Slope windows for getting some light	Pitched roof	M39 The roof became like a butter fly	Environmental – Formal (Gestalt projection)

6.2.2. Variable: The occurrence of conceptual reinterpretation

The measurement of this variable has been achieved through measuring two indicators: The number of the connected ideas, and the length of the dialogical series.

The second and third columns in table (6.4) show the final results of these two indicators respectively. Before going through and describing these results, the method of collecting the data is going to be presented. In order to meet the conditions of the occurrence of the dialogical reinterpretation two things have to be checked: the intentionality of using the previous ideas and the occurrence of changing the context of the ideas. Appendix B shows the linkograpy of every participant; the linkages between every suggested idea and the previous ideas and the written transcripts have been checked for the intentionality of using the same issue of previous ideas. The first line of the developed linkography is used for tracing the fore links and back links of the involved moves; the bolt lines show the tracing of the connected ideas. The second line marked the ideas that used the issues of previous ideas intentionally with label "Int.", which is the abbreviation of word Intentional. To meet the second required measuring condition of this variable, tables (6.9), (6.10), (6.11), and (6.12) for the four groups (A), (B), (C), and (D) are arranged to show the way of dealing with the data that present the occurrence of changing the context of the used ideas. The first column presents the previous ideas that have been reused (collected from the written transcripts and the linkography). The second column shows the generated ideas from the reused ideas. The third column examines the contexts of the reused and the new generated idea to show the transformation process of these ideas. The techniques used for transforming the context of the two ideas have been investigated in this column. The fourth column presents the category of the transformational process; whether it is a conceptual- conceptual or a conceptual-figural transformation. The transformations from conceptual qualities to conceptual qualities are the only cases considered as being the conceptual reinterpretations. The shaded rows show the failed transformations where the figural kinds of transformations (figural mental and figural physical) are taking place. That is because the conceptual – figural or the figural – figural transformations can either complete the dialogical cycle (conceptual – figural), or achieve a second version of that idea (figural – figural).

Table 6.9: Conceptual transformation through changing the context-Group (A)

Participants	Reused idea	Generated idea	Conceptual Transformation	
			Context of the reused idea – Context of the generated idea	Type of the qualities that are in focus
P	M15 I want the volume to be lower in this side towards the park .. to create some more soft form towards the park, and create more defined hard shape towards the street. (Hard part is facing the street& the soft part is facing the park)	M18 Make some transition from the urban to integrate the whole building with the Park	Urban issue – Local park issue	Conceptual – Conceptual
	M18 Make some transition from the urban to integrate the whole building with the Park	M44 Simple building is standing in the Park	The use of the opposites: integrated with the park (park issue) – separated from the park (building issue)	Conceptual – Conceptual
	M11 This seems simple but promising public space, um.. it becomes accessible to the park. M31 This provides a direct axis to the upper balcony.	M60 it could be something like the reverse from before, we will create a view over the park, it was a balcony on the street, we will make the view to the park, now we will start this idea of a corridor around the building	Physical connection – visual connection	Conceptual – Conceptual
N	M10 How one more big concrete structure could become a roof M11 It is better to use curved surfaces	M13 Separated functions /spaces rather than one whole part	Formal context – Functional context	Conceptual – Conceptual
	M13 Separated functions /spaces rather than one whole part M14 So I could try to make... remove one of the curves and drawing instead straight lines (simple geometries)	M24 The use of more complicated forms: The geometry of the first idea is more interesting but more difficult to work on, the second idea can be developed much more faster, the organization of the space is not that complicated, we have geometrical perpendicular surfaces that form the big spaces, they intersect to create the smaller negative spaces. But also they fulfil the requirements of the program/ the main hall and the service area in the back, we have another space in the second level. I'm thinking if I can do this geometry a bit more complicated, actually it is complicated but do be more interesting if have more environmental parameters as well for lighting purposes or...	Simple geometric separated forms– complicated geometries concerning environmental parameters	Conceptual – Conceptual
	M49 The units provide the continuity with the site: the building is a landscape	M62 The roof as a walking path	General idea – Specific form of it	Conceptual – Figural mental
E1	M12 Provide free inner passage for the public flow	M22 Thinking in this inner flow passage, I want to extend it out where the pedestrian passage continues through the building then goes out (strengthen this flow).	Functional relationship(inner circulation) – Spatial organization (in-out circulation)	Conceptual – Conceptual
	M2 The use of geometric forms connected with inner circulation axis	M35 I want to transform the geometric forms of the first idea to more organic, just to transform the straight line to curves.	Formal/ geometric element – Formal/ organic form of the same physical elements of the first idea(second version)	*Conceptual – Figural physical
	M35 I want to transform the geometric forms of the first idea to more organic	M47 For the final one, I'm trying to make a cross section to the roof that is more organic than the previous one	Formal-Formal (working within various degrees of smoothness of the same form)	Figural physical – Figural physical

***: The designer copied the drawings of the first idea and transformed the straight elements to curves.**

Note: Shaded rows in this and following tables not included in final calculation

Table 6.10: Conceptual transformation and changing the context-Group (B)

Participants	Reused idea	Generated idea	Conceptual Transformation	
			Context of the reused idea – Context of the generated idea	Type of the qualities that are in focus
R1	M11 Positive fragmented volumes are diagrammatic simple + M9 strong blocky facade (Judgement) M6 Very diagrammatic; the hall at the frontal edge surrounding the court and the service volume. We have this hall at the frontal edge surrounding the courtyard and service volume	M19 Looking at the building as one whole rather than fragmented volumes by filling the negative spaces	The use of opposites: Positive space – Negative space	Conceptual – Conceptual
	M15 Create a kind of out-door enclosure for pedestrian	M25 Central semi-indoor space for circulation flow	Positive space- Negative space	Conceptual – Conceptual
	M6 Very diagrammatic simple. (Judgement) We have this hall at the frontal edge surrounding the courtyard and service volume	M44The hall is in the middle of the courtyard surrounded by the U shaped service area at the front edge	Opposite spatial arrangement	Conceptual – Conceptual
S	M14 manipulate the height, em.. I'm going to reduce the height of this side and use the inclined roof surface (to reduce the massive hall size) in order to connect it with the service corridor.	M16 The building as slope units spread into the landscape.	Functional use of slope – spatial composition of inclined connected units	Conceptual – Conceptual
	M16 The building as slope units spread into L.S	M29 The building is a big slope stands in a park	Slopes within: Fragmented units – one massive block	Conceptual – Conceptual
	M28 For the third I want to respond to the corner again, let's start with a linear block, draw a rectangle, extrude it, and then I want to play with it.	M49 Well I will try something else, let's take this block (the rectangular linear block), the concept is the simple massing again, set to linear blocks which are joint by another block. (manipulate the same massing form to be divided into small joined parts)	One specific form – Fragmentation of that form (opposites)	Conceptual – Figural physical (second version)
M1	M30 Steep inclined roof for the two halls	M35 Play with the slopes	Partial use of inclined surfaces – volumetric use of slopes	Conceptual – Conceptual
	M1 One massive volume contains the hall and the entrance lobby	M19 Separated volumes instead of using one whole volume	One massive volume – fragmented parts (opposites)	Conceptual – Conceptual
A	M7 Locate the building in the corner causes the disconnection with the site. M11 The expanded structural wall should give privacy from main street.	M13 The building elements spread horizontally into the site by using strip grid	Connection with the site (opposites): separated from the site – connected with the site	Conceptual – Conceptual
	M13 The building elements spread horizontally into the site by using strip grid	M31 The wall/strip as a journey way	Spatial – Symbolic use of strip wall	Conceptual – Conceptual
T	–	–	–	–

Table 6.11: Conceptual transformation through changing the context-Group (C)

Participants	Reused idea	Generated idea	Conceptual Transformation	
			Context of the reused idea – Context of the generated idea	Type of the qualities that are in focus
MK1	M1 V Start from the main area, I have perpendicular two axes, one from the main street, the other from the pedestrian route, the geometric spaces will be a long these axes.	M44 probably doing it into steps so what I'm going to do is to draw the primary axes of the site, I'm going to use the axes again, these intersecting axes to sweep the organic forms.	The use of axes: Functional axes (site organization) – Axes achieve compositional formal purposes	Conceptual – Conceptual
	M50 This (the cylinder) becomes like an anchor like a tall point there.	M64 We are going to use the anchor again, so maybe this (square plan) becomes a kind of anchor, create a central box that connects all of the swept roofs.	A compositional formal role for the cylindrical anchor – A structural role for the square anchor	Conceptual – Conceptual
K	M5 V Now I'm thinking into actual sitting area, being close to street, I'm thinking in the idea of public privacy (the idea of void and solid), the major site open here over the street. M21 A new starting point for the next idea, very basic geometric offsetting, I'm going to use the square, which is rational.	M37 Now I'm thinking in a third idea, so far we have solid separated spaces, then we have the one big hall volume, so far the two ideas having the whole one object, the third idea we can try a separated scattered spaces creating the areas for sitting and performance or celebration	One geometrical mass for all spaces – Scattered separated cubes	Conceptual – Conceptual
E2	M1 Starting from this box, I want to separate it into units. Then connect to one continuous project. The idea of using connected units.	M27 the idea of sort of quite enclosed 3 rectangles connected together	Formal and functional connected units – Formal and functional connected rectangular units (second version)	Conceptual – Figural

Table 6.12: Conceptual transformation through changing the context-Group (D)

Participants	Reused idea	Generated idea	Conceptual Transformation	
			Context of the reused idea – Context of the generated idea	Type of the qualities that are in focus
MK2	M24The absence of the axis suggests an outdoor stage and landscape garden	M28 The axis as the heart of celebration	1.Lessen - Emphasize the function of the axis (using the opposites) 2.Outdoor celebration in the side garden- celebration in the main axis and the heart of the site (secondary function-domain function) 3. change the spatial context of the outdoor celebration from the garden to the axis	Conceptual – Conceptual
	M2 Failed to morph the cube to get more organic form, so I just follow the computer's suggestion of using geometric forms in the park M8 The axis is the heart of celebration	M30 We want to give this semi yard a kind of shape but we can try a different form of generation, we can use curves, so what we want to do first of all is, we can sweep (The use of curved elements to represent celebration)	Change the strategy: Morph the geometric form to look organic – The use of organic forms (curves) to represent celebration: associative meaning	Conceptual – Conceptual
R2	M1 The two axes arrange the location of entrance lobby in the site	M17 Thinking about this axis, think from slightly different direction may be in term of considering lifting the volumes. The two axes provide the accessibility across the site	Focus on local building context – Urban context	Conceptual – Conceptual
	M64 The use of the openings for displaying in addition of providing accessibility	M67 Provide the same formal language somewhere else for unity; the use of openings on the top parts of the halls' masses	Functional language of the openings – Emphasize the formal language	Conceptual – Conceptual
M2	M6 The idea of outdoor displaying yard and all the displaying volumes to be together	M14 Build the displaying halls around the outdoor displaying courtyard	Outdoor displaying– specific form of outdoor displaying: the court yard (second version of the first idea)	Conceptual – Figural
	M14 Build the displaying halls around the outdoor displaying yard	M41 I'm going to raise the landscape up to be used for displaying, say two meters above the ground, and the building mass behind it	A building of fragmented displaying volumes to create an enclosure – one mass building	Conceptual – Conceptual

6.2.2.1. Result Presentation: The occurrence of conceptual reinterpretation

In the following is a presentation of the final results of the two indicators: the number of the connected ideas (the second column in the table (6.4)), the length of the dialogical series (the third column in the table (6.4)). The results of the measurement show differences in the values of these two indicators among the participants in groups (A), (B), (C), and (D). The high numbers indicate high values of the variable and the low numbers indicates low values. To present this difference, the results of the participants in every group are sequenced from high to low.

1. Number of the connected ideas

The participants have achieved some connected ideas; the values are within the range of 3-0 and only two participants have got the zero value. The shaded rows in the tables (6.9, 6.10, 6.11, and 6.12), have been excluded when counting the number of the connected ideas since the designer failed to achieve the conceptual transformation.

The sequence of the participants is as follows:

Group (A): P> N>E1 respectively.

Group (B): R1>S, M1, A>T respectively, participants S, M1 and A share the same values and together form the middle group.

Group (C): MK1>K>E2 respectively.

Group (D): E1>E2, R1>R2, M1>M2, Mk1=Mk2 where there is no difference.

2. Length of the dialogical series

The participants continue their dialogues with previous ideas achieving a series of continuous ideas; table (6.4) shows series that have values within a range of 1-2. The zero value indicates that there are no connected ideas thus no continuity of dialogue; the cases of participants T and E2 have got this zero value and they will not be included in testing the relationship of this variable with productivity. The value of 1 indicates that all the connected ideas have been reused for only one time. There are some cases that achieved values of 1-2. These values represent the situation where the reused ideas have been not only used for first time but also for second cycle of dialogue as well, in which the participant has reused some ideas for only once and other ideas for the second time. For example, participant P has achieved three connected ideas (Table 6.9), he reused the idea of the integration with the site (M15) for two times (M18, M44), and has reused the idea of the accessibility to the site (M11) for one time only (M60). Although the idea of accessibility is used for a second time in (M31), it hasn't been calculated. That is because (M31) is a computer accident where the designer did not decide to continue the dialogue with (M11), rather it happened accidentally; there is no intentional connection between (M11 and M31).

The final results of this variable have been counted, table (6.4). These final results (unlike the pattern discovery calculations considerations) include the ideas that failed to meet the condition of conceptual transformation; the case of M2 is an example, table (6.12) the shaded row. Although the designer failed to achieve the conceptual transformation, she experienced a completed dialogical reinterpretation cycle; she has chosen to deal with this idea intentionally and repeated it for the second time, and managed to apply it. All of these points show the involvement in this dialogue, which this variable is concerned with.

The sequence of the participants is as follows:

Group (A): P, N>E1

Group (B): S, A>R1, M1, notice that T is excluded because he had the zero value.

Group (C): MK1=K, notice that E2 is excluded because he had the zero value

Group (D): MK2> Mk1, M2>M1, R1=R2

6.2.3. Variable: The occurrence of alternation of thinking

The measurement of this variable has been achieved through measuring two indicators.

1. The number of shifts from divergent to convergent thinking through the occurrence of figural physical reinterpretation, which indicates the completeness of the dialogical reinterpretation cycle.

The fourth column in table (6.4) shows the final results of this indicator. To collect the data, the linkography of every participant has been checked, Appendix B; the considered moves are marked with letters (ap., the abbreviation of application) on the first line of linkography (the developed part). In counting the final results of this variable, the (ap. marks) of the accidental moves have been excluded because these moves are surely regarded to the happy accidents but not the possible effect of the dynamic representation.

Each of these participants: A, MK1, MK2, M2, N1, P, and R1 did not apply one of their suggested ideas, thus the dialogical cycles of those ideas have not been completed. The linkographies of those participants have documented these cases by showing one of the suggested ideas (Unint. or the Int.) not followed by the mark (ap.).

On the other hand, one case has been documented with participant S in group (B) where the designer suggested the idea and its application was only spoken about but not actually performed:

- the suggested idea: M26 This is supposed to be the side entrance, and the main from here, there will be a continuity between the blocks
- the application move: M27 These two blocks (reception and hall) supposed to be merged.

However it is considered as an application move. That is because the solution is already drawn (the reception and hall are already linked and supposed to be merged from the inside) and the designer was describing what the existing situation was.

The final results show differences in the values of this variable among the participants. In the following is a presentation for these differences:

Group (A): P>N>E1

Group (B): R1>S, M1>A>T

Group (C): MK1>K>E2

Group (D): E1>E2, MK2>MK1, R1>R2, M1>M2

2. The number of shifts over the timeline, which indicates the effectiveness of the rhythm of alternation.

The fifth column in table (6.4) shows the final results of this indicator. To collect the data, the linkography of every participant has been checked (see Appendix B); the part of the linkography in consideration is the line of the webs (the construction and development webs). The considered moves are marked with letters (Con-Div) under the line of the linkography. All the suggested ideas (the Unit., the Int. and the D.) are considered to be the divergent way of thinking and all the application (ap.) Moves are considered to be the convergent way of thinking. All the construction webs show divergent thinking in comparison to the development webs.

In counting the final results of this variable, the (Con and Div marks) of the accidental moves have been excluded because these moves are regarded as the result of happy accidents but not the possible effect of the dynamic representation. The Con. and Div. marks that related to the designer's own suggestion (D) are also excluded because they are regarded as emanating from the designer's own background and knowledge but not from the dialogical reinterpretation to the drawings.

The final results show differences in the values of this variable among the participants. In the following is a presentation for these differences:

Group (A): P>N>E1

Group (B): R1>M1>S>A>T

Group (C): MK1>K>E2

Group (D): E1>E2, MK2>MK1, R1>R2, M1>M2

6.2.4. Variable: The occurrence of restructuring

The sixth column in table (6.4) shows the final results of this variable. In order to meet the condition of the occurrence of the restructuring, the suggested idea and the process of applying it have to be checked. The idea should be regarded as related to the whole building but not part of it and the application should be regarded to the whole. This is essential to confirm that the idea is a main idea rather than secondary.

Appendix B shows the linkograpy of every participant; the second line is the part of the linkograhy which is in consideration. It shows the kind of the application moves that are marked in the upper line; whether they are belonging to the whole or part of the building. This has been achieved by checking the content of application move/s; reviewing the written transcripts and watching the videos.

Tables (6.13),(6.14), (6.15), and (6.16) for the four groups (A), (B), (C), and (D) are arranged to show the information needed to reach the final results of this variable. The second columns show all of the suggested ideas (the pattern discovery and the conceptual reinterpretation). The third and fourth columns show the kinds of the ideas and the kinds of the applications; on whole or part of the building. The fifth columns present the results of categorizing the ideas; main ideas or secondary ideas. The last columns show the occurrence of the restructuring with mark (●) only when the idea is marked as a whole idea, applied on a whole level and determined as a main idea. Table (6.15) shows an exceptional case of the participant MK1 where the idea of the corridor (M12), which belongs to part of the building, has been applied on the whole (building) level and the idea has been extended to be a main idea of an outdoor colonnade that organizes the whole composition. This idea has achieved the restructuring of the problem and brought to light a new proposal.

Finally, it has been noticed that the proposals that come out of restructuring the idea to match a discovered "Gestalt form" do not lead to completely different forms, rather a partial change in the form. That is because the discovered pattern is already there, and the designer has to affirm and strengthen the existence of that pattern. For example, the participant R1 has discovered a "Gestalt form" in his composition: M28 the building looks like a table, Figure 6.2. The designer described his new reading of the form then followed on with some changes to present that hidden pattern and make it clearer and readable.

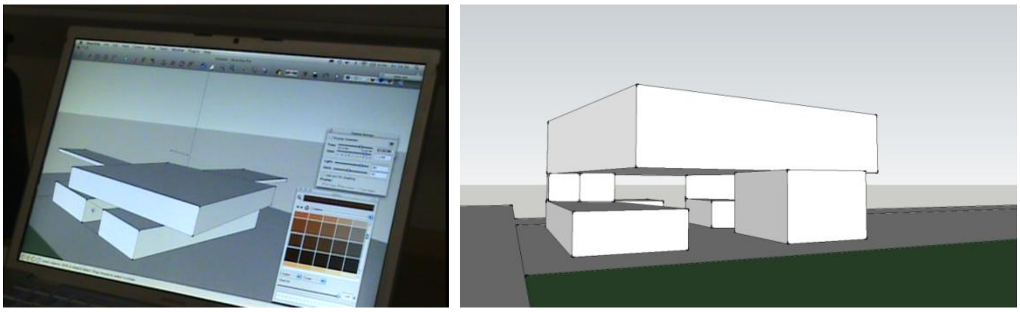


Figure 6.2: Restructuring using the Gestalt form as a discovered pattern:

Left- The discovered Gestalt pattern "the building as a table"; Right- The application of the discovered pattern

In comparison, when the restructuring of the idea is about discovering new functional or organizational relationships, the restructuring leads to new different compositions than before. For example, the participant MK2 has discovered a pattern of relationships when he was assembling and overlapping cubes randomly: M63 the building is a suspended roof volume, see appendix A, and see also Figure 6.3 below. He said in his report that he recognized a new pattern of relationship between inside and outside spaces:

"I started the third without the music notion in mind as was going simply for a more Cartesian geometry and started by assembling cubes, **upon building I realised that the indoor/outdoor relationship could be applied but in a different way, i.e. a covered area where roof was building**. Once I continued to assemble the illusion of the building not touching the ground became important but not a conscious decision of performance. And I had no idea of how I was going to inhabit the space. I had intended to subdivide the cubes into regular rectangles so I could create doorways from one to the next but the command did something unexpected by created organic divisions and I just ran with it. The space then became me navigating with the camera and cutting where was necessary for me to see into the next room, the cubes not being horizontal I needed to create flat surfaces and the route became the floors which ended up piercing the whole building. The overall fragmentation was just a continuation of the language created by the initial cuts. The building then felt as if it needs a texture and concrete seemed to fit and I tested it with that."

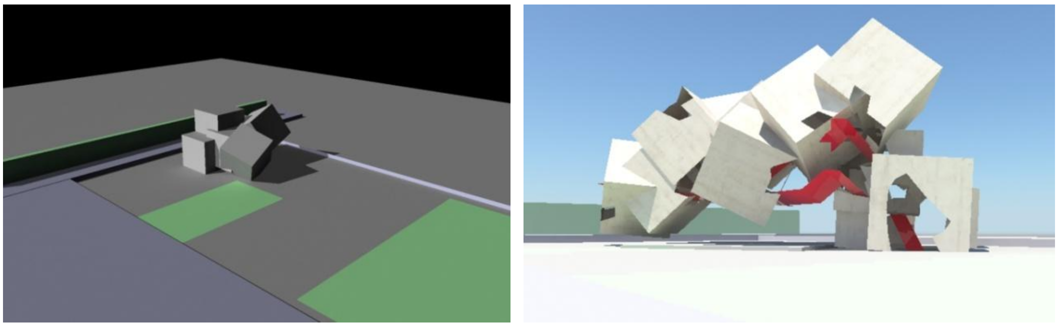


Figure 6.3: Restructuring to apply a discovered conceptual "descriptive" pattern: Left-The discovered conceptual pattern; Right-The application of the discovered pattern

6.2.4.1. Results Presentation: The occurrence of restructuring

The final results show differences in the values of this variable among the participants, table (6.4). In general, the participants of group (C) show low rates in comparison to the other groups. It seems that the work with AutoCAD or MicroStation, which demands some more details for achieving the 3D modelling, has a direct role in the low rate results. The participants of this group had to go vertically more than the other groups thus the possibilities of restructuring the ideas were weak. Designers spent most of the time in drawing.

In the following is a presentation for these differences:

Group (A): P, N>E1

Group (B): R1>S, M1>A>T

Group (C): MK1,K>E2

Group (D): MK2>MK1, R1>R2, M1>M2, and finally E1 and E2 show the value of zero where there is no restructuring.

Table 6.13: The occurrence of restructuring- Group (A)

Participants	Ideas	Focus of the Idea	Focus of the Application	Category of the Idea	Occurrence of the Restructuring
P	M18 The whole building is integrated with the Park	Whole	Whole	Main	●
	M44 Simple building is standing in the Park	Whole	Whole	Main	●
	M60 Create a view from the building over the park	Whole	Whole	Main	●
	M11 Public accessibility to the park	Whole	Part	Secondary	—
	M22 The site layer as a carpet	Part	Part	Secondary	—
	M50 The building corner looks like a sculpture	Part	Part	Secondary	—
	M84 The wall could shape the building from the inside and outside spaces	Whole	Part	Secondary	—
N	M13 Separated functions /spaces rather than one whole part	Whole	Whole	Main	●
	M24 The use of more complicated forms	Whole	Whole	Main	●
	M38 The roof shapes the interior	Part	Part	Secondary	—
	M40 Triangular units can provide the functional organization of the space	Whole	whole	Main	●
	M49 The units provide the continuity with the site: the building is a landscape	Whole	Part	Secondary	—
E1	M22 Thinking in this inner passage I want to extend it out where the pedestrian continues through the building then goes out.	part	Part	Secondary	—
	M12 Provide free inner passage for the public flow	Part	Part	Secondary	—
	M26 The columns have to be thicker to give identity to the building	Part	Part	Secondary	—

●Restructuring occurs — No restructuring

Table 6.14: The occurrence of restructuring- Group (B)

Participants	Ideas	Focus of the Idea	Focus of the Application	Category of the Idea	Occurrence of the Restructuring
R1	M19 Looking at the building as one whole rather than fragmented volumes by filling the negative spaces	Whole	Whole	Main	●
	M25 Central semi-indoor space for circulation flow	Part	Part	Secondary	—
	M44 The hall is in the middle of the courtyard surrounded by the U shaped service area at the front edge	Whole	Whole	Main	●
	M7 Give a human scale for the building	Whole	Part	Secondary	—
	M15 Create a kind of outdoor enclosure for the pedestrian	Part	Part	Secondary	—
	M28 The building looks like a table	Whole	Whole	Main	●
	M35 Exaggerate the visual connection with the park	Part	Part	Secondary	—
	M50 Seeing the building as a spiral	Whole	—	—	—
	M56 This creates a third function where people can meet before entering the hall	Part	Part	Secondary	—
S	M16 The building as slope units spread into L.S	Whole	Whole	Main	●
	M29 The building is a big slope stands in a park	Whole	Whole	Main	●
	M23 The roof of units could become part of the L.S	Part	Part	Secondary	—
	M26 the continuity between blocks by merging the interiors	Part	Part	Secondary	—
M1	M35 Play with the slope units	Whole	Whole	Main	●
	M19 Separated volumes instead of using one whole volume	Whole	Whole	Main	●
	M11 Sticky out windows	Part	Part	Secondary	—
	M27 Visual connection between the two halls	Part	Part	Secondary	—
A	M13The building elements spread horizontally into the site by using strip grid	Whole	Whole	Main	●
	M31The wall/strip as a journey way	Part	Part	Secondary	—
	M21 The grid strip could be a kind of football area and recreation	Part	Part	Secondary	—
	M47 The site as an industrial area	Whole	Part	Secondary	—
T	M26 Visual continuity with the site	Whole	Part	Secondary	—

●Restructuring occurs — No restructuring

Table 6.15: The occurrence of restructuring- Group (C)

Participants	Ideas	Focus of the idea	Focus of the Application	Category of the Idea	Occurrence of Restructuring
MK1	M12 Thinking in the corridor as a kind of colonnade extends horizontally	Part	Whole	Main	●
	M50 Seeing the cylinder as an anchor for the composition (focal point)	Part	Part	Secondary	—
	M44 The intersecting axes to sweep the organic forms	Whole	Whole	Main	●
	M64 The square plan as anchor	Part	Part	Secondary	—
	M76 The roof as a garden	Part	—	—	—
K	M12 The continuous indoor-outdoor space	Whole	Whole	Main	●
	M37 The scattered separated cubes	Whole	Whole	Main	●
E2	—	—	—	—	—

●Restructuring occurs — No restructuring

Table 6.16: The occurrence of restructuring- Group (D)

Participants	Ideas	Focus of the Idea	Focus of the Application	Category of the Idea	Occurrence of the Restructuring
MK2	M28The axis as the heart of celebration	Whole	whole	Main	●
	M30The use of curved elements to get more organic building	Whole	whole	Main	●
	M63The building as a suspended roofed volumes	Whole	Whole	Main	●
	M24 The absence of the axis suggests an outdoor stage and landscape garden	Part	Part	Secondary	—
	M34The service volume as a hanging tower	Part	Part	Secondary	—
	M38 The tower as an observatory	Part	Part	Secondary	—
	M49 The tower as a chimney	Part	Part	Secondary	—
	M72 The building as a shelter	Whole	Part	Secondary	—
R2	M17 The two axes provide the accessibility across the site	Whole	Whole	Main	●
	M67 Provide the same formal language somewhere else for unity; using it on the top parts of the halls	Part	Part	Secondary	—
	M39 The display yard is a kind of in – out space	Part	Part	Secondary	—
	M50 This space has the potential to be a nice court yard surrounded by the volumes (arranging the composition)	Whole	Whole	Main	●
	M57 The accessibility to the courtyard through the hall block	Part	Part	Secondary	—
	M64The use of the openings for displaying and they could bring the balance with the massive hall	Part	Part	Secondary	—
M2	M40 The frontal elevated outdoor display area forms the whole arrangement	Whole	Whole	Main	●
	M39 The roof became like a butter fly	Part	—	—	—

●Restructuring occurs — No restructuring

6.3. The relationship between the degree of continuity of dynamic field of images and productivity

To verify the relationship between every independent variable in consideration and every dependent variable, these are some considerations and clarifications of some of the steps to be taken.

- Review the groups that achieve the adequate difference in the independent variables. These groups are the only groups to be in consideration when testing the hypotheses of the relationships. This step is necessary to ensure the validity of the results.
- Review the ranking of the data of the productivity of every group

The previous section of productivity measurement results reveals that the ranking of the participants from high to low in every group shows almost the same pattern of sequence for most variables of the productivity except for a few differences in two of the variables; the length of the series and the restructuring. There are also some few detailed differences in the ranking of the middle group of group (B).

In general this ranking is as follows:

Group (A): P>N>E1, Group (B): R1>S>M1>A>T, Group (C): MK1>K>E2, Group (D): E1>E2, MK1>Mk2, R1>R2, and M1>M2.

- The above rankings have been used in starting an initial search for the possible patterns for the relationships with every variable of the independent variables that are in consideration

The initial comparisons between the sequences of the independent and dependent variables show that there are possible strong patterns of relationships between some of them; especially, the whole-whole navigation (active and background), the total navigation, the holistic view (the total number of times of using the types) on one hand, and the productivity variables (pattern discovery, conceptual reinterpretation and alternation of thinking).

Before working through the details of these comparisons, here is a brief clarification of how to deal with some possible critical situations.

- When all of the groups in consideration show the same pattern of relationship between the compared variables that means there is a strong pattern of relationship and the findings can be generalized for all types of software programs.
- When only one of the groups under consideration does not show the same pattern in the relationship, the accuracy of the hypothesis will not be confirmed. That is because we are dealing with more than one independent variable that is possibly affecting the relationship. So that the assumption cannot be ensured unless all the groups show the same pattern of relationship.
- The cases of group (D) are going to be used as assistant cases for supporting one possibility of relationship over another. This can be useful in the cases where the pattern is not so clear for an adequate reason in one of the groups.
- In the case where there is only one group in consideration (achieves an adequate difference of the independent variable), and this group shows a clear pattern of relationship between the compared variables, the result of testing the hypothesis is going to be accepted as a finding; however the finding is not going to be generalized, instead it will be restricted to that kind of software only.
- As group (B) is the only group that consists of five participants, the results of this group will be highly focused. In general, the previous sections show almost a repeated clear pattern of the sequence of ranking the participants in this group for the independent variables. This pattern of sequence is: R1> (S>M1>A)>T. It has been noticed that the results of the middle group are close to each other with a slight change in the sequence of ranking the participants for some variables.

6.3.1. Test of the hypotheses

This part is going to determine the nature of the relationship between the independent variables (the continuity of displaying the images due to the navigation, the continuity of displaying the images due to changing the appearance, the number of types that are used for displaying and the number of times of the types are used) on the one hand,

and the indicators of productivity variables (the degree of occurrence of pattern discovery, the degree of occurrence of conceptual reinterpretation, the degree of occurrence of the alternation in thinking, and the degree of occurrence of the restructuring) on the other hand.

To verify the accuracy of the hypotheses, a symbolic line of difference will be used to compare between the sequences of the independent and dependent variables that are under consideration. The compatibility of the sequences means that the change in the value of the independent variable is in harmony with that of productivity, in which the increase or decrease in the values of the independent variable leads to the increase or decrease in the values of the productivity variable, thus there is a relationship between the two. To determine if it is positive or negative, the general direction of this sequence can tell. The degree of the harmony between the two sequences is the measurement for the strength of this relationship.

The scale of the drawn symbolic line of difference indicator for every variable depends on the values of lower and higher extremes of each variable, where the highest value will be on the left and the lowest value on the right and the middle is in between.

6.3.2. Results of testing the relationship between the degree of continuity of displaying images due to navigation and productivity

The presentation of the results is going to present first the results of every variable of active navigation and productivity, then after the results of every variable of active and background navigation and productivity.

6.3.2.1. Active Navigation and Productivity

- Part – Same part and productivity

Figures 6.4 and 6.5 show the results of comparison on the indicator lines of difference for the groups (A) and (C) respectively. While group (A) shows incompatibility in the sequence of the participants on the navigation scale and their sequence on all of the productivity variables scale, group (C) shows a compatibility in the sequence between navigation and all of the productivity variables except the length of series and the restructuring where there are no relationships.

As for the cases of group (D), the increase in the navigation of the case of Mk is accompanied by an increase in each of the indicators of productivity variables; this compatibility is also found with the case E for all of the variables of productivity except the restructuring, (notice that this case E is excluded from testing the relationship with the length of series because it had the zero value). On the other hand, the case of R shows completely reverse relationships where the increase in navigation is accompanied by a decrease in all the variables of the productivity. As the three individual cases show different types of pattern of relationships this indicates the non-existence of these relationships. The two groups (A) and (C) show two different patterns of relationships and the individual cases do not support either one of them. Therefore the conclusion tends to support the non-existence of the relationship between this variable and all of productivity variables.

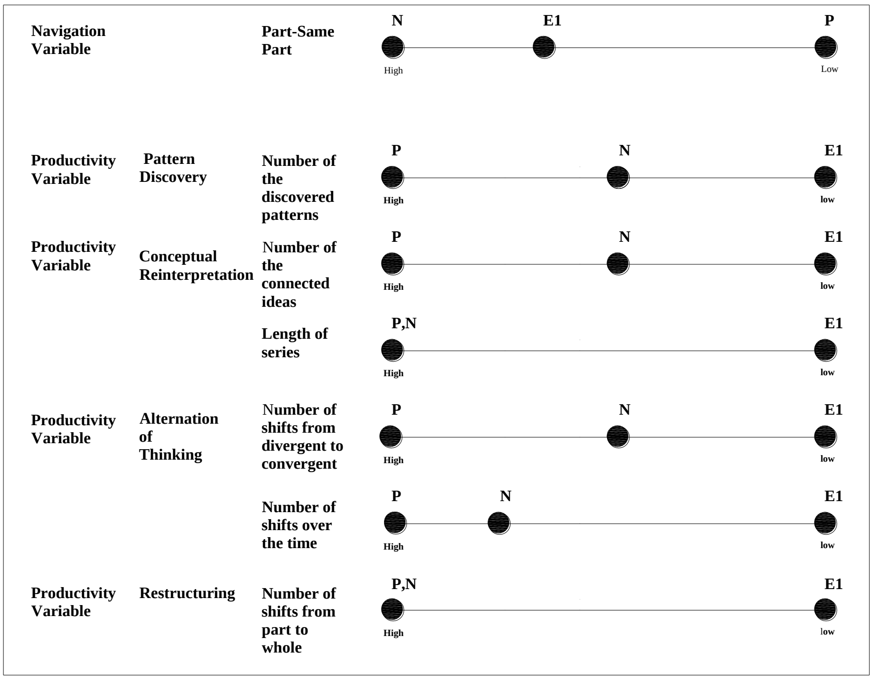


Figure 6.4: Part-Same Part Active Navigation and Productivity, Group (A)

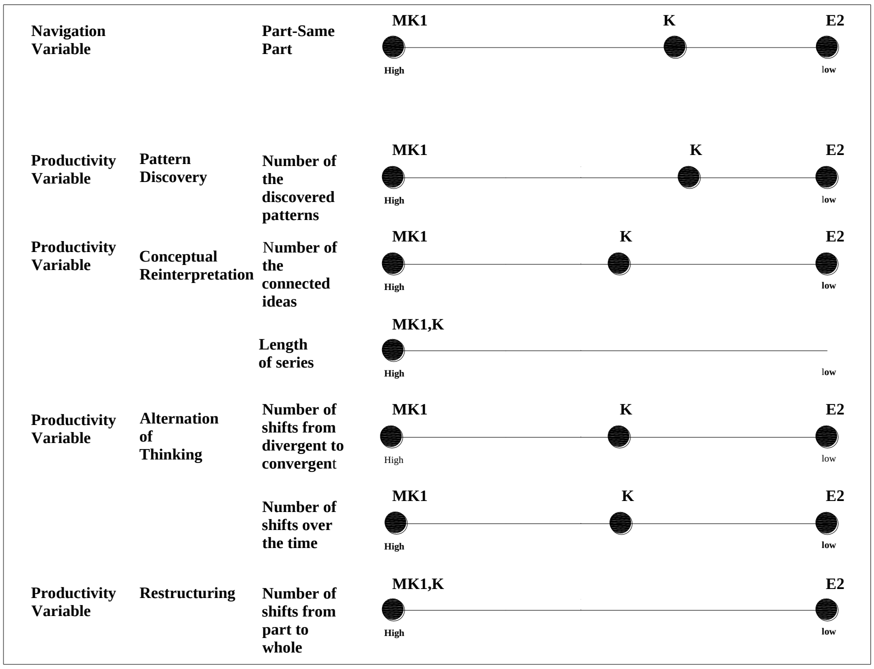


Figure 6.5: Part-Same Part Active Navigation and Productivity, Group (C)

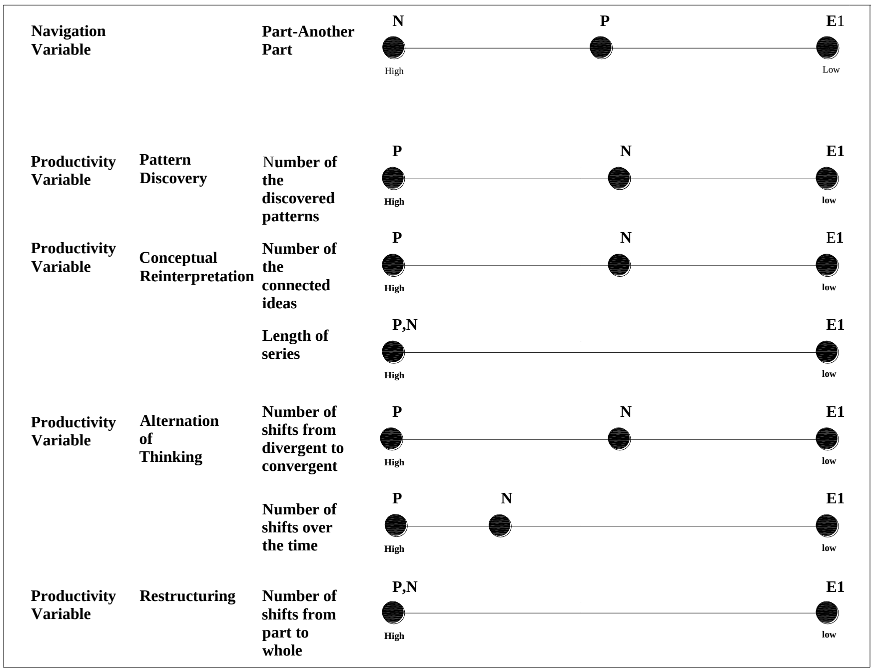


Figure 6.6: Part-Another Part Active Navigation and productivity, Group (A)

- Part-Another Part and productivity

Figure 6.6 shows the comparison between the navigation from part to another part and the six indicators of the productivity variables of group (A), which is the only group in focus for the purpose of testing the hypothesis.

It is obvious that there is no compatibility in the sequence between the two for all the variables of the productivity, thus there is no relationship between the active navigation from part to another part and productivity variables.

Since group (A) is the only group used for this test the non-existence of the relationship is regarded only in the use of the 3D Max and this result cannot be generalized.

- Whole-Whole Navigation and Productivity

Figures 6.7, 6.8, and 6.9 show the results of the comparison between the navigation from whole to whole and all of the variables of the productivity for the groups (A), (B), and (C) respectively.

As for group (A), the result of the comparison shows a compatible sequence of the participants on the navigation scale with that of all of the variables of the productivity except the length of series and the restructuring. This indicates that there are relationships between the navigation from the whole to whole and every indicator of the productivity variables except the length of the sequence and the restructuring. The nature of the confirmed relationships is positive. As for the strength of these relationships, the figure shows a very strong relationship between the whole to whole navigation and the number of shifts over the time line since there is a complete harmony in the sequences. The sequences of the other indicators show less harmony with the sequence on the navigation scale, which indicates a lesser degree of strength.

As for group (B), Figure 6.8, it could be said that there are general patterns of relationships. The general sequence of the participants on the navigation scale is compatible with that of every indicator of productivity variables with the exception of the restructuring and the length of series.

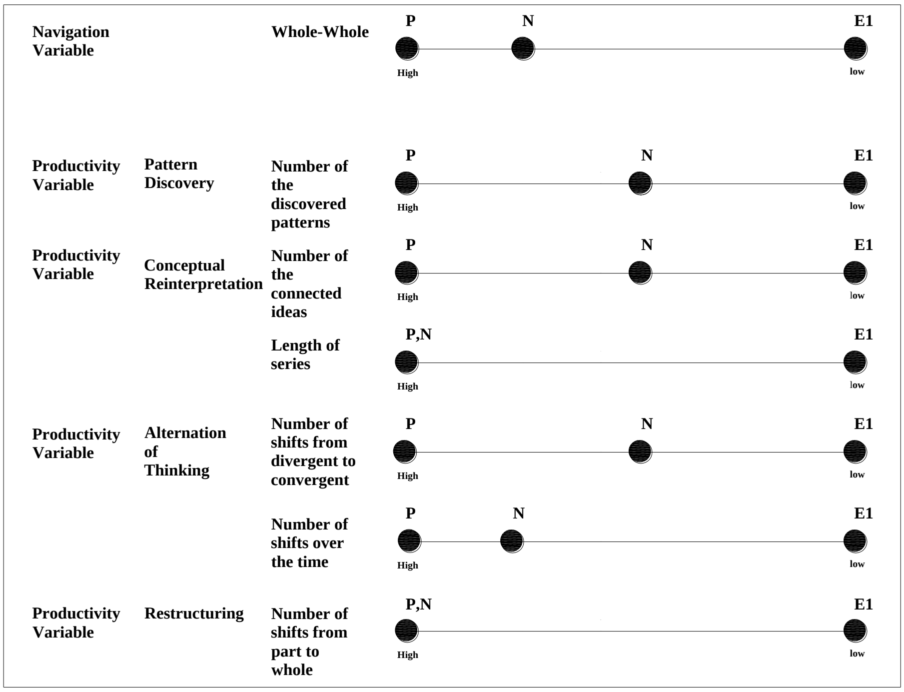


Figure 6.7: Whole-Whole Active Navigation and productivity, Group (A)

This is true as long as the three in-between participants on the navigation scale are being dealt with as one group since their values are relatively very near to each other 81, 92, and 88 in comparison to 141 for the high extent and 49 for the low extent. Going through the details of these relationships:

- first: it is obvious that there are general patterns of positive relationships between the navigation on one hand and the number of the discovered patterns and the number of the connected ideas on the other hand; however, they are not strong as the "middle" group is not exactly in the middle of the productivity scale for each indicator. These relationships are not linear in that the increase in the navigation does not lead always to the same degree of increase in each of the productivity indicators.
- second: the two indicators of alternation of thinking show generally compatible sequences with that of the navigation scale, however, the details of the sequences of the in-between group are not fully compatible. As for the number of shifts from convergent to divergent, the case of A is the only case that causes this incompatibility. The participant A suggested an idea when he

nearly finished working with the task; he was checking his three ideas then looked at the final presentation of one of them and said “this looks like an industrial building”. He started the divergent part of the dialogical cycle but did not complete the cycle and achieve the convergent part as when he completed the requirements of the task the time available was almost finished. This gives an acceptable explanation to the cause of the difference in the results. Accordingly, the comparison indicates that there is a possible positive pattern of relationship. As for the number of shifts over the time, the sequence of the in-between group is not compatible and there is not reasonable explanation for this incompatibility. Accordingly, the relationship cannot be fully confirmed; however, it cannot fully be denied as there is general possible pattern.

- third: the sequence of the participants on the navigation scale is not compatible with that on the indicator of the restructuring scale. This indicates that there is no relationship.

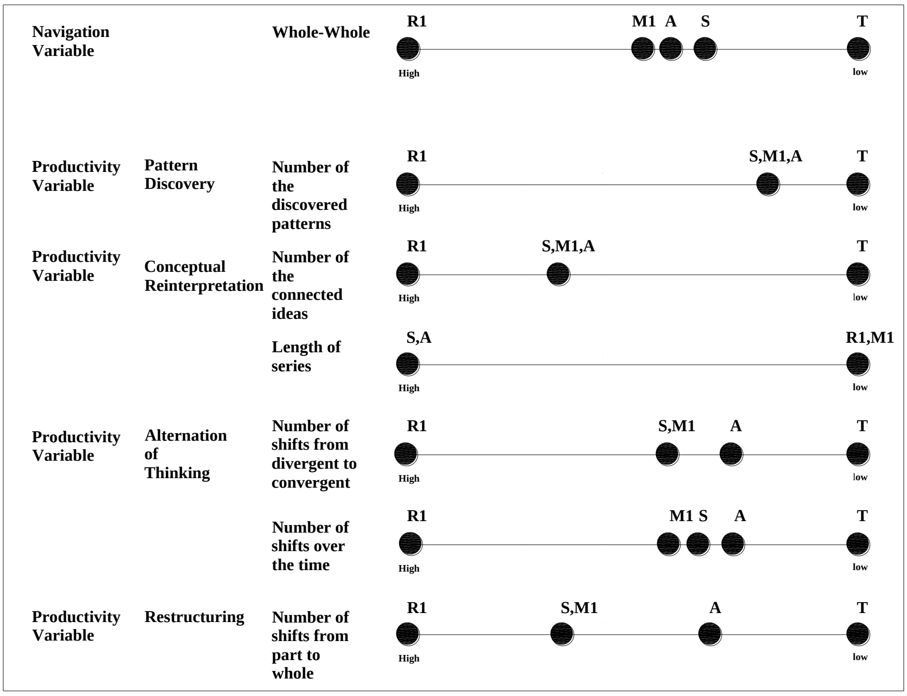


Figure 6.8: Whole-Whole Active Navigation and Productivity, Group (B)

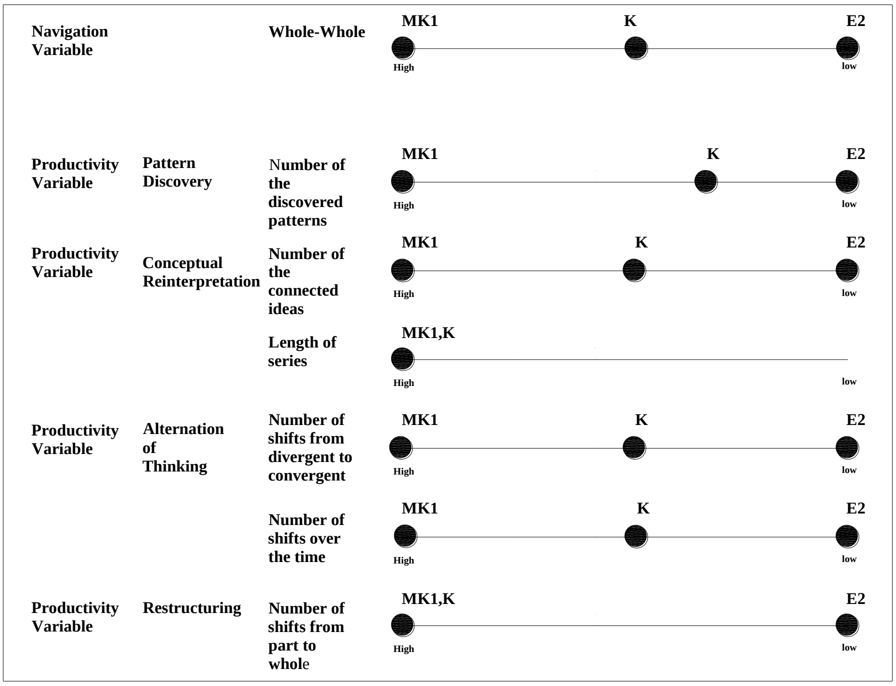


Figure 6.9: Whole-Whole Active Navigation and Productivity, Group (C)

As for group (C), the results of the comparisons, Figure 6.9 shows compatible sequence of the participants on the whole-whole navigation scale line with those of every variable of productivity except the length of series and restructuring. This indicates that there are positive strong relationships between the whole-whole navigation on one hand and the number of discovered patterns, the number of shifts from divergent to convergent, and the number of shifts over the time on the other hand. Also, there is a positive relationship between the whole-whole navigation and the number of the connected ideas.

As for the individual cases of group (D), all of the cases show positive relationships between the whole-whole navigation and all of the indicators of productivity except length of the series and restructuring. Here is a description for these two relationships:

- length of series: while the case of R shows that there is no relationship between the whole-whole navigation and the length of series, the case of M shows that there is a negative relationship and the case of MK show that there is a positive relationship. Since the individual cases of this group show three different patterns of relationships, this indicates that there is no relationship between the length of series and the whole to whole navigation.

- restructuring: while the cases of R, M, and MK show positive relationships between the whole-whole navigation and restructuring, the case of E shows there is no relationship.

Here is a brief summary of the above relationships between active navigation and productivity.

1. There are positive relationships between the whole-whole navigation on one hand and the number of the discovered patterns and the number of the connected ideas on the other hand for all of the groups and the individual cases.
2. Group (B) shows a possible relationship between the whole-whole navigation and the number of shifts from divergent to convergent thinking. This possibility is confirmed by the results of all the other groups (A), (C), and (D). Accordingly, there is a positive relationship between the whole-whole navigation and the number of shifts from divergent to convergent thinking.
3. Although the results of group (B) do not confirm or deny the relationship between the whole-whole navigation and the number of shifts over the time, this relationship has been confirmed by the other groups (A), (C), and (D). Accordingly, there is a positive relationship between the whole-whole navigation and the number of shifts over the time.
4. The four groups (A, B, C, and D) show that there is no relationship between the whole-whole navigation and the length of series.
5. Although the results of the individual cases of R, M, and Mk show a positive relationship between the whole-whole navigation and the restructuring, this relationship is denied by the results of the three groups (A), (B), (C) and the case of E in group (D). Accordingly, there is no relationship between the whole-whole navigation and the restructuring since the individual cases are used as supporting cases and their results show two different patterns of relationships.

6.3.2.2. Active and background navigation & Productivity

- Part – Same part and productivity

Figures 6.10, 6.11 and 6.12 show the comparisons on the indicator lines of difference for the groups (A), (B), and (C) respectively. Group (A) shows a compatible sequence of the participants on the navigation scale and their sequence on the scale of four of the productivity variables; these are: the number of discovered patterns, the number of the connected ideas, the number of shifts from divergent to convergent, and the number of shifts over the time. This indicates that there is positive relationship between the same-same part navigation and each of these four productivity indicators. The other two indicators (the length of series and the restructuring) show incompatibility in the sequence of the participants with that on the navigation scale, which indicates there are no relationships.

Group (B) shows incompatibility in the sequence of the participants on the navigation scale with that on the productivity scale, which combines the six indicators. This indicates that there is no relationship between the two for all of the indicators of productivity variables.

Group (C) shows incompatibility in the sequence between navigation and all of the productivity variables. This indicates that there is no relationship between the navigation from part to the same part and the six indicators of productivity variables.

As for the cases of group (D), the increase in the navigation of the case of Mk shows a compatible increase in all of the productivity variables. This compatibility is also found with the case of M for all the variables of productivity. On the other hand, the case of R shows a completely reverse relationship where the increase in navigation is accompanied by a decrease in all of the indicators of the productivity variables except the length of series where there is no relationship. Since these individual cases show reverse patterns of relationships this indicates the non-existence of the relationships between this variable and all the productivity variables. There is no obvious reason for the emergence of the above completely different or reversed patterns of relationships among the groups and the individual cases. Since the test results of groups (B) and (C) show no relationships against the test result of group (A) and the test results of the individual cases show non-existence of the relationships, this supports the conclusion of the non-existence of the relationship between this variable and all of the productivity variables.

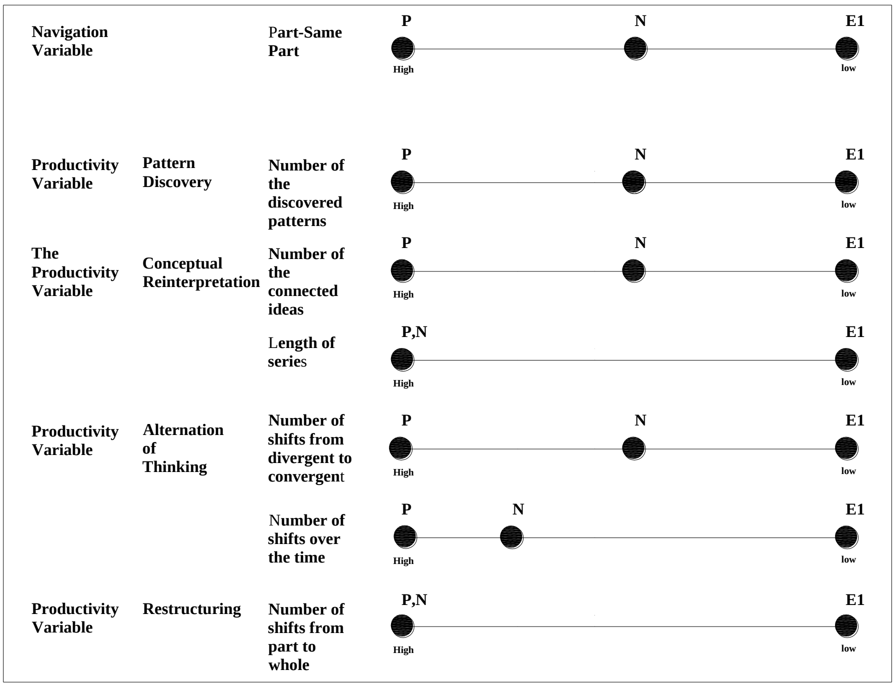


Figure 6.10: Part-Same Part Navigation (Active & Background) and productivity, Group (A)

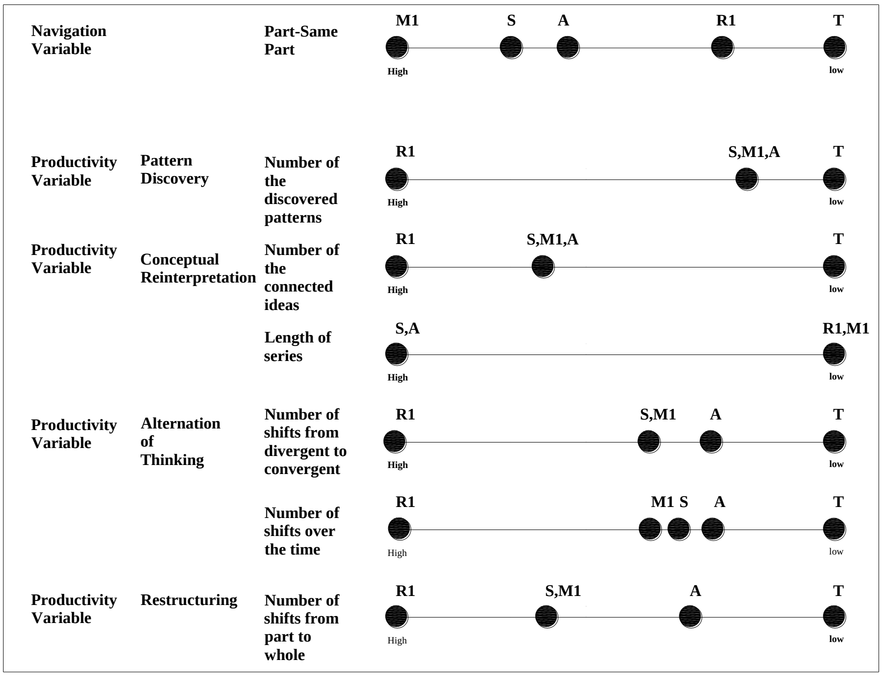


Figure 6.11: Part-Same Part Navigation (Active & Background) And productivity, Group (B)

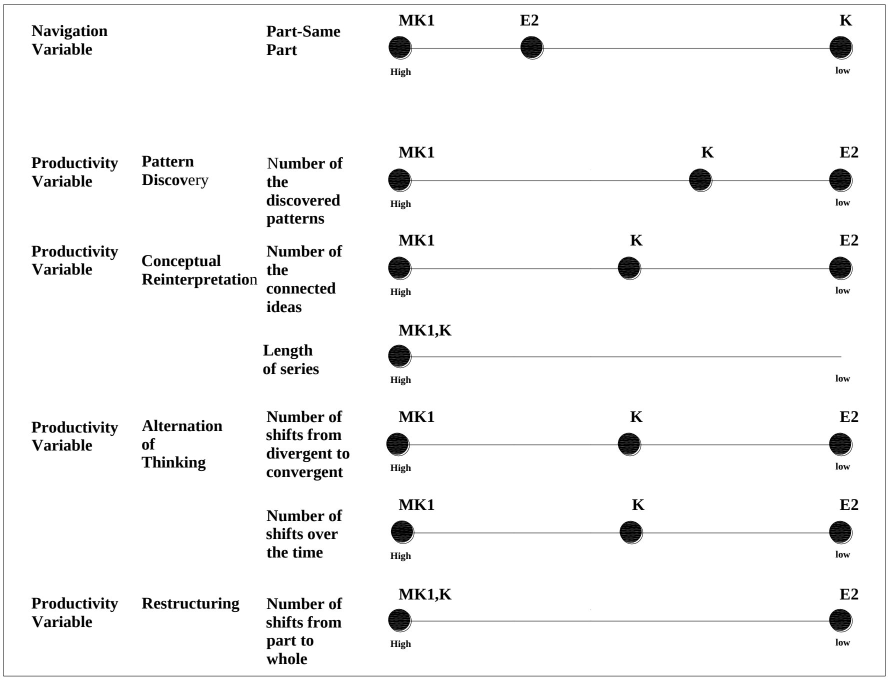


Figure 6.12: Part-Same Part Navigation (Active & Background) and Productivity, Group (C)

- Part-Another Part and Productivity

Figures 6.13, 6.14 and 6.15 show the comparison between the navigation from part to another part and the six indicators of the productivity variables for groups (A), (B) and (C) respectively. It is obvious that there is incompatibility in the sequence between the two for all of the variables of the productivity, thus there is no relationship between the navigation from a part to another part and productivity.

On the other hand, the individual case of Mk shows a positive pattern of relationship between the part to another-part navigation and all of the indicators of productivity. This pattern appears again with the case of E for all of the indicators of productivity variables except the restructuring. Although this indicates that there are positive patterns of these relationships except the relationship with restructuring, the confirmed relationships from only two individual cases cannot generalize this existence.

The three groups (A), (B) and (C) show no pattern of relationships with all of the productivity variables. Since there is no obvious reason for the emergence of the reverse results of test between the groups and the individual patterns; this supports the generalization of the conclusion of the non existence of the relationship between this variable and all of the productivity variables.

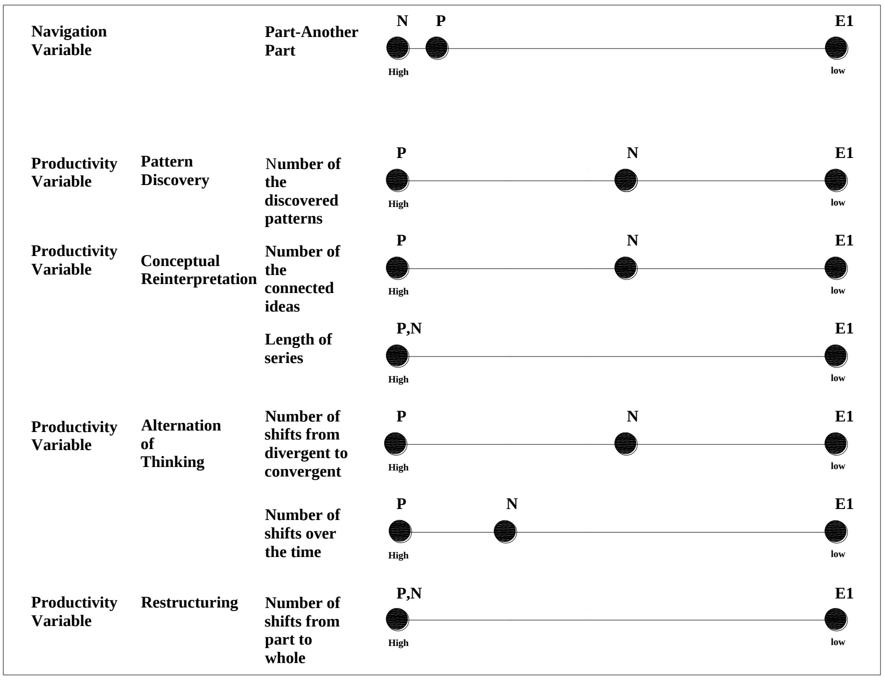


Figure 6.13: Part-Another Part Navigation (Active & Background) and Productivity, Group (A)

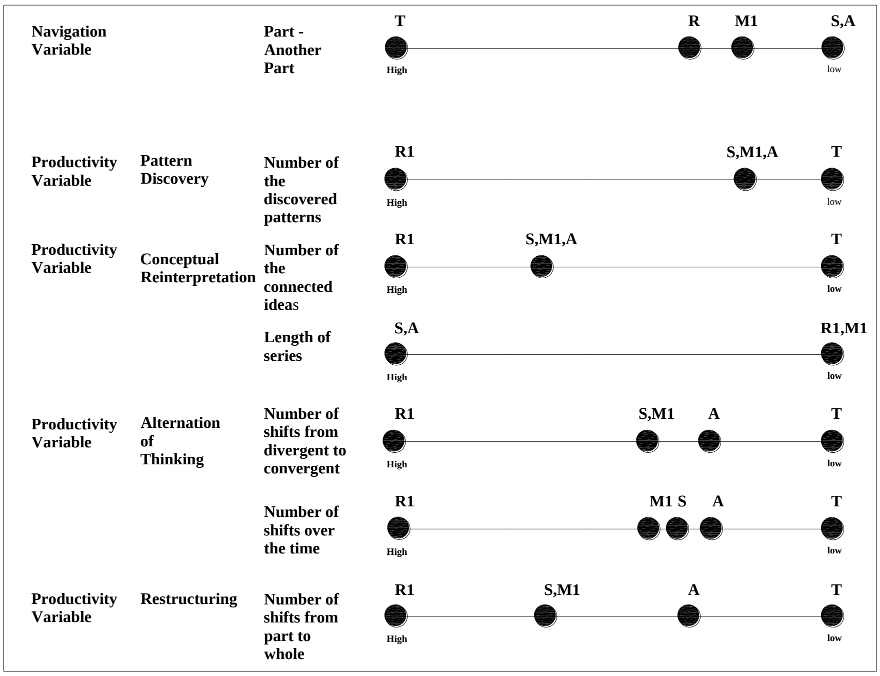


Figure 6.14: Part-Another Part Navigation (Active & Background) and Productivity, Group (B)

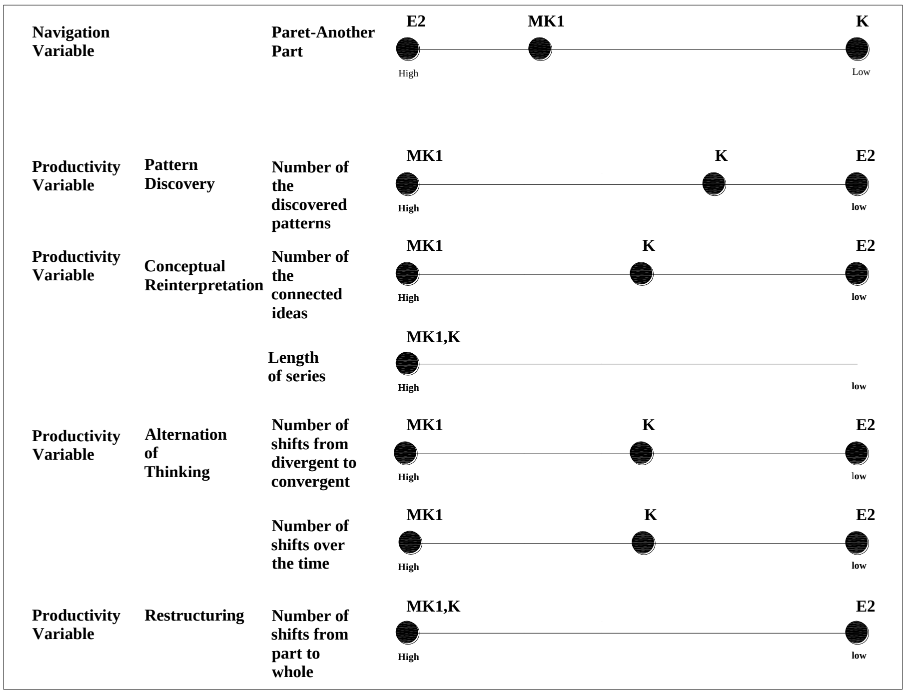


Figure 6.15: Part-Another Part Navigation (Active & Background) and Productivity, Group (C)

- Whole-Part and productivity

Figures 6.16 and 6.17 show the comparison on the indicator lines of difference for the groups (A) and (C) respectively. While Group (A) shows incompatibility in the sequence of the participants on the navigation scale and their sequence on all of the productivity variables scale, Group (C) shows a compatibility in the sequence between navigation and all of the productivity variables except the length of series and the restructuring where there are no relationships. As for the cases of group (D), the increase in the navigation of the case of Mk is accompanied by an increase in each of the indicators of productivity variables. This compatibility is also found with the cases of M and E for all of the variables of productivity except the length of series and the restructuring. The case of M shows a negative relationship with the length of series and E shows no relationship with restructuring.

There is no obvious reason for the emergence of different pattern of relationships of group (A) for these four indicators: the number of discovered patterns, the number of connected ideas, the number of shifts from divergent to convergent and the number of shifts over the time line. However, the emergence of a positive pattern of relationships between the above four variables and productivity for group (C) does not happen by chance because it is supported by the three cases of group (D) that confirm the same positive pattern. Accordingly, these positive relationships exist only when using the AutoCAD and MicroStation.

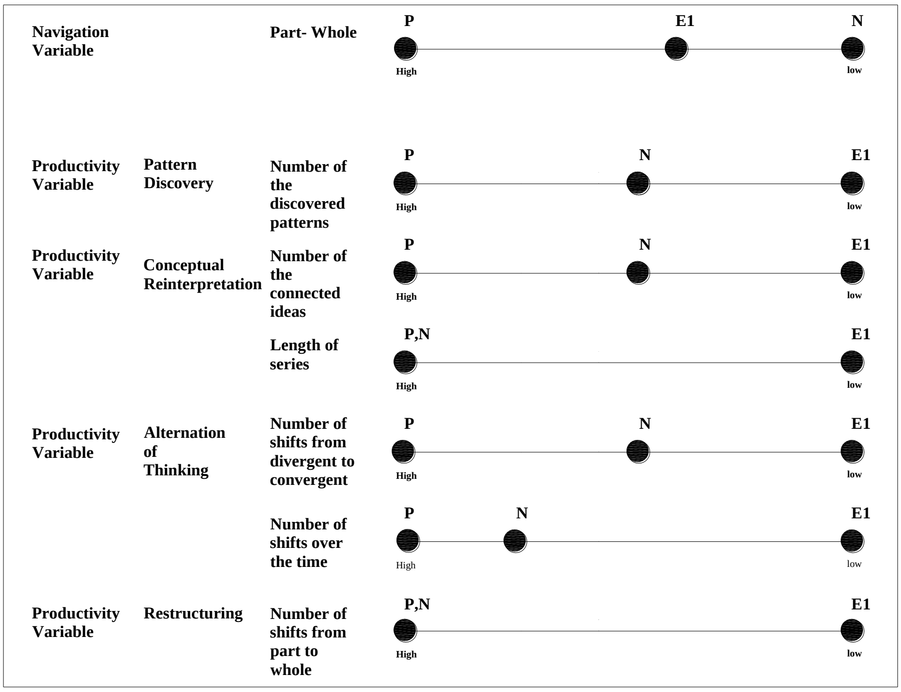


Figure 6.16: Part-Whole Navigation (Active & Background) and Productivity, Group (A)

- The Whole-Whole Navigation and Productivity

Figures 6.18, 6.19, and 6.20 show the results of the comparison between the navigation from whole to whole and all of the variables of the productivity for the groups (A, B, and C) respectively.

As for group (A), the result of the comparison shows that there are relationships between the navigation from the whole to whole and every indicator of the productivity variables except the length of the sequence and the restructuring. The nature of the confirmed relationships is positive. The figure also shows complete harmony between the whole to whole navigation and the number of shifts over the time, which indicates that this relationship is very strong. The sequences of the other indicators are not in complete harmony with the sequence on the navigation scale, which indicates a less degree of strength. Group (B) shows general patterns of relationships as long as the three in between participants on the navigation scale being dealt with as one group. Their values are relatively very near to each other 135, 130, and 118 in comparison to 181 for the high extent and 71 for the low extent.

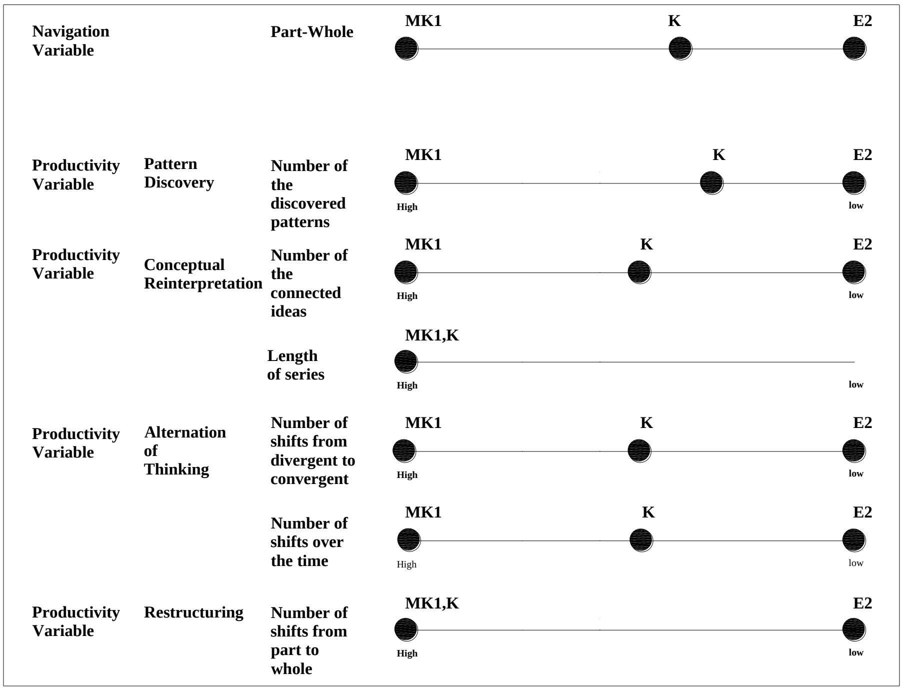


Figure 6.17: Part-Whole Navigation (Active & Background) and Productivity, Group (C)

The general sequence of the participants on the navigation scale is compatible with that of every indicator of productivity variables with the exception of the restructuring and the length of series. The details of these relationships show almost the same patterns of relationships of the active navigation (Figure 6.8, section 6.3.2.1) where a detailed description has been given, in the following is a brief description:

- first: there are general patterns of positive relationships between the navigation on one hand and the number of the discovered patterns and the number of the connected ideas on the other hand and they are not strong.
- second: the two indicators of alternation of thinking show general compatible sequences with that of navigation scale, however, the details of the sequences of the in between group are not fully compatible. As for the number of shifts from convergent to divergent, the comparison indicates that there is a possible positive pattern of relationship. As for the number of shifts over the time, the

sequence of the in-between group is not compatible; however, the general sequence (high value, middle values, and low value) is compatible. Accordingly, the relationship cannot be fully confirmed; however, it cannot be denied as there is general possible pattern.

- third: the sequence of the participants on the navigation scale is not compatible with that on the indicator of the restructuring scale. This indicates that there is no relationship.

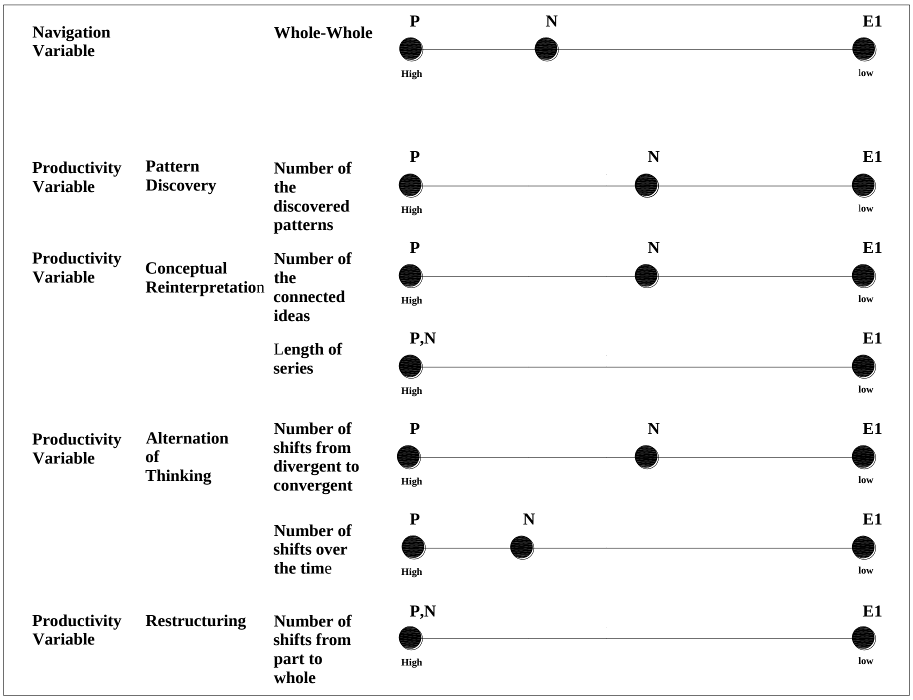


Figure 6.18: Whole-Whole Navigation (Active & Background) and Productivity, Group (A)

As for group (C), the results of the comparisons (Figure 6.20) show compatibility in the sequence of the participants on the whole-whole navigation scale line with that of every variable of productivity except the length of series and restructuring. This indicates that there are positive relationships between the whole-whole navigation on one hand and the number of discovered patterns, the number of connected ideas, the number of shifts from the divergent to convergent, and the number of shifts over the time on the other hand. These relationships are almost strong.

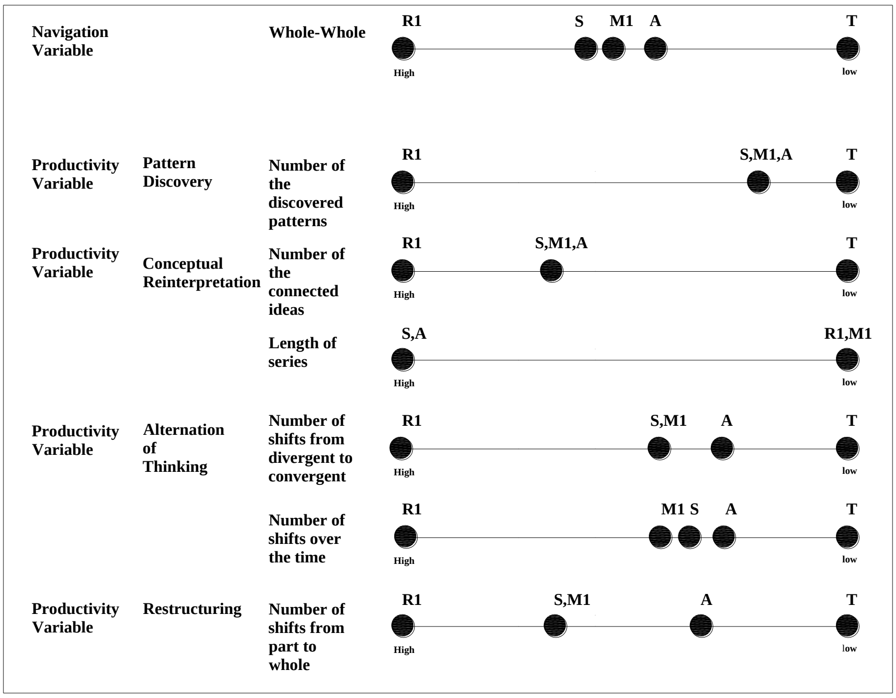


Figure 6.19: Whole-Whole Navigation (Active & Background) and Productivity, Group (B)

As for the individual cases of group (D), all of the cases show positive relationships between the whole-whole navigation and all of the indicators of productivity except the length of the series and restructuring:

- length of series, while the case of R shows that there is no relationship between the whole-whole navigation and the length of series, the case of M shows that there is a negative relationship and the case of MK shows a positive relationship. Since the individual cases of this group show three different patterns of relationships, this indicates that there is no relationship between the length of series and the whole to whole navigation.
- restructuring, while the cases of R, M, and MK show positive relationships between the whole-whole navigation and restructuring, the case of E shows that there is no relationship. Accordingly, the individual cases show two different results. Although there is only one case that denied this relationship, the above results of the three groups (A, B, C) strengthen and support the non existence of this relationship.

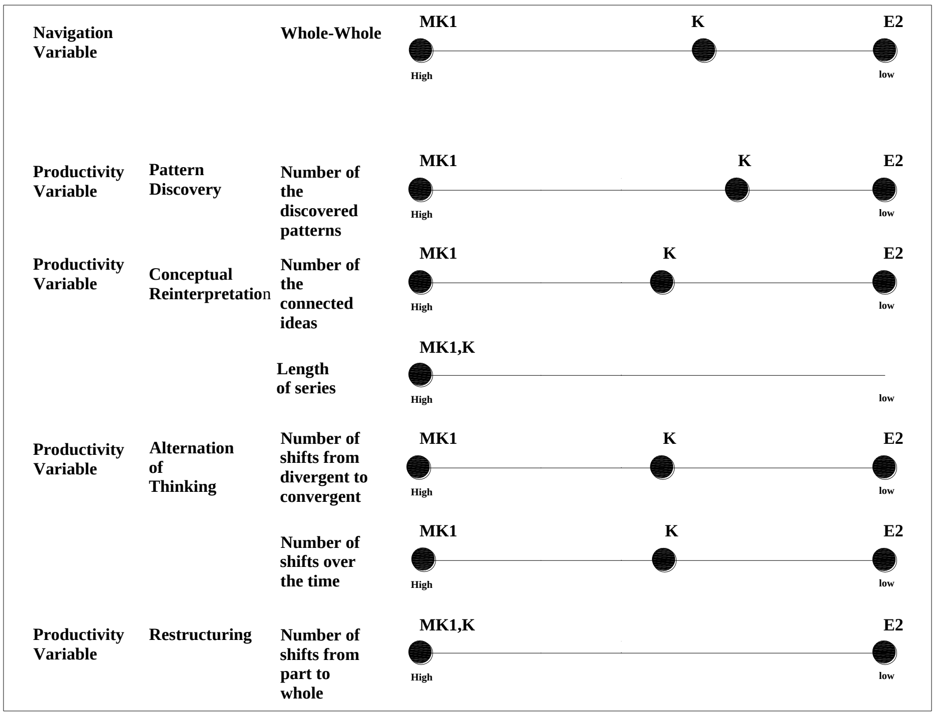


Figure 6.20: Whole-Whole Navigation (Active & Background) and Productivity, Group (C)

- Total Navigation (Active & Background) and productivity

Figure 6.21 shows the comparison results for group (A). The results show positive relationships between the total navigation on one hand and the number of discovered patterns, the number of the connected ideas, the number of the shifts from convergent to divergent, and the number of shifts over the time on the other hand. These relationships are quite strong except the relationship with the number of shifts over time. The figure also shows that there are no relationships between the total navigation and both of the number of series and the restructuring.

Figure 6.22 shows the results of comparison for group (B). The values of the in-between group S, M, A are very close (190, 195, 195) so that dealing with them as one value is quite reasonable. The comparison shows almost the same patterns of relationships of the Active whole-whole navigation and the Active and Background whole-whole navigation. Here is a brief description of these patterns:

- there are positive relationships between the total navigation on one hand and the number of the discovered ideas and the number of the connected ideas on the other hand. However these relationships are not so strong.

- there is a possible positive relationship with the number of shifts from divergent to convergent as the general patterns of the sequences on both scales are compatible; however, the detailed patterns of sequences of the in-between group shows incomplete compatibility. The cause of the incomplete compatibility of the sequences of the participants on both scales has been explained earlier (see paragraph: whole-whole active navigation, result discussion-Group B) and it is quite reasonable.

- the relationship with the number of the shifts over the time is not denied; however, it is not confirmed. That is because the sequence of the in-between participants on the navigation scale is not in complete harmony with that on productivity scale and there is no obvious reason for this incompatibility.

- there are no relationships with both the length of series and the restructuring.

Figure 6.23 shows the results of the comparison for group (C). They show that there are positive relationships with the number of the discovered patterns, the number of the connected ideas, the number of shifts from divergent to convergent, and the number of shifts over the time. However they are not strong as the sequences are not in full harmony. The figure also shows that there are no relationships with both of the length of the series and the restructuring.

All of the individual cases of group (D) show positive relationships between the total navigation on one hand and the number of discovered patterns, the number of connected ideas, the number of shifts from divergent to convergent thinking, and the number of shifts over the time. On the other hand the cases show different patterns of relationships between total navigation and the length of the series: positive pattern of relationship MK, no relationship R and negative relationship M. Accordingly there is no relationship between the total navigation and the length of the series. Finally, the cases show positive relationships with the restructuring except the case of E shows that there is no relationship. However this cannot confirm the existence of the relationship since the three groups of (A), (B), and (C) deny this relationship.

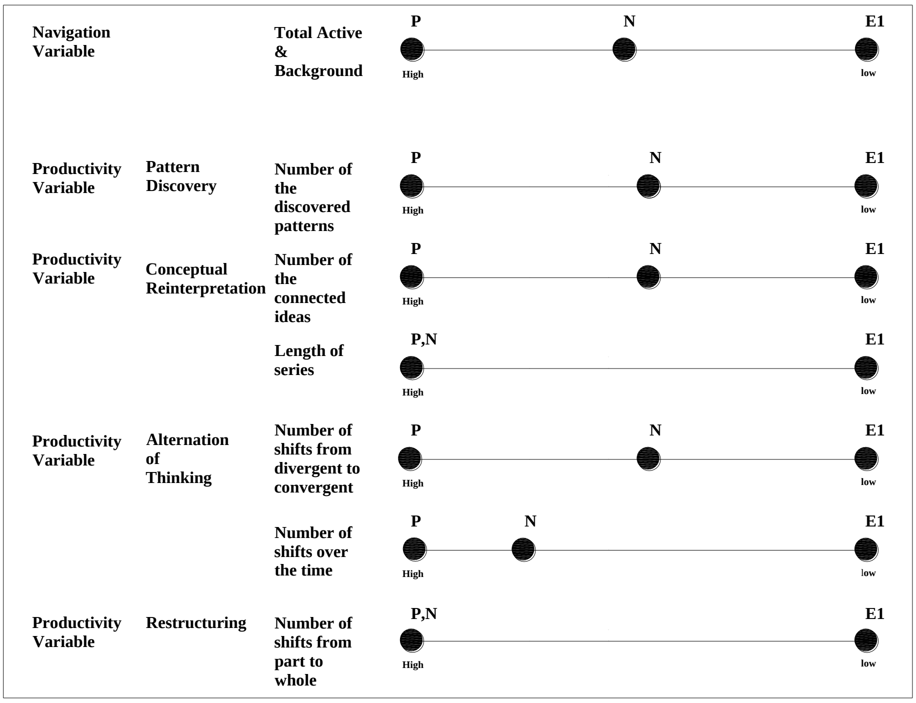


Figure 6.21: Total Navigation (Active & Background) and Productivity, Group (A)

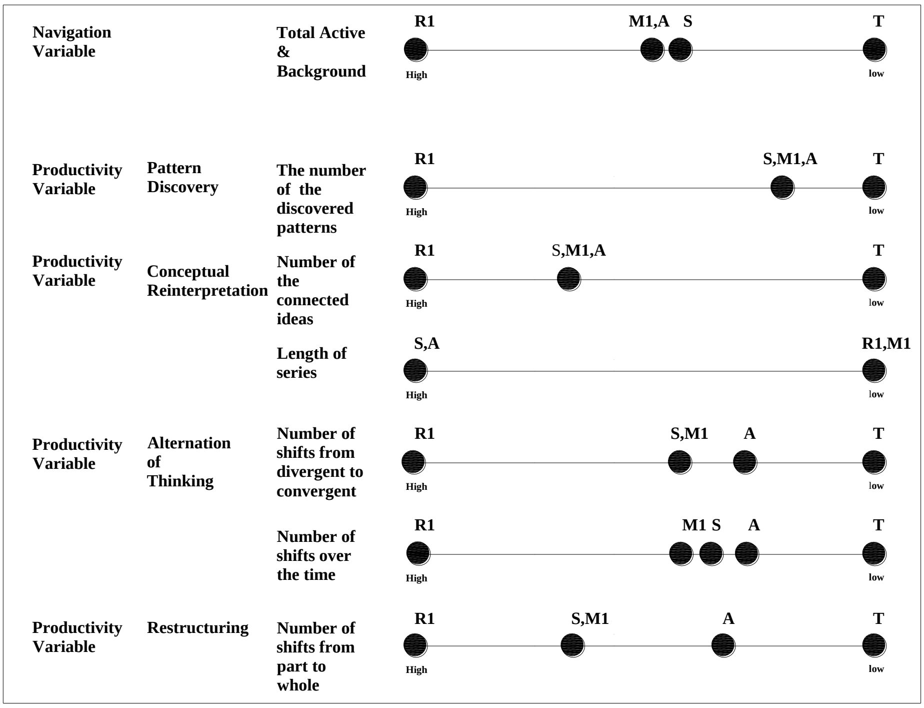


Figure 6.22: Total Navigation (Active & Background) and Productivity, Group (B)

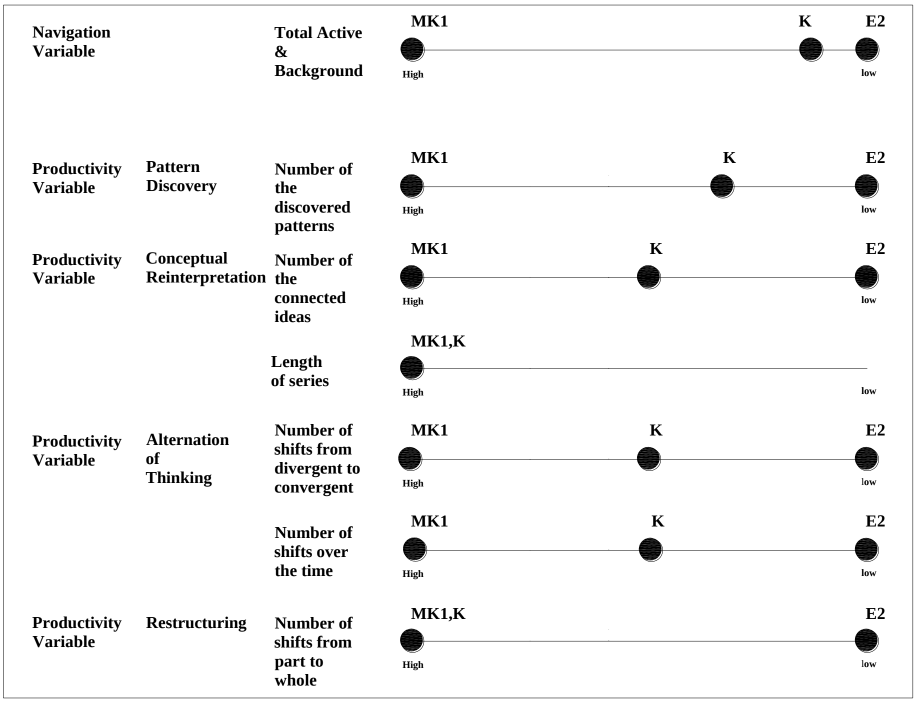


Figure 6.23: Total Navigation (Active & Background) and Productivity, Group (C)

6.3.3. Results of testing the relationship between the degree of continuity of displaying images due to changing the appearance and productivity

This relationship has been tested through examining the relationship between four variables of changing the appearance (move from inside to outside, move from two dimensional drawings to three dimensional drawings, move from mesh to solid, and the total change in appearance) on the one hand and all of the indicators of productivity on the other hand. A presentation of the test results follows.

- The move from Inside to Outside (In-Out)

Figures 6.24 and 6.25 show the comparison results of groups (B) and (C) respectively. The figures show the incompatibility between the sequences of the participants on the scale of the move from Inside to Outside on the one hand and their sequences on the scale of every indicator of the productivity variables on the other hand. This indicates that there are no relationships between changing the appearance (Inside-Outside) and productivity. As for group (D), the only individual case of R shows that there are positive relationships with the number of discovered patterns, the number of connected ideas, the number of shifts from divergent to convergent, and the number of shifts over the time. Since one individual case cannot prove the existence of these relationships, the non- existence of this relationship is confirmed by the two groups and this result can be generalized.

- The move from two dimensional drawings to three dimensional drawing (2D-3D)

Figures 6.26 and 6.27 show the results of the comparison for groups (A and C). Both groups (A and C) show negative relationships between the move from 2D to 3D (and vice versa) and every indicator of the productivity variables except the length of series and the restructuring where there are no relationships.

The two individual cases of group (D) show two different patterns of relationships. While the case of participant E shows that there are positive relationships with all of the indicators of the productivity variables except the restructuring, the case of M shows negative relationships with the four indicators of the productivity variables. Although the case of E gives a positive pattern of relationships, this case alone cannot prove this pattern. It has been mentioned earlier that the cases of group (D) are to be used as assistant cases for supporting one possibility of relationship over another where the pattern is not so clear for an adequate reason in one of the groups. The case of this variable is different. The groups in consideration (A and C) show very clear patterns of negative relationships. One of the individual cases confirms this pattern and one case denies it. While, in this latter, the designer used two different software systems (3D Max and Micro Station), in the former, the designer used the same software (Sketchup), which strengthens the position of the existence of the negative pattern.

Accordingly, we are going to accept the existence of the negative pattern of relationship of this variable with all the productivity variables except for the length of series and the occurrence of restructuring where there are no relationships.

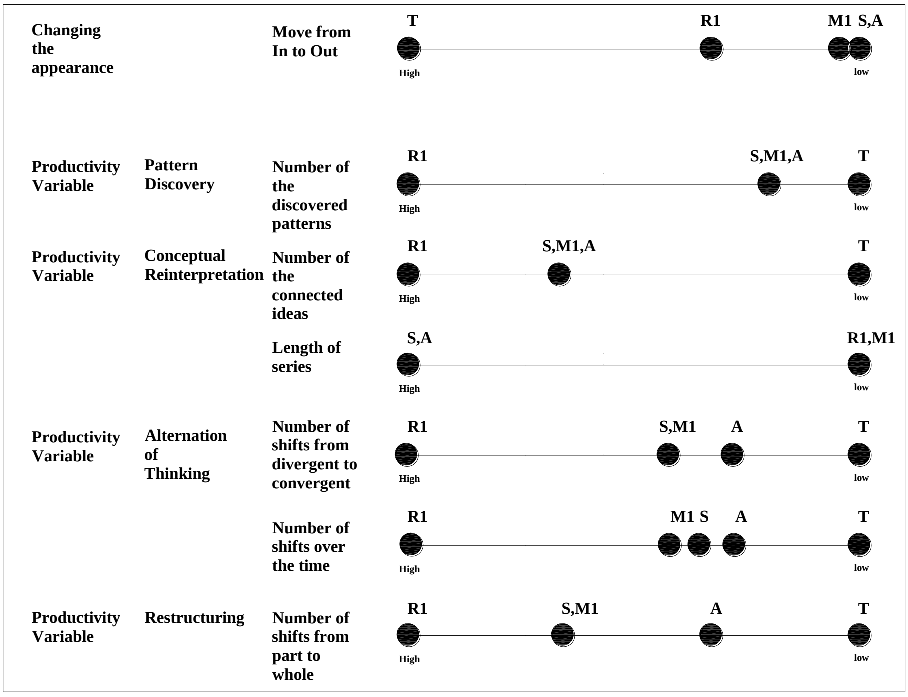


Figure 6.24: Changing the appearance due to move from inside to outside, Group (B)

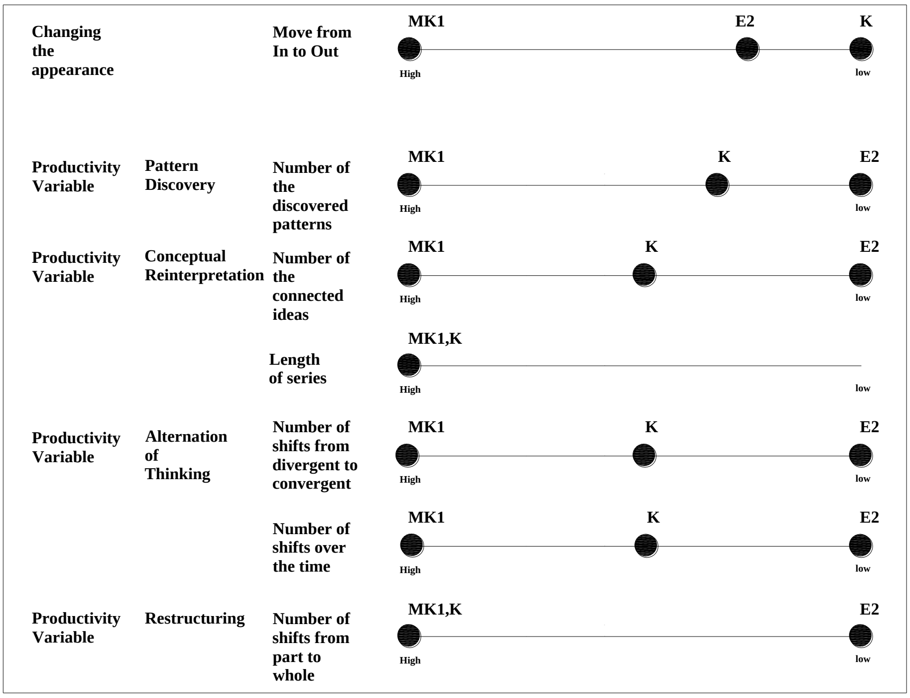


Figure 6.25: Changing the appearance due to move from Inside to Outside, Group (C)

The existence of the negative patterns with these indicators (the number of the discovered patterns, the number of the connected ideas, the number of shifts from divergent to convergent), is confirmed by groups (A, C) and the individual case M of group (D) as well. The emergence of the negative patterns with the above indicators is not expected. It refutes the assumption of the increase in the number of moves from 2D-3D and vice versa will increase the productivity. It suggests that the frequent deal with plans, sections and elevations can have a negative effect on the productivity of conceptual stage of design.

- The move from Mesh to Solid (Mesh-Solid)

Figure 6.28 shows the results of the comparison for group (C). The figure shows that there are no relationships between the move from Mesh state of the drawings to Solid (and vice versa) on the one hand and all of the variables of productivity on the other hand.

However, the case of R in group (D) shows that there are positive relationships between this variable and all of the indicators of productivity variables except the length of series.

Since group (C) shows no relationship between the move from solid to mesh state (and vice versa) on the one hand and all of the indicators of the productivity (except the length of series) on the other hand, the individual case of group (D) alone cannot confirm the existence of positive relationships. Accordingly, there is no relationship between the (Mesh-Solid) move and productivity. Since group (C) is the only group used for this test the non-existence of the relationship is regarded only in the use of the AutoCAD and Micro Station and this result cannot be generalized.

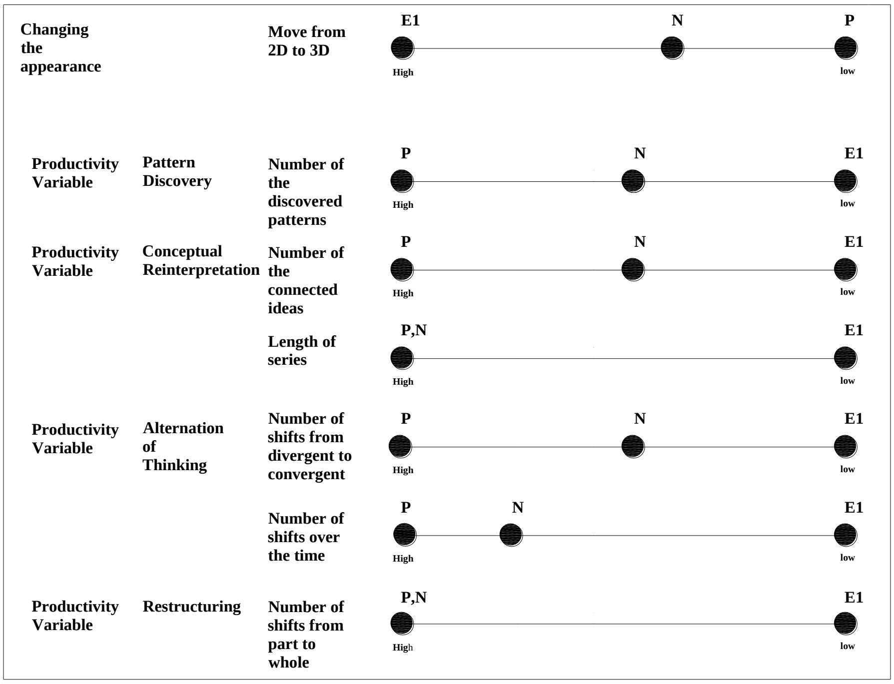


Figure 6.26: Changing the appearance due to move from 2D to 3D drawings and Productivity, Group (A)

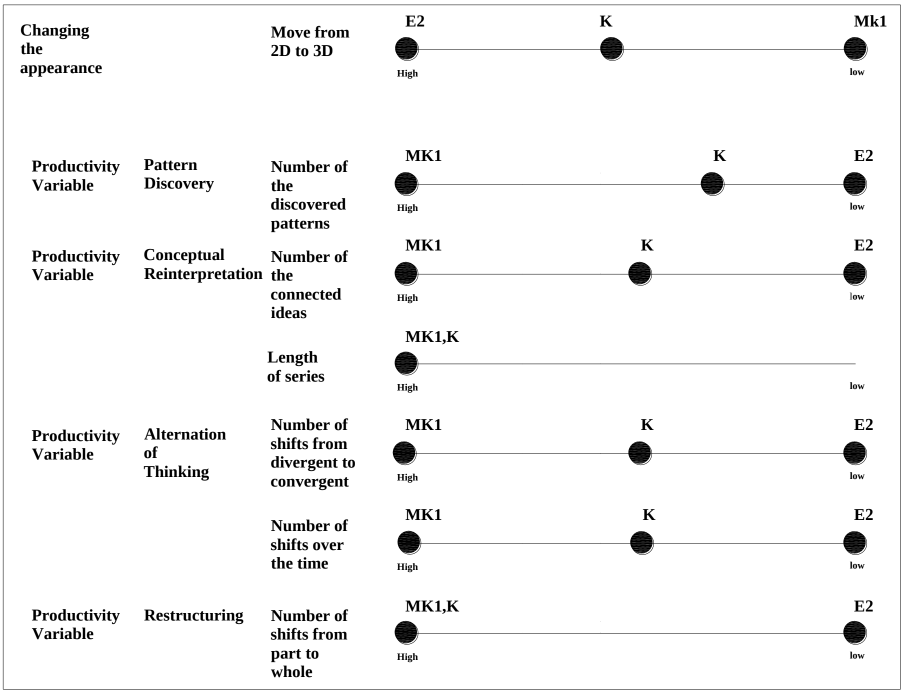


Figure 6.27: Changing the appearance due to move from 2D to 3D drawings and productivity, Group (C)

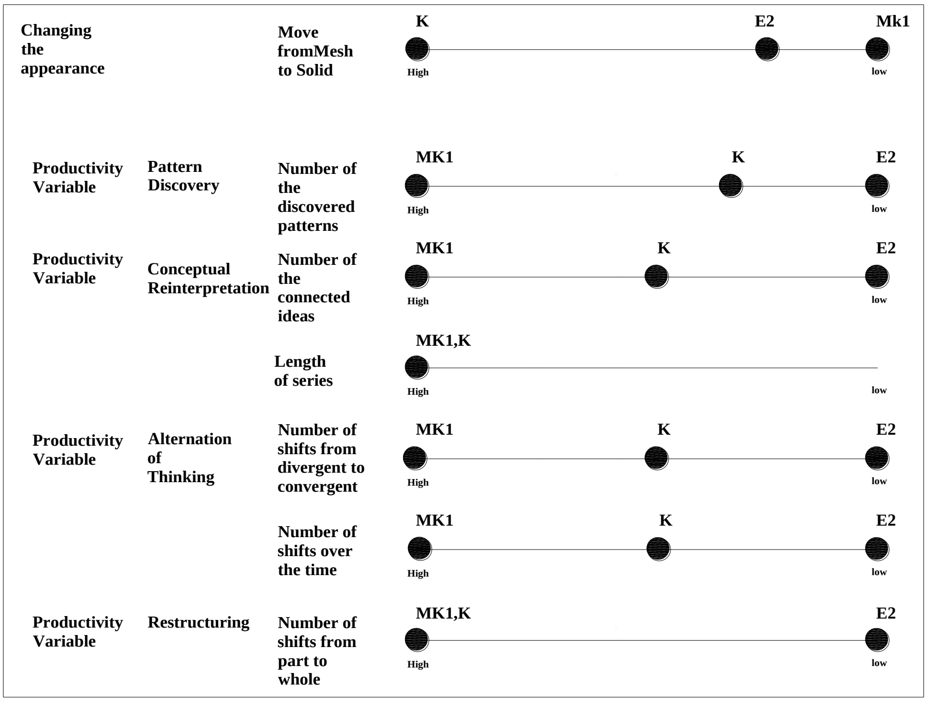


Figure 6.28: Changing the appearance due to move from Mesh state to Solid state and productivity, group (C)

- Total change in appearance

Figures 6.29, 6.30 and 6.31 show the results of the comparison for groups (A, B and C). While group (A) shows negative relationships between the total change in appearance and every indicator of the productivity variables except the length of series and the restructuring where there are no relationships, group (B) and (C) show that there are no relationships with all of the indicators of productivity variables.

The individual cases of group (D) show two different patterns of relationships. While the cases of R and E show positive relationships with all of the indicators of the productivity variables except the restructuring in case of E and the length of series in the case of R (E is excluded from testing this relationship-the length of series with all the indicators of productivity- because he had zero value), the case of M shows negative relationships with all of the indicators of the productivity variables.

Since there is no obvious reason for the emergence of these reverse patterns among the groups and the individual cases, there is no relationship between the total change in appearance and productivity.

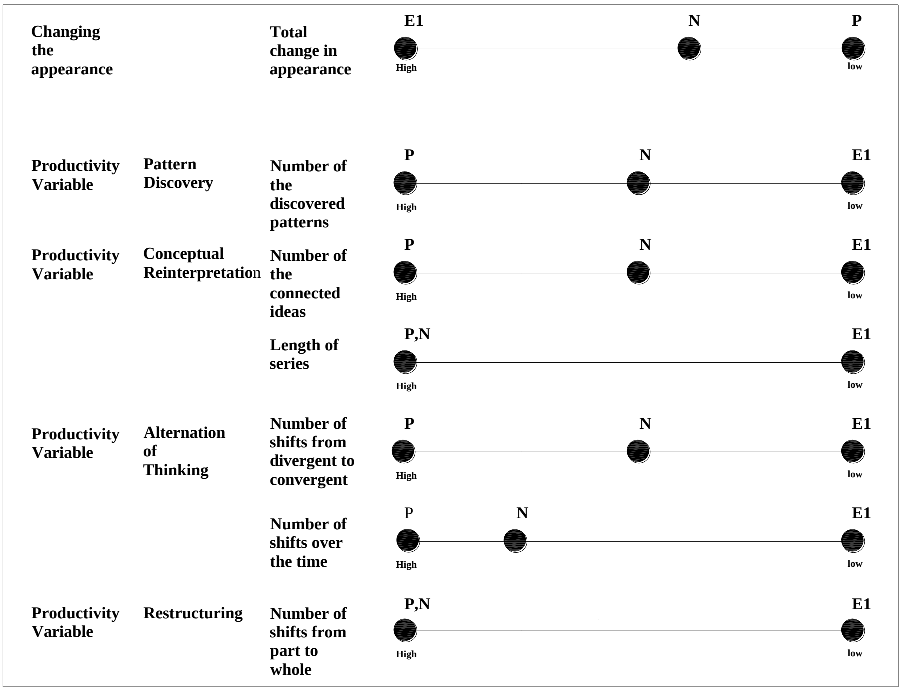


Figure 6.29: Total change in appearance and Productivity, Group (A)

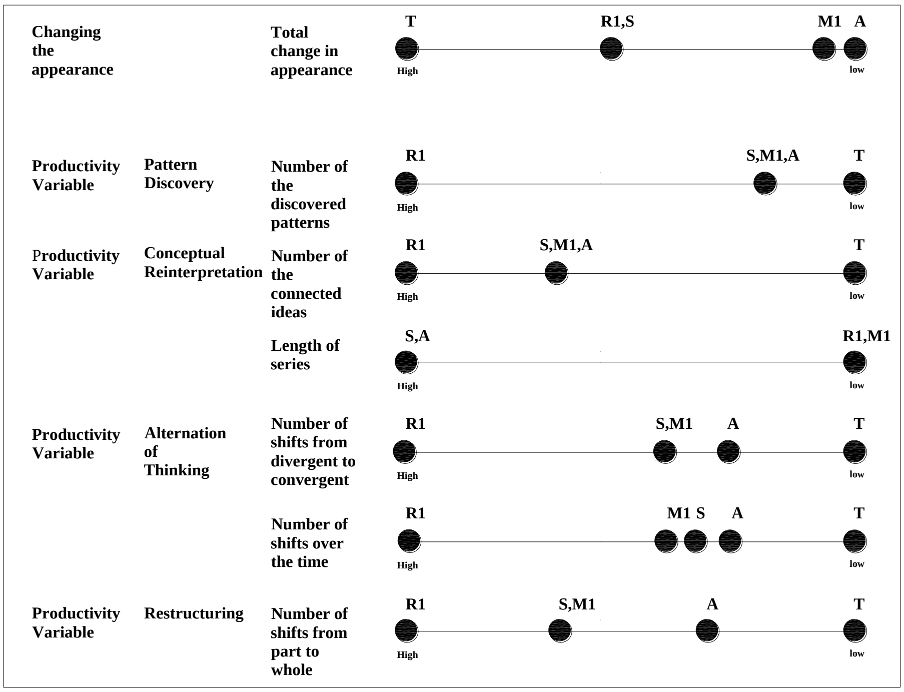


Figure 6.30: Total change in appearance and Productivity, Group (B)

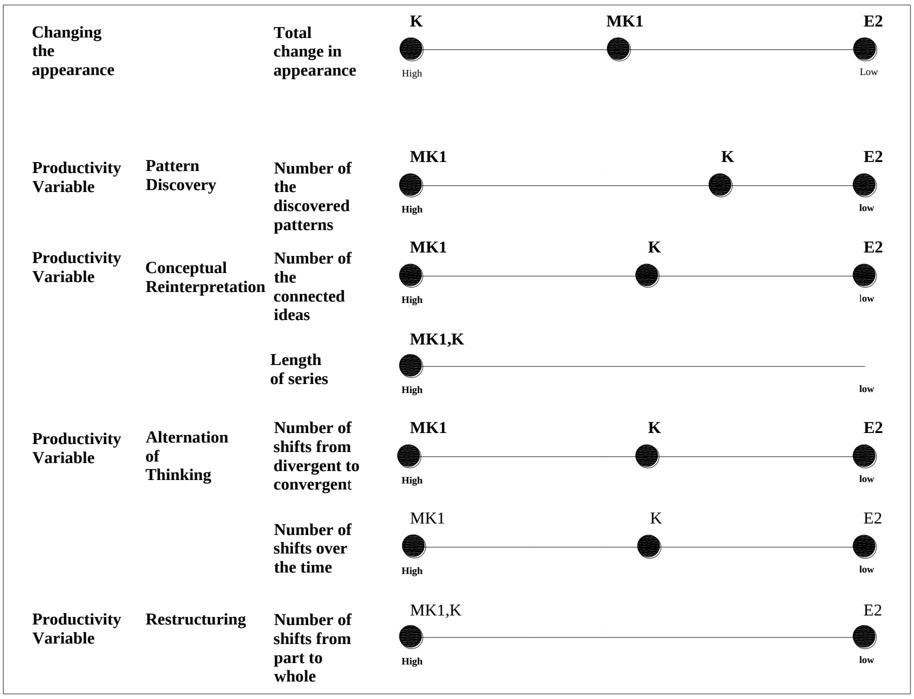


Figure 6.31: Total change in appearance and Productivity, Group (C)

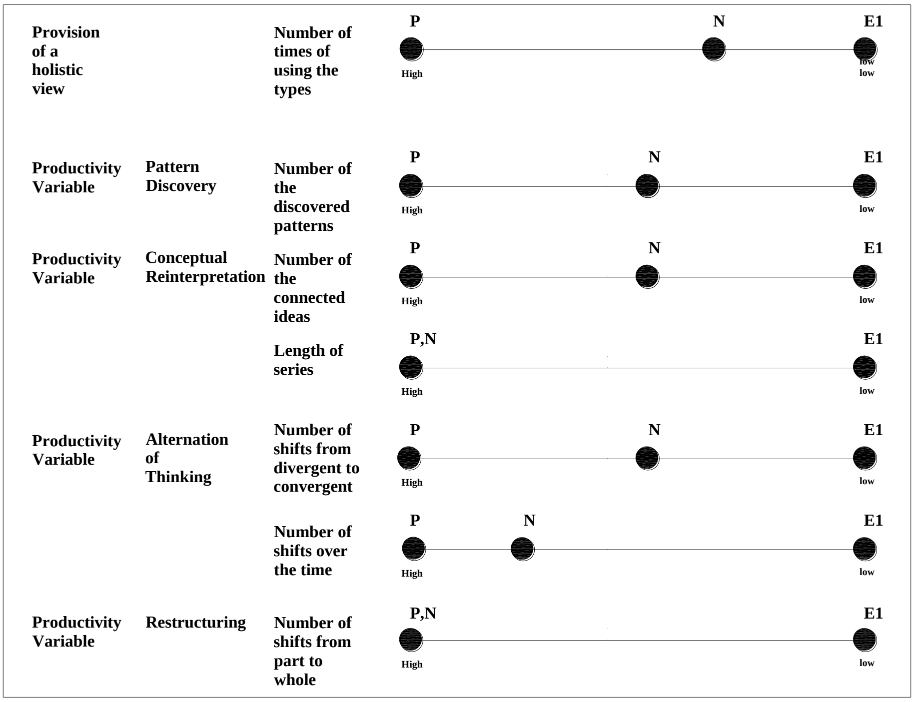


Figure 6.32: Provision of a holistic view; Number of times of using the types and Productivity, Group (A)

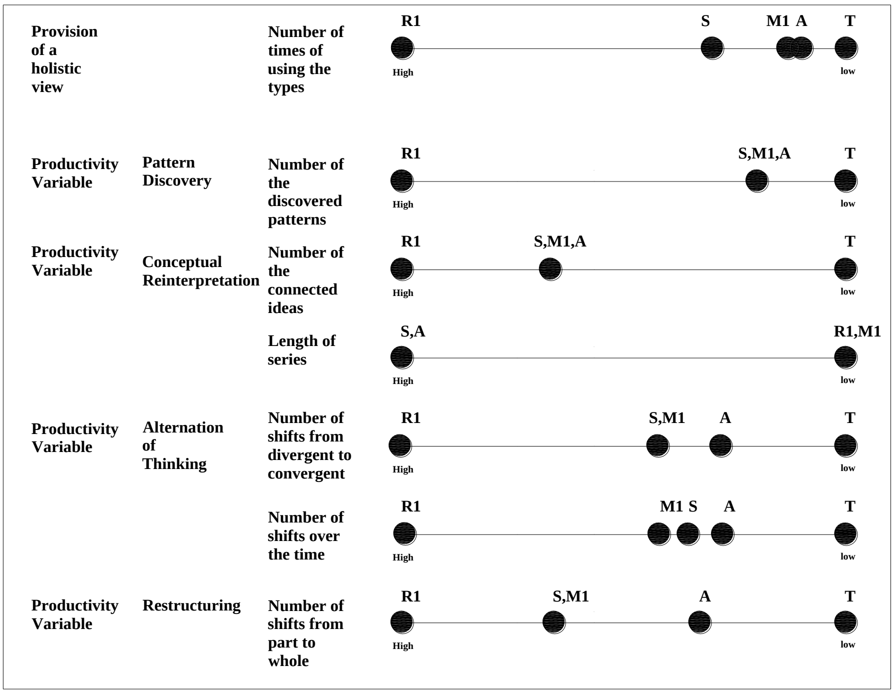


Figure 6.33: Provision of a holistic view; Number of times of using the types and Productivity, Group (B)

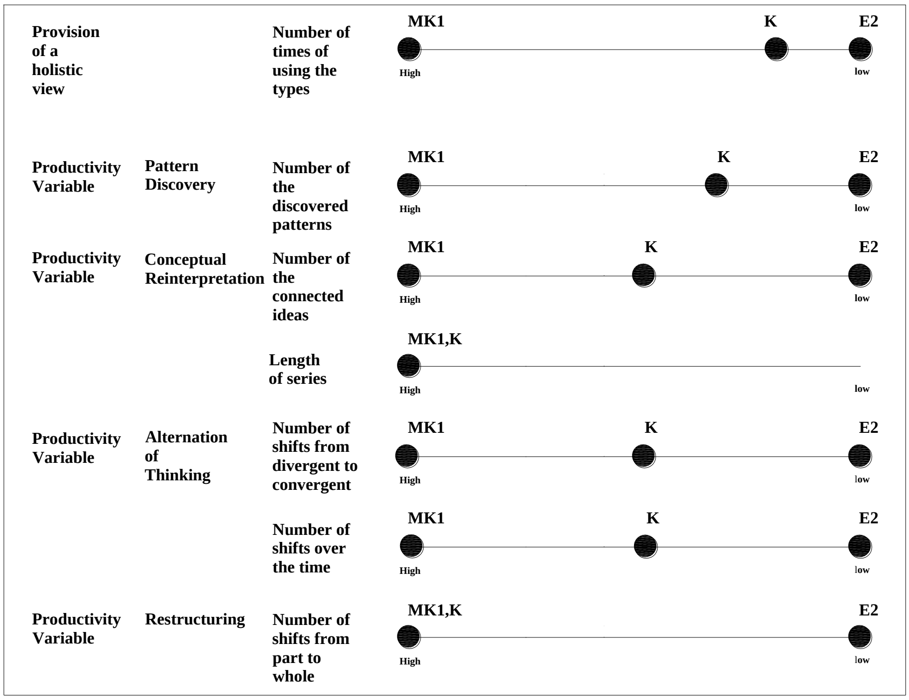


Figure 6.34: Provision of a holistic view; Number of times of using the types and Productivity, Group (C)

6.3.4. Results of testing the relationship between the degree of provision of a holistic view and productivity

This relationship has been tested through examining the relationship between number of times of using types of displaying views and all the indicators of productivity. In the following is a presentation for the test results.

- Number of times of using the types and productivity

Figures 6.32, 6.33 and 6.34 show the results of the comparison between the number of times of using the types and all of the variables of the productivity for the groups (A, B, and C) respectively.

The results of the comparisons for both of group (A) and group (C) show that there are positive relationships with all of the indicators of productivity variables except the length of the series and the restructuring where there are no relationships. The figures show also that these relationships are not so strong since the sequences of the participants on both scales (the number of times of using the types and productivity) are not in complete harmony.

On the other hand group (B) shows an unclear pattern of relationships. The general sequence of the participants on the scale of the number of times of using the types does not give a quite close middle group where M and A are very close but S is showing relatively a noticeable difference. The other noticeable point about this middle group is that, while they show an adequate difference from the high extent (participant S is 64 times less than the high extent, and participant A is 83 times less than the high extent), they do not show such an adequate difference from the lower extent (they are only higher 9-28 times respectively); the values are polarized towards this lower extent. Those two points and especially the second one, prevent dealing with the three cases as one group. However the general pattern can still give compatibility in the sequences.

As for the individual cases of group (D), all of the cases show positive relationships with all of the indicators of productivity variables except the length of the series and restructuring. These results support the results of groups (A and C) for these four indicators: the number of the discovered patterns, the number of the connected ideas, the number of shifts from divergent to convergent thinking, and the number of the shifts over the time.

The testing results of group (B) are highly affected by the polarization of the middle values towards the lower extent. This group is biased towards the lower extent but that certainly does not imply that the general population would be. Therefore it is believed that they are not reflecting the real pattern of these relationships, thus the results of this group have to be cancelled. Accordingly, the final conclusion tends to accept the existence of the positive relationships since the repeated appearance of the positive pattern for groups (A, C and D) suggests that this appearance does not occur by chance. Although the results of group (B) are cancelled, the general pattern of the sequences supports the existence of positive relationship.

As for the length of series indicator, the case of R shows no relationship, the case of M shows a negative relationship, Mk shows a positive relationship, and E has been excluded from testing this relationship since he had the zero value. These different patterns of relationships indicate that there is no relationship with the length of series and support the results of the groups (A, B, and C) about this variable.

Although the results of the individual cases of R, M, and Mk show a positive relationship between this variable and the restructuring, this relationship is denied by the results of the two groups of (A and C) and the case of E in group (D). Accordingly, there is no relationship between the number of times of using the types and the restructuring since the individual cases are used as supporting cases and their results show two different patterns of relationships.

6.3.5. Results Summary

The testing results have shown that there is a relationship between the continuity of the dynamic field of images and the productivity of the conceptual design stage. However, neither all the variables of the continuity of the dynamic field of images, nor all the variables of productivity have shown patterns of relationships. This indicates that not all of the ways that help in keeping the pace of continuity of dynamic field of image can improve the productivity in the conceptual phase. Table (6.17) shows a brief summary of testing results where the (+) sign refers to the existence of a positive relationship, the (-) sign refers to a negative relationship, the (x) sign refers to the inexistence of the relationship, and the (NG) refers to those results that are limited and restricted to using only special kinds of software and cannot be generalized.

Table 6.17: Testing results of the relationship between the degree of continuity of field of images (degree of continuity of displaying images, degree of provision of holistic view) & Productivity variables

			Productivity variables					
			Occurrence of pattern discovery	Occurrence of conceptual reinterpretation		Occurrence of alternation of thinking		Occurrence of restructuring
			Number of the Discovered Patterns	Number of the Connected Ideas	Length of Series	Number of Shifts from Divergent to Convergent Thinking	Number of Shifts over time	Number of ideas that have been applied on whole building (No. of shifts from part to whole)
The degree of continuity of dynamic field of images	Active Navigation	P-SP	x	x	x	x	x	x
		P-AP	x (NG)	x (NG)	x (NG)	x (NG)	x (NG)	x (NG)
		W-W	+	+	x	+	+	x
	Active & Background Navigation	P-SP	x	x	x	x	x	x
		P-AP	x	x	x	x	x	x
		P-W	+ (NG)	+ (NG)	x (NG)	+ (NG)	+ (NG)	x (NG)
		W-W	+	+	x	+	+	x
		Total	+	+	x	+	+	x
	Change the Appearance	In-Out	x	x	x	x	x	x
		2D-3D	–	–	x	–	–	x
		Mesh-Solid	x (NG)	x (NG)	x (NG)	x (NG)	x (NG)	x (NG)
		Total change in appearance	x	x	x	x	x	x
	The Provision of a Holistic	Number of times of using the types	+	+	x	+	x	+

x: Non-existence of relationship, (NG): Finding is not generalizable, + : Existence of positive relationship, — : Existence of negative relationship

The following is a description of these results.

- The Relationships that have been proved to be exist

The proven relationships between the indicators of the three variables of the continuity of the dynamic field of images (the display due to changing object' s position/navigation, the display due to changing object's appearance, and the provision of a holistic view) and productivity are only five, these are: the whole-whole active navigation, whole-whole active and background navigation, the total active and background navigation, the display due to changing the appearance (the move from 2D to 3D), and the provision of a holistic view (the number of times of using the types). Their relationships are confirmed with only four indicators of the productivity variables; these are: the number of the discovered patterns (the degree of occurrence of pattern discovery), the number of the connected ideas (the degree of occurrence of conceptual reinterpretation), the number of the shifts from divergent to convergent thinking (the degree of occurrence of alternation of thinking), and the number of shifts over the time (the degree of occurrence of the alternation of thinking).

All the relationships are positive in nature except the relationships between changing the appearance: the move from 2D to 3D and the four indicators of productivity variables are negative. These latter results were unexpected; they refute the initial assumption that the increase of change in appearance of the objects by moving from 2D to 3D leads to the increase in the productivity of the conceptual phase. This sheds light on some specific properties of thinking and designing in the conceptual stage.

The five confirmed relationships show varied degrees of correlations. The degree of harmony in the compatibility between the sequences of the participants on the two scales (the variables of the continuity of the field of images on one hand and the productivity variables on the other hand) has been used to determine the degree of correlations. The degree of harmony has been determined by comparing the length of the intervals on both scales; the equal length of intervals represents the high degree of harmony.

Table (6.18) shows the degree of the strength of the relationships where the complete solid circles represent the strong relationships and the empty circles represent the weak relationships. The strength of the relationship has been determined for the groups (A, B, and C) separately and then the average has been given, which can give a general picture of this correlation. While the active whole to whole navigation and the active and background whole to whole navigation show almost strong relationships with the four indicators of productivity variables, the total navigation (active and background) and the changing appearance from 2D to 3D come in second position. As for the number of times of using the types of view display, the table shows fewer degrees of correlation for this variable.

Table 6.18: Degree of strength of confirmed relationships

		Variables of continuity of the dynamic field of images																	
		Changing the images due to Navigation												Changing the appearance:			Provision of a holistic view		
		Active whole-whole navigation				Active & background whole-whole navigation				Active & background total navigation				Moves from 2D-3D			Number of timesof using the types		
		A	B	C	Av.	A	B	C	Av.	A	B	C	Av.	A	C	Av.	A	C	Av.
Productivity variables	Number of the discovered patterns	◕	◕	●	◕	◕	◕	◕	◕	●	◕	◕	◕	◕	◕	◕	◕	◕	◕
	Number of the connected ideas	◕	◕	●	◕	◕	◕	◕	◕	●	◕	◑	◕	◕	◕	◕	◕	◑	◕
	Number of shifts from divergent to convergent Thinking	◕	◑	●	◕	◕	◑	◕	◕	●	◑	◑	◕	◕	◕	◕	◕	◑	◕
	Number of shifts over the time line	●	◔	●	◕	●	◔	◕	◕	◕	◔	◑	◑	◑	◕	◕	◑	◑	◕

Note: Solid shading ● = maximum, no shading o = minimum

- Findings with limitations: findings not generalizable (NG)

These are the cases where the evidence for the existence or non-existence of the relationships is limited to one group only. Although these relationships are partially confirmed, their findings cannot be generalized.

In the following there is a detailed description of these cases:

1. the move from part to another part navigation and productivity: the non existence of the relationship is restricted to the use of 3D Max program.
2. the move from part to whole (Active & Background) Navigation and productivity: the positive relationships with four indicators of productivity (the number of discovered patterns, the number of connected ideas, the number of shifts from divergent to convergent thinking, and the number of shifts over the time) are restricted to the use of AutoCAD and Micro Station. The non-existence of the relationships with two indicators of productivity (the length of series, and the restructuring) is also restricted to using the AutoCAD and Micro Station.
3. changing the appearance due to the move from mesh to solid and productivity: the non- existence of the relationship with all of the productivity variables is restricted to the use of the AutoCAD and Micro station.

- The non-existent relationships

1. All of the variables of the continuity of dynamic field of images show that there are no relationships with two indicators of productivity: the length of series, and the restructuring.
2. The following variables of the continuity of the dynamic field of images show there are no relationships with all of the variables of productivity: the move from part to the same part-active navigation, the move from part to the same part-active and background navigation, the move from one part to another part- active and background navigation, changing the appearance due to the move from inside to outside, and the total change in appearance.

- The untested hypotheses

The relationships between the following variables and productivity have not been tested because of the unavailability of suitable samples: the move from part to whole- active navigation, and the two indicators of the provision of the holistic view: the number of times of using the four displaying ports, and the number of types used for displaying the images

6.3.6. Chapter Summary

This chapter has displayed the results of the practical case study. The difference in the results of the variables of the continuity of field of images has been presented, followed by presenting the difference in the results of productivity variables. The analyses of the data have revealed that there are relationships between some of the variables of the continuity of field of images and productivity with varied degrees of correlations.

7. Discussion and Conclusion

The general problem of this research has addressed an important design issue concerning the use of the computer as a medium of drawing to “think with” in the conceptual design stage. It is concerned with the role of sketching using the computer’s environment and its effect on the process of formulating design ideas in the early stages. This main subject consists of several specific issues, one of which has been exploited to be the research problem and then contributed in determining the specific research problem.

Previous studies differed in defining the effectiveness of using the computer in this stage; they also differed in presenting the factors that played an effective role in this stage. The effectiveness of the process of using the computer is defined in terms of productivity and productive thinking. The research problem has been defined as: the available knowledge of the relationship between sketching using the computer as a medium and the productivity of conceptual design phase is not clear in some of its aspects.

Accordingly, the research objective has been determined to identify all factors influencing the crystallization of design ideas in this stage thus affecting the productivity of conceptual design phase. This objective demanded three requisites: to build a comprehension theoretical framework that identifies these factors, and then to apply it in a practical case study, and finally to reveal and extract the relationships between these factors and productivity indicators.

The specific research problem has focused on exploring the relationships between some chosen influential computer factors related to human performance and the productivity of the conceptual design phase.

In the light of this, the final conclusions for this research are going to be presented under two headings: the first includes the conclusions that relate to the theoretical framework, and the second includes the conclusions that relate to the results of the practical case study.

7.1. Conclusions related to the theoretical framework

This section is going to clarify the effectiveness of the previous design studies in building the theoretical framework and the differences between the present framework and the previous studies. The main related conclusions are:

- the previous computer studies have provided the base knowledge for identifying the related computer variables affecting the conceptual process, although the base was not clear or comprehensive.
- the lack of knowledge in the previous theoretical framework is in the part that deals with improving the performance of the designer in using the computer, especially the part of involving the imagination and its relationship with reinterpretation and the related mechanisms were unclear. This lack in knowledge required the use of hand sketching studies and visual thinking studies in order to define this process and its relationship with the generation of design ideas.
- the fields of hand sketching and visual thinking, cognitive studies, and literature have contributed effectively to the building of the present framework.

The above conclusions can be discussed within the section that defines the main factors of digital sketching that influence productivity, and also can be discussed within the section that defines and evaluates the productivity of using the computer in the early stages. In general, the previous studies identified reinterpretation as the main operation that is responsible for the occurrence of lateral transformation and thus the generation of new ideas. Accordingly, they evaluated the effectiveness of using the computer in the early stages by the occurrence of the reinterpretation and lateral transformation. This part has contributed effectively in defining the productivity of the conceptual design stage.

In the following is a discussion for the above conclusions:

First- the contribution of the previous framework in formulating the sketching variables that influence the productivity of conceptual design stage

The previous studies identified the main problems of sketching using the computer that influence the conceptual stage and the generation of ideas, these are: first, the low degree of ambiguity of the computer's drawings that reduces multiple readings of the digital mark; second, the complicated interface of the computer that prevents rapid transfer of the idea onto the sketching medium; and third, the focus on parts rather than the whole work that prevents the holistic view of design work. On the other hand, these studies suggested that visualization of the 3D drawings is a great power that might affect positively in this stage. The previous knowledge was clear about the relationship between the ambiguity and its influence on the conceptual design process. Most of the theoretical and empirical studies were concerned with the effect of the ambiguity of the drawings on reinterpretation and were concerned with defining the mechanisms that lead to lateral transformation. They attributed the ineffectiveness of the computer in producing design ideas to the precision of the digital drawings that were produced and the low degree of ambiguity of the digital mark, which do not help the designer in seeing more clues in the drawings and in interpreting them. However, the previous studies did not go further in defining the ambiguity of the computer images by looking at the issue of ambiguity from another point of view, that is the ambiguity of images rather than the ambiguity of lines. Some computer 'accidents' can result in ambiguous images in terms of providing strange views of the designed objects.

On the other hand, the definitions of the other factors of the computer that affected the productivity of the conceptual design stage, such as the complicated interface, the rapid visualization, and the holistic view of the work, were not clear enough. The previous framework was unable to clarify the mechanisms that link reinterpretation operations and these factors. However, these studies were able to provide the base for defining these factors, which have been re-categorized, redefined and exploited effectively in identifying the sketching characteristics of the present framework. The rapid visualization of the 3D drawings and the holistic view are regarded as being highly linked to the performance of the designer and the habit of using the modelling software tools. The previous studies assumed that the imagery and imagination are highly affected by these two latter factors; however, they did not clarify the mechanisms of imagery and its relationship with the process of generating design ideas. This required the present research to investigate the field of visual studies and free hand sketching, which enrich the present framework with the potential that is implied in visual thinking. This helped in crystallizing an essential vocabulary that describes the role of sketching in improving the imagery and the possibility of enhancing reinterpretation, that is: the degree of continuity of dynamic field of images. The formulation of this vocabulary has contributed in giving new dimensions to the definition of “visualization”: it is not mere a move from 2D drawings to 3D drawings. This vocabulary has been defined by two variables: the first is the degree of flexibility in forming design images (degree of ease in projecting the design images, degree of continuity of displaying images); the second is the degree of the provision of holistic view. While the degree of ease in projecting design images is a technical issue related to the design of the software, the degree of continuity of displaying images and the degree of provision of holistic view are related to the designer’s performance and habits in using drawing software.

Second- The contribution of the previous framework in formulating productivity variables

The previous framework has considered reinterpretation as an essential operation for the generation of new ideas since it indicates the multiple readings of the design drawings and the occurrence of lateral transformation on the semantic level.

However, the previous framework was unable to define neither the specific types of reinterpretation experienced when reading the design drawings nor it was capable of giving procedural applicable definitions for the operations and techniques used for lateral transformation that accompanied the generation of new ideas.

To solve this problem, this study has made use of the fields of free hand sketching, visual thinking, cognitive studies, and literature. While the hand sketching and visual thinking have contributed in describing reinterpretation as being a dialogical response to what the designer sees in the drawing, in which this response is iterative and takes place at different levels, the cognitive studies contributed in identifying operations such as reframing and restructuring that are involved in producing design ideas and their role in solving the expected fixation inherent in visual thinking, thus allowing lateral transformation to take place. The studies of hand sketching were able to describe some specific aspects of the dialogue experienced with drawings by presenting two models of this dialogue: the seeing-moving-seeing model and the two modalities of “seeing as” and “seeing that”. These two models were able to describe the discovery of new patterns and the techniques used to generate the new ideas from the discovered patterns. However, they were unable to describe the other aspects of possible continuous dialogue that lead to the continuity of using the same patterns for creating new ideas. Literature was an effective field in providing the present framework with information to fill this gap; it identified “changing the context” as the technique used for continuing the dialogue with the same issue and transforming previous ideas into new ideas.

These fields were very effective in crystallizing the vocabularies that give a comprehensive definition to the dialogical reinterpretation at different levels. The vocabularies have been exploited in evaluating the productivity of the conceptual design process using the computer since they can indicate the occurrence of dialogical reinterpretation. Moreover, the specialized studies in productive thinking have been also used to define two other operations that indicate the occurrence of complete cycle of dialogical reinterpretation: alternation of thinking and restructuring. These various operations of dialogical reinterpretation formulate the present definition of productivity, which considers the productive conceptual process is the process that is rich in the operations pertaining both to the occurrence of dialogical reinterpretation and the occurrence of complete cycle of dialogical reinterpretation. While the former is defined by the occurrence of pattern discovery and conceptual reinterpretation, the latter is defined by the occurrence of alternation of thinking and restructuring.

Finally, it has to be mentioned here that looking at reinterpretation as a dialogical process that could happen at different levels has enriched the definition with variables that can describe the different stages of the process of generating ideas while sketching. This in turn has expanded the concept and definition of a productive process. The previous design studies evaluate the process of design using the computer by only counting the number of the produced design proposals; they evaluate the process by looking at the quantity of the final outcome only, without paying attention to the quality of the thinking that produced this outcome. In other words, the evaluation was confined to a specific aspect rather than other aspects and lacked the integrated understanding of the mechanisms and the operations involved that lead to the final outcome. This has resulted not only in reducing the understanding of the conceptual design process using the computer but also has failed to diagnose areas of strength or weakness in this performance. Expanding the concept and definition of a productive process by considering the operations and the techniques used gives a better understanding of the way of thinking with the computer and sheds light on the different aspects of this experience.

Third- the contribution of the previous framework in developing the tool for measuring the productivity in the conceptual design stage

The previous framework of using the computer did not provide the means of measuring the productivity. However, design studies of hand drawings introduced "linkography" as a tool for measuring the productivity of the design process. It has been defined in accordance with the consistency of the designer's actions and moves and the linkages between these moves. Linkography was designed especially to be capable of tracing the designer's moves and the links between the moves. Despite the fact that this tool is very effective in presenting the number of linkages between the design moves and actions, the number of links is not the focal concern of the present framework. Therefore this tool has been developed to be suitable for tracing a specific kind of moves and operations, which are the indicators of productivity through dialogical reinterpretation, and their links that present the operations necessary for insuring the occurrence of dialogical reinterpretation. Accordingly, the present linkography has been developed to be used as an assistant tool for presenting the needed information of the design protocol, and also tracing the connections between some specific kinds of moves. It becomes a useful tool for the purposes of this study and has been used effectively not only as an assistant tool for completing some stages of the proposed measurements of the indicators of productivity variables, but also it has been used as the only possible tool for measuring one of the indicators of alternation of thinking, that is the number of shifts from divergent to convergent thinking and vice versa over the time. As for this latter, it has been mentioned that the rhythm of alternation is the focus of this study rather than the time spent in experiencing each type of thinking. However, this developed tool is useful in presenting the time spent in experiencing each type of thinking, thus the stages inside the conceptual design process can be recognized. This developed linkography is capable of presenting the construction webs of moves and the development webs of moves. Study of the properties of these webs such as their lengths and sequences may give a specific picture of the stages of conceptual design. This tool is flexible enough to be developed further to facilitate this purpose.

Finally, examining the features of the drawn linkographies of this research leads to some conclusions. It has been noticed that the length of the linkography can give a general but not precise picture of the productivity of the conceptual process. The comparison of linkographies of participants who achieve high levels of productivity in every group with those belonging to participants with low productivity levels, reveals a finding. Long linkographies (not less than 70 moves, participants: P, R, MK2) reflect more productive conceptual processes than short ones (less than 45 moves, participants: E1, T, E2), see appendix B. It seems that taking more actions and moves can establish new cycles of dialogical reinterpretation when drawing using the computer drawings.

7.2. Conclusions related to the results of the practical study

The conclusions in this part pertain to the results of applying the built theoretical framework. To examine the relationship between sketching using the computer and the productivity of the conceptual stage, three variables of the degree of continuity of field of images, which are related to designer's performance, have been chosen to be tested. These are: the continuity of displaying images due to navigation, the continuity of displaying images due to changing the appearance, and the provision of a holistic view.

The following sections are going to present the discussion and the conclusions of these relationships, which include:

- conclusions related to the present findings and their similarities or differences from the previous findings of previous studies.
- conclusions related to the variables of the characteristics of the dynamic field of images
- conclusions related to the indicators of productivity

Before going through these conclusions, we have to clarify some areas of uncertainty of the results of the practical study and the limitation of the findings: The uncertainty due to the small sample, and the uncertainty due to the way of collecting the data.

First-The uncertainty due to the small sample

Ten postgraduate students have participated in the experiment; some of them have taken part twice, which raises the total number of the cases to fifteen. However, the comparison did not take place among the 15 cases as the participants used different software. They were divided into groups; each group consisting of at least 3 participants. Therefore the comparison took place only among 3-5 participants and sometimes between two cases of the same participant. Although the reliability of the results depends on the re-appearance of the same pattern of the relationship between the independent and dependent variables in these groups, such a small sample limits the related findings. It should be clear that this study is only a first step in this direction of research; using bigger samples in future research project can lead toward generalizing these findings.

Second-The uncertainty due to the way of collecting the data

The measurements of the independent variables have been achieved by counting the number of using exact tools and watching the change in design images displayed on the computer's screen. The reliability of this method of data collection depends on repeating the counting more than once and following some basic rules in the method of counting. However, mistakes in counting can take place as it depends on the researcher's decisions according to what is seen. Also the drawing of the linkography and the number of moves and links all are decisions governed by the researcher's subjective judgements. This issue could be an area of uncertainty as these judgments are based on the researcher's common sense. However, the number of moves and links are not the focus of this study. The focus is on certain kinds of moves and links, which have been traced on the linkography and counted using objective methods to infer the occurrence of certain operations of reframing and restructuring. However, common sense has been used to connect between some suggested ideas and previous moves dealing with them as source ideas that simulate the suggested ideas that followed.

7.2.1. Conclusions related to the present findings and their similarities or differences from the findings of previous studies

This section presents the conclusions of the results of the relationship between the chosen variables of the degree of continuity of the dynamic field of images and productivity variables.

The sketching variables that have been demonstrated to have relationships with productivity are only five.

- Whole- Whole active navigation (which indicates the intentional change in images while contemplating the drawings)
- Whole-Whole active and background navigation (which indicates the intentional and the unintentional change in the whole image of the drawing)
- Total navigation (which includes all kinds of navigation: active and background navigation, navigation around the wholes and around the parts)
- Change in appearance due to the move from 2D to 3D drawings
- Provision of holistic view (number of times of using the types)

Their relationships are confirmed with only four indicators of the productivity variables; these are: number of discovered patterns, number of the connected ideas, number of the shifts from divergent to convergent thinking, and number of shifts in thinking over the line time. The following paragraphs display the conclusions drawn from these findings.

7.2.2. Navigation and productivity

- Navigation and the occurrence of dialogical reinterpretation

The results demonstrated that the increase in navigation (active whole-whole navigation, active and background whole-whole navigation and total active and background navigation) increases the occurrence of reinterpretation (the occurrence of pattern discovery, the occurrence of conceptual reinterpretation through one indicator that is the number of the connected ideas).

This implies that designers can establish more cycles of dialogues with their drawings when they increase the use of all kinds of navigation (active or background). This can be regarded as due to the fact that the increase in navigation not only increases the speculative time but can also let the designer look at the drawings from another point of view; the frequent updating of the memory with new information increases the possibility of capturing new patterns of forms and relationships, or reusing the same patterns in different ways. Designers quite often experience the figural-conceptual transformation (by discovering a pattern) and the conceptual-conceptual transformation (by reusing the same issue of the previous idea) after they have spent period of time in navigating around the designed objects.

These findings are compatible with the findings of free hand sketching studies. Goldschmidt in the “dialectic of sketching” found that all of the arguments of “seeing as” were taking place while designers were sketching, and the “seeing that” arguments while designers were both sketching and pausing[20]. Similarly, the present findings confirm that the occurrence of pattern discovery and the conceptual reinterpretation has been affected positively by both the active navigation (the pausing from sketching) and background navigation (the active sketching). This implies that the pattern discovery and conceptual reinterpretation are taking place in both

[20] Goldschmidt, G. (1991). The dialectics of sketching. Creative Research Journal, 4(2), 138.

situations of active and background navigation. The findings also imply that designers actually spend time in thinking after every move and action; that is the active navigation, watching the results, judging their actions and thinking in the next move, which in turn increases the possibility of the occurrence of pattern discovery and the conceptual reinterpretation. In this sense, designers follow a pattern of behaviour similar to Schon's model of seeing-moving-seeing for hand sketching; however they spend more time in "seeing". These findings explain the result of Won's study that designers spend more time in imagining when using the computer in comparison to free hand sketching.

- Navigation and the occurrence of a complete cycle of dialogical reinterpretation

The results demonstrated that the increase in navigation (active whole-whole navigation, active and background whole-whole navigation and total active and background navigation) leads to the increase in the degree of occurrence of alternation of thinking (number of shifts from divergent to convergent thinking, the number of shifts in thinking over the time line). This implies that the increase in navigation leads to altering the way of thinking not only to complete the dialogical cycle but also to keep the pace of alternation from convergent to divergent and vice versa all through the process. This latter is essential to keep establishing new dialogical cycles all through the process and avoid being stuck in only one style of thinking that either goes vertically through working with the details (convergent way of thinking), or keeps the flow of thoughts and suggestions without exploit them in producing new design proposals (divergent way of thinking). This finding is consistent both with the theoretical literature of cognitive psychology and with hand sketching studies that affirm the importance of updating the memory with new images to prevent the fixation to one pattern of thinking.

7.2.3. Changing the appearance and productivity

The only variable of degree of continuity of displaying images due to changing the appearance that is shown to have a relationship with productivity is the move from 2D-3D view and vice versa. However, it is a negative, rather than a positive relationship as was expected. This refutes the hypothesis of the increase in the number of moves from 2D-3D and vice versa will increase the productivity. The only logical explanation to this finding is that designers do not have to work with the details in the conceptual design stage; instead they have to work with rough objects that can express the target idea. The frequent switch to 2D drawings and return to 3D views could mean that the designer is working within the details of the idea.

It was expected that the intensive exposure to any kind of continuous changes in images (no matter what kind of change) can positively affect the productivity. This hypothesis was built on the assumption that the imagery can be improved by keeping the memory filled with updated information by the frequent change of the images; this was the opinion that the studies of cognitive and visual thinking arrived at. The finding of this study shows a different picture from this assumption, but it is not completely different. It adds new information about the use of 3D modelling programs in the conceptual stage; designers can achieve the work in 3D views only. It seems that designers do not need the frequent use of the 2D sections, elevations or even the plans to represent or watch their ideas in this conceptual phase. It seems that the use of 3D views and the navigation around the 3D objects can satisfy the requirements of the conceptual stage.

This conclusion gives a different explanation to previous findings of the study of Bilda and Demirkan to the relationship between the intensive exposure to visualization in the conceptual stage and its relationship with imagination. In their practical study with the interior design students they found that the participants did not frequently check the features or the spatial organization of the designing space when they were actively sketching. The study regarded it either as related to the designer’s ability to imagine the 3D space by looking at 2D plans so there is no need to visualize the space, or it might be regarded as an action needed to provide some ambiguity which can enhance the imagery while sketching. The study suggested that designers may not need excessive exposure to images while experiencing the interactive imagery (descriptive or conceptual imagery, and pictorial or figural imagery).

The present findings show that designers do need the frequent exposure to the 3D drawings in the conceptual stage and this need is satisfied by using the navigation for the 3D views of the exterior drawings. The intensive exposure to 3D views and keeping the continuity of changing the images can improve the imagination and thus increase the productivity. This implies that the continuity and variety of the 3D images can improve imagination.

7.2.4. Degree of provision of a holistic view and productivity

The relationship between the degree of provision of a holistic view and productivity has been tested. The number of times of using the types of displaying views shows a positive relationship with the productivity. This variable is a subset of two variables: first is the total active and background navigation; second is the total change in appearance. One might say that the results are highly affected by the positive results of navigation therefore the results show a positive relationship. It has to be clear that the emergence of this pattern of relationship is not related to the dominance of navigation results, rather it is related to the contribution of both variables; navigation and changing the appearance. Table (7.1) shows the percentages of the total change in appearance (TCA) to the total navigation (TN). Generally, the percentages show low rates of the contribution of changing the appearance in the continuity of the field of images. However, digging deep into the results in table (7.1) can tell something else. The results of navigation of participants E1, K, E2 show percentages of 39%, 41%, 43% respectively; they are relatively lower than the contribution of changing the appearance 61%, 59%, 57%, though the pattern of the sequence of the participants in their groups still shows a positive relationship. This supports the conclusion that this pattern does not exist by chance nor is it due to the dominance of navigation results.

It has been noticed that almost all the navigation is conducted while the objects are in 3D and solid state rather than 2D and mesh states. Further, most of the navigation is conducted for exterior views rather than interior views. These results confirm some points mentioned in the previous paragraph about the need for using the 2D drawings (plan, section, and elevation) in the conceptual stage, designers do need the 3D drawings in the conceptual stage and use them more than the 2D when using the modelling programs.

Table 7.I: The percentages of total change in appearance (TCA) to the total navigation (TN)

Groups	Participants	Degree of Continuity of displaying images due to Changing the Appearance	Degree of Continuity of displaying images due to Navigation	The percentage of TCA/TN
Group A	P	20	345	6%
	N	55	274	20%
	E1	118	193	61%
Group B	R1	29	254	11%
	S	29	190	15%
	M1	8	195	4%
	A	5	195	3%
	T	49	142	35%
Group C	MK1	61	228	27%
	K	66	111	59%
	E2	55	96	57%
Group D	MK2	57	312	18%
	R2	2	235	1%
	M2	23	151	15%

7.2.4.1. The continuity of the dynamic field of images and the length of dialogical series

This study has demonstrated that the continuity of the dynamic field of images improves the ability of using the same issue as in the previous idea to generate new ideas. However, it does not have any relationship with the length of dialogical series. It seems that using the same issue more than twice depends on the designer's preference.

7.2.4.2. The continuity of the dynamic field of images and restructuring

There are two conclusions regarding the findings of this relationship:

First, this study has found that the three indicators of the continuity of the dynamic field of images (the degree of continuity of displaying images due to both navigation and changing the appearance, and the degree of provision of a holistic view) do not have an influence on restructuring. It seems that there are factors other than the continuity of field of images that affect the occurrence of the restructuring. These factors could include the preference of the designer, which plays a role in adopting the suggested idea and dealing with it as the main thematic idea. Other factors are related to the nature of the idea itself and to the possibility and practicality of applying it on the whole level of the building. However, it seems that the continuity of the dynamic field of images affects restructuring in an indirect way. It has been mentioned earlier that the restructuring is a subset variable of these two variables: the first is the occurrence of pattern discovery and the second is the occurrence of the conceptual reinterpretation (the number of the connected ideas). It has been noticed that restructuring is correlated with and highly connected with the latter (the number of the connected ideas). All the reused ideas arising from the issues related to the whole problem have been applied at the level of the whole building, thus the restructuring has taken place effectively. Table (7.2) shows all the suggested ideas arising from the issues related to the whole problem, but not to the parts, which were applied to parts of the design. (The data of this table can be found in tables 6.13, 6.14, 6.15 and 6.16 in Chapter six). It has been noticed that these ideas are discovered patterns rather than reused ideas. In other words, all reused ideas and their issues that are related to the whole have been applied to the whole level of the building. This suggests two things: first, the preference of the designer in adopting an idea to be the main idea is playing an essential role, thus directly affecting the restructuring of the problem; second, the continuity of the dynamic field of images affects the restructuring indirectly through its positive effect on increasing the number of connected ideas (reused ideas). This increases the chance of the occurrence of restructuring.

Second, the results show that most of the participants have performed the process of restructuring a few times. These results show that lateral transformations have taken place literally, thus new design proposals have been produced through the dialogical reinterpretation of the computer drawings. These findings have some similarities and differences with the previous studies' findings. Stones & Cassidy (2010) found that the reinterpretation of the digital mark has been occurred verbally rather than literally but did not lead to new design proposals, whereas the occurrence of reinterpretation using free hand sketching is relatively more frequent and does lead to design proposals.

Table 7.2: Types of the ideas in students' protocols dealing with issues related to the whole problem and which have been applied on parts of the building

(Source of information: table 6.13, 6.14, 6.15, and 6.16)

Participants	Ideas of students' protocols that have been applied on parts of the design rather than being the main idea	Type of the ideas
P	M11 Public accessibility to the park	Pattern discovery
	M84 The wall could shape the building from the inside and outside spaces	Pattern discovery
N	M49 The units provide the continuity with the site: the building is a landscape	Pattern discovery
R1	M7 Give a human scale for the building	Pattern discovery
	M50 Seeing the building as a spiral	Pattern discovery
A	M47 The site as an industrial area	Pattern discovery
T	M26 Visual continuity with the site	Pattern discovery
Mk2	M72 The building as a shelter	Pattern discovery

Stones & Cassidy regarded it as due to the ambiguity of free hand sketching, confirming Goel's findings of the ambiguity of the dense marks of freehand sketching. Goel's experiment results excluded verbal reinterpretation. The claim of Goel's study was that the lateral transformation of the digital mark does not take place literally; however one of the examples of his experiment shows that the Shakespearean character has been reinterpreted as Shakespeare himself (see section 1.4.4.2 Chapter One). This point can be explained using current study's definition of dialogical reinterpretation to give a clearer picture to this claim. In this example, reinterpretation has taken place at the level of figural physical-figural physical transformation; that is to give features to the abstract idea of Shakespearean character. Therefore this kind of reinterpretation introduced a new version of the first idea rather than a complete new idea. However, the alternation of thinking (divergent-convergent) has taken place as the Shakespearean character is a more abstract idea than Shakespeare himself.

The present study confirms the occurrence of the reinterpretation and lateral transformations not only verbally but also literally, and they do lead to new design proposals. The occurrence of the dialogical reinterpretation (or the multiple readings in Goel's term) at all levels (the pattern discovery and the conceptual reinterpretation) and the occurrence of a complete cycle of dialogical reinterpretation (the alternation of thinking and the restructuring) have been demonstrated.

7.2.5. Conclusions related to the dynamic field of images

This section presents some conclusions related to the dynamic field of images and the information required for updating the memory while sketching in the conceptual stage.

The appearance of the positive patterns of relationships with some variables of navigation (whole-whole active navigation, whole-whole active &background navigation, total active & background navigation) and their absence with the others such as (part-same part, and part-another part), reveals two things:

- the way in which designers read their drawings, deal with the reflected images in their minds, and the kind of information they need and search for in conceptual stage.
- the role of variety and continuity of designing images that the dynamic field of images can provide.

First, the above findings confirm Lawson's observation that designers do not read their drawings as abstract geometries only but they also read the contents behind these geometries at the same time (functional relationships, structural relationships, environmental relationships, among others). Moreover, the findings give a clearer picture pertaining to these two kinds of readings in the conceptual stage. It seems that to keep the memory filled with updated information demands maintaining the pace of changing the images that can give new information about both the contents and the abstract geometries. In other words, in order to increase the possibility of establishing a conversation with the drawings, the dynamic field of images has to provide a whole picture about the problem, which can satisfy the two levels of readings design drawings: as abstract geometric forms that support the possible discovery of the Gestalt forms, and as content that supports the discovery of conceptual generic patterns of relationships.

The results show that the designer should be concerned with the whole work rather than with the parts in order to be more effective in the conceptual stage. This conclusion becomes quite obvious when looking at the nature of the field of images caused by the types of navigation that do not show any relationship with productivity (the move from part to the same part and the move from part to another part). These moves lead to changing the images thus creating the dynamic field of images while manipulating the design problem. Although they can provide a field of images of changed geometries and information related to the parts of the design drawings they cannot update the designer's information about the whole work. The designers cannot be sufficiently effective as the field of images is dealing with parts rather than the whole. This conclusion is supported by the results of the total navigation variables and the results of the provision of the holistic view variable (which is the total number of the types used). Once the field of images provides the designer with more information about the whole, the results become positive. This conclusion can also be supported by the results of changing the appearance due to the move from 3D drawings to 2D drawings where the conclusion is that the frequent work with the details (parts) can influence the process negatively. Similarly, the non-existence of the relationship between the rest of the types of changing the appearance (Inside-outside moves and solid-mesh moves) and productivity can lead to the same conclusion. This study found that the move from 3D outside drawings to 3D inside drawings, working with the interior in order to check some details, does not help in improving the productivity. Although these moves change the geometric images and give new information about the content, they all deal with the parts and details. Similarly, the frequent move from solid to mesh state of the design objects can support the transparency of design objects by showing more details; however, this did not improve the productivity or show any relationship with it. This reveals that although these kinds of moves can provide the designer with a field of changing images, they cannot give a whole picture for the problem concerned. It seems that in order to be a meaningful dynamic field of images, this field has to provide the designer with related information that supports the whole picture of the design work.

All of the above confirm that in the conceptual design stage the work should be with the whole design problem rather than the focus on parts and details of it. Designers need to update their minds with images and with information about the whole.

There is another conclusion pertaining to the way the designers think when they navigate around the objects being drawn. The main purposes of navigation around the design drawings are either to check the appearance of the drawings and evaluate the results of the previous actions and moves or to search for new patterns. These in turn can satisfy the two possible ways of interpreting design drawings; as Gestalt forms (reading the drawings as geometric abstract forms) and as conceptual generic patterns of relationships as well. It seems that searching for the latter is the common purpose of navigation; designers do not use navigation very often to search for the "Gestalt patterns", rather the discovery of Gestalt forms happens mostly while looking for patterns related to the content of the drawings. This may explain why the continuity of the dynamic field of images created by changing the images when dealing with parts of the design objects does not increase the rate of discovered "Gestalt patterns". When navigating from part to part, designers are active in searching for relationships related to the content (functional, environmental, structural among others). It seems that designers' priority of using the navigation is to look for generic conceptual relationships rather than the "Gestalt form".

Second, deducing the results of the total navigation (active & background) and the kind of dynamic field of images it can provide, arrives at conclusions about the variety and the continuity of the field of images. While each of the "part to same part" and "part to another part" navigation does not have a relationship with productivity, the total navigation (which consists of all of the types of navigation: part-part, part-whole, and whole-whole) shows a positive relationship. The logical explanation is that such a field of images can give a clearer picture of the whole work as it consists of variant types of images on different levels (parts and wholes). However, the increase in the rates of the part to part does not increase the productivity: this suggests that the percentage of the part-part navigation to the percentage of the whole-whole navigation in calculating the total navigation should be within limits. The part-part navigation alone cannot give a meaningful picture to the reader but it can when being read together with the whole-whole navigation. The abstract and content readings of the images can be significant to the reader if all kinds of navigation work together creating a continuous field of variant images that is related to the whole and also to the parts. It seems that designers need variant and continuous fields of images in order to update the memory with meaningful information so that they can establish new dialogues, sustain previous one and alternate the style of thinking.

7.2.6. Conclusions related to the indicators of productivity variables

In this section some conclusions related to the transformational operations used for the dialogical reinterpretation will be presented.

First- Techniques of changing the context

While changing the domain is the mechanism used to achieve the reframing and ensure the occurrence of pattern discovery, changing the context is used to ensure the occurrence of conceptual reinterpretation. This study found that designers use different techniques for the latter mechanism of transformation (changing the context); they reused the issue of previous ideas to keep the dialogue and changed the context while they performing the conceptual reinterpretation. The data in tables (6.9, 6.10, 6.11, 6.12) in chapter six reveal the techniques being used to sustain the dialogue with the drawing of more than one cycle. These are:

- the use of the opposites where the designer highlights one statement in the first idea then keeps the same frame and uses the reversed statement for the next idea (urban scale verses building scale, one mass building verses multiple masses, present verses absent)
- the use of changing "the domain" of the previous idea (functional, structural, formal, spatial domains).
- change the strategy for achieving the same idea; this technique has been used when the designer failed in using the software tools to achieve an idea as he or

she imagined or expected the final outcome. Ideas related to achieving organic forms have been reused more than once with different strategies: either by morphing geometric forms to be more organic or by composing curved elements and surface.

These techniques are in accordance with the techniques used in authoring the novels to keep the continuity of the dialogue and create a "genuine" dialogue. Bakhtin's study on Dostoevsky's work arrived at similar techniques where the author puts his characters in new environments imagining their possible behaviours and getting involved in a "genuine dialogue" with them. This is Dostoevsky's technique to invoke "the surprise" through creating the "genuine dialogue" where the author plans to keep the dialogue but never pre-prepares for the content.

Similarly, the designers used the above techniques to stimulate possible new design ideas within the frame of the previous proposals. They planned to continue the dialogue but never knew the outcomes in advance.

Second- Conclusions related to the types of transformation of the design representations

There are four types of transformation performed in the conceptual design stage while sketching: figural physical- figural mental, figural physical-conceptual mental, conceptual mental –conceptual mental, and conceptual mental –figural physical. Each one of them represents a stage in the dialogical reinterpretation for producing design proposals.

The first two represent the types of transformation necessary for pattern discovery, the third represents the transformation necessary for conceptual reinterpretation and the fourth represents the alternation of thinking from divergent to convergent thinking. Restructuring includes all of these types of transformation; it includes a series of transformations that should complete the dialogical cycle of reinterpretation. The series of transformations can have four routes.

1. Unintentional discovery of Gestalt form (reframing), then the alternation of thinking from divergent to convergent style takes place by transforming the constructed mental idea from mind to paper, and finally the restructuring.

2. Unintentional discovery of a formal pattern (reframing), then the alternation of thinking takes place and finally the restructuring.
3. Unintentional discovery of a pattern of relationship (reframing), then the alternation of thinking takes place and finally the restructuring.
4. Intentional reuse of a previous idea and change of context (reframing), then the alternation of thinking takes place and finally the restructuring.

Each one of these routes can produce new design proposals through sketching when dealing with patterns related to the whole design problem and at the same time being implemented on whole design objects. In this way restructuring takes place. Two points have been found by following these routes.

First- Earlier in this thesis (Chapter Six, paragraph 6.2.4), we mentioned that the proposals that emerge by following the first route are not completely different from the initial proposals. We attribute this to the fact that the discovered Gestalt form is already there and the designer has to affirm its image in the new proposal. In comparison, it has been noticed that following the second and third route leads to new, different proposals from before. We attribute this to the abstract information and abstract constructed mind image of both the formal pattern and the pattern of organizational or functional relationships. This opens the way for the designer's imagination to achieve these patterns in several possible ways as there is no certain exact reference image. The conclusion that could emerge from this point is that while sketching, designers need to work with more abstract images in order to reach new different proposals from before.

Second- It has also been noticed that when the designer discovers a new pattern or wants to reuse a previous idea to achieve new one, it is better not to continue working within the same setting of previous drawings. Designers who do not change the setting in order to implement the discovered or desired patterns, do not produce completely new different proposals from the source proposals. To clarify this point two examples from the protocols of the experiment are going to be used. Participant T discovered a new pattern of relationships (visual connection through the site). He made a copy of the setting of the previous drawing then modified it to implement the new discovered pattern. The implementation takes place on part of the proposal; the designer simply lifted up the roof to achieve the visual connection. Instead of thinking about drawing another different composition that would achieve the visual continuity, the designer just partially amended the previous proposal. This prevents the production of a new different proposal. It seems that combining a new idea in the setting of a previous idea can sometimes support the previous idea rather than create a new one. This kind of combination encourages vertical thinking rather than horizontal thinking.

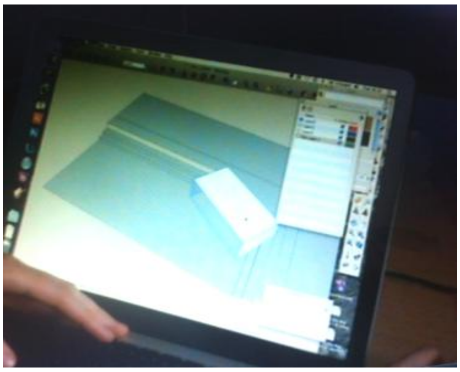
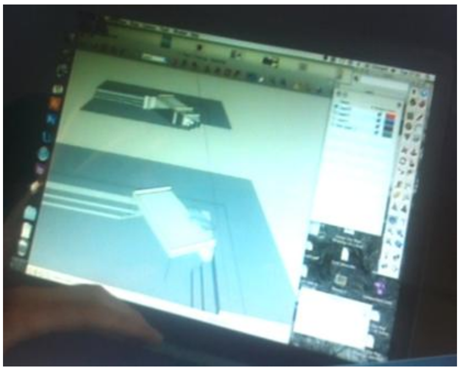
a  b 

Figure 7.1: participant T Group B, copy the drawing setting of previous idea,

a: source idea setting, b: second idea setting

In comparison, participant MK2 decided to cancel the side entry to the main hall; he changed the entrance area to become a landscape area for outdoor celebration, Figure 7.2 (a). Then he wanted to reuse the idea of celebration landscape in his next idea. First, he changed the setting of the previous idea, cleared the design objects of the previous idea from the site and kept the initial components including the main axis. At that moment, the designer came up with the idea of an “outdoor celebration axis”; this leads to the birth of new idea, Figure 7.2 (b and c).

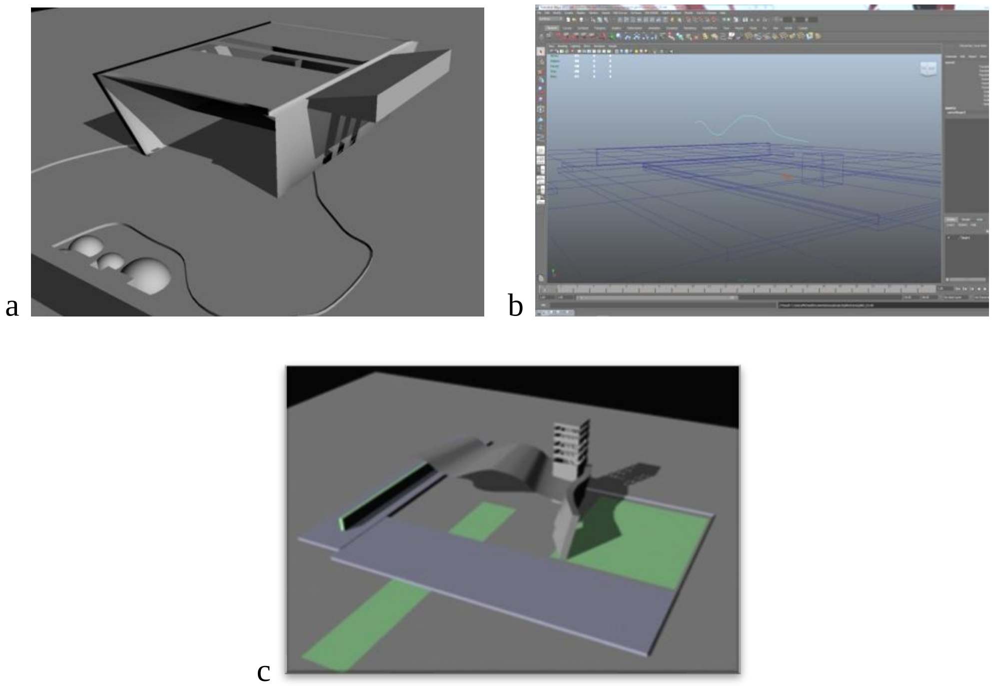


Figure 7.2: participant Mk2 Group D, change the drawing setting

a: setting of previous idea, b: change the setting for composing new idea, c: the new idea

The part of the design protocol that describes these steps is as follows:

- M23 Looking at form from out: [What I'm going to do is to test views, and cameras, I can imagine it a person view. I should look to the corner, what I probably do is to draw a wall to one side of the building] (because there is no entry anymore).
- M24 [What we can do, this side entry has now changed, it will be some kind of garden, a kind of outdoor stage. OK this area becomes a kind of landscape area]. (the designer looks at the whole drawing from top).
- M25 The designer creates a landscape area or sitting area, fixing it in place -the volumes are in mesh situation. [We can add some random shapes which can represent some art work, it doesn't really matter]....[Let's think about the main view]. Looking at the whole design from inside and outside: [Checking the shadow, the light. Do some tests, we can see the entry, the skylight, the frame, the car parking. Save that. Starting the second idea]
- M26 [The wall still there, the entrance should be shifted. It is ok, the parking over there, what we going to do.........., the parking covers two square here, so we can give that different material, give it green colour].
- M27 [What we want to do is to keep that entrance, it is going to be the same colour, see the symmetry. so in terms of axis....we want to keep this open area], manage the surfaces of the site by turning the platform of the drawings and modify them from

beneath:[turn off the grid, this is the wall, this is the road], again fixing everything from beneath.

- M28 [Thinking in the outdoor celebration...Keep in the axis becomes the heart of celebration].

The conclusion that could emerge from this second point is that while sketching, designers need to lessen the strong image of previous drawings. It has been mentioned earlier that the modification of the hand drawings can be achieved by overlaying strips of tracing layers. This demands redrawing of the design content every time; it is a kind of recreation of the objects. It seems that this process of regenerating the drawings by using pieces of tracing paper is helpful not only in keeping the pace of rapid change but also in abstracting the images of previous drawings. Overlaying the tracing paper on previous drawings fades their strong images and abstracts them. In comparison, changing the computer drawings takes place on the same drawing; designers do not have to regenerate the objects. They keep drawing on the same set of previous drawings where the previous image is still strong. Therefore designers who change the set of drawings and deal with different materials can produce different ideas and proposals.

This leads us to a more general conclusion: the technique of changing the context has to be used at two levels in order to let the restructuring take place and to reach a new different proposal.

- The first level is to change the conceptual context of the problem, which supports the generation of a new idea.
- The second level is to change the physical context of the generated idea when drawing, implementing and composing the generated idea.

The expectation was that the increase in the use of navigation, changing the appearance and provision of holistic view can help the designer in putting forward a plan of how to restucture the drawings, and how to implement the discovered new pattern. What is happening in the real work of design is that designers do look for plans to implement the discovered pattern; however, they look for the easiest and shortest way to achieve it. They prefer to make some partial changes rather than major reorganization. Instead of “physical” restructuring, they perform “physical” combining. All of these findings explain and give a partial answer to the initial question of this study: why the lateral transformation does not take place if the reinterpretation of digital mark occurs?

To sum up, it seems that in the conceptual design stage designers need abstract visual information to produce more different ideas and design proposals. They need to work with more abstract patterns and to implement them in physical contexts which are different from the previous ones. Therefore they need a medium of drawing that supports the regeneration of drawings and at the same time supports the abstractness of the previous generated images. Current computer systems have to be developed to be able to achieve these two points.

7.3. Recommendations for future research

This study defined the productivity of the conceptual design process through dialogical reinterpretation. The definition through its identified indicators has been implemented in relation to the computer based design process. This definition could be applied also on the design conceptual process using hand sketching. Future recommended research, therefore, is to find the similarities and differences between the patterns of dialogue performed in both cases: computer-based versus hand sketching, and also to differentiate between the techniques used for the transformations in each case. The definition could be developed further to be applied to the whole design process rather than just the conceptual stage so that future research can focus on investigating the differences between the dialogical reinterpretation of the conceptual stage and the developing stages when computer based. This will reveal the essential role of visualization in the two stages.

In the context of dialogue and establishing patterns of conversations with the drawings, there are several suggestions for future research:

- in this research we used post-graduate students in the practical study. Their work could be compared with that of novice students to show the difference in patterns of dialogue related to different design skills and experiences.

- the notion of polyphonic working could be expanded and used to reveal how the voices of team members can create different patterns of dialogue. Such extended research could reveal the role of collaborative work and varied viewpoints of team members in establishing design experience different to that of the single voiced dialogue of the designer with his drawing. The big question here is how the voice of the computer can contribute effectively to teamwork.
- the notion of deep involvement in a dialogue with the drawing opens the way to the notion of engagement in a dialogue. In this research, the reuse of early design ideas is regarded as related to how well the designer appreciates and values them. The length of the series of reused ideas is considered as a measure of the degree of involvement in the dialogue. The question here is: how to reach the high state of engagement in a dialogue and how this can contribute in creating new ideas? Study the psychology of design can enrich our understanding of the creation process using the computer.
- in this research we examined the patterns of dialogical reinterpretation under controlled conditions of the experiment. Examining these patterns in long term projects, and observing architects while managing real projects, can shed light on the role of the period of idea incubation. The influence of prolonging the incubation period on productivity could be examined further, focusing on conceptual reinterpretation and the deeper engagement in dialogue.

In this research, the role of the computer's "happy accidents" is found to be very effective in suggesting new ideas. How do we plan for happy accidents and what are the strategies that can encourage surprise? Architects (like Peter Eisenman) create their own strategies of using new drawing conventions to create new design events and surprises. Recently, the fully digital design process does not only exploit the accidents of drawing conventions, but also it creates these accidents[21]. Some designers use concepts from biology and genetics to create these accidents. Searching

[21] See (Lynn, 2004), (Lynn, 2008) and (Spuybroek, 2004)

in this field and comparing various design procedures can enrich our understanding of creation through using "planned accidents."

Finally, there are three untested hypotheses in this study[22].These are:

- first, the relationships between the move from part to whole active navigation and all of the indicators of productivity.
- second, the relationships between the first indicator of the provision of a holistic view: the number of times of using the four displaying ports on the one hand and all of the productivity indicators on the other.
- finally, the relationships between the number of the types used for displaying the images and all of the productivity indicators.

Accordingly, the study recommends these hypotheses be verified in future research where suitable cases can be provided.

[22] For reviewing the hypotheses of this study return to table (5.1), section 5.1.1. , Chapter Five. To see the circumstances those prevent testing these hypotheses return to section 6.1.3., Chapter Six.

REFERENCES

Abdelhameed, W. (2006). *How Does the Digital Environment Change What Architects Do in the Initial Phases of the Design Process?* Paper presented at the Communicating Space(s) [24th eCAADe Conference Proceedings Volos (Greece)

AIACC. (2012). Parametric Design: a Brief History. from http://www.aiacc.org/2012/06/25/parametric-design-a-brief-history/

Akin, O. (1978). How do Architects Design? In J. C. Latombe (Ed.), *Artificial intelligence and pattern recognition in computer aided design: proceeding of the IFIP working conference*. Grenoble, France.

Anderson, M. (2000). Greg Lynn: Embryological Houses. *Architectural Design, 70*(3).

Arnheim, R. (1962). *The Genesis of painting: Picasso's Guernica*. Berkeley And Los Angeles, California: University of California Press.

Arnheim, R. (1970). *Visual Thinking*. London: Faber and Faber Limited.

Arnheim, R. (1980). A Plea for Visual Thinking. *Critical Inquiry, 6*(3), 489-497.

Bilda, Z., & Demirkan, H. (2003). An insight on designers' sketching activities in traditional versus digital media. *Design Studies, 24*(1), 27-50.

Bilda, Z., & Gero, J. (2005). *Do we need CAD during Conceptual Design?* Paper presented at the Computer Aided Architectural Design Future Proceeding of the 11th international CAAD Futures Conference, Vienna, Austria.

Bosia, D. (2011). Long form and Algorithm. *Architectural Design, 81*(4).

Broadbent, G. (1973). *Design in architecture : architecture and the human sciences* London: John Wiley & sons Ltd.

Brugellis, P., & Brizzi, M. (2006). Digital Architecture: a meeting with Greg Lynn. Retrieved 2011, from http://www.targetti.com/targetti-foundation/osservatorio/digital-architecture---a-meeting-with-greg-lynn

Cai, H., Do, E. Y.-L., & Zimring, C. M. (2010). Extended linkography and distance graph in design evaluation: an empirical study of the dual effects of inspiration sources in creative design. *Design studies, 31*(2).

Chambers, D., & Reisberg, D. (1985). Can mental images be ambiguous? *Journal of Experimental Psychology: Human perception and performance, 11*, 317-328.

Clark, K., & Holiquist, M. (1984). *Mikhail Bakhtin*. London: Cambridge, Mass., President and fellows of Harvard College.

Coyne, R., Park, H., & Wiszniewski, D. (2000). Design Devices what They Reveal and Conceal. *Kritische Berichte: Zeitschrift f˙r Kunst- und Kulturwissenschaften, 3*, 55-69.

Cross, N. (2001). Design Cognition: Results From Protocol Other Empirical Studies Of Design Activity. . In C. Eastman, M. McCracken & W. Newstetter (Eds.), *Design knowing and learning: cognition in design education* (pp. 79-99). Oxford: Elsevier Science Ltd.

De Bono, E. (1970). *Lateral Thinking: A Textbook of creativity*: London : Ward Lock Educational.

Do, E. Y.-L. (2005). Design sketches and sketch design tools. *Knowledge-Based Systems, 18*(8), 383–405.

Do, E. Y.-L., & Gross, M. D. (2004). Let There be Light! Knowledge-Based 3-D Sketching Design tools. *International journal of architectural computing, 2*(2), 211-227.

Dorta, T. (2008a). Design Flow and Ideation. *international journal of architectural computing, 6*(3), 299-316.

Dorta, T. (2008b). The ideation gap: hybrid tools, design flow and practice. *Design studies, Vol 29 No. 2*, 121-141.

Dorta, T., Lesage, A., & Perez, E. (2009). *Design tools and collaborative ideation*

Paper presented at the Joining Languages, Cultures and Visions: CAADFutures 2009.

Ericsson, K. A., & Simon, H. A. (1984). *Protocol Analysis: Verbal Reports as Data*. Cambridge, EUA: The Massachusetts Institute of Technology.

Fallman, D. (2003, 5-10 April). *Design-oriented Human-Computer Interaction.* Paper presented at the Computer-Human Interaction: New Horizons, Fort Lauderdale, Florida.

Finke, R. (1995). Creative realism. In S. M. Smith, T. M. Ward & R. A. F. (Eds) (Eds.), *The creative cognition approach*. Cambridge: MA: MIT Press.

Finke, R. (1996). Imagery, Creativity, and emergent Structure. *Consciousness and cognition, 5*, 381-393.

Finkelstein, H. N. (1979). *Surrealism and crisis of the object*. The University of Michigan: UMI Research Press.

Goel, V. (1995). *Sketches of thought* Cambridge: Massachusetts Institute of Technology.

Goldschmidt, G. (1991). The dialectics of Sketching. *Creativity Research Journal, 4*(2), 123-143.

Goldschmidt, G. (1992). Criteria for design evaluation: a process-oriented paradigm. In Y. E. Kalay (Ed.), *Evaluating and predicting design performance* (pp. 67-79). New York: John Wiley & son.

Goldschmidt, G. (1994). On visual design thinking: the vis kids of architecture. *Design Studies, 15*(2), 158-174.

Goldschmidt, G. (1995). The designer as a team of one. *Design studies, 16*(2), 189-209.

Goldschmidt, G. (2003). Cogntive economy in design reasoning. In U. Lindemann (Ed.), *Human behaviour in design: individuals, teams, tools* (pp. 53-62): Springer-Verlag Berlin Heidelberg.

Graham, L. (2008). Gestalt Theory in Interactive Media Design. *Journal of Humanities & Social Sciences, 2*(1).

Guilford, J. P. (1961). Basic conceptual problems in the psychology of thinking. *Annals of the New York Academy of Sciences, 91*(1), 6-21.

Hanna, R. (2012). *Computer Aided Cognition and Creativity: A Three Year Monitoring Exercise* Paper presented at the Digital Physicality - Proceeding of the 30th eCAADe Conference 12-14 September, Czech Technical University in Prague, Faculty of Architecture (Czech Republic).

Hanna, R., & Barber, T. (2001). An inquiry into computers in design: attitudes before–attitudes after. *Design studies, 22*(3), 255-281.

Hanna, R., & Barber, T. (2006). Digital processes in architectural design: A case study of computers and creativity. *International journal of architectural computing, 04*(02), 95.

Haynes, D. J. (2008). *Bakhtin and the visual arts*: Cambridge University Press.

Herbert, D. M. (1993). *Architectural Study Drawings* New York: Van Nostrand Reinhold.

Holquist, M. (2002). *Dialogism: Bakhtin and his world*. London: Routledge.

Holquist, M., & Liapunov, V. (1990). *Art and Answerability Early Philosophical Essays by M. M. Bakhtin*. Austin: The University of Texas Press.

Jones, J. C. (1970). *Design Methods Seeds of human futures*. New York: John Wiley & Sons Ltd.

Jonson, B. (2005). Design ideation: the conceptual sketch in the digital age. *Design Studies Vol 26 No. 6 November 2005, 26* (6), 613-624.

Kalay, Y. E. (2004). *Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design*. USA: MIT Press.

Kan, J., Bilda, Z., & Gero, J. (2006). Comparing entropy measure of idea links in design protocols. In J. Gero (Ed.), *Design computing and Cognition '06* (pp. 265-284). University of Sydney: Key centre of Design Computing and cognition.

Kan, J., & Gero, J. (2005a). Design Behaviour Measurement by quantifying Linkography in protocol studies of designing. In J. Gero & U. Lindemann (Eds.), *Human Behaviour in Design 05* (pp. 47-58): Key centre of Design Computing and Cognition.

Kan, J., & Gero, J. (2005b). Entropy measurement of Linkography in protocol studies of designing. In J. G. a. N. Bonnardel (Ed.), *Studying designers'05, International workshop on Studying Designers '05 University of Provence, Aix-en-Provence, France* (pp. 229-245): Key centre of design computing.

Kaplan, C. A., & Davidson, J. (1989). *Hatching a theory of incubation effects*. University of Pittsburgh: Carnegie-Mellon university technical report.

Kotnik, T. (2010). Digital Architectural Design as Exploration of Computable Functions. *International journal of architectural computing, 08*(01), 1-15.

Kwon, D. Y. (2003). *ArchiDNA: A Generative System for Shape Configuration.* University of Washington.

Lawson, B. (1990). *How designers think*. London: Butterworth.

Lawson, B. (1997). *How Designers Think: The Design process Demystified*. Oxford: Architectural press.

Lawson, B. (2004). *What designers know*: Oxford [England] ; Burlington, MA : Elsevier/Architectural Press.

Lawson, B. (2006). *How Designers Think: The Design process Demystified*. Amsterdam; Oxford, UK: Elsevier.

Lawson, B., & Loke, S. M. (1997). Computers, words and pictures. *Design studies, 18*(2), 171-183.

Legendre, G. L. (2011). IJP Explained: Parametric Mathematics in Practice. *Architectural Design, 81*(4).

Lloyd, P., & Scott, P. (1995). Difference in Similarity: Interpreting the architectural design process. *Planning and Design, 22*, 382-406.

Lynn, G. (2004). *Folding in architecture*: Chichester, West Sussex : Wiley-Academy.

Lynn, G. (2008). *Greg Lynn FORM*. New York: Rizzoli.
Marx, J. (2000). A proposal for alternative methods for teaching digital design. *Automation in Construction, 9*, 19-35.
McLachlan, F., & Coyne, R. (2001). The accidental move: accident and authority in design discourse. *Design Studies, 22*, 87-99.
McLoughlin, C., & Krakowski, K. (2001). *Technological tools for visual thinking: What does the research tell us?* Paper presented at the e-Xplore 2001:a face-to-face odyssey, Proceedings of the Apple University Consortium Conference, James Cook University, Townsville, Queensland, Australia.
Mitchell, W. J. (1977). *Computer-Aided Architectural Design*. New York: Van Nostrand Reinhold Company.
Morson, G. S., & Emerson, C. (1990). *Mikhail Bakhtin: creation of a prosaics* Stanford, California: Stanford University Press.
Murty, P. (2006). *Discovery processes in designing.* University of Sydney.
Murty, P., & Purcell, T. (2003). *Discovery methods of designers*. Paper presented at the In proceedings of 5 EAD, 5th European Academy of Design Conference. from http://www.ub.edu/5ead/PDF/8/MurtyPurcell.pdf.
Narayan, K. L., Rao, K. M., & Sarcar, M. M. M. (2008). *Computer Aided Design and Manufacturing.* New Delhi: PHI Learning Pvt. Ltd.
Niblock, C., & Hanna, R. (2008,). *An Investigation of the Influence of Using the Computer on Cognitive Design Actions.* Paper presented at the Architecture in Computro 26th eCAADe Conference Proceedings 17-20 September, Antwerpen (Belgium).
Oh, J.-Y., Stuerzlinger, W., & Danahy, J. (2005). *Comparing SESAME and Sketching on Paper for Conceptual 3D Design.* Paper presented at the EUROGRAPHICS Workshop on Sketch-Based Interfaces and Modelling.
Pallasmaa, J. (2009). *The Thinking Hand*. Chichester: Chichester : Wiley.
Porter, D., & Hanna, R. (2007). *An Empirical Investigation into the Influence of Media Types on Design Cognition and Methodologies.* Paper presented at the CAADRIA 2007 [Proceedings of the 12th International Conference on Computer Aided Architectural Design Research in Asia 19-21 April, Nanjing (China).
Reed, S. K. (1974). Structural descriptions and the limitations of visual images. *Memory and cognition, 2*, 329-336.
Richardson, J. T. E. (1980). *Mental imagery and human memory*: London : Macmillan.
Runco, M. A., & Pritzker, S. R. (1999). *The Encyclopaedia of Creativity* (Vol. 1). California: Academic press.
Schon, D. A. (1983). *The reflective practitioner: how professionals think in action.* United state of America: Basic books, Inc.
Schon, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Knowledge-based system, 5*(1March), 1-14.
Schon, D. A., & Wiggins, g. (1992). Kinds of seeing and their functions in designing. *Design studies, 13* (2), 135-156.
Self, J., Dalke, H., & Evans, M. (2009). *Industrial Design tools and design practice an approach for understanding relationships between design tools and practice*. Paper presented at the IASDR 2009 - Rigor and relevance in design.

Shepherd, D. (1989). Bakhtin and the reader. In K. H. a. D. Shepherd (Ed.), *Bakhtin and cultural theory*: Manchester University press.

Shepherd, D. (1998). *The context of Bakhtin: philosophy, authorship, aesthetics*. Amsterdam: Harwood Academic Publisher.

Siamopoulos, E. (2012). *Authorship in algorithmic architecture from Peter Eisenman to Patrik Schumacher.* National Technical University of Athens, Athens.

Smith, S. M., Ward, T. B., & Schumacher, J. S. (1993). Constraining effects of examples in creative generation task. *Memory and cognition, 21*, 837-845.

Snodgrass, A., & Coyne, R. (2006). *Interpretation in Architecture: Design as a way of thinking*. London: Routledge.

Spuybroek, L. (2004). *Nox: Machining Architecture*. London: Thames & Hudson, Limited.

Stones, C., & Cassidy, T. (2007). Comparing synthesis strategies of novice graphic designers using digital and traditional design tools. *Design Studies, 28*(1), 59-72.

Stones, C., & Cassidy, T. (2010). Seeing and discovering: how do student designers reinterpret sketches and digital marks during graphic design ideation? *Design studies, 31*(5).

Sutherland, I. E. (2003). *Sketchpad: A man-machine graphical communication system*: University of Cambridge, Computer Laboratory.

Van der Lugt, R. (2000). Developing a graphic tool for creative problem solving in design groups. *Design studies, 21*(5), 505-522.

Van der Lugt, R. (2002). Brainsketching and how it differs from brainstorming. *Creativity and innovation management.11*(1), 43-54.

Van der Lugt, R. (2003). Reconsidering the divergent thinking guidelines for design idea generation activity In U. Lindemann (Ed.), *Human Behaviour in Design Individuals, Teams, Tools*. (pp. 272-282). Verlag Berlin Heidelberg New York: Springer.

Verstijnen, I. M., Hennessey, J. M., Leeuwen, C. V., Hamel, R., & Goldschmidt, G. (1998). Sketching and creative discovery. *Design studies, 19*(4), 519546.

Visser, W. (2006). *The cognitive artifacts of designing.* New York: Routledge.

Visser, W. (2010). The Three Visions of Design in the Field of Cognitive Design Studies. *Collection "Art + Design & Psychology"*(2), 7-43.

Ward, T. B. (1994). Structural imagination: The role of category structure in exemplar generation. *Cognitive Psychology, 27*, 1-40.

Ware, C. (2005). Visual Queries: The Foundation of Visual Thinking. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization: Searching for Synergies* (Vol. 3426, pp. 27-35). Verlag Berlin Heidelberg: Springer.

Ware, C. (2008). *Visual thinking for design*: Elsevier Inc.

Wertheimer, M. (1959). *Productive thinking*. New York: Harper.

Wiscobe, T. (2005). Emergent process. 2010, from http://www.emergentarchitecture.com/pdfs/OZJournal.pdf

Won, P. H. (2001). The comparison between visual thinking using computer and conventional media in the concept generation stages of design. *Automation in construction, 10*, 319-325.

Youmans, R. J. (2011). The effects of physical prototyping and group work on the reduction of design fixation. *Design studies, 32*(2), 115-138.

Zhu, Y., Dorta, T., & De Paoli, G. (2007). *A Comparing Study of the influence of CAAD Tools to Conceptual Architecture Design Phase.* Paper presented at the Digital Thinking, Proceedings of EuropIA'11: 11th International Conference on Design Sciences and Technology, University of Montreal in Canada.

Appendix- A: Transcripts of design protocols

Note: 1. sentences within square brackets [] are the student's own words, while the rest is the researcher's own notes. 2. M= Move

Group A- Participant P

M1 [I will start by drawing the spaces like the program...] In the meeting he said "In the beginning I was thinking in transforming geometries."

M2 create cubes, [this is the cafe and the service area], he drew the site, [this is the park. The proportion should be ok], change the sizes.

M3 Change the composition, [the service cube becomes part of the hall, then move it out]

M4 Pull part of the hall [I want to change the form], return to previous situation.

M5 [I want to transform the geometries], change the position of the service volume.

M6 pull the hall volume, return.[It seems interesting]

M7 [I think... I prefer the service area to be close to the park].

M8 Try to modify the intersection between the service area and the hall...

M9 [I'd like to create some out space ...like a garden because it is near to the park then I will manipulate the form]. Create walls to define an enclosure [..because in a public space I think outdoor spaces are important..]Change the position of one of the walls to add an access to the street

[I will change the view to something that could give me more information..] change it mesh

M10 [Now.. I want, I think I will start creating spaces toward the park, outdoor public spaces]. Manipulate the surrounding walls: create an opening, make it bigger.

M11 [This seems simple but promising public space, um.. it becomes accessible to the park].

M12 Change the height and form of fence wall

M13 [I will start to work on the main volumes I will add some divisions..] change the view to mesh..add division lines to the service and hall volumes, M14 Push one of the parts..return..

M15 [I want the volume to be lower in this side towards the park .. to create some more soft form towards the park, and create more defined hard shape towards the street].

M16 Select the corner point and push it down to change the height and shape of the volume from the park side, return

M17 Pick group of points and pull them down, modifying the volume to be softer... look at it from the park[...um]

M18 [I will try different strategy.. I will duplicate the surface of the park, I'm trying to use this to accommodate..my point is to make a small transition from the urban, which is the corner, make the whole integrates with the landscape].

M19 [I'm adding some sub divisions to the site].. pull the layer of the site up

M20 [wow it is better you can see from the park the building becomes the park, it is a park]

Looking at it from different points..

M21 [ummm.. this part doesn't need to be high], push it down (the building becomes part of the park)

Looking at previous situation and return to present situation..

M22 [The hall is about 10meters high, it is interesting to see it this high so I will keep it.. AND I WILL TRY TO LIFT THIS CARPET]

M23 manipulate its height.. [from the park I want to see the roof of the building only...it is better..]

M24 change the shape of the carpet from the side..

M25 [I want to keep the garden that I have created], change the view to mesh [..pick up some points of it to change the topography of the carpet so it can fit with the location of the created garden, perforate the carpet to be open to the created garden beneath it...so we have an opening to that park..aha this is what I wanted..]

[This is like integral partial that gives an axis to the garden.. an axis from the street]

M26 [So I will refine my idea], (the main hall becomes lower and part of the carpet) [..aha it is nice]

M27 [Here (at the corner) I want to have an entrance, I want to extrude these surfaces in so I have..but (pulling it out).. let say it is an entrance, it is satisfactory]

M28 [I want to cut the landscape so I can make the balcony in this side]

M29 [we will go back to landscaping, I will have to refine it.. I will prompt it] (the side list of options), [I will take this one (to create the balcony he copied part of the landscaped and lift it up), I can go to this part and I will take the all parts of this ..]

M30 [bring them to this part, fix them in the new place, and I will go back to the other part..Oh.. Look Actually Interesting From This Side] (the computer suggested another layer of landscape).

M31 [This provides a direct axis to the upper balcony].

M32 [I want to do it now soft, here is this part, cut it.. aha it is more interesting] Work on the roof part, rotate it ,

M33 change its position,

M34 fold it, [it is a soft landscape that coming up], modify it,

M35 [the street has much more defined distinctive facade, the other thing I want to do here is to create a balcony so can walk from the park and getting to first floor], modify the balcony layer left it up..

M36 change the view to mesh, [it is very interesting inside space], change the height of it,

M37 [now we have a balcony that comes from the park and goes up, look at it from the street in the same time, perhaps we can go up stairs to the multipurpose hall]

M38 manipulate the roof, change its size and position

looking at the whole form from different angles,

M39 working with the back of the site, manipulate the landscape,

M40 manipulate the central part of the site, adjust the garden of the building to be integrated into the landscape

[look at the corner side]

M41 work on the balcony,

M42 modify the roof, refine the connection with the building, [it is Ok it is the idea that I want].

M43 Refine the balcony from the front side, [we will go back to the camera]

M44 Draw the site, [I will try another one, before I tried the landscape project, now I want try something different, something start out in the park as a building, may be try different geometries so lets see]

[I will come here to the corner], draw a cube, looking at it, [try something less interested to the landscape, a simple building stands in the park].

M45play with the form..push and pull, rotate [..it looks like Frank Gehry's forms], delete it.

M46 Start with a cube, draw it in mesh, [create a… BLOB]

M47 go back and add the mesh and subdivisions to the skin, becomes more smooth,

M48 [buried part of it into the ground]

M49 push- in the front facade, return to previous [... I'm trying to create something like an entrance], push the facade in place underneath the site platform, [create something to be the entrance].

M50 [.. that is not bad, it looks like entrance so the corner becomes entrance, it looks like a sculpture].

M51 [In this case I will do two boxes, first one is the Cafe, a bit small but it is alright I will make it higher, I will make it with mesh]

M52 create another bigger box this will be a hall,

M53 move them to be inside the BLOB (a space within space),

M54 Change the view to mesh, hide the BLOB, [this hall a bit big I will make it narrower and wider]

M55 shift the cafe box and intersect it with the hall,

M56 reveal the BLOB, modify it to be fit with the hall volume,[OK more or less that's it].

M57 [Let's create the park entrance, well it is a simple building that stands in the park,

for the third I will try play with smaller object rather than manipulate the geometry].

M58 [let's start with a box, creating its four separated free elements (walls) leaving gaps between them... multipurpose hall, for this project we will play again or do something we have done before].

M59 create a frontal deck.

M60 [it could be something like the reverse from before, we will create a view over the park, it was a balcony on the street, we will make the view to the park, now we will start this idea of a corridor around the building]…

[then I will try to find the areal shape, I want to stand out of this building and I also try to create a small public square at this corner, we will see from the plan, so I can make the public square at the corner]…

[may be a corridor goes with in to the park, the corridor advanced through to go to the park, something for accessibility, this will be a covered corridor, so the one side will be the cafe cross the corridor and goes the hall, it seems like promising here]

start to work with the deck (platform),

M61 stretch it around the park side of the building, lift it up, modify the frontal side, it becomes a ramp, shift it

M62 Work with the frontal wall of the square (transform this element to a corridor): [ok this will be the corridor just to turn it round, this will be the void (hollow) and I want to do it wider, so it will be a wide corridor across the building]

M63 shift it and intersect it with the park wall leading to the park and the ramp,

M64 change its height, [I will edit it into mesh, make it hollow so I can see through, so I have (in one side) the services area]

M65 Work with the back wall, change the height,

M66 return to the corridor, change its position

M67 [we have This bigger public surface space toward the main street, which is important in public space like a public facility..]

M68 move the back wall towards the frontal facade,

M69 move the branch side wall [.. a bit back creating a bigger open public space at the corner]

M70 Change its position, shift it, move it, put it at the corner, [yes it may be like this]

M71 Work with the back wall, move it, change its position, change the height of the front facade, [it seems it is becoming more difficult to adventure, I really need the sketch]

M72 [May be becomes more creative of doing what was past, it becomes easily and now becomes about the design process and also this idea of working with slabs was not very fruitful because we might need a few other buildings so it doesn't seem really very inventive, everything of what I do. I can see from where it comes from, a famous building that looks like it, I'm not really satisfied at this point..]

M73 turn the back wall upside down, move it to front, lift it up, transfer to a box becomes the hall, Buried part of it into the ground, it is a bit childish, stop work and just think..

M74 Create a sphere, delete it,

M75 [Create a floating plain to see how to cover the hall], modify its shape,

M76 Create bridge structure to support the ramp.

M77 [That's my room (the hall), I will lift it and put it here]

M78 make it bigger, adjust its place..

M79 delete the corridor, [I do not need it anymore]

M80 Change the wall's size and position, intersect it with the hall, and make it inclined: [I have a big room and an axis from the corner, I also left this small public space at the beginning, I'm trying to define the form for this]

M81 Create another slab and intersect it with the frontal inclined wall to become the roof (envelop roof), adjust their connect with the hall,

M82 [If I try to axis to this hall here, I will put this cafe here]

M83 [the problem is that this big unused area underneath, so I have to put it on the ground, fix its relation with the ramp, sided wall and roof], A gap is created between the hall and the facade wall by moving down the elevated hall.

M84 the inclined sided wall covers the hall and the ramp, adjust it with the envelop roof, [The facade wall could shape the space, it covers the ramp and shapes the roof].

M85 [So now the ramp is inside, change the hall roof shape , create a box, may be the service is here, may be it will content a stair case to go up to the balcony and ramp].

render, [then I want to render it from here] (other corner)

M86 [I'm trying to create an entrance, may create some sort of plaza here.. play with this geometry, I'm using the roof to create what is called the piazza], pull one of its point, push the other up,

M87 change mind and return to the previous situation,

M88 try again push the front side in, twist it, create the entrance plaza. Render it.

Group A- Participant N

M1 [I first want to make the general plan somehow, so I can have the territory]. Draw curves to create the multi-purpose hall. Give it a height.

M2 Manipulate the height of its ends.

M3 [Try to see how we make the distribution of the space related to function]

M4 Draw another curve , extrude it, [so it is like creating more complementary space, to define the main open and close space]

M5 Manipulate the height of the second curve.

Looking at the objects from different angles, rotating the views:

M6 [I was thinking in the roof, how it'll be cut and enclose the space. I'm not quite sure but let's try this:]

M7 Create a third curved wall, [I guess this passage is going to be used as a corridor or exit passage], give it a thickness,

M8 Adding another straight element,

M9 intersect it with the curve, Add materials to the curved walls

[I'm thinking in how to move from outside to inside]

M10 Create the roof, modify it to fit. [How one more big concrete structure could become a roof... rather than more free].

M11 [It is better to use curved surfaces...]

M12 draw one big rectangle surface and put it up ward to form the roof, delete.

M13 [Probably better I think within these curves to separate the function, the main spaces should have a bigger space..the multipurpose hall will be this space, the service will be this smaller one and cover those two things instead of covering the whole].

M14 [So I could try to make...] remove one of the curves and drawing instead straight lines,

M15 Shift the other curve to side of the composition, [this will be part of the landscape, or general thing one, but the main function should be concrete]

M16 [It looks like creating a variety of elements which will host space and the curves could... so the state of these perpendicular more concrete not so fluid elements become the main elements]

M17 Copy one of the perpendicular elements and add it to the composition to form the space of the hall.

M18 Change the height of the separated walls of the service area

M19 Manage the connection between the curved wall and the perpendicular straight wall.

M20 Modify the intersection with the other curve

M21 Draw a square that connect the perpendicular straight walls

M22 Extrude it up ward to form the roof

M23 Modify its size and its position in relation to the bearing perpendicular walls.

[The second idea, the curves that we developed in first idea become more secondary and some concrete walls that follow the space, they create the actual quality of the space, the curved walls are less important, they just represent some general walls in the plan, they represent an enclosure to create the entrance, we were looking how to create the entrance, but the main space was created by more concrete elements].

M24 [The geometry of the first idea is more interesting but more difficult to work on, the second idea can be developed much more faster, the organization of the space is not that complicated, we have geometrical perpendicular surfaces that form the big spaces, they intersect to create the smaller negative spaces. But also they fulfill the requirements of the program/ the main hall and the service area in the back, we have another space in the second level. I’m thinking if I can do this geometry a bit more complicated, actually it is complicated but do be more interesting if have more environmental parameters as well for lighting purposes or...]

M25 Looking at the volume from different angles [..for example these parts are going to be more triangular base..]

M26 change the height of the second floor, enlarge its size ...

[although it doesn't look so beautiful from this view, I think this might let to a more complicated...]

M27 [I need to copy it first...] Copy the whole composition and move it and drag it to another part of the site area [.. this could be another version of it].

M28 [I have to get rid of these elements so I can read the composition, some kind of very simple very basic... I mean it is quite more clear, I was about making these surfaces into..instead of square I mean plane.. into a triangular surface.. maybe I have to begin from scratch, this square has scale ... hopefully should be]

M29 [I'm just trying to imagine..to create a triangular surface as I call], (Draw a random polygon).

M30 [Where to create the entrance...] manipulate the shape..

M31 so I think... leaving this, elevating this.. do further modification to the angles to create a 3D triangular form [... let's see how does it look in perspective]

[So what happened I was looking here (the square roof in the second idea), it was not interesting, I kept it because it is more functional, it could be fully functional but it will be more interesting if this could be more triangular, even though it doesn't look very successful at this moment]

M32 Modify the angles of the triangular form

[Let's hide the plain, the whole structure arise from the ground, may be it needs to be...]

M33 again modify the angles of inclination.. manipulate the ends and the edges, [so this completely different from the other, it is non folding surface from the ground, actually it could be the ground as well]

M34 [I think I can split this.. I was thinking about this one big surface, I'm thinking I can do this but in separated triangles]

[…so this idea is completely different from the second so I can delete these elements]

M35 [I want to extract the triangle from the surface, this is going to make the surface to be different], draw a triangle

[so for example this (joint) will look different if we change the height and angle...]

M36 hide the other elements and look at the result, [ok..] (reveal the hided elements), [based on this surface I'm going to make a variety in the heights], create different heights

M37 draw another triangle, then another 3 triangles.

M38 [I think this could be more fluid, this could provide an interesting space for the interior], Manage the joints between the connected triangles; change the height of the points of the triangles

M39 Check these connections and do further refinements; change the angle and the height

M40 [Obviously we do not know how these triangles will be stand ...] Looking at the whole composition: [but these triangles can provide the organization of the space].

M41 [Focus on one of the triangles], Draw anther triangle that connected it to the ground...

M42 [I was looking to organize this space to be a gate, I mean it could be a gate..but how does the gate 's space locate underneath], Modify it, change the position of the connection

M43 Looking at another part; [I think the solution here could be the same as that one...This will control the flow of the people..how they get inside this kind of structure, So may be the entrance could be at this point, widening the triangle's base]

M44 [I'm going to create more triangles (to support the enclosure)...something like this could be the entrance..]

M45 [this of course could be more complicated..identify three points on the entrance.. divide it into three triangular parts; I'm trying to make it more human, I mean the scale]

M46 [Make much more subdivisions to the triangular volume of the entrance, then try to empty some parts and choose the opening shape].

M47 Making further refinements by changing the position of the joints, stretching them

M48 [I do not know if it is really functional, we may do the size of the spaces more appropriate, for example you can choose the space under this triangle here, it could be double ground] (volume)

M49 Looking at another part [...the building is a landscape as well, how this kind of interaction with landscape take place....It is possible that someone could walk up here] (find issue)

[I'm just thinking how this idea could be more functional.. the form looks interesting but it doesn't have appropriate spaces for a multipurpose hall].

M50V [It looks like a moving from wider space to another rather than the main space itself. For example if someone see this part he thinks that this space is to go to another space(circulation space) rather being a space itself].

M51 [Depending on what kind of multi-purpose hall...I'm trying to make it much more bigger, changing the size of the triangular volumes], (while trying to fix the edges, a gap is left between the two by accident)

M52 [It might look less fluid less dynamic, im.. looking internally..these edges of triangles do not touch each other so we can use the gap for interesting lighting]

M53 [em.. looking at the whole.. somebody could walk through here the service park here (under a cantilevered part), someone who come from the parking.. looking at the top view..]

M54 [it is almost will be here near the entrance, This will require another triangle here (draw a new triangle in vertical direction, which touches the ground to define an enclosure) ...]

M55 draw another triangle.. I'm trying to organize the space, this could be a kind of triangle service area].

M56 [This could be used as a parking].

M57 Looking at the whole composition, [for these triangles could be something solid not transparent, these voids do not have to be open , could be accessible or closed with glass or more transparent, this space in the back could be the service area]

M58 [hope there is space to pass from these triangles..this triangle is processed by creating doors, windows, even the height is not enough we can create.. this space as a main hall. I can see in the plan more..]

M59 change the size of it [..in comparison to this one but the surface is more suitable for the multipurpose hall].

M60 [These triangles touch the ground and can be part of the landscape, someone can walk here, make the space under it not functional at all, I will make another surface to separate this.. draw a triangle.. this make it better I think]

M61 [This is going to be the main hall, it could be closed by a transparent material]

M62 [The form at the moment looks very fragmented, but is reasonable to create a path here (over the roof), they can be extensional landscape. Lets seek how this could be done, I mean creating the path way to the top. Modify the connection between two triangles to be accessible].

M63 Add another triangle that connect the ground level.

M64 Then draw another one [... it much more better now considering the concept of continuous landscape]

M65 [This is small to MPH...Enlarge the size of the triangle that cover the hall... MPH must be bigger].

[I can imagine the whole site to be in triangular shapes, I do not want the building to stand alone in this site, it emerges from it..]

[This car parking I can imagine it being full triangle...some triangle do not host anything they are just part of landscape... this building arises from them]

Group A- Participant E1

M1 [Starting with a box, the main display hall is the biggest space so probably it is going to be in second floor. We start by setting an entrance, and the lobby], draw a square.

M2 [And this is the outdoor display, I want it somewhere inside, it will be covered by a roof, You feel you are inside but potentially you are outside]. He said in the meeting “I was thinking in how to bring day light, which I believe is important.”

M3 Draw two squares, [this is for the outdoor display and this is a temporary display hall].

M4 [The main hall will be in the second floor, have a balcony to look below with opening for light], draw a square give it thickness, penetrate it to create opening for lighting the gallery

M5 [I will give the gallery a height].

M6 Draw columns.

M7 [I'm thinking in circulation], draw stairs.

M8 [I will start actually working on facade, so I can get a general idea how the space works and then I'm going to extend it, create a panel].

M9 make copies of it, [I'm going to use them between windows].

M10 Leave a place for the entrance, change mind and add another bar.

M11 Looking at the whole composition; create a box to create the entrance opening, modify it and fix it in place, create the opening, [the pedestrian route is from here.. I need more free passage underneath the stair case]

M12 [for the public flow.. this provides free inner passage for the public flow]

M13 [I have to change the layout of the stair case]. Change the size

M14 [Thinking in the roof, create a rectangle. Create a skylight, create the opening of the interior court.

M15 [I'm going to copy all of these panels to the other facade, manipulate their position with the roof].

M16 [Start to close the site… pull the roof above the opening]

M17 [And on this side, this is the space I need for the gallery below, we start extending the blocks, this will give me a passage to go through, across the building].

M18 [Here we will start the idea how the building is going to have a gallery space underneath here with a sort of open lobby, and connecting to outdoor gallery it is going to be just a roof, so we start closing this space a little bit], draw wall to close this side facade.

M19 and cover it with ceiling; [So we gona have a lighter gallery on the top here, and a darker gallery here with a sort of pedestrian axis, it will start from here].

M20 [This roof is going to be a kind of balcony; start to manipulate the top, draw a fence, give it material].

M21 Give the building materials. Draw the balcony's window.

M22 [Thinking in this inner passage I want to extend it out where the pedestrian passage continues through the building then goes out]. Draw the columns of the balcony's wall.

M23 Copy the roof of the ground gallery, [..use it as a cover] (in the opposite side of the building).

M24 change the shape, and create the structural columns.

M25 9Start to close the back wall to direct the light from only these two sides and a bit through the balconies, and mainly filtering from these side columns (pillars)], modify the size.

M26 [these columns become much more thicker, this gives the rest of the building a sort of identity].

M27 Change the dimension. Modify the size, I'm taking the window for the other balcony. (copy the bars of the balcony's window)

M28 [Draw the walls of the second gallery, just finished them and I'll go to the next building].

M29 Add the fence around the interior court of the gallery

M30 Copy the building of the first idea and use it as the base of the second idea.

M31 Move the columns of the interior gallery, fix them in place,

M32 Copy the window of the upper balcony and move it to the wall opening down stairs.

M33 [OK I think that's all for the first building], looking at the roof, draw the skylight; create a cone

M34 then change, it becomes a pyramid volume.

M35 [Ok let me start with the next one, I'm thinking in using the block of the first as a layer to start from, I want to change it to be more organic].

M36 Create an arched bar, [this is a bit more organic, I'm trying to use this language].

M37 Adjust it and fix it on the facade.

M38 make several copies of it.

M39 and replace the existing bars by these copies.

M40 Copy them to the opposite facade.

M41 Extend the side wall to intersect with the arched bars.

M42 Manipulate the opposite facade, extend the side wall and intersect it with the arched bars.

M43 Extend the floor of second floor level and intersect it with the bars.

M44 Turning to the ground floor gallery, [I will try to make it more organic]

M45 [Start with the structure, a little more light], draw a curve shape, extrude it and make multiple copies of it, then lift them up,

M46 [replace previous structure of the gallery by the new one]

M47 [For the final one, I'm trying to make a cross section to the roof that is more organic than the previous one], draw a curved bar,

M48 fix it, delete the previous structures of the entrance and the gallery,

M49 Multiply the curved bars

M50 Modify their ends,

M51 [Create supporters (pillars) for the envelop], fix them in place, [I think this is the final version]

Group B- Participant R1

M1 [Starting from the brief], draw separated shapes: [a rectangle to represent the hall area at the corner, another rectangle to service area, and then the parking].

M2 [just thinking this main road will be more busy than the branch road, so it will be nice if we create a gate way and brought people from the branch road, the hall will be prominent in the corner].

M3 [You do not enter from the main side]. Create the hall, the service volume.

colour this park with green, the multi-purpose hall with orange, the service with a brawn.

M4 [It would be nice to make a park gate from this side, so if we want to have an entrance may be a pedestrian entrance from this side, so thinking in separating the vehicle entrance, it will be from that space]. (two entrances).

M5 [so setting back off the street with 3 meters in each direction], reduce the hall volume and increase its height, become more as a cube

M6 pull side of it to be like L shape, [so very diagrammatic; the hall at the frontal edge surrounding the court and the service volume. We have this hall at the frontal edge surrounding the courtyard and service volume]

M7 [we have this entrance quite pedestrian], adding human figure to recognize the scale. (giving the human scale to this building by making the pedestrian root the heart of it).

looking at the service volume from the back of the composition

M8 making a change in the MPH volume, becomes stepped shape .

M9 turning the view, looking at the facade of the main road , [so I think volumetrically if we look at this corner, it is very strong, very blocky].

M10 cut a volume at the other corner, change mind and redraw it, try another shape for cut and saving it.

M11 looking at the whole composition:[it is quite diagrammatic simple].

M12 [May be we integrate the service space with hall], pushing it fusing it with the volume, intersect it. Push the hall back, stretch it, then he decides to return to the initial situation.

M13 modify the arm of the L volume, making it shorter. Pull part of it in other direction stretching it, return to previous situation.

M14 cut another part of the L volume from the pedestrian entrance side. Returning to the previous situation:[...Immmm, looking at the pedestrian entrance. I think may be if we over hang it]. He stretched the same part, covering the pedestrian passage.

M15 [It is a sense of enclosure before entering the building].

M16 cut part of the edge diagonally, and reduce the height of the entrance volume.

looking at frontal corner of main street: it is quite prominent front.

1CAV Whole Have a look at the whole composition from other side and back, [thinking in the service volume]

[It is difficult to decide where to put this service volume, may be it does need to be kept back

1CAV Whole]

looking at the hall:[I can imagine inside this area is quite valuable, looking out this park, so I do not want to push this in that direction]

M17 Have a look at the back view: [move the service area: it stays here]

M18 Have a look at the pedestrian entrance, then looking at the back:[maybe we should create a second entrance, this provides an outdoor public flow]. Save the setting.

M19 [the form isn't that interesting at the minute, it is very blocky, there is less concept coming from it. The next movement is to try consider ..what.. what the building is going to be, perhaps developing the shapes more, see some less orthogonal lines, What I'm thinking next is to think reductively about volume. So we group that (putting the all parts of the composition in cubic skeleton). The next starting point may be trying give new design that's building working shapes together so what I want to do next is trying to think about reductively working with the volume].

M20 the negative volume/cubic skeleton becomes solid and integrates the existing volumes.

M21 change its (the negative volume) height, bringing it out, twist, (forming a cantilever)

M22 draw an opening beneath it (at ground level) for entrance.

M23 [I have to create the circulation passage, carve the volume of the ground floor to create the inner passage].

M24 make a groove in the other direction, which intersects with the first inner passage.

M25 [still keeping the idea of strong frontal edge, but working to direct the flow inside the space and between the park and two directions] (passages).

M26 [I'm thinking in these spaces (fragments of ground floor) for what could be used, thinking in the second floor to be flexible as possible, it is one large volume, the fragments can be used for different activities and requirements].

M27 the view become transparent, (changing the height), the volume will be a bit larger.

M28 navigate the volumes:[I think this volume look like a table, which is been supported by spaces in beneath. But before, there is the orange block (the upper floor from the previous idea), I will bring it back (it was hided) to see how it is look like ; It looks very piecemeal, and not much a novel concepts, let's start again (hide it)].

M29 (study the relationship between the upper and lower volumes and how to fill the in between slot), extend one of the entrance masses upward to touch the upper floor. Looking and navigating the result: [it looks an interesting interior, which is still supposed to be.... much with a large whole squeezed button].

M30 extend the other side mass of the entrance to touch the upper floor.

M31Turn the model and looking at it from the back. Extend another mass in the back, upwards to touch the upper volume.

M32 Navigate the interior, going inside the ground floor, remove one of the masses

M33 Going out, looking around the model: [ok I’m happy with the elevated public space. But I think this shift could be much more interesting, getting away from the square]. Navigate the model, focusing on the upper volume:[thinking of it as a space rather than just a volume].

M34 [So let us taking this out], looking at the result from different corners, raise up the entrance mass to the upper floor:[it is one layer talk to the other layer, it would be one of the accesses, thinking in this multipurpose hall to be flexible, conceptually, the celebration area above the service area on ground level. I’m thinking in the other axis towards the park].

M35 Navigate around it:[I think it needs to emphasize the park visually a bit more].

M36 shift the upper volume to be parallel with the park direction. Looking at the result;[May be explore more].

M37 Navigate the model, looking at main entrance:[may be this void (entrance opening volume) is too much], stretching part of the side mass to reduce entrance volume, modifying its direction (cut the corner) to indicate the access.

Looking from inside, then going out, looking at frontal facade,

M38 cut part of the side mass:[I’m not happy with this, I think it would be better if more simplified move. So try to replace this with an improved move], hide the other components on the ground floor and looking at the sided mass, change mind and return to previous shape.

M39 [try to simplified it again], looking at the whole masses together, change the height of the sided mass, then reduce the height of the upper volume, navigate around the model.

M40 make further refinements to the upper volume, cut part of it.

[These two parts need to be, somewhat too far from each other].

Navigate the model, making it transparent, looking from top pointing at a mass piece in the ground, looking at it from ground level:[this is quit volumetric and ..]

M41 modify its shape

M42Turne the camera to the entrance side mass, cut and modify its proportion.

M43 [Put in shadow trying to give the form a bit of distinction], changing the color of the floor:[Start another, we can approach it slight differently, starting with a different shape, draw half of cylinder at the corner, delete it.

M44 [I think I have an idea comes from the concept of THE HALL IN THE MIDDLE].

M45[which is protected by other spaces: the hall is a cube surrounded by a U shape volume].

M46 [And directed to the park]

M47 [the sharp edges to the streets].

M48 Modify the hall proportions, reduce the size to create a courtyard:[so creating a court garden close to...], navigate around the form from different views:

[It is rather difficult to think with this program, need a pencil and paper for this idea]

M49 Move the hall and attached it with the end of one arms of the U shape

M50 [thinking in the spiral, ..., let's explore if it does work].

M51[trying to modify the shape],

M52 then change mind and return to previous

M53 Looking at it from beneath, reducing its size, and lift it up the ground, stretch it to touch the other arm of the U shape,

Shift it, trying to shift the other side:[again the problem with sketch-up, this idea of straightening, pushing and pulling , so what..]

M54 [I want to start push this by removing one arm of the U shape], try to modify the shape of the hall, then it becomes prism.

M55 [So trying to buffer the design from the road and really focused it towards the park and create a space between the buffer …the surface of this and the hall],

M56 [This creates a third function so people could meet before using this hall]

M57 Change its direction, shift it, [try not to keep this space (the park) so separate. Try to bring this space/park into the building].

Navigate the form, working on the L shape of the service area:

M58 [May be just to break this facade a little bit], lift the volume of service area up, cut piece of it to become the opening of the entrance.

Navigate the result, making the volumes transparent:[I have to extend this device]

M59 Enlarge the entrance's opening groove:[it is may be an issue]

M60 [Again very simple, but here require attention], (the connection between the hall and service area).

M61 Move the hall to strengthen the connection, then change mind and return to previous situation.

M62 Then open the two ends of the hall, trying to solve the connection touch:[Sometimes rather than to alter this shape into what you want, just start to as a frame work for..]

M63 change its size, Remove.

M64 re-change the shape. Then change mind and return to previous situation.

[This place is going to be open up towards the park as well as towards the city; I think it is expensive space. What is wrong with this it is rather regular end, which I don't think this what it will be]

M65 Again, modify its shape, spread it in one direction. Remove.

M66 [What I want to do is to break this regular volume] (this is a regular volume, and the hall breaks from it), change the shape.

M67 further changes, push and pull the surfaces of the hall. Then he was unsatisfied.

M68 Redraw the whole composition with regular simple forms.

M69 Modify the proportions of the hall and service area.

M70 Lift the hall upward, then return it on the ground.

M71 [The first design was lifting the hall up. I think I try to challenge this regular form, let's keep it pointing to the park by keeping its access in this direction].

Remove all the drawing, and

M72 [start from the beginning with the same idea, with much regular form paying attention to the proportion].

M73 [The space between the two volumes is narrower; I think it is better just to leave this space narrow].

Working on the service L shape volume,

M74 push one of its arms to become a wall:[extend this wall to other direction to form an enclosure, so if you arrive here how are you going to become in there, we need more service area]

M75 Enlarge the height of the hall: [And if you be there what you are going to see]

M76 [let’s work with the park, bring it close to the hall. Open the wall of the hall facing the park].

M77 Work on the connection area; stretch a new volume that connects both.

M78Adjust this new connection; the connection from the top,

M79 lift the model upward and start drawing,[it is a basement]. Change the colour of both.

M80 [Let’s drop it to the ground. Let’s see it in x ray]. Navigating the whole :[this will be for kitchen, or clock room]. Navigate around it again.

Group B- Participant S

M1 Draw a square and offset it from the corner, [so I have entrance from here and entrance from the other side, and here the hall, the reception area and in the back I will put the service area]. She said “I wanted to create zones and articulate them by areas.

M2 Modify the place of the two axes.

M3 [first think I will draw the top view and then extrude the 3D]. Draw the reception and colour it, [I will move it toward the corner], extrude it.

M4 Draw a square for the service area, colour it.

M5 Stretch the entrance to create a corridor, extend it.

M6 Extrude the service area, connect it with the entrance, this will lead to service area and the back yard.

M7 Stretch the corridor to create the hall volume,

M8 [I’m going to pull this space (the service volume) to create a service corridor]. Draw line on the ground from the entrance to define the end of the hall block. The line extends toward the park.

M9 looking at the drawing:[.. I want keep this axis (from the side entrance through the courtyard)], draw it and colour it. It became the main axis for the whole composition.

M10 Draw the main entrance opening

M11 modify the public corridor and extend it.

M12 Create a big volume at the end of the corridor.

M13 [This (hall volume) becomes too massive].

M14 manipulate the height:[emmm.. I'm going to reduce the height of this side and use the inclined roof surface]. Manipulate its relation with the service corridor.

[What to do with this block (at the end of the corridor)?]

M15 Trying to manipulate the joint between the hall and the service corridor:[let's do this 3 meters (height), and extend it there (intersect it with the corridor), how much..]

M16 [em.. look at the drawing from another point of view, ok let us try do these slopes..many of them in the site]

M17 Draw the outline of the site, draw one strip, and then extrude it.

M18 manipulate the height and create the slope volume. Draw second, and third one.

M19 We have main entrance from here, back entry from there.

M20 Draw a green yard at the corner.

M21 Draw a forth strip, extrude the volume. Create boundaries around the slope.

M22 Draw a fifth strip, give it a thickness with inclination. [This could become the hall and the top is a roof garden]

M23 [These (roofs) could become part of landscape].

M24 Give them a texture of garden.

M25 Give one of the slopes a transparency.

M26 [This supposed to be the side entrance, and the main from here, there will be a continuity between the blocks]

M27 [These two blocks (reception and hall) supposed to be merged].

M28 For the third I want to respond to the corner again, let's start with a linear block, draw a rectangle, extrude it, and then I want to play with it.

M29 [Let's try if the block starts from the corner then it will rise towards the back of the site]. Create a triangular volume. [I was thinking that the first idea was about zoning and the hall was the slope volume, so this third idea could be the whole building within this slope block standing in the landscape].

M30 Modify it, becomes a slope volume.

M31 Draw another block with additional extensions.

M32 Manipulate the shape, push and pull.

M33 Draw two perpendicular blocks (T shaped block).

M34 Choose the second one with the slope. Manipulate its height.

M35 Divide the volume into parts, make one of them transparent.

M36 Bring it to the site, put it diagonally.

M37 Check its position with edges of the site.

M38 The computer suggests a pattern of division to the site landscape.

M39 [Create the landscape into different levels] following the computer's divisions.

M40 [The mass contains multi dimensional spaces, we need to add another mass].

M41[I'm trying to expand the back], draw a rectangle perpendicular to the site divisions.

M42 Intersect it with the building and extrude the volume.

M43 [I will try something else, I'm copying it..], manipulate the rectangular volume

M44 [it is a multipurpose hall, em.. let's do it straight], draw an additional part that its lines parallel to the site boundaries.

M45 modify it, make another copy for the whole design, deal with it as a study drawing, draw the extension part, manipulate it.

M46 [ok I need to try the mass of it], extrude it. Fix it in the site.

[I want to try something for the site and landscape].

M47 Draw the entrance opening.

M48 make the upper part of the building transparent.

M49 [Well I will try something else, let's take this block (the rectangular linear block), the concept is the simple massing again, set to linear blocks which are joint by another block].

M50 [Let's check its dimension], make it narrower.

M51 copy it, move them to the corner, and fix the distant between them.

M52 [I think this is so long], modify the length of the blocks.

M53 Draw a courtyard that connects the blocks.

M54 [I want to draw the hall block at this end (to close the composition)]. Create the block.

M55 Modify its position, draw the division lines of the stories.

M56 Draw the service axis in the site, then draw the main entrance..

Group B- Participant M1

M1 [First I start from a basic idea and working from there trying to do something more interesting], draw 2 attached rectangles (hall, service) and extrude them.

M2 [I'm going to separate them].

M3 [I think the service entrance should be on the branch road, therefore I leave this box (service) somewhere here (near the branch road) and the main hall should be somewhere near to the main road].

M4 Create the main entrance, subtract part of the main hall, create an entrance space.

M5 [May be it is better to take this up and put that bottom, reverse the place of entrance's void and solid, push the upper solid part of the entrance a bit in].

M6 Work on the main hall:[may it will be interesting to cut of these corners], become rounded corners

M7 [Start carving the volume], Work on frontal facade:[push-in rectangular surfaces].

M8 Reveal the cut part as transparent box:[need to work with section to take it in "Ok I have this section I can read this wall, Ok fix it"].

M9 Looking at it:["It would probably be able to be a sort of focal point of the hall area, but I think it would be nice to have some form of look out from the window to outside"]; draw a big window area.

M10 [May be we take it out a little bit to increase the view], make it transparent, push in the next part of the first transparent box.

M11 [So it is the idea of sticky out windows].

M12 Cut off the prominent corner completely, round it:

[Now we have to look how to connect these (the hall and service volumes) together]

M13 [I think for the service it need to be quite boxy, but smaller], Change its height, change the angular corners to rounded corners.

M14 Rotate the box, move it towards the centre:[I'm thinking in the service area as a kind of kitchen so it would be nice to bring food from up; lift the box up].

M15 [let's don't worry about connection now, I'm going to hide the hall to focus on the service area " just sitting like a pie in sky", just thinking in connecting with the building with something like a tunnel, am they connect in strange way].

M16 [I do like to think about the inside of the building, just how these two are going to be connected from the inside. For that I will do a section, so we have some form of entrance, come out into the main plane. And some kind of stair case is coming down].

M17 Looking at the whole volumes:[we have these prominent yellow glass boxes, I think this service volume should be metal; the rest may be in contrast].

M18 Draw the trees of the landscape:[this is the idea number one].

M19 [I think for the second option I have the idea if these separate boxes]… draw a box and make 2 copies of it…[so I have these three boxes enough for 300m, so one of these has to be smaller, so I can have the service area]. She said in the interview: (Instead of using one volume for the two halls in first idea I use separated volumes).

M20 [So rather than being straight, I'm going to arrange them diagonally].

M21 [I'm going to take the middle one and slice it off to have the service area,

Connect it with back hall], return

M22 [May be there are different rooms in this multipurpose hall, connected to each other through the central wall].

M23 Connect the service with the central part.

M24 [Probably it is quite more sense to have the entrance in the centre].

M25 [I do not really like this service area; I'm going to rotate it again].

M26 Work on the connection between the central part and the two halls:[I think they still need to a kind of separation]. Move them slightly.

M27 [But they do need the connection, so if they are connected like this, it is very nice to have some kind of visual separation between them, So what I'm going to do just (open part of the hall and change its material to glass), Then I just need to check is this (the glazed opening) wide enough to look through], (this is to support the visual connection).

M28 Do the same thing with the other hall.

[So what can I do to these main hall parts?]

M29 Start to play with their forms, push and pull.

M30 [oh it seems nice, maybe I will keep this inclined form instead of just being a cube].

M31 [What I want to do is to lift this edge up], delete. [Let’s do it again: so now I have slightly slop roof].

M32 Modify the inclination of the cube.

M33 push and pull the edge: [here we are, so let’s create the other side, work with the cube, slop it down].

M34 Working on the connection between the main entrance centre and the service, leave a slot between them and been attached from very small part. Save it.[Let’s start another one].

M35 [I do like the previous idea of the slopes, so let’s try it again]. (all volumes will have slopes)

M36 Draw a rectangle [“ok that is the basic area”], divide it into three linear parts.

M37 extrude them with different heights and sizes.

M38 Move the bigger one to be in the middle, the service in the back and the main entrance in the front.

M39 [I’m going to play with the idea of slopped roof], divide the roof into equal parts.

M40 stretch the edges up ward, play with it, [let’s try to see what makes this visible from the bird’s eye], keep stretch the edge: [oh.. that is quite unintentional but it could be] (the computer broke up the surfaces into organic divisions)...[let’s go back].

M41 Work with the service volume, push it down, stretch it, return, [let’s see how can we do it], draw a line on the top of the surface, play with it; stretch it.

M42 [this space will be for storage, so that is for service area].

M43 [Let’s now just focus on the entrance volume, that will definitely be the focal point, cut off the corner edges].

M44 Divide the frontal surface into parts, pull, push and stretch the edges…[bringing out some parts which could be the entrance].

M45 the volume becomes more flexible and a kind of a polygon, modify its edges..[make some parts of it transparent so we can see through].

[It's quite nice to play with these combines].

M46 [Let's just see how to connect them, this face of the main hall with that of the entrance, so I'm going to open these volumes].

M47 [lets connect these points, stretch the edges, pull them out, maybe we can do the reverse push them in, it's quite interesting angles, modify it stretch on point out, interesting].

M48 [Lets go back], divide the surface arbitrary, pick up the edge point and stretch it.

Look at the whole composition:[let's think about the entry].

M49 Pick up few fragments of the hall polygonal surfaces and make them transparent.

M50 Modify the site arrangement, Turn the whole composition toward the corner, the main entrance face the corner.

M51Go back to the service, let's move it to the back.

M52 rotate it:[so it still has a connection with the hall]….

[so we have this space here, a whole outer area, which could add a very nice feeling here if you suddenly discover it], draw its outlines,

[I suppose we can add some very nice trees, and it suddenly it becomes very nice area]

Return to the first option, pull the glass boxes out, create a kind of a front yard.

Go back to service volume:[what I would like to do is to draw some pipes (structural elements) to support this mass].

Group B- Participant A

M1 [I start to draw the site, draw a rectangle, I start duplicate that 5 or 6 times]….

[I'm just thinking in the entrances of the main street and the corner as keynote to the site].

M2 [I'm thinking in the size of the service area to the size of the MPH], draw a rectangle.

M3 Move the main hall area to the front, keep the service in the back:[I just made the service area as an elongated piece down the celebration area].

M4 [I'm thinking in giving the roof a height of two stories, and that emulation to the main public space].

M5 [I made the entrance area a bit generous, double space that could contain the reception and maybe the office], move one of rectangles to the corner: [I just change entrance part of a square form, reduce the size, then make the volume double space].

M6 [Basically I've got three components], extrude the hall volume.

M7 [It is one height volume, which may be need a bit change as a transition zone between the entrance and the hall], reduce the height of the corner part. [So I've got almost all the elements towards the actual junction, which lead them a little bit disconnected with park]

M8 [So might begin to think in how elements of the form of my structure begin connected to the land a bit more].

M9 [I'm just making these individual components into a group into sketch up], move the hall; [I'm giving a prominence to the entrance in the corner…. The hall wall may be extended out suggesting a structural wall].

M10 draw the wall, fix its height:[So just I slump it down from high near the building to lower height from the other way].

M11[The expanded structural wall should give a privacy from main street].

Work on the joint, make it prominent, return to the previous situation.

M12 [Just thinking in how the service may integrate much better rather than being a separate entity in the back, It will be interesting if park has some integration facilities, in the scheme it does not seem that relevant].

Save it.

M13 [In thinking in version two I was quite interested in how the elements of the building come to the park, maybe I'm going to save out this rhythm of spread horizontally in the site]. In his report he said "Developed from the idea of the wall against the road to protect the park I used the idea of a thick, heavy wall to form a grid to the site in the aim to connect the building & park more successfully."

M14 [I will draw horizontal panels of may be thick walls, which might be long].

M15 Extrude them, the in between space will contain also the outdoor spaces.

M16 Fix their position in the site.

M17 [So we will begin with entrance, it is going to be located roughly at the corner of the site, I think I'm going to identify this bar actually where it becomes close to the site boundary].

M18 [Push three bars inside the site and keep the first one to be something prominent at the corner].

M19 [I'm going to create an actual void in this wall which guide an axis in this way, in entrance way].

M20 [I'm going to try to locate these service spaces and hall spaces within this grid]. Create a cube for reception and create concrete orthogonal strips.

M21 [I'm thinking in this area, it could be a kind of a football area, recreation area].

M22 [So this means the horizontal rhythm need to be broken someway, so might leave a piece of end just to indicate the rhythm of these horizontal bands]. Cut part of it and leave a trace on the floor.

M23 Repeat the same act with the second band and then decide to recess the wall of the third panel:[This indicated area might be a kind of playing area, so it defines a park for me].

M24 [Start to think in how the hall space is going to be sit, emulation to this might be divided into several spaces rather than one whole space].

M25 [So I'm going to the space behind the reception the entrance space, which is actually a circulation space goes in perpendicular orientation to actual horizontal bands, create this circulation space, which intersects the bands].

M26 [so I can go out of this space to create the other space of the main hall, take out one portion of the circulation spaces then redraw it]….

[I can look round and through the model to see where to locate this main hall]

M27 [I will be quite lucky if there was a way when you came through the entry you can see the hall down to the park, which would mean these first two grid space would need to be partly empty].

M28 [So the main hall can be in a position in the middle of the park], create the main hall.

M29 Add another cube for circulation

M 30 [Go back to the grid would be prominent within this structure create recesses in the wall, they could be a kind of windows and voids in the main hall, create more recesses in the other grid wall. So I think this scheme no. 2]

M31 Using the existing site as a base:[I think after developing that second scheme, I'm quite interested in how the visitor's connection may be journey through the park before actually get to the meeting] (thinking in the bands as some kind of journey ways) referring to move 27.

M32 [We should locate the entrance in place against the intersection of the road, may there will be an old fashion of a gate in the park, which could be a smaller public visitor space]... [Draw quite small building that will be a single story].

M33 [Quite traditional shape, like a simple pitched roof], move it to the end of the site, [there will be an actual walk way through the site to reach the main hall in the other side].

M34 [So again I can create this long wall against the main street, set it a little bit back from facade of the entrance building. It will be a kind of covered root], create the canopy.

M35 [The other end could be a kind of entrance across the road, the wall could be integrated will the volume of the MPH], cut part of the canopy.

Draw a rectangle for the main hall:[may be the service area will be interlocked, it could be an L shape, and because of the service element is a small element in the opposite side of that entrance gate way, we can take more of prominent height in comparison to the volume, MPH also could allow the identity of stories within the space is supposed to be one level one story, the service area could be a rectangle and not an L shape].

M37 Extrude the hall volume.

M38 Modify the main hall as a separate entity.

M39 [I'm going to create the service block which does not interrupt with the block of the main hall, it will be higher].

M40 Modify the height, stretch the roof, then stretch it down touching the ground.

Looking at the volume of the MPH:[it is a big mass].

M41 [I'm going to go back to my option one]. (the designer tries to have an over look at his previous designs):[I created the entrance ,the multipurpose hall and the service as separate entities, this service volume is thin, let's highlight it, turn it around].

M42 [May be the height of the main hall space becoming a little too big], change the height.

[The entrance is the largest scheme], Move the service to the site boundary; connect it with the circulation space, return to the initial situation.

M43 Change the size and the shape of it, stretch the roof to create a frame.

M44 [Use the same language of framing at the entrance volume].

M45 [Identify the circulation space by drawing lines on the roof].

M46 [Use the same language of framing on the main hall], create a frame.

M47 [I'm quite happy with the option one and three, let's check option 2, It almost like industrial park area with important services and structural elements stand in the park].

M48 [I'm just thinking in one of these bands should be set a bit back service block suggesting more invited sort of area. Using this space for parking]

M49 Looking at the whole composition:[I'm just taking these lines traces, lines of the floor, because maybe this area is used for recreation, football area].

Group B- Participant T

M1 Draw the site: [Draw a rectangle, we have the main entrance from this side].

M2 [Offset the rectangle 10 meters from the street, so this must become the entrance, and the service area in the back].

M3 Create the hall with the entrance.

M4 [actually I can access it from front and back, the service entrance will be from the back and the main entrance from the corner].

M5 change the height of the service area becomes lower.

M6 Work with the roof of hall, create a curved roof and refine its shape, becomes thin.

M7 [I'm thinking in how it looks from the park, and how it looks from the main street, I have to solve the landscaping].

M8 [We have the base of the structure in the back (the service solid volume), which is completely solid, and a thin roof….Thinking in span of the roof], Remove the wall of the front facade, draw interior columns.

M9 fix them in place, draw constructional details, hide the walls and look at the columns from inside, draw a row of columns on the opposite side.

M10 Draw a column stand base, make copies of it, and put them in a row as bases for the side wall pillars.

M11 Move the frontal columns a bit inside and fix their connection with the roof.

M12 Make a copy of the pillar's stands, move them to the opposite side. Extrude the pillars. Manipulate the joints.

M13 Draw glazed panels between the pillars, delete one side, manipulate the other. Copy it and move it to the opposite side…[The entry will be from this side]. (in the meeting he said "we have large corner entrance, then how you get in the park, which is in the other side of the building? You would have all of these walls; which are glazed, so you can see straight the whole scene of the park.

[Jump to the other option].

[So we will copy the design, and what kind of change that could happen? Decide to delete it and start from beginning].

M14 Draw a rectangular surface.

M15 In his report he said "Finding the parameters of the site too open, flat, with no information regarding the surrounding buildings, I decided to change the shape of the land".

M16 [Just want to build a terraced site], push the rectangular surfaces down. Offset it and change the level

M17 Change the shape of the terrace, becomes L shape.

M18 Create a rectangular volume for the building; place it at the corner on the lowest level.

M19 Fix its size and height, its roof becomes almost within the site level.

M20 Change its position:[place it at the corner of the terrace… Intersect it with the corner, dig and stick it with the terrace's corner]. He said "It is dug in the landscape, I wanted the building to address both of the park and the roads."

..[Modify the terrace outline to match the building shape. Move the building away from corner to see how it reacts, yes this is a bit better], then return to previous situation.

M21 [I will try to pull its top, becomes a steep roof, change the height and rotate it to fix its touch with the terrace].

M22 Fill the gap between the corner and the building. He said “This allowed the building to be dug into the land, enabling a relationship with the park and giving space to the road, by cutting off the corner.”

M23 Modify the interior of hall and manipulate the stepped interior walls.

M24 [Simple, this is very simple form of the building… I’m trying to draw a frame (structural frame), fix it in place]. Make copies of it. Distribute them on a grid.

M25 Change the height of the roof.

Manipulate the ends of the frames:[pull them up being the base for the roof’s fence, am...], delete.

M26 [Ammm.. trying to change the height of the roof..., it becomes flat floating roof]. He Said in the meeting “I was thinking in the roof as a simple kind of frames, then I pulled it up to give some sort of edge to the building but this becomes thick and chunky, so maybe instead of just stuck into the site, we have this floating piece (roof), so when you stand here, you can actually see through.”

M27 Draw the fence of the roof’s edge leaving a slot between them:[So we have this visual continuity with the site].

M28 [Still this is service area in behind], (the buried part of the corner).

M29 Looking at the whole composition [..ammm..], remove the back edge of the roof’s fence.

M30 [..thinking in the gap between the roof and the site terrace] (because of the difference in level), [ammm... Ok let’s do a copy of this], he said “I thought in tearing it (the roof platform) so I have enough height.”

Draw an arched extension to the roof’s platform. Change mind, delete.

M31 Duplicate the roof’s surface.

M32 then make another copy, becomes a terraced roof with in between gaps to see through.

M33 Manipulate the steps from the interior space.

M34 create the walls.

M35 manipulate their connection with the roof and the site’s terrace.

M36 Modify the roof stepped levels.

M37 Change the height of the in between gaps.

M38 Create another step.

M39 Manipulate the joint between the building and the site's steps and change their shapes.

M40 Do the same thing for the other side.

M41 Draw the service doors to be accessible from back.

M42 Modify the details of the joint between the roof and the side walls.

M43 Draw transparent panels of the frontal wall, extend them to the corner.

M44 Modify the side walls.

M45 Check the roof of the service area (corner yard), draw the inside big service door.

M46 Fix the upper part of the side walls.

Group C- Participant MK1

M1 [I Start from the main area, I have two perpendicular axes, one from the main street, the other from the pedestrian route, the geometric spaces will be along these routes].

M2 Draw a square for the main entrance, and another one for the pedestrian

M3 Draw another two squares for the temporary hall, and the permanent hall,

M4 Draw a circulation space,

M5 [May be I will start to break up this space here (the main square) to be a series of private areas] (divided into two squares)

M6 Add another square:[may be a kind of space in this area, Start to think about this space here]

look at it in perspective view

M7 Extrude the entrance, the main exhibition…[hall may be this one, the temporary hall, the pedestrian entrance, that will be a massive taller].

M8 [This will be the outside exhibition], extrude a wall.

M9 [May be start to think about the connection between]… (the pedestrian entrance and the main hall)….[maybe I will start to carve, what kind of spaces actually we have]

He starts to reinterpret the volumes and transform them to spaces.

M10 make a copy to the whole composition from a top view:[just start to think about..]

M11 [this is actually a wall (give a thickness to every volume to be actual space, to create a plan), give details to the door openings, draw an entrance desk, draw the walls of the other spaces, the corridor "being connected to the outdoor exhibition and the enclosed main exhibition."

M12 [Instead of being an enclosed space start think that maybe it will be a kind of colonnade], extends horizontally.

M13 draw columns in the corridor.

M14 draw the walls of exhibition hall.

Looking at the whole composition in 3D, thinking in the lobby space and fix it, return to plan

M15 Change the shape of the outdoor exhibition, give it a thickness, solve the connection with the corridor and draw a stair case,

M16 Fix the corridor, carve up its connection with the lobby,

[Ok this is the reception, the secondary hall, the out exhibition, and the main hall]

M17 [May be this main hall should be into two spaces] carve the walls, draw the door opening,

M18 divide the hall into two separate spaces, [this is for services].

M19 adjust its position and size, draw a space that connects it with the main hall.

M20 […the connection space between the main hall and the lobby, ammm..], draw it.

M21 [I do not want this box (the tall tower) to stand here, may be it will be a kind of secondary pedestrian entrance], draw a long corridor that connects it to the lobby:[maybe it (the tall tower) becomes a roof only].

M22 Draw the columns of the pedestrian entrance.. [the shed…amm].

M23 Change the view to 3D, extrude the walls: [the main entrance and lobby, one side is completely solid, the other…these…ammm… slots]. Extrude the reception desk, make a copy of it and use it as a vertical element that indicates the reception desk.

M24 Extrude the colonnades (the corridor columns),[different heights.. indicating the connection with the outside display].

M25 Extrude the secondary exhibition hall,[.. making it so big ..ammm….or so small] (decided to make it one volume)

M26 Extrude a low wall …[wall..surrounds the outdoor exhibition].

M27 Draw the slabs of the colonnade corridor: [maybe we have a second floor, modifying the floor of the ground floor, change the height of the slab]. Adjust the situation of the outdoor exhibition and its relationship with the colonnades,

M28 Look at the volumes from different angles, create the stairs between the colonnade and outdoor exhibition.

M29 the colonnade volume: [Spring the slab up there, it is too big], modify it,

Navigate around the volumes.

M30 Work on the main hall, fix its connections with the service and lobby.

M31 Extrude the walls,

M32 Work on the pedestrian entrance, extrude the columns, the slabs,

M33 Extrude the second circulation corridor (left corridor).

M34 Create the pitched roof of the main hall, [..its intersection with the pitched roof …of the lobby..I have to fix it].

M35 [May be this (the walls of the lobby) should be lifted up], (intersect it with the pitched roof),

M36 [May be this piece here (the intersection piece) is going to be a kind of window]

M37 [We can now rise up the left corridor slab,..]

M38 [May be this (the pedestrian entrance slab) comes up, may be it becomes series of slabs at different heights,..]

Looking at the main lobby:[what to do here with the slab?]

M39 Fixing the height of the colonnade slab:[it becomes lower, the columns are lower now….amm..The tops of central group of columns become interior elements, may be.. they will become… seats].

M40 Navigate around the 3D volumes, looking in top view: [creating the pitched roof of the secondary exhibition hall, What we need is to locate the stair case somewhere], Looking at the lobby:[This is a massive space it can be used for a spiral stair case], draw a circle, Delete it, [Just to shift this (the main hall volume)here], fix its roof. Modify the left corridor's slab. Return to previous situation.

M41 Decide to construct an outdoor stair and place it in the colonnade corridor, fix it,

M42 [Just let me look at that lobby there, decide to draw a flat roof to the lobby, may be this part will be skylight]

OK, looking at the whole composition, navigating around it, checking the top view: Ok the main entrance here, the exhibition hall, the outdoor, the pedestrian entrance, everything is Ok. Save it.

M43 [For the second option probably, I'm going to use more organic forms].

M44 [probably doing it into steps so what I'm going to do is to draw the primary axes of the site, I'm going to use the axes again, these intersecting axes to sweep the organic forms].

M45 draw intersecting spaces (squares) for the entrances, the main hall, and other spaces of the program.

M46 [What we have are organic spaces, which are going to sweep from out to in, sweep from this point (the main street) into the space, and this point (the pedestrian root) into this space].

M47 Draw variety of curves that sweep into the space,

M48 [This space (next to the main street) could be a kind of entry and a parking area].

M49 [Start to give a thickness to the curves], Extrude them:[this is bigger, this is smaller].

M50 [This (the cylinder) becomes like an anchor like a tall point there].

M51 Extrude the squares, become slabs, intersect them with the curved forms.

M52 Extrude a rectangular space, intersect it with the cylinder.

M53 [Now what I want to do is a kind of sweeping roof and intersects from this level to that level and then to that. We will distract series of points, what we want to do is to do a kind of one roof that can sweep there, we will start this from the plan].

M54 [Think what can sweep later, for instance may be this, from this direction, so may be start from this point, this point and this] (indicate few points on the curves).

M55 [what I can do is to connect up these curves, connect them randomly, connect this one to that one, here to here, to create the planes to sweep].

[We gona see what would happen to these curves].

M56 [We will change the display], (change the connecting straight lines to more smooth curves)

M57 [In terms of surface we have to give them a texture, so let's see what we got]

M58 [We have to rise them (curved surfaces) up]

M59 Look at them in top view: [pick up some points that define the plains, we have to bring them up]

M60 Pick some points and change their height and fit their places on the walls:[we have these 3 dimensional spaces, we can rock and roll, we can sweep them].

M61 Go to another part of the roof:[See if it can work here, pick up points to create a curved surface], Reveal the curved roofs, Go to another part of the roof, pick up some points to formulate a curved surface, Reveal the curved roof: [Ok that works]

M62 Change the height of one of the supporting walls, to capture this roof.

M63 try to pull the curved roof toward the supporter:[it is going to work, no it doesn't work (the computer failed to bring it). We will try with this square].

M64 [We are going to use the anchor again, so maybe this (square plan) becomes a kind of anchor, create a central box that connects all of the swept roofs].

M65 Carve this box, it becomes a skeleton walls.

M66 Create another box, intersect it with the skeleton:[maybe we subtract it, then delete it, this creates an opening in the skeleton/fence] (of the courtyard) .

M67 [We have a kind of central core here] (becomes a functional core), Create two smaller boxes, bring them up become towers, which intersect the skeleton, Carve their bases, become like the main entries.

M68 [In term of scale, this has to be changed]; move one of the curved walls (to create an invitation space to the central core/court yard).

M69 rise one of the rectangles on ground level, rearrange the composition:[this rectangle becomes roof that covers the court and, may it become a special bigger space, connect it with the… this area here] (the court yard and the cylinder).

M70 Looking at the composition [suggest changing the roof to a curved shape].

M71 Pick up points to form a new swept curved surface, fix the points, fix it in place, and reveal it as a swept curved roof.

M72 Looking at the whole composition, fix the one part of the swept curve; intersect it with the supported wall,

M73 Look at it from the top:[oh I do not like that..] (the curved roof), delete it.

M74 so maybe just make it simple, how to make it, just do something, it can be a kind of solid (trace the underneath rectangle and create a solid),

M75 bring it up, fix it in place, modify its intersection with the cylinder.

M76 [maybe it becomes a roof garden or something connected with nature].

M77 [Something is missing, this (cylinder) is too high], change it

M78 [One more roof], copy curved roof, bring it to the core,

M79 intersect it with the solid, fix it, lift it up, and fix its intersection with the cylinder, bring the rectangle solid down,.

M80 [one more thing to do is to tie all things together, we have the roof of this piece (the core), create a flat roof].

Group C- Participant K

M1 [Start from the basics, a rectangle for the hall, and another one for the service area]

M2 [Start to occupy the corner itself, putting it (rectangle) offset from the street]

M3 Extrude the building in 3D,[do some rough mass modelling].

M4 Change the form of the hall volume.

M5 [Now I'm thinking into actual sitting area, being close to street, I'm thinking in the idea of public privacy (the idea of void and solid), the major site open here over the street].

M6 [So coming from that edge extract piece of the volume and change the form (becomes L shaped section), we have sort of space open to street, obviously elevated off].

M7 [Think in the section], draw a rectangular volume, [so we have another solid here, should be working as a sitting area]

M8 [Thinking in the end side corner, this should be glazing], extend the sitting volume to the corner.

M9 [this should be a diagrammatic form, so now we have a service area, with the solid hall open to public area, and we have the park, which does not have anything to appear here].

M10 extract part of the solid on the ground level, change it to a glazed volume. [So we have two solid volumes, and two glazed volumes one elevated from the public level, one open to park level].

M11 [I'm doing very quick test, trying to separate the volumes], move the park glazed volume and separate it from the building block.

M12 [We have open space here, it is a kind of physical barrier, suddenly we have the idea of indoor- outdoor, one continuous void, approach of the site].

M13 Move the street glazed volume forming a cantilevered edge.

M14 [So we have now two areas, in which to converge the street area and the park area, and built in these massive solids, can obviously be some kind of private area; W.C., storages offices].

M15 [We can carry off this while we respect the corner of the street, when quite easily cross it].

M16 extend the upper part of the block, becomes a bridge across the street.

M17 Make an opening that connects the bridge with the block, [so intend to subtracting objects to groove the block].

M18 Make a continuous void and then extend this circulation space to outside by drawing another bridge that connects the block with the site from the other end.

M19 Then, he creates another bridge across the branch road and connects it with upper part of the building.

M20V [This is essentially our concept an open building reaches out to latterly connected to adjusting areas with a public network].

M21 [A new starting point for the next idea, very basic geometric offsetting, I'm going to use the square, which is rational].

M22 [Then we can have a public space; that is transparent, with a service core, in which the building elements can be generated around. So I state that core and extrude 10 meters, buried part of it in the ground].

M23 Draw a grid inside the square.

M24 Extrude the boundaries of the square.

M25 Extrude the wall beams

M26 Extrude the grid on the ground level and lift it up to be the rib slab for the ceiling.

M27 [This is (square) really accessible from all sides], draw front- back axe, draw the entrance opening, and the back opening, [So we have this enclosed volume with complete transparent].

M28 Draw a deck around the volume to be a public area, [so we have this public space].

M29 [If I reduce the height of this object I'm going to lose the identity of the pure solid].

M30 [I want to lift the entire building, I'm going to pick up few points, lift it up, I'm going to copy some points] (from the rib slab to construct the platform).

M31 [So we have this cantilevered box with this service core (and structural core), I'm going to add some columns].

M32 [Of course I want to keep the idea of floating mass; these columns are helping in supporting the space. So now we have objects around the centre].

M33 [Thinking in accessing the building from the site, create ramp].

M34 [We have a major entrance, so I'm going to block the back opening].

M35 [We have this service area which can serve as a circulation space; elevators].

M36 [We have this grand outdoor circulation ramp], modify it. Save it.

M37 [Now I'm thinking in a third idea, so far we have solid separated spaces, then we have the one big hall volume, so far the two ideas having the whole one object, the third idea we can try a separated scattered spaces creating the areas for sitting and performance or celebration just by denoting outline of space within the park as a solid including building elements, both first ideas were generated from symmetrical lateral principals, so we can try contrasting that by something slightly more abstracted].

M38 [Let try generating random scattered elements with associated surface intersection. We can take 25 meter square areas], draw a square 5 by 5, extrude it, draw an opening:[so we are going to find roughly for sitting and celebration so we would have about 10 elements of this], distribute them randomly on the site,

M39 [What we could do is to make a great entire ceiling above the whole park to has perforated openings intersect the cubes, to cover some areas and left the others exposed so you have dry cubes wet cubes]

M40 [so we have to keep these (cubic elements) on a straight x-y axis].

M41 [Rotate them in various directions so we do not have a strict direction for the openings]

M42 Draw plan of one cube and extrude it.

M43 Repeat this plan for the all cubes.

M44 [We still have the service area, we could make it dynamic, again we have the edge here (the left edge of the site), it could be an anchor but we want to keep the idea of randomness, we could make it randomly here because we have an opening, no it'll be over there (choose another place) because this one is quite central]

M45 Draw a square, [this is the service area], keeping the same height of the cubes, draw its walls.

M46 draw the grass (of the site), decide to push the service volume down ward, it becomes a cubic hole.

M50 Draw the roof, which covers the entire site.

Group C- Participant E2

M1 Starting from this box, I want to separate it into units. Then connect to one continuous project.

M2 So start with over all out line shape divide it into square units.

M3 Gather them into groups, move them toward the corner, M4 [this is a sort of random layout that I have made, taking decision more related to the surface actual area to develop this base]

M5 [Just try to make an outline of how this is going to look, start doing this by circulation around the space], draw the outline of the lay out.

He faced a technical problem, delete the drawing and repeat the steps again.

M6 [This surface area should be the entrance because it is near the street].

M7 [I will start making my walls basically, I'm trying to draw the isometric of these], give thickness to the outlines.

M8 [This is going to be the main hall and this is the public celebration area]

M9 [Start to work on the volumes, start generating these volumes]

M10 extrude selected parts of the walls, create the roof

M11 Create windows and create the entrance.

M12 [so I guess this the first idea, you have the entry here, with a shape made from squares, then you have circulation spaces that lead to the main hall, with a sort of exits and light coming in, then the service area…Let's go to the second].

M13 Copy the same site: [I will try a different approach may be in sort of block now, draw a square].

M14 [Try to draw different shapes], divide them into triangles.

M15 separate them and then gather them in new linear composition, move them to the corner.

M16 [thinking in spaces for circulation I want to separate these triangles, leaving gaps for lighting].

M17 Draw plan outline, Give the outline some thickness.

M18 [This is going to be the entrance], draw a corridor connecting the triangles, the entrance with hall,

M19 Draw the openings and then draw the walls.

M20 [so we have enclosed space with some sort of light comes through these gaps and some from top roof].

M21 [so I'm going to isometric view, get start extrude some shapes, I'm going to give them different heights for example this one to be three meters, I'm going to extrude these shapes, the first shape that I got is this and then I extrude these shapes in this side with height of 3 meters].

M22 [the other side I'm going to make it higher], extrude

M23 [So I'm going to draw the roof of this unit], pick up some points, create the roof surface, [it doesn't work].

M24 [I'm going to change the height of this side and make it the same].

M25 Draw triangles, extrude them and create the roof: [I'm going to create the last one].

M26 Copy the site outline

M27 [possibly for this I'm going to try.. the first example is a sort of extruded versions, the second is a sort of more separated objects, the third one I'm thinking in making it a sort of quite enclosed space so..3 rectangles connected together]

M28 draw a rectangle and cut some regular geometric shapes, became irregular U shape,

M29 move it toward the corner, modify the shape.

M30 give it a thickness.

M31 divide the wall into units.

M32 [So this space is going to be a celebration area and this one is the hall and service area].

M33 He started to extrude the panels, create the window openings.

M34 Draw the roof as one part.

M35 [in fact I have changed my mind about the shape from the top, I'm going to, I will create these as separate sorts of entities], create the roof as separated rectangular parts, leave gabs between them.

M36 [We can add some more details; add bars to the side facade of the entrance. Copy and move them to the other side]. Add it to the front, delete it.

M37 Extend the roof surface over the entry opening

M38 Copy and move the bars to the other volumes, modify their intersection with the other bars.

Group D- Participant R2

M1 [We have these two axes; pedestrian and main, we make an entrance lobby as simple square].

M2 [I think this corner of the site could be developed, it might be good location for the permanent exhibition], draw a rectangle and raise it up.

M3 Move the entrance lobby to be close to main hall.

M4 Create the temporary hall.

M5 [The outdoor display will be this rectangle area, just to give it a present, rise it half meter up].

M6 Create a copy of it to the storage.

[Both of exhibition halls have an access for vehicles].

M7 [May be we split the storage into two volumes].

M8 [We can extrude the pedestrian passage].

M9 [So we have one entrance, which is centric to the other volumes, affords the outdoor display. Maybe this entrance could afford some views as well].

M10 [Lift up one of the storage volumes forming a bridge that connects the two display halls and one can walk under it to reach the entrance].

M11 Create a link between the two exhibitions for the public.

M12 Move the outdoor display area and attached it with the entrance lobby.

M13 Modify the other storage volume to fit with the entrance lobby.

M14 [I'm just trying to bring some more light to this entrance].

M15 [widening the axis].. by cutting part of the temporary hall and modify the volume.

M16 Modify the permanent hall:[So we have this walking axis to the other side].

Turn on the shadow, save.

M17 [Option two I'm thinking about this axis, I think from slightly different direction may be in term of considering lifting the volumes].

M18 Draw a simple volume for the main exhibition.

M19 Draw another rectangle for temporary display.

M20 Draw a rectangular yard for the outdoor display.

M21 [Add one more volume for the storage and another one for lobby].

M22 Modify the main hall and the temporary hall:[bring the storage near the temporary hall].

M23 [Try to push and lift of these volumes 3 meters up].

M24 Move the whole composition across the site.

M25 Put the entrance at the middle of the building underneath the elevated halls connecting them together put the storage underneath the hall. Rearrange the composition.

M26 [May be I put this outdoor space under this hall]. Modify its location.

M27 [So we have these elevated display areas, what could potentially support them?]

M28 [We have the storage area, we can break it into two units].

M29 [It seems they have been drifted to the far corner, I want to pull them back towards the centre].

M30 [So we've got an entrance from this side, which provides quick access to this hall, then to the service storage....Maybe we just turn this entrance around the service area].

M31 [so I will hide the elevated galleries, I'm just going on the way to create a curved volume].

M32 modify its form...[I think we have this shape (almost L shape)].

M33 switch on the hided galleries, [so we have boxes, maybe we just work with height].

M34 Modify the connection edges,[it will add something].

M35 pull the end surface of the gallery…[to change the shape, to keep consistency with other geometries].

M36 [I think just bring this end up for each gallery].

M37 [so we have to connect them with the storage...umm I think just push and pull the storage, I think it is ok]

M38 Manipulate the other end, cut the edge, Push and pull the second storage space.

M39 Take a look at the open area that touches the ground: [it is quite nice defined by these service storages; it is a kind of in-out space].

M40 [Pull the building a bit to this corner, this shape of the entrance is ok with the corner]. Add human figures to feel the scale. Save.

M41 [So what is the third idea that I could explore with this site? So the three exhibits, the circulation joints and the storage area supporting them, let's gets the shapes].

M42 Create simple shapes for the exhibitions.

M43 Create the storages and entrance. Colour them.

M44 [How to read these, for the moment, I will attach each of the exhibitions with storage area].

M45 [This entrance let's put it central].

M46 [May be it is better to put the storages to the back], rearrange the composition.

M47 [Because of this pedestrian axis may be this will be a foreyard].

M48 Manipulate the entrance location and its connection with the halls. [It should be away from that last square area].

M49 [This (small gap between the exhibitions) is dark, it just needs to be wider]. Push and pull the arrangement.

M50 [It would be quite nice to keep this space, it has a potential to be a nice court yard surrounded by the volumes].

M51 [Ehhh, what if we sloped down this to connect...the storage will be added. We have entrance flight between two halls, this is the pedestrian axis].

M52 Change the height of the hall,[just to break up].

M53 [Twist its direction to south where the light can come here, twist the other hall, it will be nice to have this overlap] (the two halls overlapped the entrance volume).

M54 [So where to use this overlap again, these storages], overlap them with the halls.

M55 [The shape of the main hall is scary].

M56 Manipulate the outdoor display area. Manipulate the storage area, [may be push back this edge].

M57 [An opening is created towards the courtyard because of the push], return to previous situation.

M58 [Emmm .. I will try to concentrate here (the created opening in previous move).. create centric opening in the hall's back facade to link it with the court yard I'm thinking in tunnel and passage].

M59 [this is (the hall) very large, let's make this opening attractive], modify its shape.

M60 [break it into tunnels, keep on these incisions to this side].

M61 [Punch them through the exhibition volume to that side].

M62 modify their size and shapes.

M63 Manipulate the storage connection with the hall.

M64 [Just be playing with the passages. what if we use them for displaying],(In the meeting he said :they balance this massive hall) .

M65 [put some aspiration, tilt their ceilings, use their walls for displaying art].

M66 [What will be with this area? Let's put some shadowing so some sun shine will come through].

M67 [It will be nice to use the same language on the other hall for unity].

M68 [Let's add some slots to roof].

M69 Modify the entrance volume. Save.

Group D- M2

M1 [In order to get an idea of the size I can take up on the site, I'm going to draw just a volume will be indicating to the volume I can take up]. Draw a rectangle and create the 3D. Its location in the site is fixed.

M2 [Currently it is quite nice because it is connecting the street from the pedestrian entrance to the site and already gives an access, but the main entrance is supposed to be here (another direction) so I do like to do something about it].

M3 [May be I will keep the pedestrian entrance... the entrance lobby which I can use for that. May be I will split the lobby, I will cut this part, I do like to rearrange it, I'm going to cut it off a part].

M4 [What I'm thinking now is that this will be the pedestrian entrance and this will be the main, let's make the door], draw the door...

M5 [ammm actually let's do both entrances at the corner. (a corner volume with two entrances)… I want to make it glass…..Add transparency.]

M6 [I have the rest of space to play with in terms of the requirements of the brief. So the second important part will be the permanent display hall. It might be quite nice to think of all the displaying spaces; the permanent, the temporary and the outdoor displaying yard, together and to be able to reaching them easily from this entrance].

M7 Draw the temporary display hall.

M8 [The main display hall I think it should face the main road. So I'm going to use this space, I think it would be so nice to turn it around the outdoor exhibition space].

M9 [Just in terms of layout that fits together nicely, it would be quite nice to be able to walk from the entrance into the outdoor area, so I'm going to cut up a little bit this here to give easy access to outdoor display area].

M10 [let's colour these different spaces, so I got this space for outdoor display and leave the other space for the storage. I do not think this is a proper place for storage, but let's leave it just right now].

M11 [So this outdoor display is surrounded by other volumes, maybe I can make it bigger, I think it is quite nice place, I would like to expose the potential and have it as a very nice part of the whole design but for now let's focus on the main areas].

M12 [I'm going to pick this area and make it slightly higher than the rest, the height of the main hall became bigger; It will be the first thing to see from this area (pedestrian walk)].

M13 [It is nice to have a high ceiling for the entrance and lobby as well, but it would be quite nice to walk into something higher for the exhibition spaces. Probably I will come to this idea later but now I'm going to save it as a first copy].

M14 [So this is the second design I'm going to start with, in previous design I did I do like the idea of the outdoor displaying yard, this time instead of starting with the lobby I will start with the displaying yard, draw a rectangle shape].

M15 [I'm going to build around this area, for some clarity I'm going to give it green. (second version of the first idea)].

M16 [I'm going to draw the main display hall]. Draw an L shape.

M17 [I'm going to raise it up...op.. I was to bring it up, I think it may be interesting to get down] (computer's accidental move: the computer gets it down)

M18 [Not something I thought about but it might be a kick point to have the outdoor area to be raised and the indoor area lower than the outdoor area. It can be something interesting] (create a hole).

M19 [I do like to take these walls up, rise the block up, so we have two levels for the main display hall].

M20 [May be it is better to make it transparent to make it easy to see what is going on. It might be nice to look from outside. I will think about it more back later].

M21 [Then of course we need the temporary display hall. I'm going to put it here beside the outdoor display area, which have been connected to two inside areas].

M22 [This time I decided the temporary could be lower].

[so what you got here is an interesting volumes of different levels, in which the permanent exhibition becomes down, you have the 60 meters for the outdoor display area, you've got the red temporary area].

M23 [I want to enclose the outdoor yard almost completely. I'm going to put the entrance and lobby in front of them, I'm going to make a long thin entrance lobby],

M24 [We have to add the stores. you have these lovely trees on the back of the site so maybe we are going to break it up so you can see the trees but still think it is a good place to put the storage, so maybe we have two storage areas, one here for the temporary hall, and one on the other side for the permanent hall. It may be stick out because of its place but I think it will be interesting]. Draw.

M25 [It just give an interesting field, you've got this angle, the building sticking out, you do not know what quite to expect when coming here from the entrance. Then we need one more store on this side], draw.

M26 [So now what to do to make the building look nicer, it is quite blocky, we have nice ideas of different levels, the idea of the surrounded court but I want to take them to further step. So I'm going to take a section through this direction I'm going to move it, so we can look at what is happening].

M27 [I'd like to think in this area which goes down, we have this area down, the other a bit up, I would like to raise this area up (the ground floor of the temporary hall), I will add these figures to feel the scale].

M28 [Let's go back to the plan here, we want to see people to feel welcome here, we need doors], draw a door, delete it.

M29 [So how to make this space quite welcoming, may be a lower and wider door is needed]. Draw a wider door…[in comparison to Scotland national museum where that goes underneath space].

M30 [Still these volumes are blocky; let's try to make it a little bit prettier. Probably we do not need all these walls of the permanent hall, I'm going to play with these volumes].

M31 [I will take this part to break off parts. I cut a triangle here so if u look from the entrance, it looks like that triangle saying come inside, we want to see you inside this gallery not outside].

M32 [It is a quite nice space inside this court yard area, I do not know the efforts to take this floor down, I think I can try once more time and see it, lift it up, looks much nicer from here, to look at the court..]

M33 [I think we need just part of these walls to be solid and have part of it not solid, add a clearstory window].

M34 [I said before I do like the views of these trees, let's make these solids and leave this central part not solid]. Add solid walls from the other side.

M35 [I just want to go back to the section, let's think how does the space of this temporary hall links with the space of permanent, and do we use this court yard only to link or do we use something else as well].

M36 [I will add these clearstory windows to the temporary hall].

M37 [We need to make a study about these windows how do they look like from the inside. I think I'm going to change these clearstories, change to solid], add glass parts from the court direction. [That is a lot better].

M38 [Still we have a dark edge over here, so perhaps what we would have to do is to elevate this area a little bit to catch some light I'm going to slope that window].

M39 [so you have two triangles echoing each other, so we have elements, light elements, triangular elements. I think I'm going to slope this roof, it became like a butter fly. I'm going to save it as the second idea].

M40 [I still like the idea of outdoor yard, again I will make it thinner].

M41 [I'm going to raise the landscape up to be used for displaying (instead of outdoor yard for displaying), say two meter above the ground, so when you are walking, this will be the first think to see and may the rest of the building directly attached to it this time, something behind it along its side, perhaps what you have is this display]

M42 draw a rectangle for the building.

M43 [perhaps we are going to expand this yard].

M44 [Then make a groove for the entrance, you can walk through it] , draw the door.

M45 [I will put some subjects in this yard, so this the first thing you will see an entrance feature to the gallery, and behind that you have the two main spaces, let us keep it simple, draw the permanent hall, which is quite blocky].

M46 [beside it the small exhibition hall, we can make them with different ground levels, but let us now make them with one level. Give them colours, I do like the idea of different colours].

M47 [Then we have this area for the storage, so there will be access to both halls].

[So this is much simpler design than the rest but I think it is quite practical].

M48 [Bring the door out and give it transparency].

M49 [I'm going to put trees on the site because they very much form part of the architecture].

M50 Let's make the corner less blocky, just to change the shape a little bit, round the corners.

M51[Let's make a section to see what is inside, I will take up the ground floor of the temporary hall. Ok save it].

Group D- Participant MK2

M1 [First I'm going to use the service area as anchor].

M2 [then the celebration hall is going to be an organic shape]

M3 [First is to start with a primary solid, scale, what I want just to address the corner, property and give it prominence].

[The service area, the parking to be located back, pedestrian entrance at the front].

M4 Draw a quick pedestrian entrance. [Thinking as an axis point here], Looking at the object in four ports, (a bird's eye view): [the parking at the back, roughly somewhere. Do not know how big is the service area so give it rough guide just to work with (draw the site) [So the service and park will be together at back..We may need to spread over these]

M5 Give a scale, 5 meter height for the hall, 2.5m for service area] (extruding the hall in 3D)

Rotate the views, looking at the hall,

M6 [we will start with mesh, we start with modem. smooth it out. Give them some divisions first. so coming here, start to cut it up. To see division work well, we can smooth them].

M7 [What we do to give them a lattice which is to put it as you want to give it better shape]. Change the height.

M8 [Ok just follow the computer]. He said in his report "I had planned to mould the shape into an organic one but the results from dividing the cube did not go as planned. I just followed the computer at that stage."

M9 [I want the top wider. Divide the surface into units and give order to stretch the surface].

M10 [For the service volume], changing the size,

M11 [it can be more angular geometry]

M12 (also he moves it to corner). Intersect it with hall.

M13 Started to pull the geometry a bit to make some grove (from the entrance side), keep pull it to inside.[Give the corner a prominence].

[This is.... open over here to celebration space. I'm going to free the view from there] (from side)

M14 [I want to create some access to layout the top. (further divisions of the top). Smoothen the geometry].

M15 [Cut some part from the top]

M16 Make the service area more smooth:[What we want is to address the connection between service space and hall.... I'm starting to think what like actually be].

M17 cut an opening on its surface,

M18 pull the volume up

M19 increase its height and be a bit curved corner.

M20 Start to work on the side that facing the main street. Change the divided lines. Focusing on the centre and make openings. (change the main entrance).

M21 [Continue the same language across the top], remove the previous skylights and open strips of new skylights after moving their places.

M22So [we have axis from this side. So we give it a roof]. Create this roof in other place then move it and place it just at the top of the door opening.

Looking at the interior of the hall. The openings of skylights.

M23 Looking at form from out: [What I'm going to do is to test views, and cameras, I can imagine it a person view. I should look to the corner, what I probably do is to draw a wall to one side of the building] (because there is no entry anymore).

M24 [What we can do, this side entry has now changed, It will be some kind of garden, a kind of outdoor stage. Ok this area becomes a kind of landscape area]. Looking at the whole from top:

M25 [the designer creates a landscape area or sitting]. (fixing it in place, the volumes are in mesh situation). [We can add some random shapes which can represent some art work, it doesn't really matter. Let's think about the main view].

Looking at the whole design from inside and outside:[Checking the shadow, the light. Do some test we can see the entry the skylight the frame the car parking. Save that]

[Starting the second idea]

M26 [The wall still there, the entrance should be shifted. It is ok, the parking over there, what we gona do.........., the parking covers two square here, so we can give that different material, give it green colour].

M27 [What we want to do keep that entrance, it is going to be the same colour, see the symmetry. so in terms of axis....we want to keep this open area], managing the surfaces of the site by turning the platform of the drawings and modify them from beneath:[turn off the grid, this is the wall, this is the road], again fixing everything from beneath.

M28 [Thinking in the outdoor celebration.....Keep in the axis becomes the heart of celebration].

M29 [It is bounded by this box here, the surface area of the given block site… is locked off here, we can now move it out], (he is managing it from beneath), [so we have boundaries, roads, we are going to give them colour. The service area will be kept in the back, create a cube, so as to be a boundery..]

M30 [We want to give this semi yard a kind of shape but we can try a different form of generation, we can use curves, so what we want to do first of all is, we can sweep..]

M31 [we can create...curve, flowing curve a kind of music note, we just have a curve shape, a floating surface]. (roof)

M32 [Thinking where is the anchor again], the service area, create the cube.

M33 [make it taller…a taller tower]

M34 [a kind of hanging point… it is a hanging tower]

M35 [we can slot it.. start to cut it up, we got a free standing..]

M36 [we need something to hold it up so, I'm going to create something to hold it up, go back to top view, put it..]

M37 [I'm going to spread it up].

M38 [It is a double space a kind of observatory].

M39 [we need to open ....., we will copy the same curve bring it down, role it, we can adjust it cut it there , the screen up there, we can rotate the road it can hide parking element there. We can use the same language of the ground floor] (use the curve to create the screen).

M40 [We can use it by using NURBS, we can subdivide, but it is difficult to.., we can do it in another way, lets hide that, create an entry to the car park].

M41 [We can give it a thickness. It can be a thick frame]

M42 [we do not know what's in the back, so may be it can be a landscaped area]. (changing the view to mesh and start to work)

M43 [let's start do it, some curves and cubes of piano keys].

M44 [What we can do to the facade let's create surface].

M45 [I want slight it down], (try to fix it) it becomes lower.

M46 (change mind and make it higher, it intersects the roof).

M47 (from the roof he creates the surface of the side view)

M48 [We can shoot it down, it becomes anchor or something. We can shift that].

M49 [For that chimney] (service tower)….immmmmm

M50 [we can open a door].

M51 [We can do a public stage or something].

M52 [We can add a glass wall at front] (so it can reflect the piano keys)

M53 [I'm going to give this a transparency]

Changing the view to mesh/wires

M54 [May be the reflections are too high, change the reflectivity, light, give it (come on speed up) a physical light sky, let's see what's going here using different circumstances].

M55 [Before I stand it actually am I make a physical sky or some.................... see it to be sure(the computer render it).................................]

[See that image from another side view, let us back in to see it (the computer visualize it), jump on to another one].

M56 [Prepare the setting, leaving, the axis, the car park and the small wall].

M57 [What we are going to do, I'm thinking in the multipurpose hall, someone can get in rooms, open and close, ...start cubes] (thinking of flexibility of use + multiple spaces/ fragments). In his report he wrote "I started the third without the music notion in mind as was going simply for a more Cartesian geometry and started by assembling cubes."

M58 [Place them on side, …imm]

M59 [let's start to pass cubes and see what could happen,..imm]

M60 copy and overlap the cubes, then change position and incline some of them, putting them in a linear form.

M61 Check their positions and the way they've been overlapped, calculating the number:[1,2,3…]

M62 [Locate this box across, what will happen to these boxes, (the inclined group) should be suspended].

M63 [The building is a suspended roof volume]. He said in his report "I recognized a new pattern between inside and outside, the building is a suspended roof."

M64 (locate them above and fix their connection point with the first group). [This group started to be supported].

M65 [How can they extend].(start to extend the group)

M66 [what touch to the ground can be?] Add cubes.

M67 (Add more cubes and change the position toward the ground).

M68 [Appears to touch the ground. It can be slightly up to the ground].

M69 [The question is that how do you get start to create actual space inside this place?]

M70 [So may be under side this building is actually a play ground area].

M71(add another floating box in the middle of the assemblage)

M72 [these assemblages create a shelter] (the play ground will be under it).

M73 [the service entry is still here beside the parking, may be bringing all the group together.....] (start moving the group, turning it, the left becomes right, putting it diagonally across the site and above the axis, the service area beside the parking).

M74 [Create outdoor axis… underneath] (the shelter).

M75 [What we want to do with this space is to start navigate, so get all these and start to subdivide the cubes' surfaces] (the strategy is to navigating through the cubes, by subdividing their surfaces, then delete and cut some parts of these surfaces, and penetrate the building to navigate the inside).

M76 [we start the division setting,..]

M77 [what we are going to do is trying to go through the space, we start to cut shapes, what we are going to do is going through one by one].

M78 [cut where we need actually some].

M79 [as we cut through we need some stairs here, ..immm]

M80 [The entry to the building, Initiate a journey inside the collection of boxes see what kind of spaces, thinking in what kind of functions....., outdoor functions (visualizing the view) what I can see is a random ....]

M81 [we are going through the building, this is the stair].

M82 [I cut this I do not need it. We are going up stairs we need a window here]

M83 [we will keep this here (going out looking at the box from outside). We have to subdivide the surfaces in order to cut and create the openings].

M84 [Cut this part,(giving the command), it is random selection to cutting parts I just follow the command]. In his report he said “ I had intended to subdivide the cubes into regular rectangles so I can create doorways from one to the next but the command did something unexpected by creating organic divisions and I just ran with it.”

M85 [cut here, I do not need it].

M86 [go down cut here].

M87 [going through the inside cut here, need to formulate the ground, the walking path]. (the journey path is the ground surface)

M88 [create surface, put it here,..] it becomes the ground.

M89 [cut here, will be a path].

M90 [Go up there, need another root here, in this direction, cut here], navigate.

M91 [cut here, maybe this changes the direction of path], nav.

M92 [cut here and add some elements may help in define the space]. Nav.

M93 [cut a big peace that keeps the flow and circulation].

M94 [cut, ok we reached the end so we create this tunnel], nav.

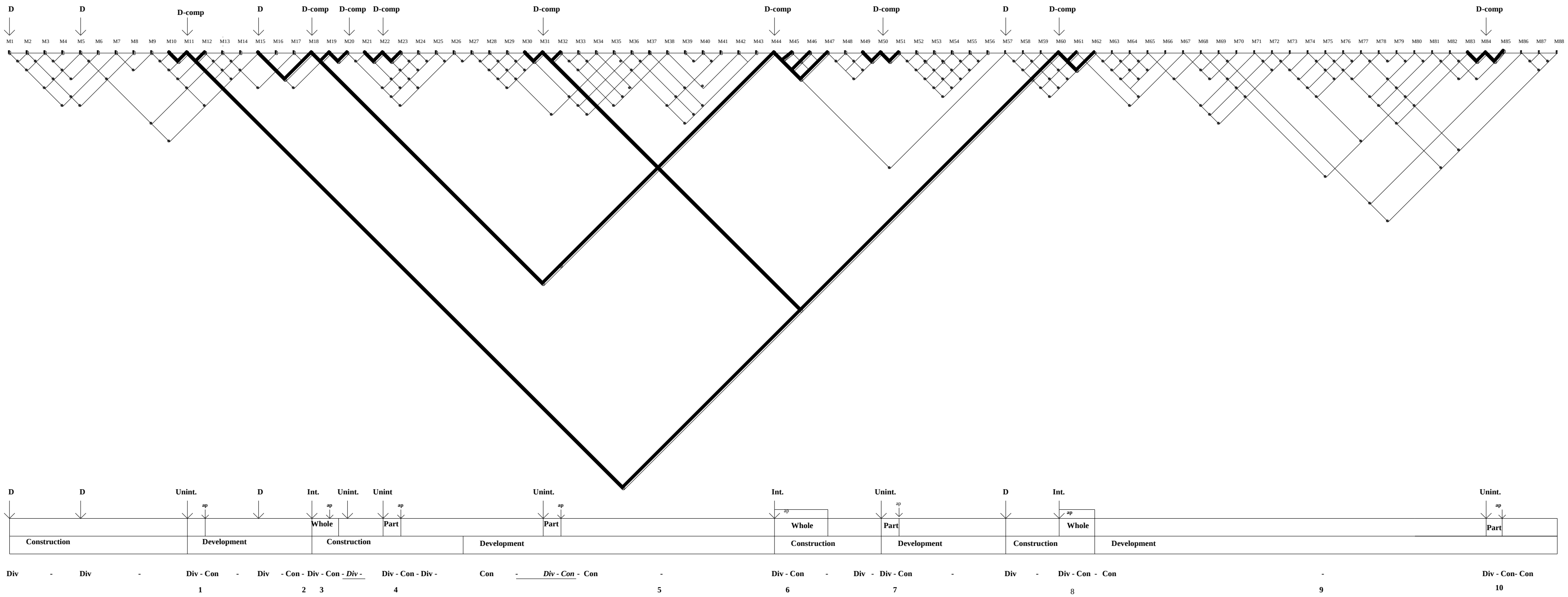
M95 [What we can do is a quick test,(trying to see these strips), where to locate these points (points of the path inside the cubes), So we can follow, we locate the cross (tool) here, we can put cross there, down there, ..the path of the curve, what we can do is create a curve, snap these points here, there, and the last one is there, this is the path the camera can follow].

M96 Create a camera, touch the path.

M97 [We can render; we can view it from different points, parking here, axis there].

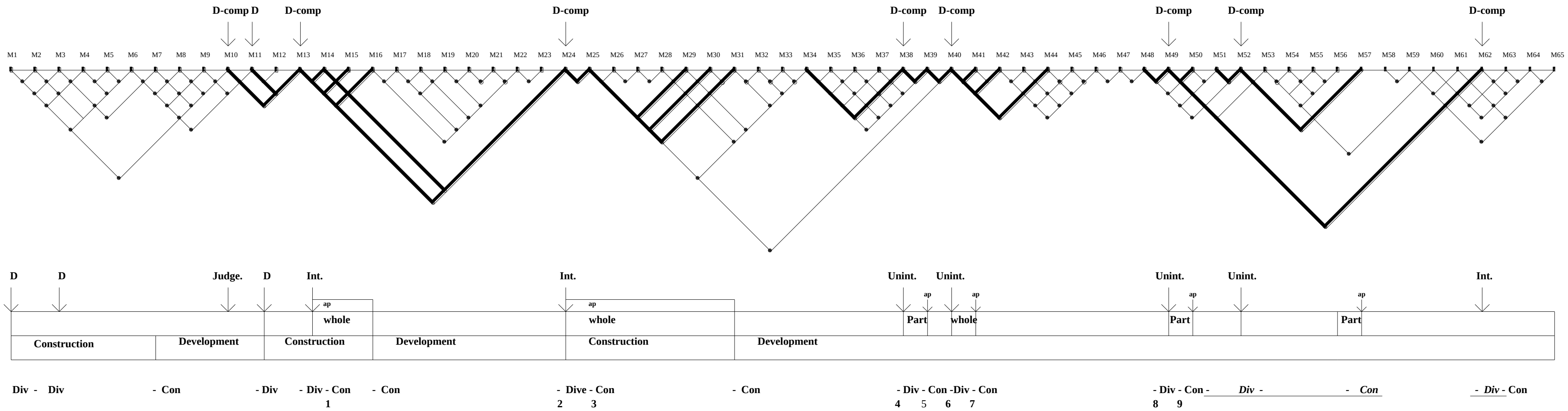
Appendix- B: Linkographies of design protocols

Group A, Participant P



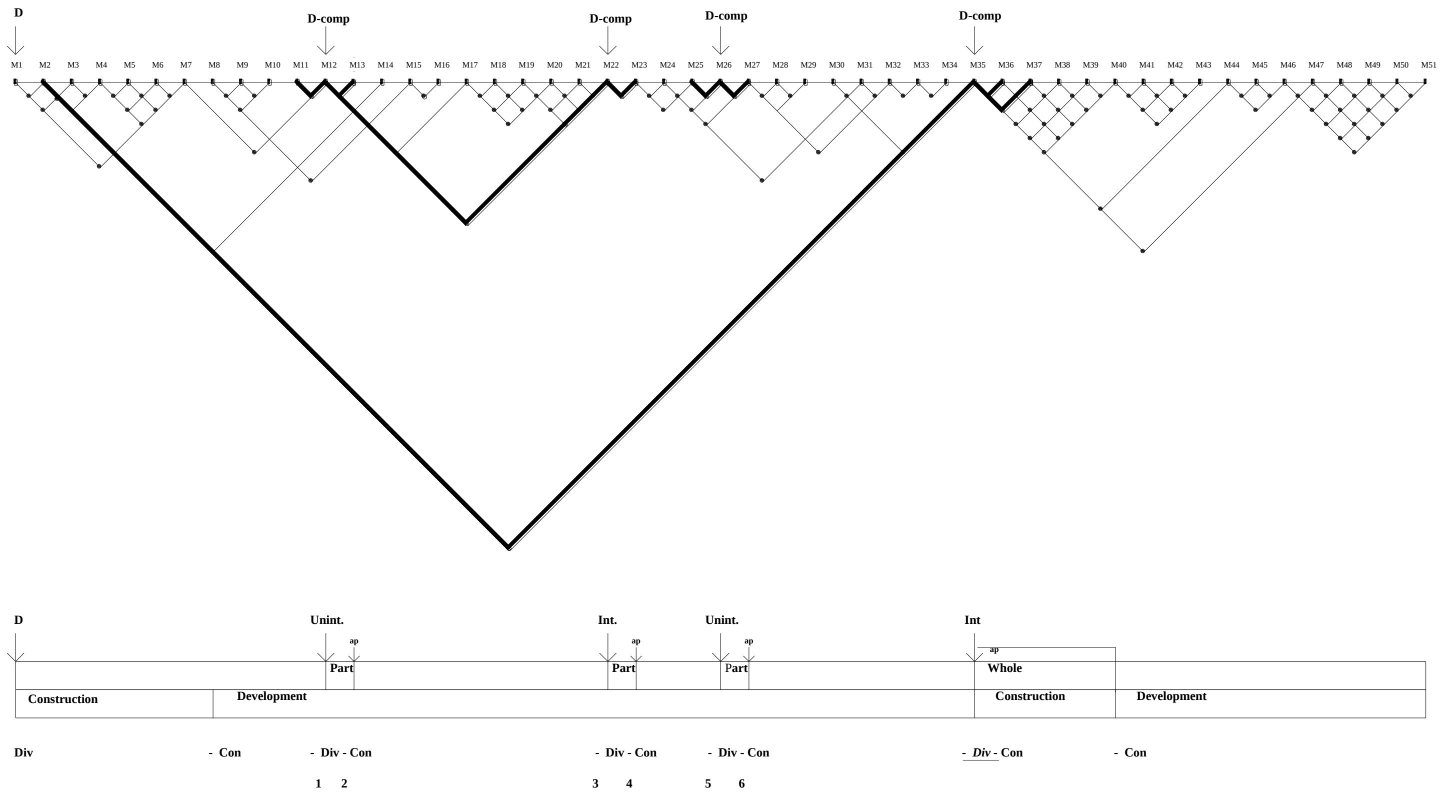
Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

Group A, Participant N



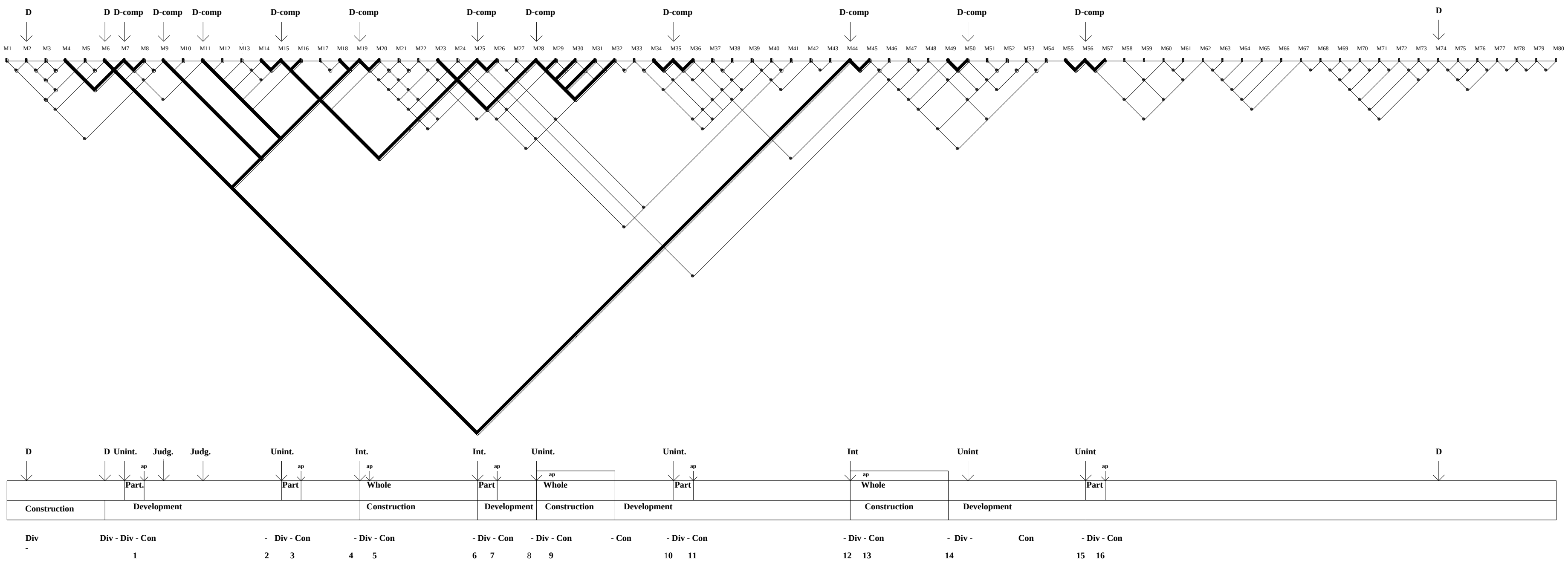
Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

Group A- Participant E1

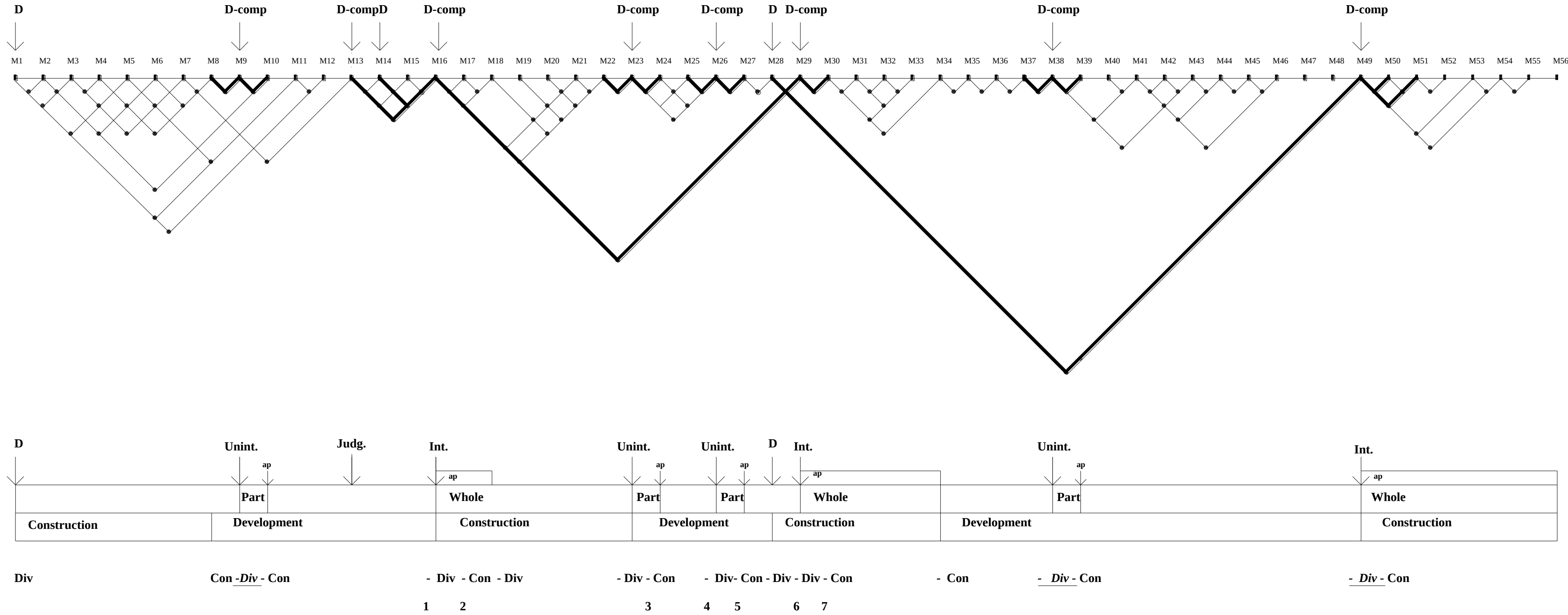


Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

Group B- Participant R1

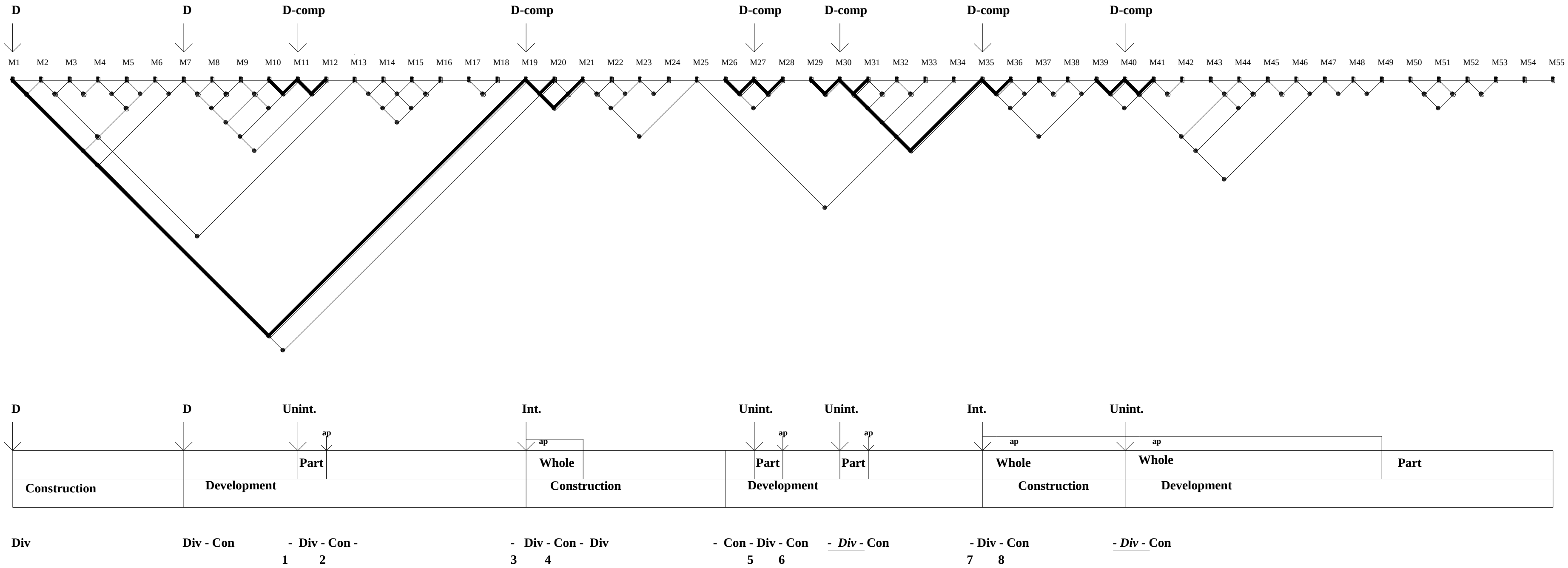


Group B- Participant S



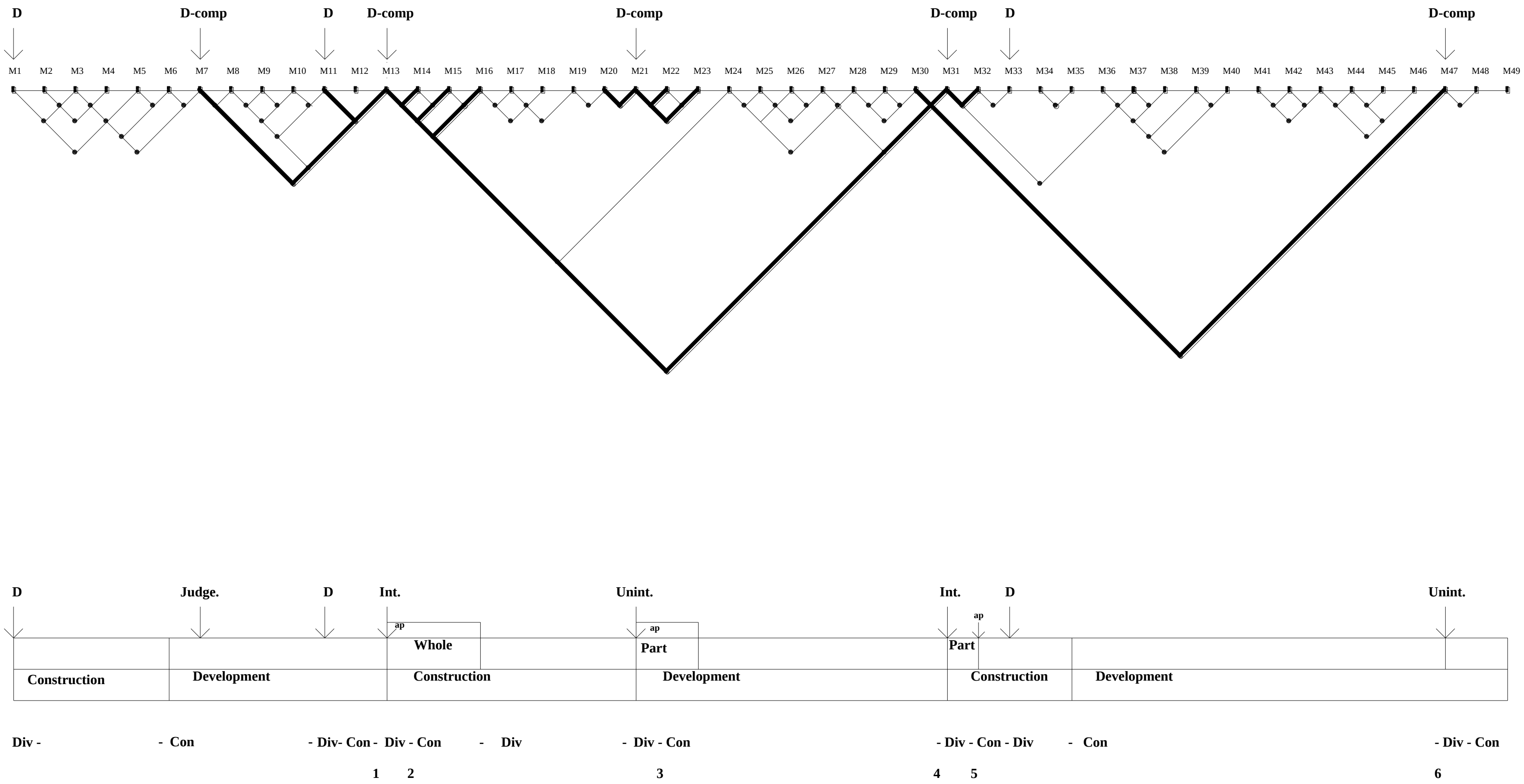
Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

Group B- Participant M1

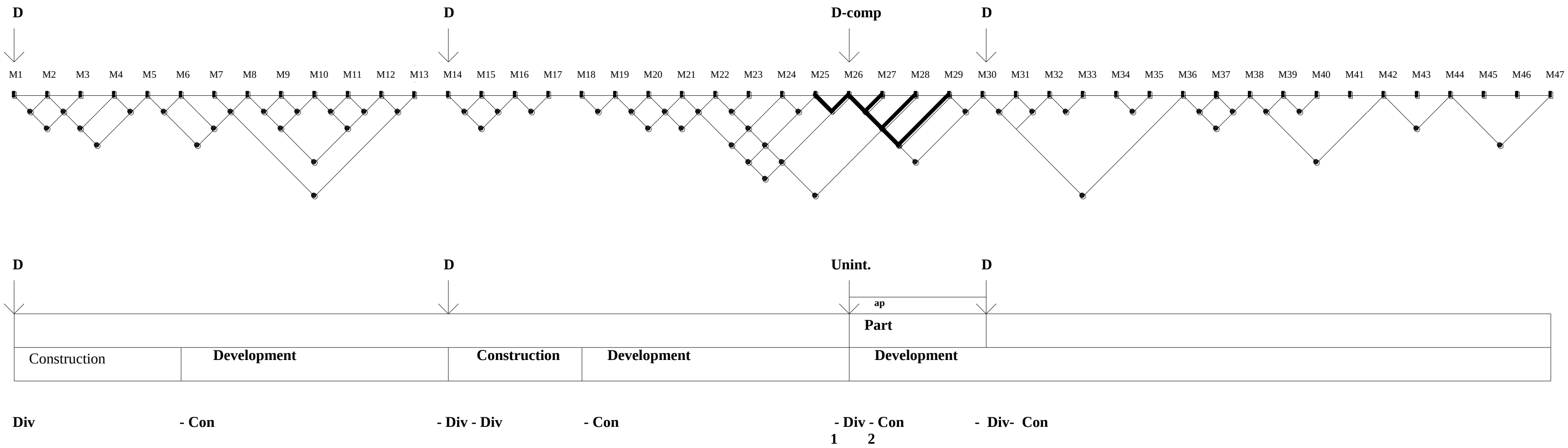


Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

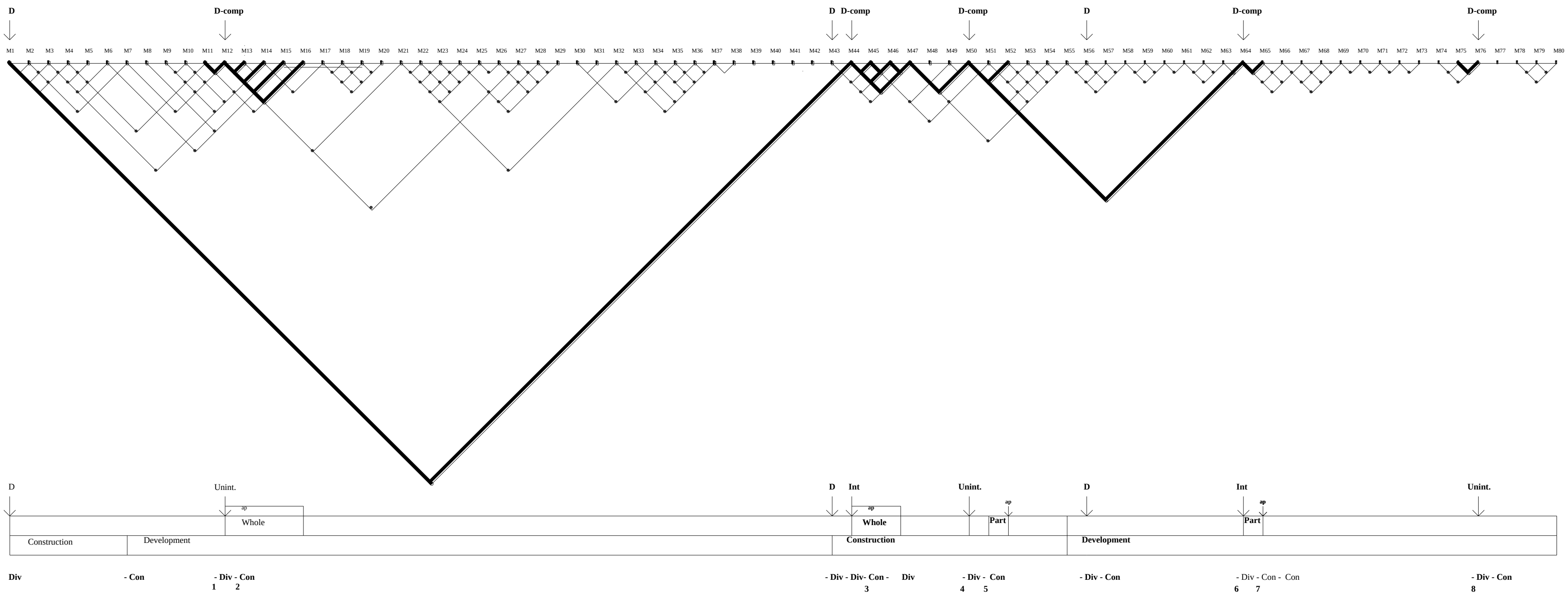
Group B- Participant A



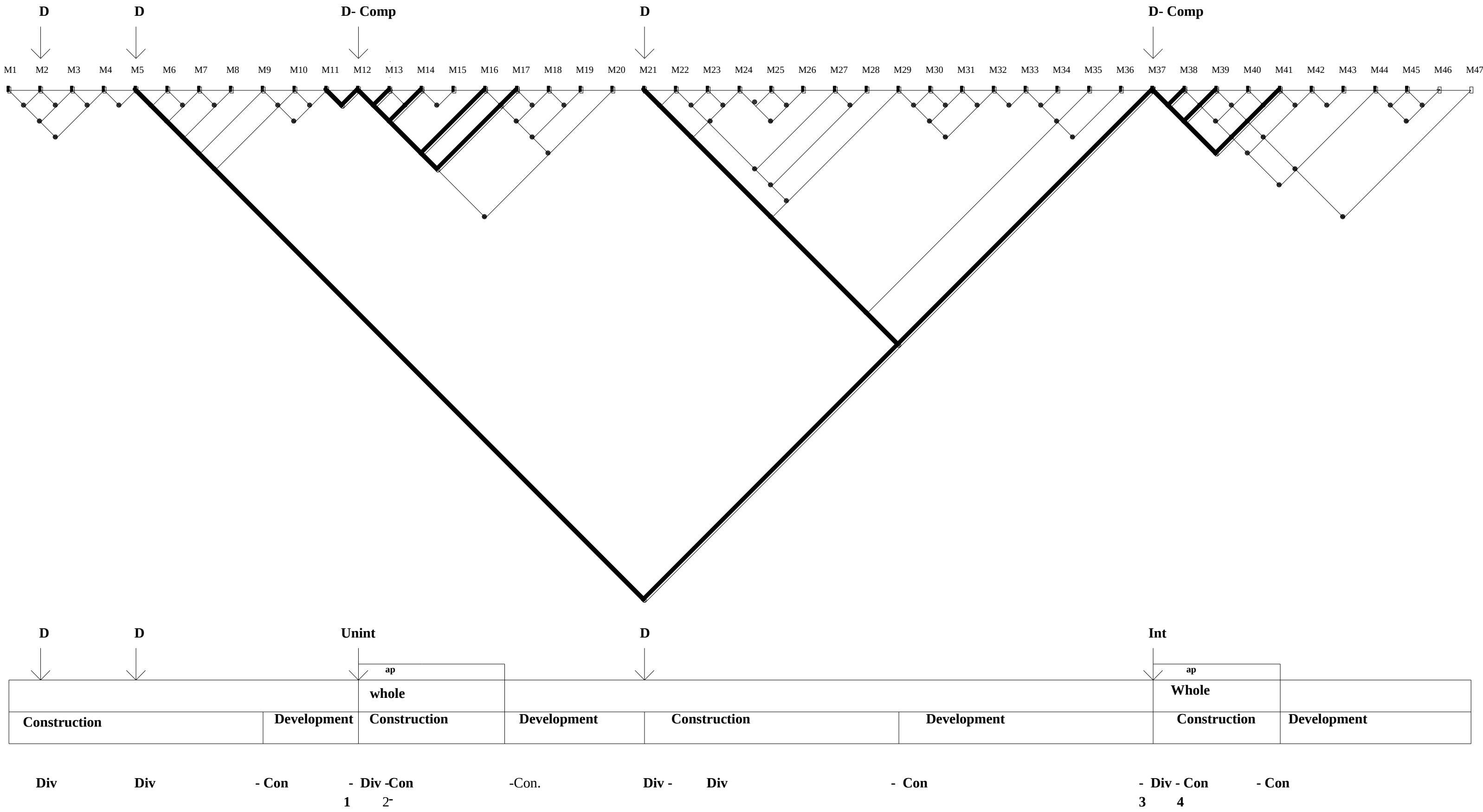
Group B- Participant T



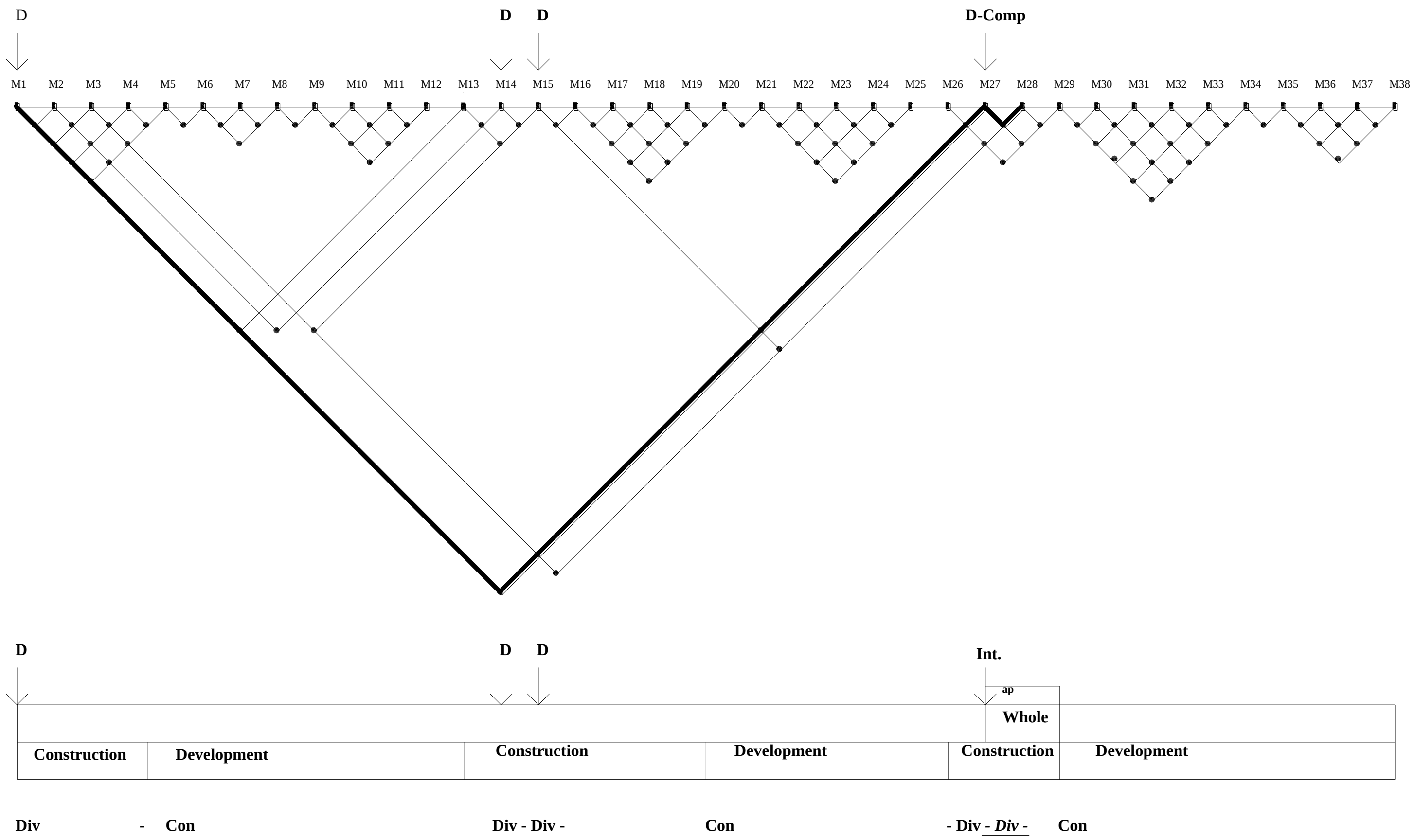
Group C- Participant MK1



Group C- Participant K

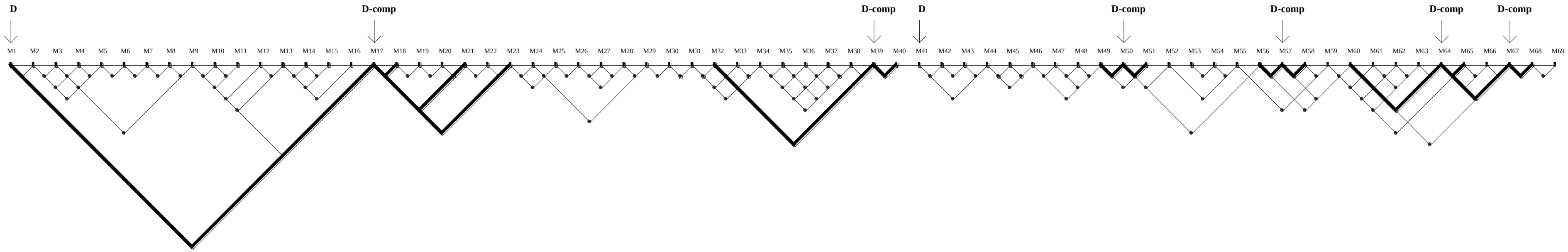


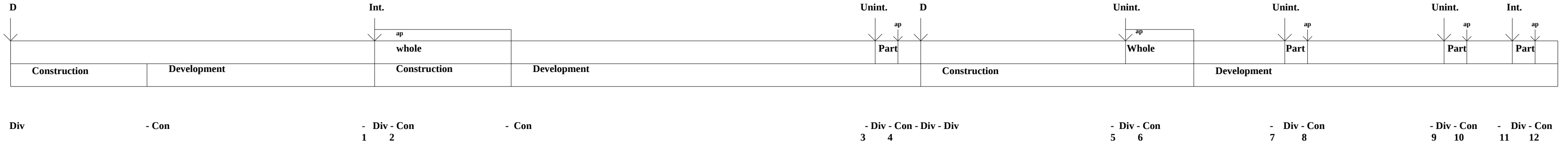
Group C- Participant E2



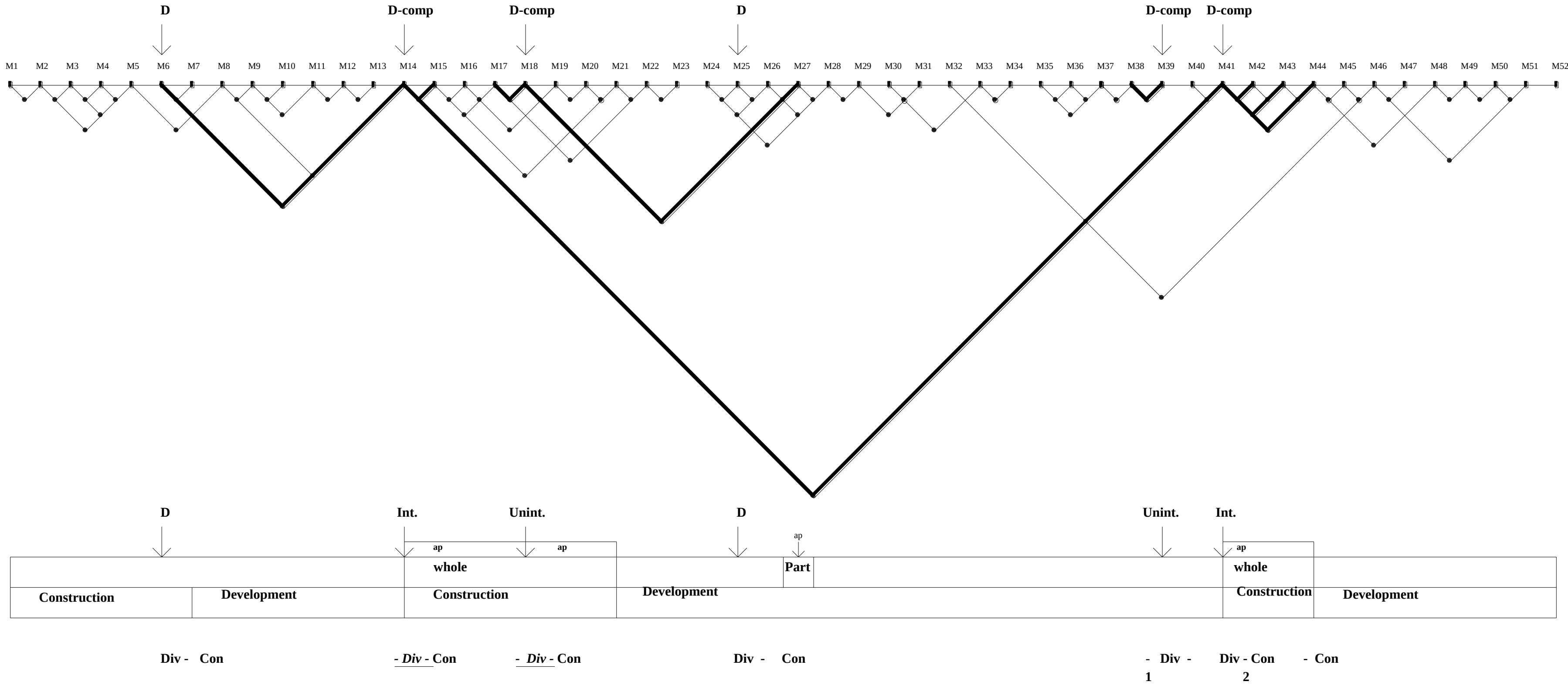
Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

Group D- Participant R2



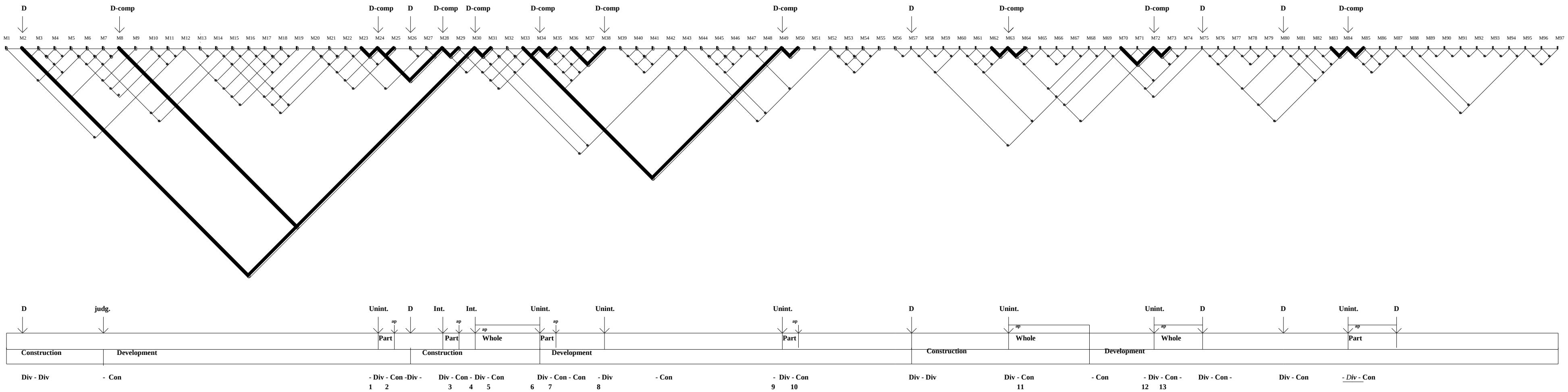


Group D- Participant M2



Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

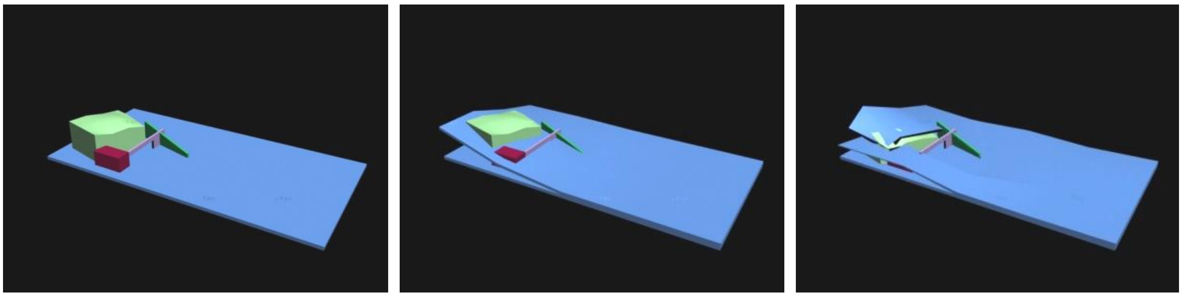
Group D- MK2

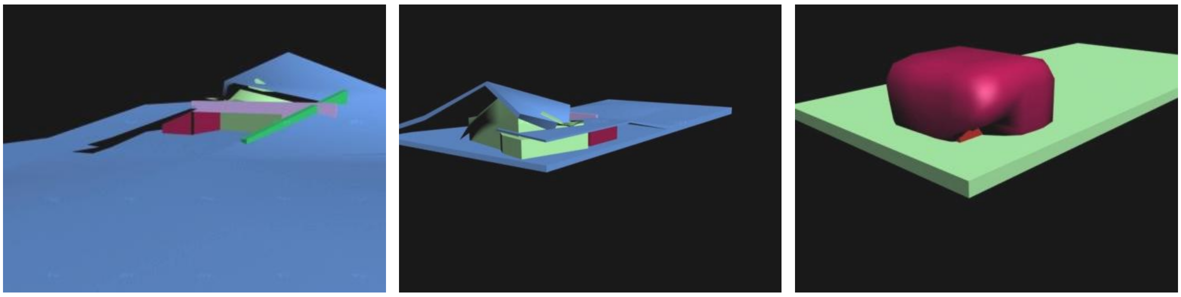


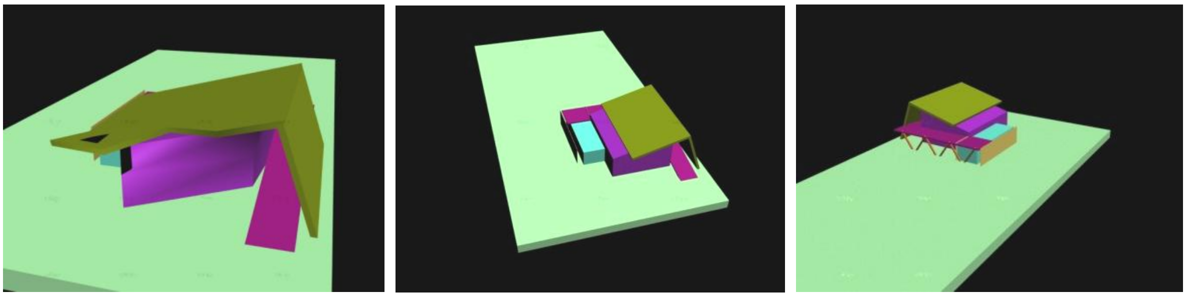
Note: the italic underlined text of Div and Con refers to computer accidents, which are excluded from final count.

Appendix - C: Participants' projects; Photos of work in progress

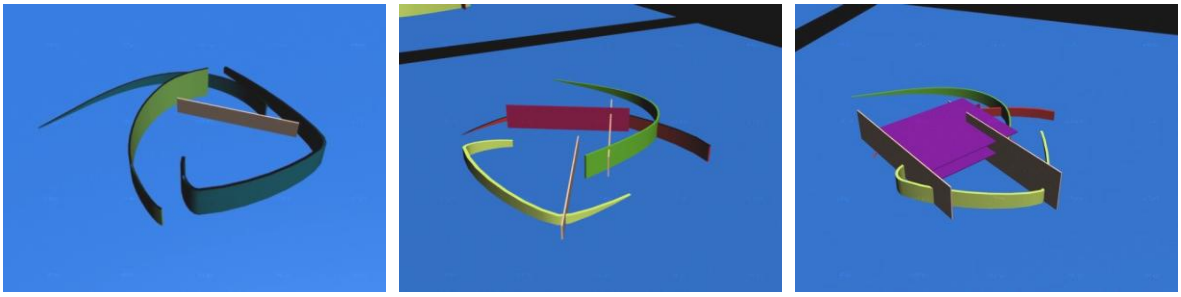
Group A- Participant P

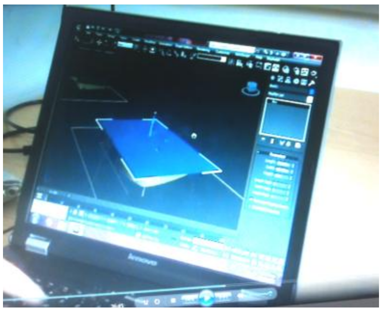
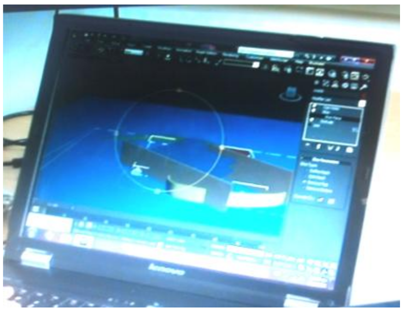
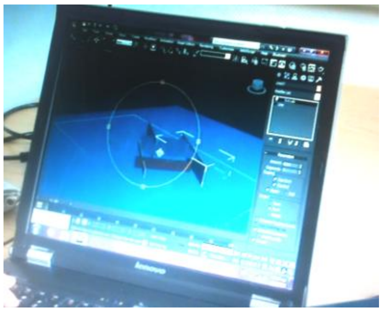
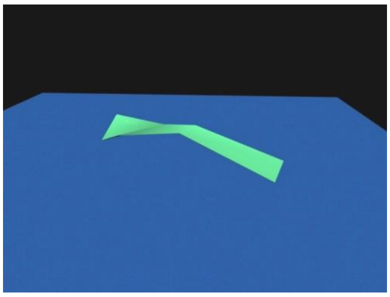
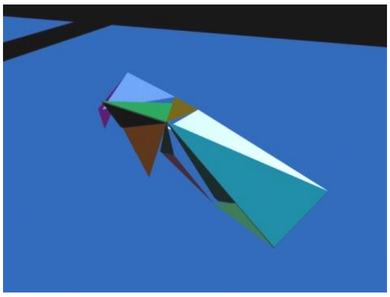
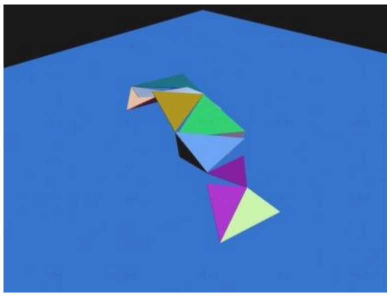




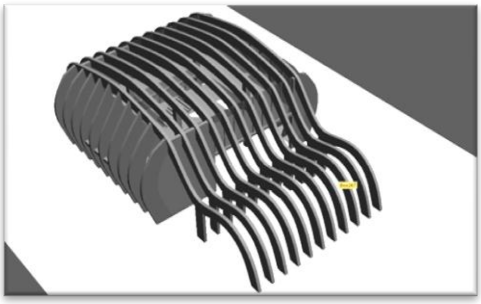
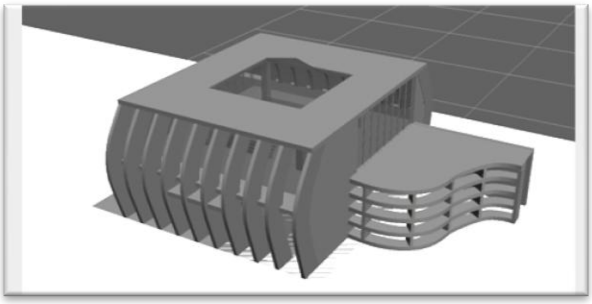
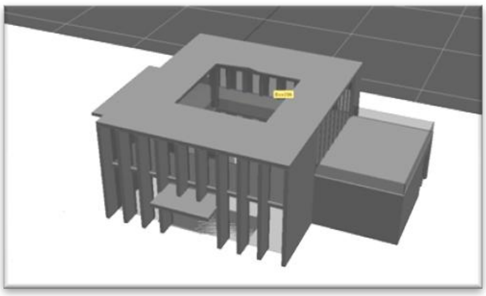
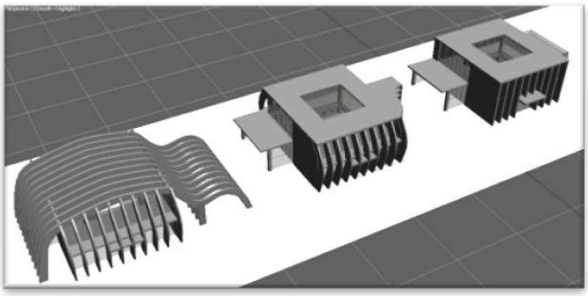


Group A- Participant N

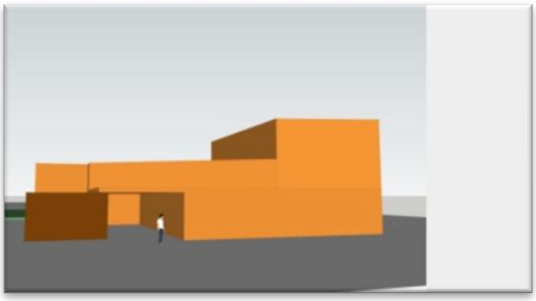


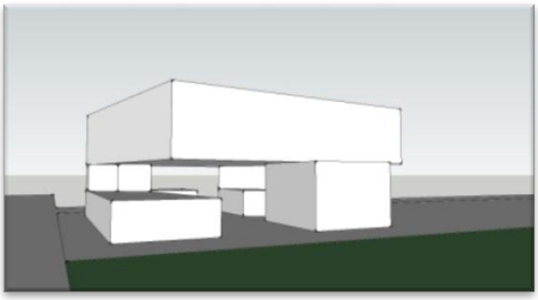







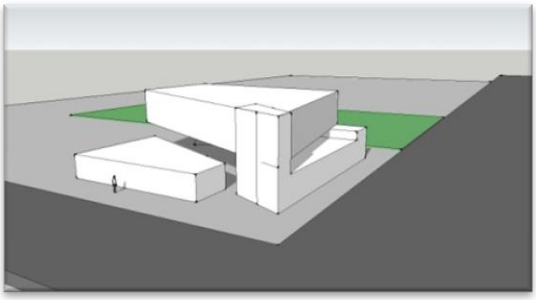
Group A- Participant E1

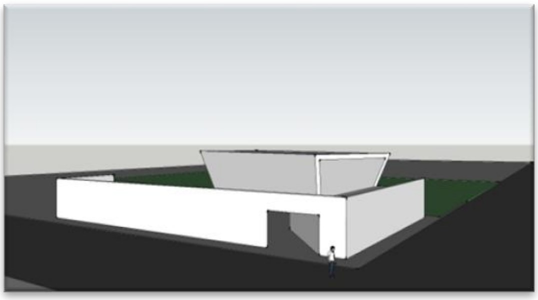





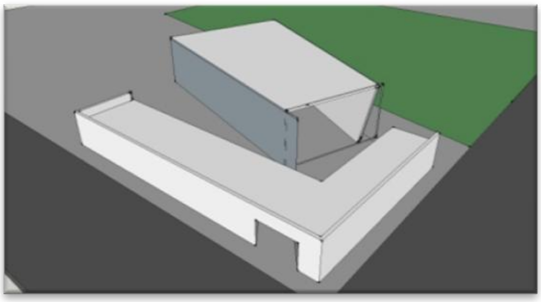
Group B- Participant R1

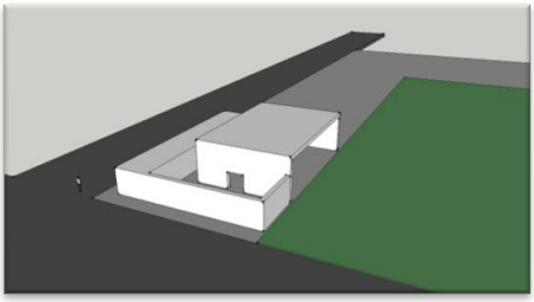


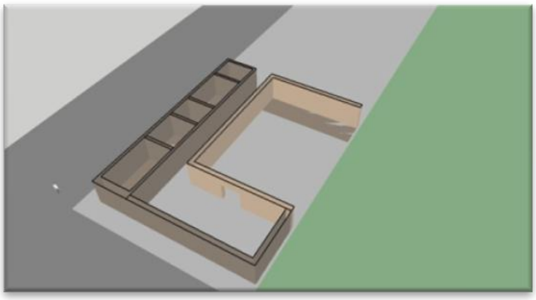




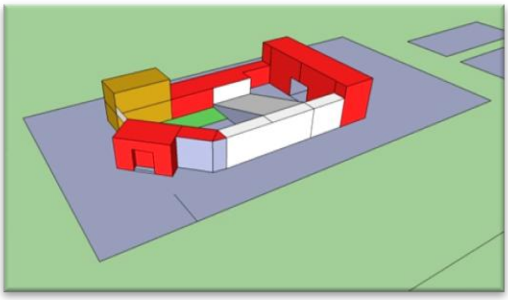


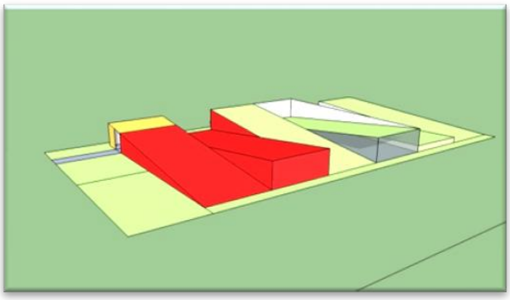


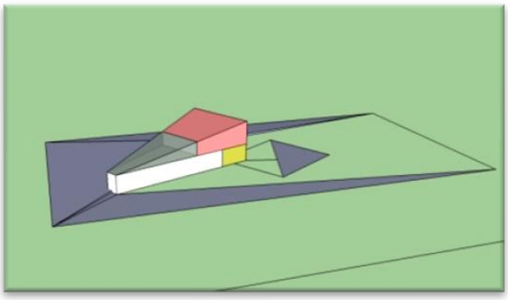


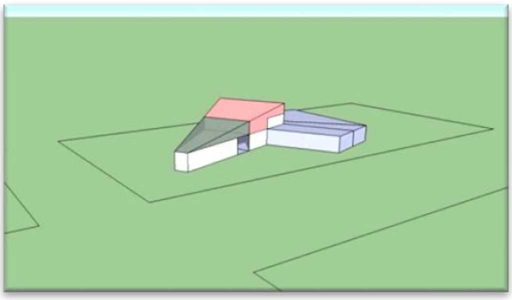


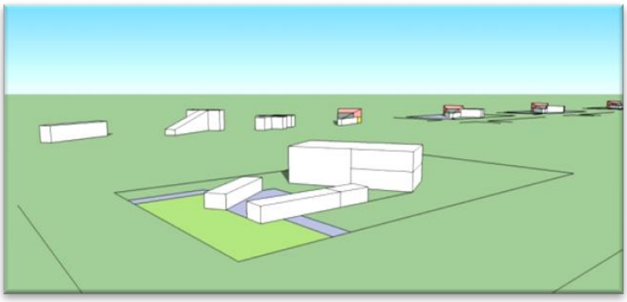
Group B- Participant S



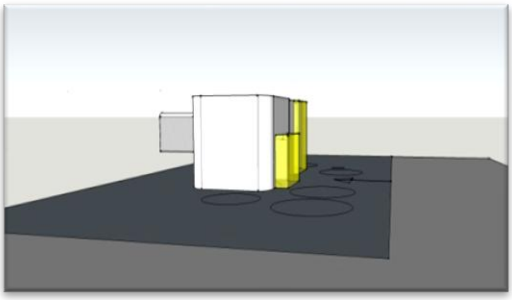


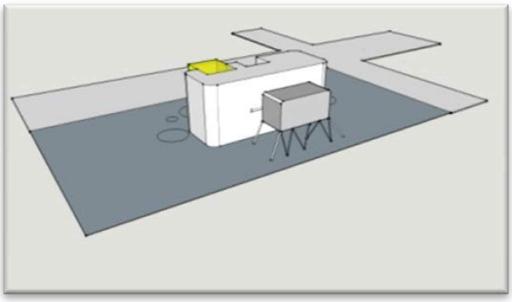
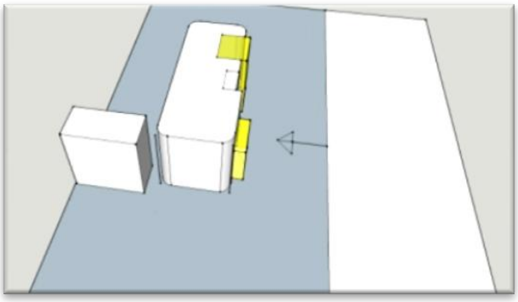
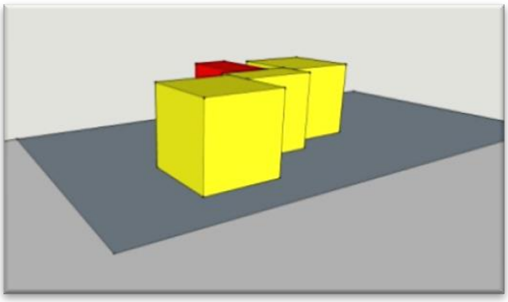
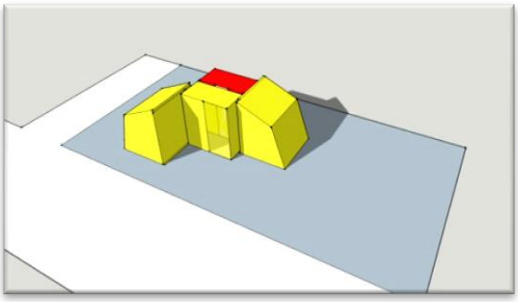
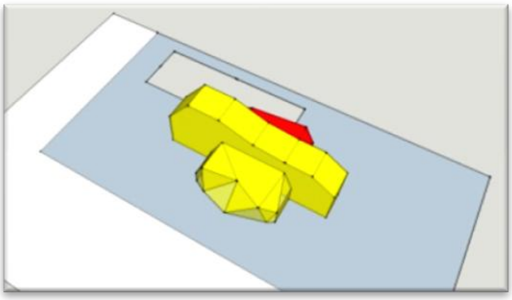
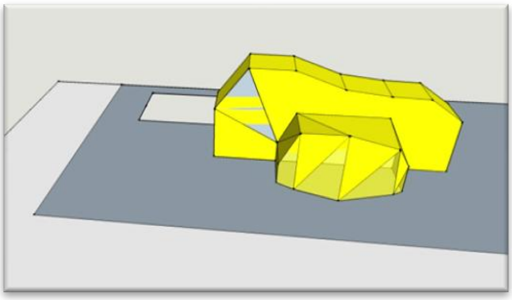
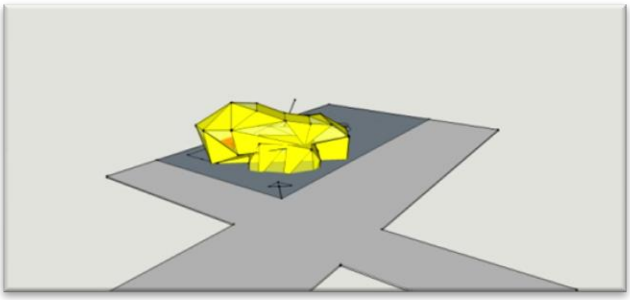




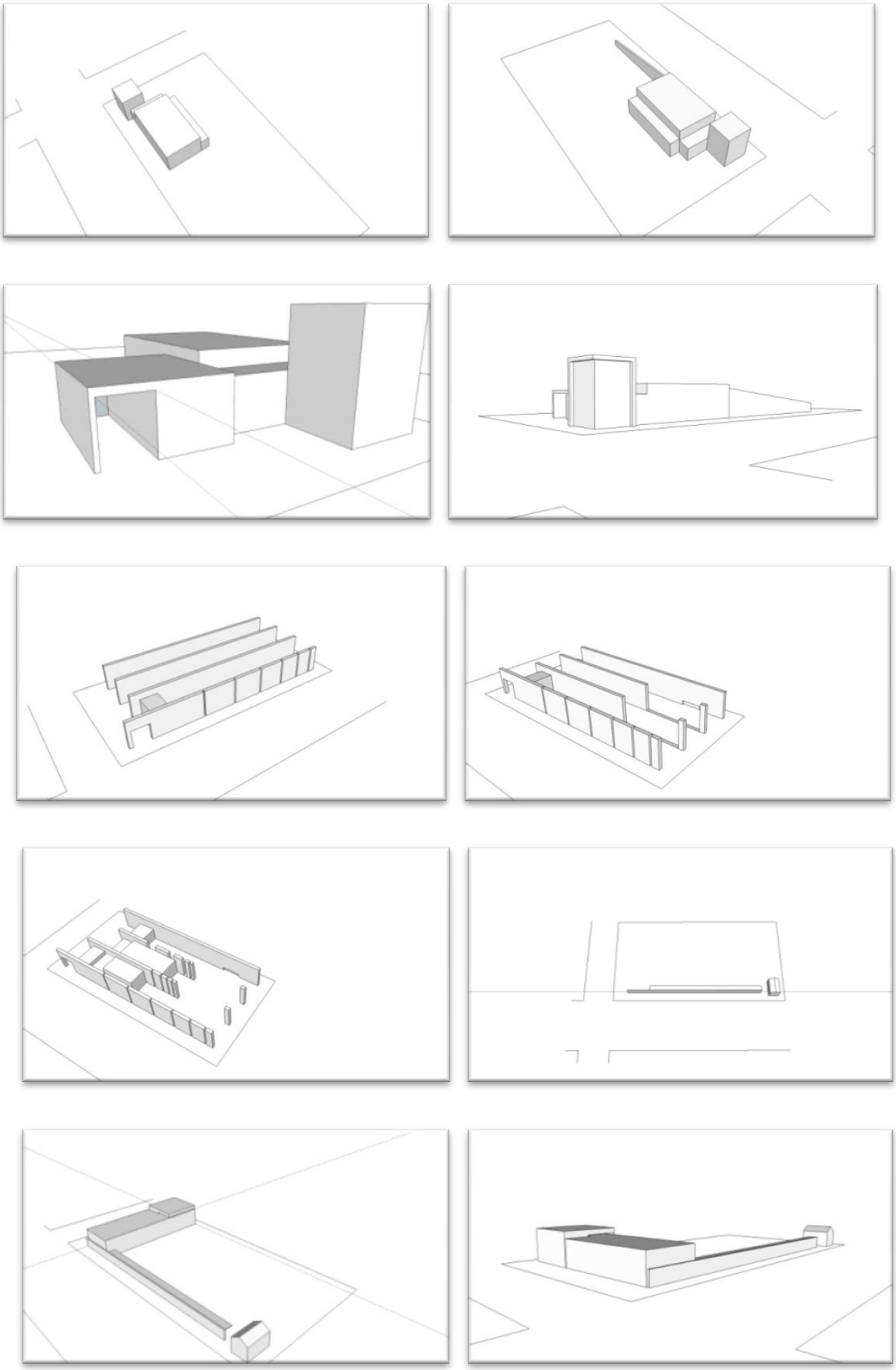


Group B- Participant M1

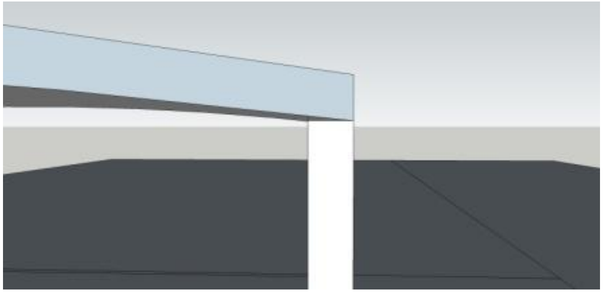
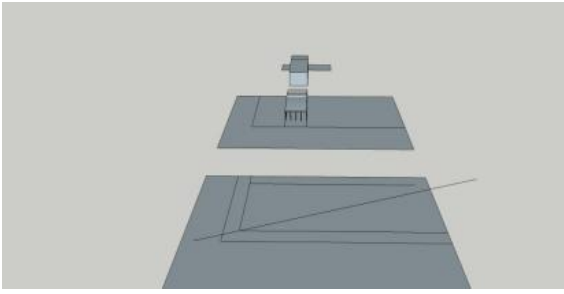
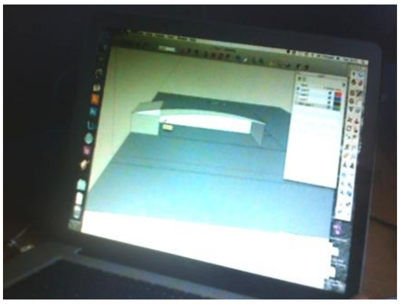
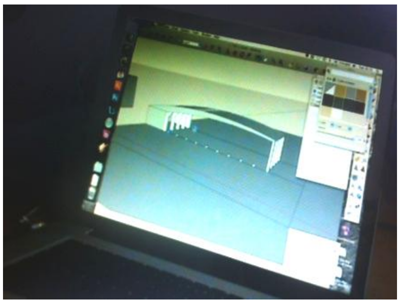
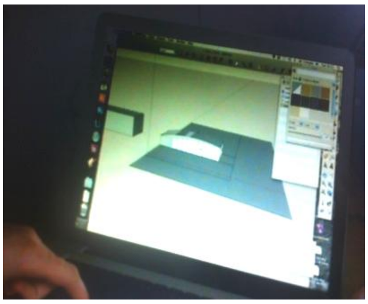
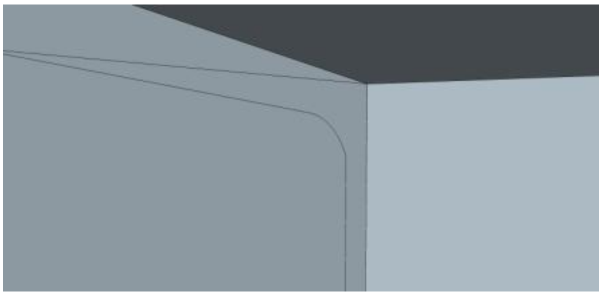
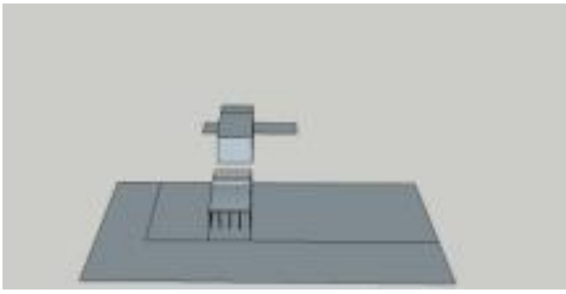
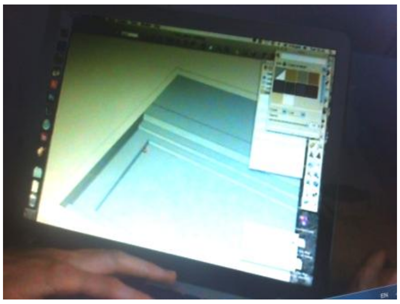
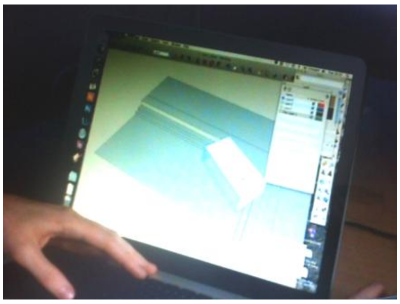
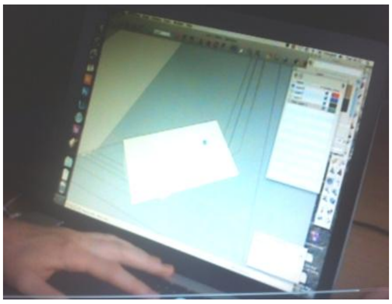
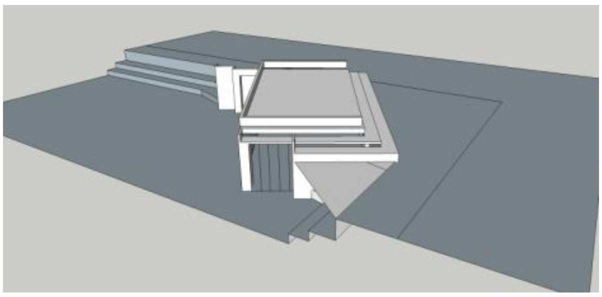
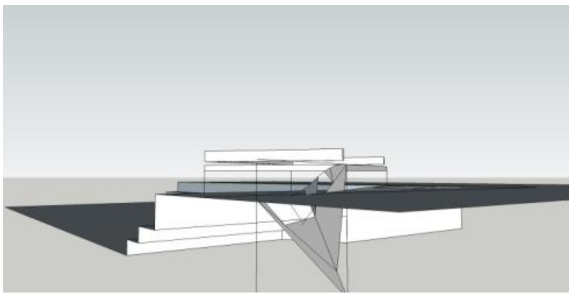


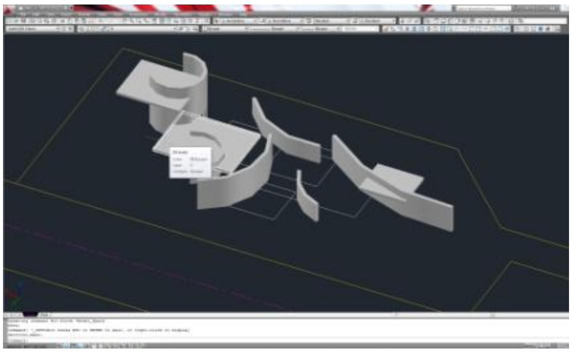
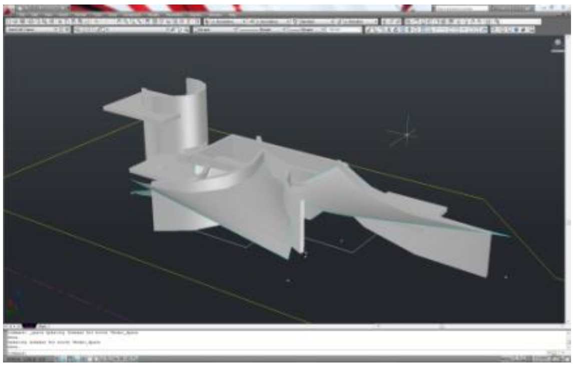
Group B- Participant A

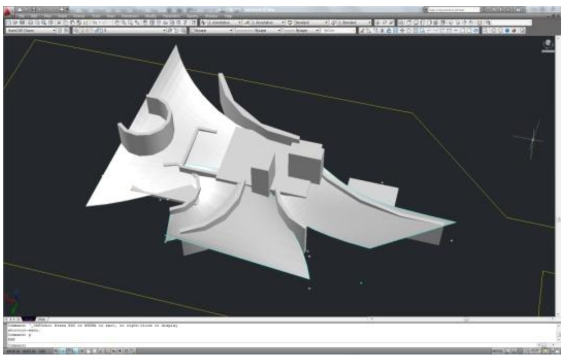
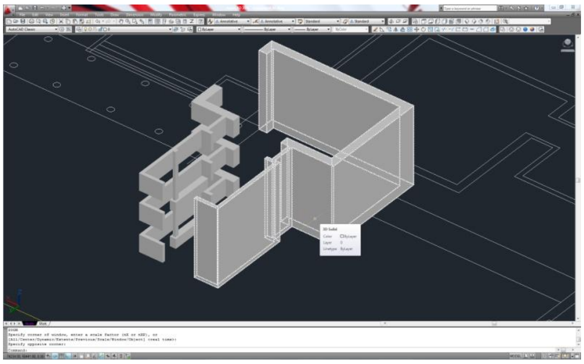
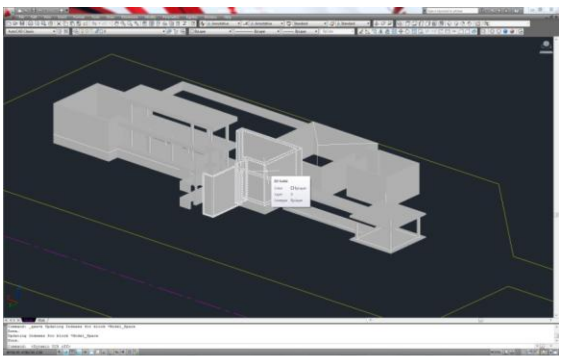
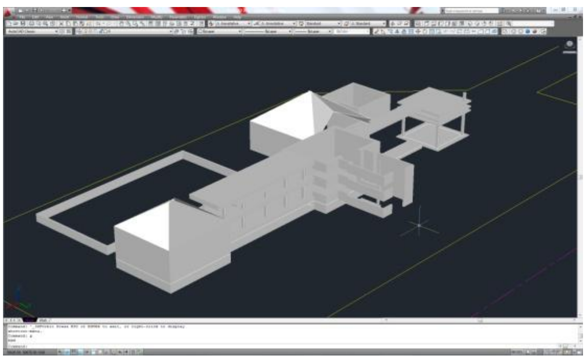


Group B- Participant T

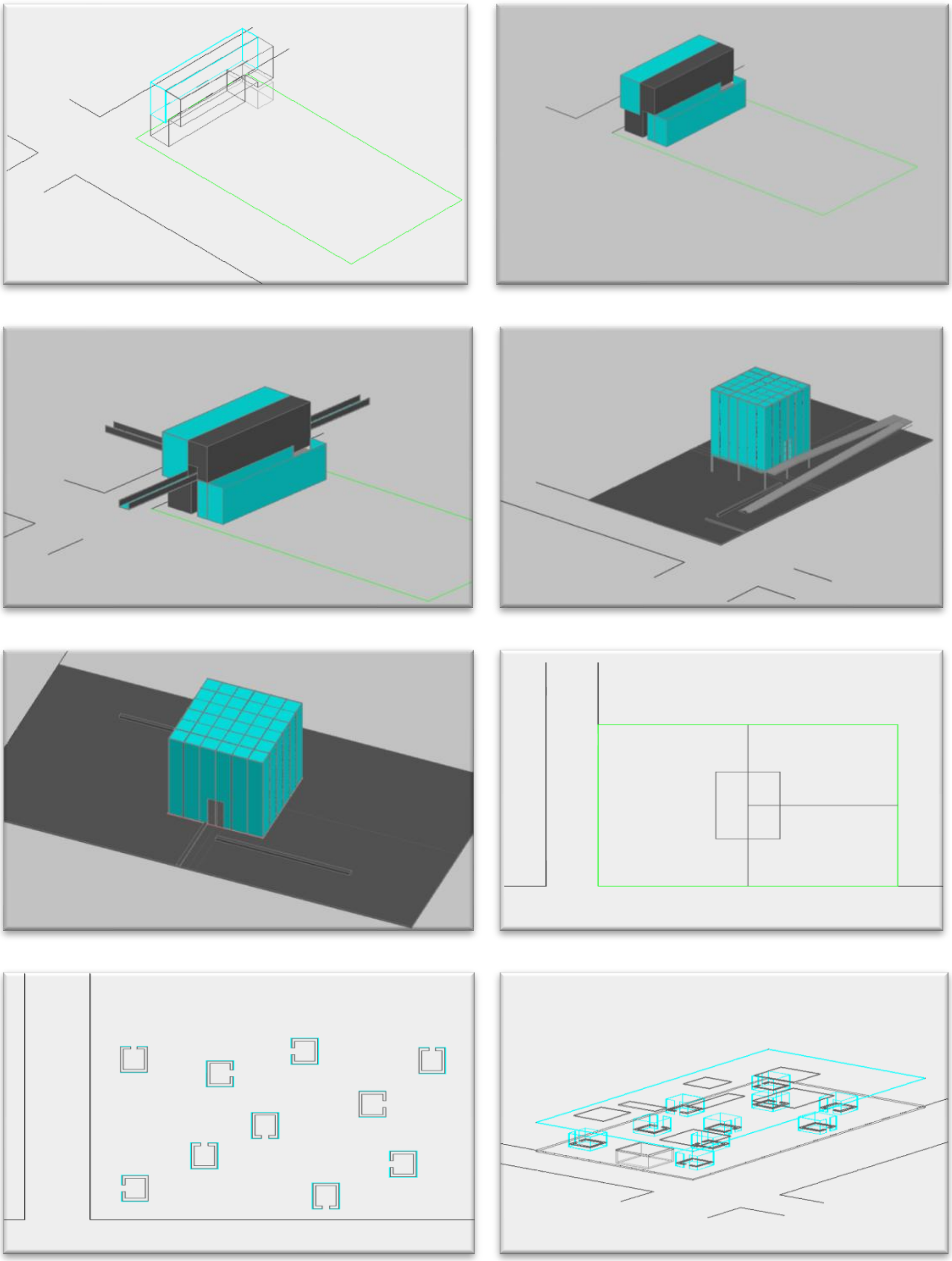













Group C- Participant MK1

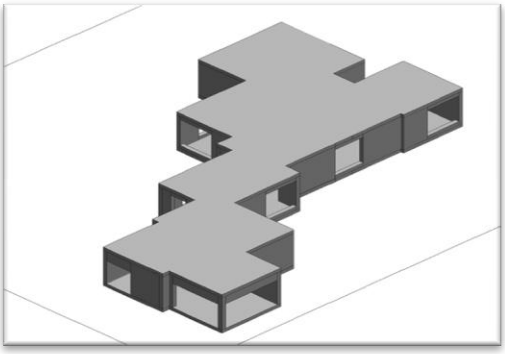
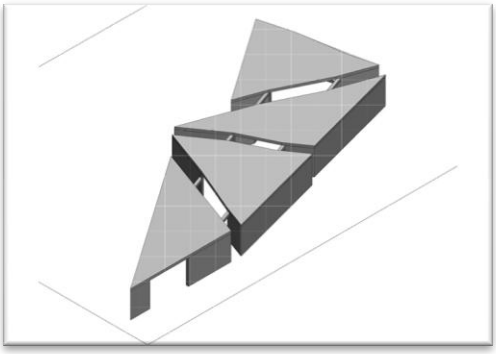
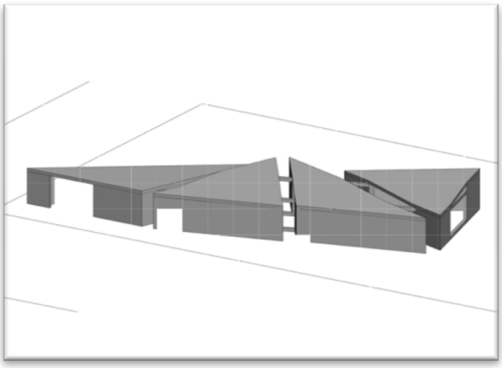
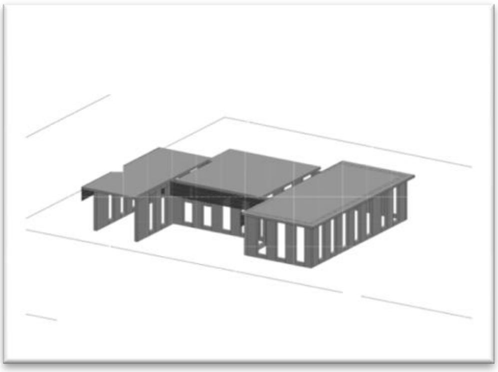




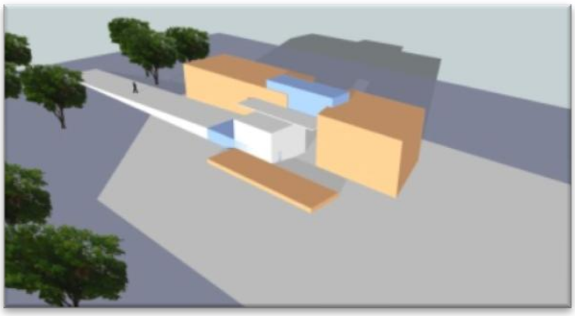
Group C- Participant K

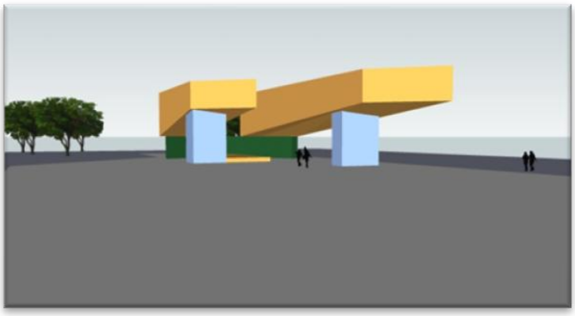
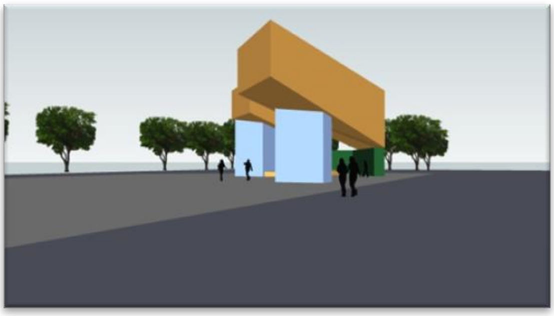


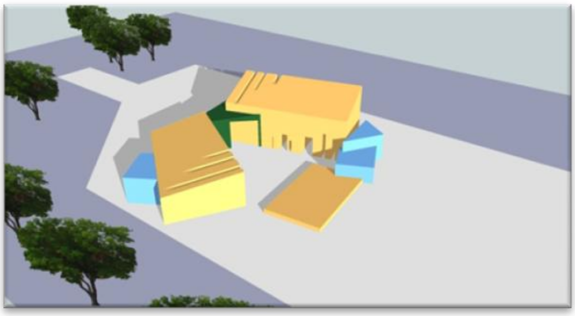
Group C- Participant E2

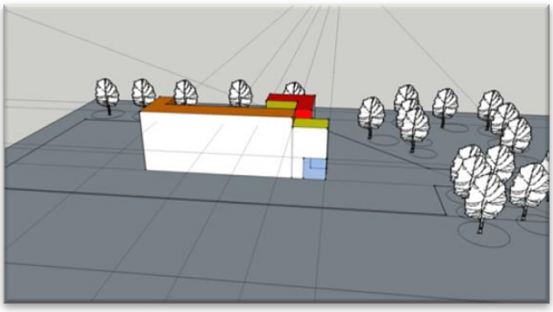
Group D- Participant R2

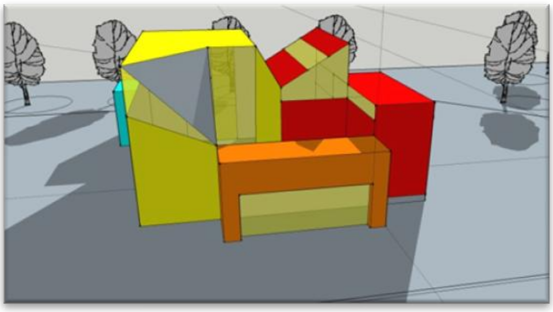


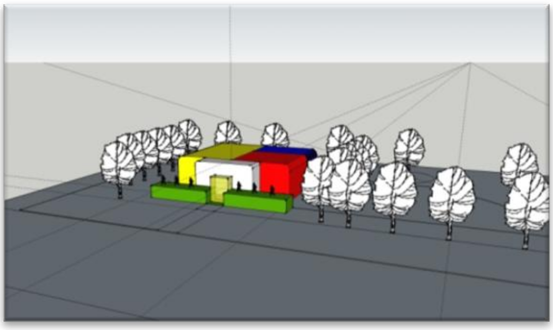



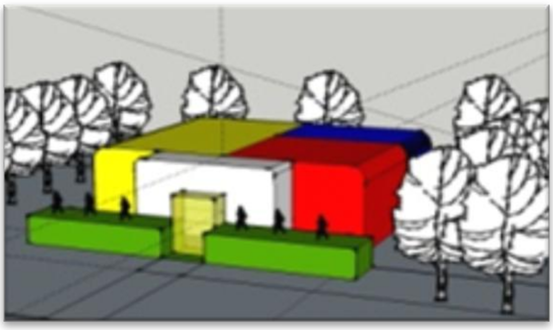


Group D- Participant M2









Group D- Participant MK2