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Variations in design process: A case study about tool and task as design variants

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Abstract

Several researchers question the nature of design. Although design has specific characteristics that distinguish it from other cognitive activities, it also takes on different forms depending on the main factors of the design setting.

To test this idea, this study has adopted design tools and tasks as the factors that change a design situation. In order to do that, a case study with one graduate student enrolled in Design Computing Program at Istanbul Technical University, Istanbul is conducted. The case is composed of four design sessions, each consisting of a unique combination of a tool and task.

The analysis of the protocol aims to show how the different phases of a design process come together in different weights when working on the task depending on the problem given and the tool adopted.

This study can be framed as adopting an activity based model where the actions of the participant are in a problem-oriented setting that requires re-production before re-iteration and are assessed through an analytical approach of coding activity in order to understand the impact of the design tool as a variant of the process.

The results suggest that tools have a diverging effect on the process as they require different operational methods. On the other hand, the nature of design tasks converge designer's thoughts into a predictable pattern. The combination of the divergence and the convergence yields a spectrum of unique design situations.

Keywords
Design tool, Design process, Design variant, Tool cognition.

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1. Introduction

This study is conducted as part of a Ph.D thesis inspired by Visser's work on augmented generic design, and argues that tools adopted act as design variants affecting the design process. In addition, Fish (2004) claims that a mental tree of design possibilities exists in designer's mind; and this study claims that the adopted design tools are variants that effect the paths that the designer follows among the branches of this tree. Fish also argues that each path requires the designer to practice a certain set of cognitive acts in shaping the design process which, this study aims to quantify through the use of design tools.

However, a design situation can not be reduced to an isolated setting consisting of merely one variable being tested. Thoughts of a designer are as much related to the type of design task given as it is to design tool adopted. Therefore, this study comparatively analyzes tools against two types of design tasks. This allowed for a better understanding of dependencies between design variants that can be defined by triangle of the actor target and tool (von Leeuwen, Smitsman, & von Leeuwen, 1994) in the most basic approach.

The case study has aknowledged for a deeper understanding of the interdependent relation not only between the designer and the tool, but also between the type of design problem and the tool studied through a lens investigating the design process in a variety of design settings. It has attempted to incarnate Visser's approach with tangible examples and data that reveal the inner workings of the design process. These examples and data indicate cognitive differences due to the adopted design tools and the type of the design task given.

The case study involved one voluntary graduate student enrolled in the Architectural Design Computing Program at Istanbul Technical University. The case is composed of four design sessions, each consisting of a unique combination of one of the two types of problems to be tackled using physical modelling and one of the two distinct physical modelling tools utilized for the shared act of cutting.

The case is analyzed in three ways. The first set of analysis considers the tools as means of production by comparing them in a non-design task in terms of mental representations; and the second considers the tools as means of design by comparing tools in a design task. Third reading studies the design process altered by the adopted tools for the given tasks through phases of design activated in each tool and task combination.

This article deals with the third reading that tries to understand the interactions between design variants in hand, the design tool and the design problem, at the scale of design phases in order to give a general sense of the impact that the tool and the task makes on the process. It attemts to quantify how the different phases of a design proccess come together in different weights to accomplish the task depending on the design problem given and the adopted tool.

2. Theoretical background

Visser (2009) poses that although "design has specific characteristics that distinguish it from other cognitive activities, it also takes on different forms depending on the main dimensions of the design situation" (p. 2). Consequently, she confirms that "there are both significant similarities between the design activities carried out in different situations" (Visser, 2006) and important distinctness between design and other cognitive activities as put forward in the generic design hypothesis (Goel, 1995; Gero & Purcell 1998).

Visser introduces a new position to augment the generic design notion by proposing that characteristics of a design situation introduce specifities in the corresponding cognitive activities and structures that are used in the resulting design (Visser, 2009). She defines three dimensions as source for difference in design: the *process*, the *designer* and the *artefact* with relevant subsets to each. The focus of this study, design tools, are categorized under process with an emphasis on cognition.

2.1. Tool cognition

Technologies are advanced and expanded so that we can do things that are not possible to achieve without the help from technological advances, or so that they are inexpensive, speedy, and simple (Volti, 1992). Left with only the inherent physical capabilities, humans cannot reach certain capacities such as speed, strength etc. Overall, humankind is physically weak but it compensates for this physical weakness through intelligence which in return makes technology possible. (Volti, 1992)

Simondon (2012) distinguishes between a technical object and a tool by defining that technical objects are always embedded within larger networks of technical assemblies, including geographic, social, technological, political, and economic influences. On the contrary, like Hayles, I find it difficult to find a tool, as simple as it may be, that does not suit this definition. Accordingly, I depart from Simondon and find parallels with Hayles (2012) by considering tools as part of techniques and their potential in allowing for exponential change.

At the root of the word technology is the ancient Greek word tekhne, which is translated as "art," "craft", or "skill" (Volti, 1992) which we associate with craftsmanship; and "logos", which refers to a framework of principles derived from the cognitive act of reasoning. "Tekhne" and "logos" were used together in classical literature to reveal the art of reason, or the skill involved in making. And this study values understanding the reasoning behind tools and technology that are in fact so powerful that change our own reasoning.

However important it may seem, bibliometric studies indicate that role of tool in cognition is an under studied field compared to its language counterpart. In 1998, Preston has noted 15736 entries under the subject heading 'language', 28 entries under "tool" and another 94 under "artifact" (Preston, 1998). On the other hand, Andy Clark (2003) suggests that "what makes us distinctively human is our capacity to continually restructure and rebuild our own mental circuitry, courtesy of an empowering web of culture, education, technology, and artifacts" (Smedes, 2005). With his quote, he frames why tools are worth studying contrary to what bibliometric data might suggest.

Our brains re-structure and re-build our mental circuitry so seamlessly that the tools or technologies become transparent, meaning that they become very well integrated. Smedes (2005) exemplifies this through sticks becoming an extension of the touch sense, in the case of the blind person; or cars extending our bodily motor capacities; or pens and pencils becoming extensions of our hands, and the paper becoming an extension of our cognitive device: by writing something down, we do not need to remember it any more as it is now externally stored on a piece of paper. In short, by technology and tools, we both manipulate human nature, and we also push ourselves beyond our physical and mental capabilities. (Smedes, 2005)

When technologies are used ubiquitously surrounding and defining our environment, they do more than just allowing for the external storage and transfer of thoughts. According to Clark (2003), they constitute "a cascade of mind ware upgrades". Many of our tools are not just external aids, but they are "mind ware upgrades" that are also deep and integral parts that re-define our problem-solving systems. Therefore, design tools are taken as variants that shape the design process; and this study focuses on the impact of a design tool on design process. Variety of definitions and approaches to models of design processes is explored next.

2.2. Design process models

According to Broadbent and Ward (1969) Jones defines six design methods and the most important three of them are: "black box", "glass box", problem structure. The "black box" method reveals a mysterious approach to design and claims that design process can not be analyzed because is an abstract process that takes place in the designer's mind. The "glass box" method takes design as a sequencce of happenings that consists of identification, analysis, synthesis and evaluation (Broadbent, 1969). In the "problem structure" method, consisting of many iterations, Asimow (Asimow, 1962) makes a diagram of preliminary design and shows the steps to identify the best design approach from a number of other alternatives. A latter view by Rittel and Webber (1973) suggests that design process can not completely be described thus, it is not susceptible to a complete analysis (Cross, 1975). Royal Institute of British Architects (RIBA) on the other hand, lists a lineer structure of design process consisting of eight phases starting with identifying requirements and ending with post-construction feedback (RIBA, 2016).

Many definitions of the design process either elaborate the process at a macro level or reveal the order of comprehended results and not how the designer behaves (Gericke and Blessing, 2011). Most of the process models suggest a market driven process (market pull) contrary to technology driven processes (technology push) (Gericke & Blessing, 2011). Opposingly, Maffin (1998) suggests that new models of the design process should be informed by interpretation of context istead of prescribing the ideal process. According to Design Council's (2007) report, "Our world is evolving so quickly that there may never be an ideal methodology or process". Although there is no universel design process applicable in every design context, they agree with Eckert and Clarkson (2005) and Best (2006) that common generic stages exist, independent of domain and that this core needs adaptation to context (Gericke and Blessing, 2011).

In order to analyze design processes shaped by the context which is a tool variant in this case, this study asks whether it is possible to compare tool related differences between design processes in the case of design problem situations; non-design problem situations and accross design and non-design problem situations, according to the framework put together by Wynn and Clarkson (2005).

Wynn and Clarkson (2005) define three schemes that have interrelated dimensions: stage based model vs. activity based model; problem oriented vs. solution oriented approach; abstract approaches vs procedural approaches vs. analytical approaches.

According to this framework, stage based models structure the design process according to its design phases and activity based models represent the design process through activities conducted during the course of design (Blessing, 1996). A typical characteristic of an activity is that it reappears for a number of times during the design process.

Solution-oriented models propose a solution, analyse it and repeatedly modify it to explore the design space. On the other hand, problem oriented models put emphasis on analysis and understanding of the design problem before generating a range of design alternatives (Wynn and Clarkson, 2005).

Abstract approaches tend to describe the design process at a high level of abstraction which corresponds to a broad range of situations (Wynn and Clarkson, 2005). Procedural approaches on the other hand, are more concrete and they focus on certain aspects of design projects relating to practical situations. Analytical approaches are used to better understand the design process through the use of techniques, procedures or computer tools (Browning, 2001).

This study adopts an *activity based* model where the actions of the participant in the case study is noted and assessed in terms of repeating chunks in a *problem-oriented* setting where, the first phase of the case requires re-production of the given problem geometry and the second phase requires a design activity through re-iterations to generate a range of possible solutions; and the results are assessed through an *analytical approach* through an approach that encodes activity in order to understand the impact of design tool as a variant of the process.

3. Method

Activity Theory is a qualitative research method that helps finding patterns and making meaning across actions. An activity is a goal oriented interactive stage where the actor interacts with an object through the use of a tool. "These tools are exteriorized forms of mental processes manifested in constructs, whether physical or psychological. Activity Theory recognizes the internalization and externalization of cognitive processes involved in the use of tools, as well as the transforma-

Table 1. *Coding actions of Drawing, Move and Inactivity.*

D(rawing)	
Dnp	Drawing new parts
Dm	Drawing marks and guides
Dn	Drawing numeric input
Dtd	Tracing design
Dtp	Tracing problem

M(ove)		
Mg	Gesture	
Mcu	Cut	
Mco	Mcop	Count_Problem
	Mcod	Count_Design
Ma	Assembly	
Mm	Measure	
Mal	Align	

I(nactivity)	
Ip	looking at the problem
Id	looking at the design
Is	staring
Ipoz	PanOrbitZoom

Table 2. *Coding phases of design.*

Seeing	
Is	Staring
Mal	Align
Mg	Gesture
Dtd	Tracing design
Dtp	Tracing problem

Execution	
Dm	Drawing marks
Dn	Drawing numeric input
Mcut	Cut
Ma	Assembly

Evaluation	
Mcod	Counding desing
Mcop	Counting problem
Mm	Measure
Ipoz	Pan orbit zoom
Id	Looking at the design
Ip	Looking at the problem

tion or development that results from the interaction" (Fjeld, et al., 2002).

This study finds parallels with the theoretical background of Activity Theory developed by Nardi and Kuutti (1993) and adopts a similar approach focusing on the activities taking place during design sessions and their interdependent relation with eachother. Each four design session is video taped, the recordings are divided into five minutes intervals and each interval is analyzed using the acts performed by the participant. Each act conducted by the participant is noted, composing a sequence of activity. This data provides insight about the design process according to patterns that emerge from identification of repeating action couples, which are defined as chunks of action that appear in the same order for multiple times during the design process.

This study re-interprets Suwa and colleagues' (Suwa, Gero, & Purcell, 1998) content oriented approach to protocol analysis and coding scheme to provide data that yields a process oriented understanding of the design phases in the end.

3.1. Coding scheme

Video recordings taken during design processes are analysed and each move the participant made is noted. The activities recorded are then grouped into three action categories. Meanings are drawn from the frequencies of these action categories, and patterns emerging from repeatedly coupling actions, forecasting indicators regarding the nature of the process. Activites, action categories and concepts that emerged are detailed in the following sections.

The participant's activities are grouped into three groups: Drawing, Move, Inactivity. These categories emerged from observations and generalization of various actions during the process. Inactivity category refers to the state of being motionless and the categories of Drawing and Move refer to state of motion. Action categories related to each activity are listed and assigned a code as abbreviation (Table 1).

Concepts on the other hand, are interpretations of data regarding actions and activities and reveal insight about the design process. These concepts have emerged through repetition of action chunks that reveal meaningul intentions/decision and dependency analysis where the intentions behind actions are sought for by looking at proceeding and preceeding actions for each move (Table 2).

4. The study

The study is pursued in two phases: In the first phase the aim is to understand the effect of a design tool during the process of physically building a geometry that have been given to the participant (non-design situation). In the second phase the aim is to understand the impact of the same design tool during the process of re-interpreting the geometry in a creative fashion (design situation). The first phase therefore, investigates the design tool as means of production and the second phase investigates the same tool as means of design.

The time allowed for re-production of the image is 15 minutes during the first phase and during the second phase of the experiment,the participant is asked to produce at least two iterations of her understanding of the initial geometry with a time limit of 15 minutes for each iteration. Sketching is allowed during all phases of the experiment. The whole proccess is conducted with two design tools chosen to be compared.

4.1. Tools

Comparison criteria selected are production method, operator and modeling method. Production method criteria refers to the type of production process such as additive, subtractive, cut or formative which are abbreviated as Ad, S, Cu and F respectively. Additive method proceeds with adding layers/parts of the model proposed. Subtractive method proceeds with the removal of the parts of the whole that are not needed for the model. And formative method proceeds with modelling of the negative space around the positive that needs to be modelled, which is then filled with a porous material to form the positive parts.

A distinction is made on who is operating the process. The reason for this assessment is the belief that although human factor is involved in designing the pre-production phase in either case, running a process manually (M) or digitally (D) involves or excludes technology and alters the procedural steps needed to operate the tool. Thus, it alters the method of production and the way a designer thinks.

Modelling method is also taken as a criterion since it is possible to think computationally (Co) through a manual process or analogous (An) in a digital medium.

According to this, laser cutter and x-acto knife pair is selected for further study. The reason behind it is that these two tools show similarities both in modelling and production method and only differ in by whom they are operated. They both pursue the act of cutting through analogue methods but the designer has to mark where to cut either manually or digitally; the path is not generated computationally as it would be in three dimensional modelling software.

4.2. Tasks

Two distinct geometries were designed for the experiment on a 3D modelling software. The relations of the parts were designed by the author so that the participant is not allowed to design during the first task (non-design), where the task is solely to replicate the image as a physical model to test the tools as means of production.

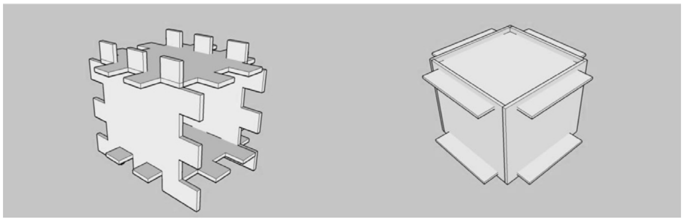


Figure 1. *Geometry given during non-design task.*

Tasks consisted of two different geometries named G1 and G2 and they are addressed with both of the design tools in total of 4 experimental settings. Each geometry is assigned a design tool to be utilized both in a design task and a non-design task. The geometry named G1 is based on a rectangular prism and G2 is based on a cube (Figure 1). It has been useful in avoiding a serial position, which refers to the experience gained during the first phase and may be carried out onto the second phase, by allowing a fresh start with the new design tool.

5. Results

5.1. X-acto knife use in design

This design process consists of 74% of *Moves*, 11% of *Drawing* and 14% of *Inactivity*. At this scale, it is clear that the *moves* are the driving force behind the design decisions. This should show us that process of physical model making is independent of sketching and proceeds with variety of Moves. The array of moves recorded in this process are as follows: Malign, Mcut, Massemble, Mmeasure and Mgesture.

Acts of *Drawing* and *Inactivity* provide either visual aid to the designer or an opportunity to re-interpret, evaluate or further evolve the model. Acts of *Inactivity* recorded are I_looking_at_design and Ipan_orbit_zoom, where I_looking_at_design provides an opportunity to review the design proposal and a basis for re-interpretation and Ipan_orbit_zoom allows the designer to view the model from different angles.

The only act of drawing that is recorded and that makes up the 14% of the actions is Dmarks. Dmarks are utilized to make a record of the decision made rather than to produce ideas in

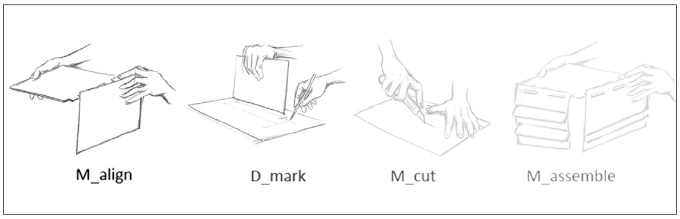


Figure 2. *Action chunk 1 during x-acto knife use in design task.*

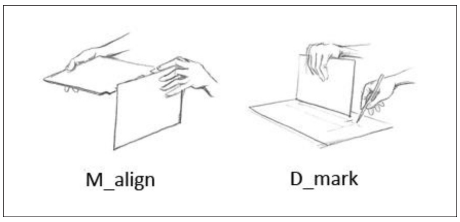


Figure 3. *Action chunk 2 during x-acto knife use in design task.*

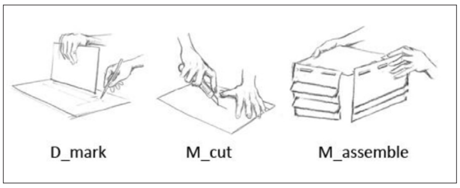


Figure 4. *Action chunk 3 during x-acto knife use in design task.*

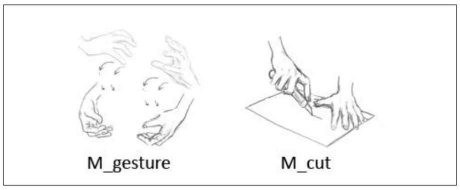


Figure 5. *Action chunk 4 during x-acto knife use in design task.*

the form of a sketch.

Moves are interrupted by Drawing activity especially by Dmarks action for the first ¾ of the process and interrupted by Inactivity for the last quarter. This means that the first ¾ of the process consists of making design decisions and elaborating the design proposal by seeking guidence from the Marks made and the last quarter of the process consists of evaluating the proposal through inactive states of looking at the design proposal.

Notable patterns of action are Malign + Dmarks; Malign+Dmarks+M-cut; Malign+Dmarks+Mcut+Massembly (Figure 2). These patterns indicate that the designer reflects on what she sees –that is what she builds- therefore a move that aligns two parts is frequently followed by marking the position which is then cut and assembled in the end. The smallest chunk of this pattern is to align+mark. The designer may chose not to continue to other parts of the chain and revise her decisions according to what she sees emerging. Or she may evaluate the proposal as she builds and sees it to complete the whole pattern of align+mark+cut+-assemble. Therefore, this part of the experiment is said to present compliance with Schön's (1983) reflection in action process.

During the first five minutes, Malign, Dmark, Mcut and Massembly acts take place (Figure 3). Most prominent of those is the Malign + Dmark action chunk. These two acts initiate the decision making phase of the process. The designer visualizes the outcome of his proposal through simulation provided by the act of aligning. She manipulates it and ends the decision process through marking.

During the next five minutes, until the 10 minute mark, Malign drops yielding the executive act of Mcut accompany the external marks of design decisions (Dmark) so that the see-move-see cycle (Goldschmidt, 1991) can be completed through Mcut+Massemble action chunk to review the outcome (Figure 4).

In this part of the timeline, Mgesture starts to appear for the first time. 85 % of the time, Mgesture is followed by Mcut. Mgesture+Mcut action chunk reveals that Mgesture acts as a visual aid supporting seeing that yields a design decision followed by a design move, executing the decision (Figure 5).

During the next five minutes, until the 15 minute mark, Mcut makes a peak. The reason for this may be that a single act of cutting is not enough to complete the execution of a design move, therefore the act itself is repeated multiple times. The chunks of moves analyzed show that design decision process is still on, but through a slightly different sequence. Ilooking_at_design+Mgesture +Mcut+I-looking_at_design action chunk in this part appears frequently to make up the see-move-see cycle (Goldschmidt, 1991) (Figure 6). The designer looks at the design to evaluate the proposal, makes a gestural move to simulate the design move in her mind in order to see, and executes the decision through Mcut followed by another actor evaluation with Ilooking_at_design. Absence of Dmarks does not point to an absence in design decisions. It shows that Dmarks act as an external way of storing the information embedded in the decision. This is why we observe Mcut right after Mgesture and nothing else in between. Means of execution available here eliminates the need to externally represent design decisions.

During the part that is post 15 minutes, the rate of Mcut drops and acts of evaluation such as I_looking_at_design or Ipan_orbit_zoom appear. The designer makes her last decisions through gestures and executes them through new cuts followed by pauses to look at the design and orbit the model so that it is viewed from different angels (Table 3).

The seeing phase of the design process makes its peak as the design process initiates but falls in a decreasing trend throughout the overall process. Execution phase of design starts at a relatively lower rate, but draws an increasing trend untill the end of 15 minute mark (Table 4). Evaluation phase presents an increasing trend for the first 15 minutes and a constant rate for the rest of the time remaining. These trends provide us with insight regarding the nature of the process. The design task when x-acto knife is utilized utilizes doing rather than visualizing, because the design itself is an emerging prototype as the designer acts on it. Therefore, evaluation phase supresses seeing, and the ease of acting on the tangible physical model puts emphasis on the execution phase. Thus, this process can be characterized with doing and reacting.

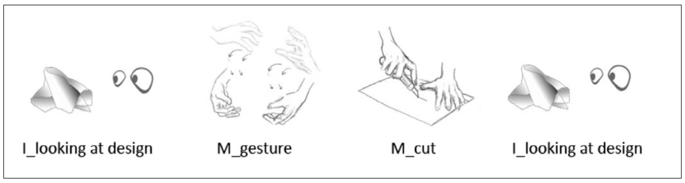


Figure 6. Action chunk 6 during x-acto knife use in design task.

Table 3. Time based design actions.

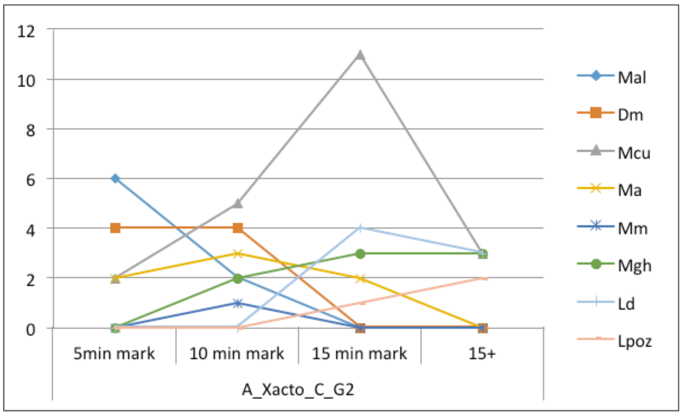
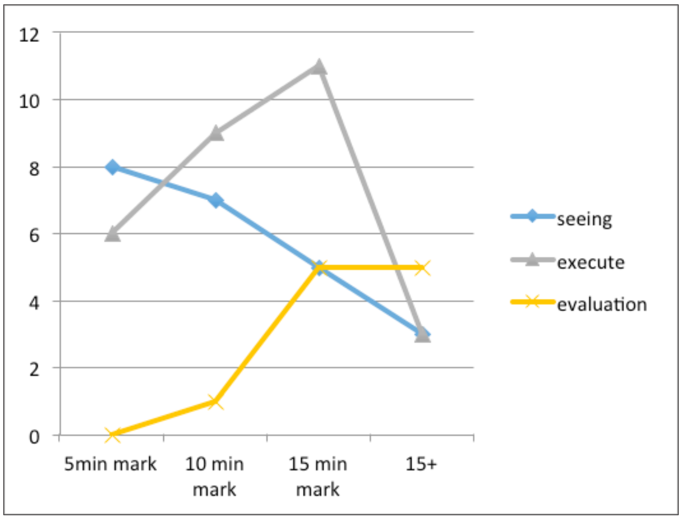


Table 4. Time based design phases.



5.2. X-acto knife use in non-design

This session consists of 33% Drawing acts, 37% Moving acts and 29% Inactivity. The balance in the use of specified activities present a wide spectrum of actions related. Drawing acts recorded during this session consists of Dtracing_problem, Dnumeric_input, Dmarks_guides, Dtracing_design, Dnew_parts. Moving acts recorded in this session consists of Mcounting_problem, Mgesture, Mmeasure, Mcut and Mcounting_design. And Inactivity in this session consists of I_looking_at_the problem, Ilooking_at_the_design and Istaring.

During the first five minutes of the session, the designer makes acts of intense measurements and marking along with acts of looking at the problem in order to understand the geometry. Here, the action chunk Mmeasure + Dmarks is recorded frequently. The designer starts the session with investigating the problem geometry, mark numeric input on the given geometry and then a long sequence of Mmeasure+Dmarks starts.

The other acts recorded in this part of the session and are worth mention-

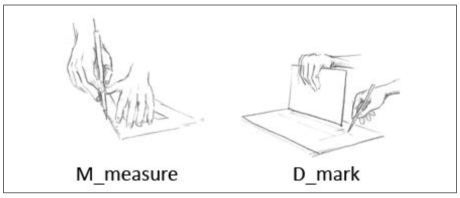


Figure 7. Action chunk 1 during x-acto knife use in non-design task.

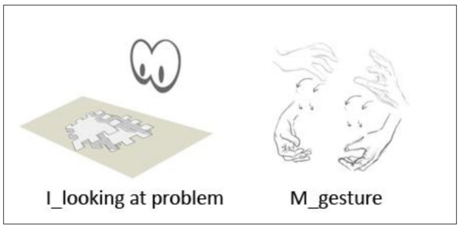


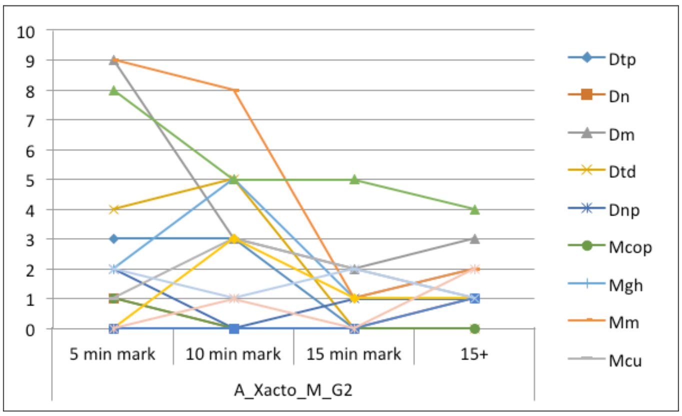
Figure 8. Action chunk 2 during x-acto knife use in non-design task.

ing are Dtracing_problem and Dtracing_design (Figure 7). These acts are carried out to either understand the geometry or the part that is planned to be cut.

During the second five minutes, the act of Mmeasure continues at the same rate along with the act of Ilooking_at_the_problem in order to make sure parts designed will make up the geometry given when constructed. Dtracing_design here also helps the designer to specify the contours of the parts to be cut.

Gestural acts of Mgesture are recorded at its peak in this session when the designer is in the stage of designating the parts to be cut through Dtracing_design and the act of Mgesture is hypothesized to help the designer visualize how the part will fit with the other parts once it's constructed in 3D. Therefore the action chunk I_looking_at_the_problem+Mgesture appears frequently as the result of the designer's intention to simulate the results of his action, to make sure it replicates the problem given (Figure 8). And the act of cutting is more frequently recorded during this part. This means that the designer has taken design decisions and is in the phase of executing them.

Table 5. *Time based design actions.*



During the next five minutes, the activity of the designer drops but the rate at which Ilooking_at_the_problem stays constant for the designer constantly checks if the parts drawn are in accordance with the problem geometry given. In addition to Ilooking_at_the_problem the designer, makes Dmarks and moves of Mcut and evaluates her design through Ilooking_at_the_design.

During the last five minutes, the rate of Ilooking at the problem stays constant but she records many other acts at dipensable times. The reason for this messy character of activity is that she realizes that her model is not sufficient to replicate the geometry given when constructed in 3 dimension and that she looks for ways to understand the reason why such an inconsistency has happened. Therefore, she makes random acts once or twice each to see if she can sort the problem through them. Finally, the allotted time ends during her search for a solution before the model is complete. (Table 5)

This design process shows a decreasing level of activity overall, and an ondulating phase of seeing that starts with an increase in the first ten minutes, then drops dramatically for the next five minutes and increases again for another five minutes. In this process, the activity level of the evaluation phase is always the highest, although it shows a decreasing trend as well. Similarly, although execution starts at mid-levels, it shows a decrease during the design process and stays constant after the middle of the process (Table 6). The nature of the task given has forced the designer to force her visualization skills and evaluate it to execute the correct solution. However, she has failed to do so because the requirement of both visualization and execution with the task combined with manual operation required by the tool had a negative influence on the cognitive process of the designer. She has failed in visualizing and making sure what she visualizes complies with the given geometry, thus the execution phase has failed as well, requiring a constant need to evaluate the problem geometry to figure out a strategy to construct it. This design process can be characterized to put emphasis on evaluation.

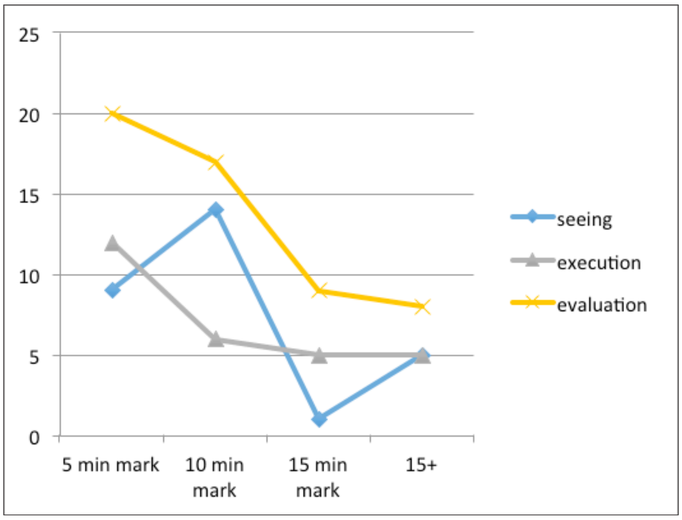
5.3. Laser cutter use in design task

This session consists of 47% of drawing acts, 34% of inactivity and 18% of moves. This distribution of activity suggests that the designer has experienced a design session driven by drawing which is supported by phases of evaluation through inactivity. Drawing activity consist of Dnew parts, Dnumeric_input and Dtracing_design actions; inactivity is observed through Ipan_orbit_zoom and Istaring and moves that are recorded are Mgesture and Mcounting_design.

Often recorded action chunks during this session have been Mgesture+Istaring, Istaring+Dnew parts and Mgesture+Dnew parts (Figure 9). All the three couples signify the presence of an image in mind, and that it is transformed and kept alive through Mgesture + Istaring. Istaring+Dnew parts couple indicates that the decision made in the internal representation is stored as an external representation. And finally the occurance of Mgesture+Dnew parts suggests that gestures are representations of acts taken on the internal image and the concluding form is stored in the sketches.

During the first five minutes of the session, an intense dialogue between Dnew_parts and Istaring starts. Dnumeric_input and Mgesture support this couple. The designer is hypothesized to create an image of her design in her mind's eye when she pauses more then 3 seconds and then makes a sketch on paper to externalize the image created. The precise nature of the design tool forces the designer to think in exact numbers, make a record of those values and think of new parts of the design according to those values. And finally in this session Mgesture is hypothesized to be a resemblance of the model created as an internal representation. Dtracing design is also observed as an act that helps the designer to image her design in her mind's eye

Table 6. *Time based design phases.*



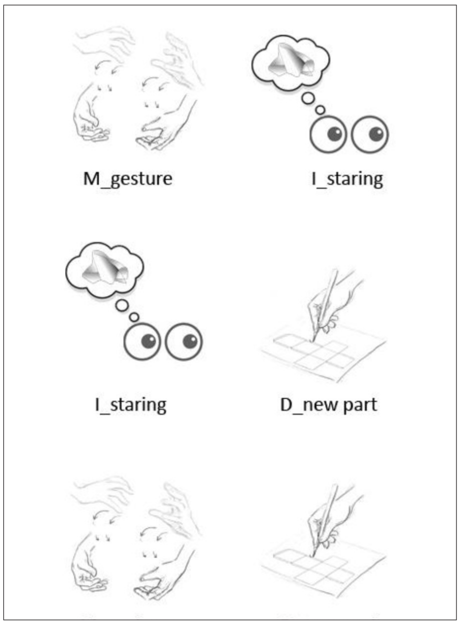


Figure 9. *Action chunk 1 during laser cutter use in design task.*

to make sure that all the pieces will fit once they are constructed. The acts that are recorded so far suggest that the first five minutes of the session has been about constructing the design proposal through creation of an image in the mind and transferring it on paper aided by the acts of tracing and shaping the model with gestures.

In the second five minutes, in addition to Dnew parts and Istaring, the designer also starts evaluating the design proposal through Ilooking at the design. Moves of gesture keep supporting the act of creation along with the evaluative act of Ipan_orbit_zoom in order to review the design proposal achieved so far. Dtracing design remains occurring at the same rate in this part of the

Table 7. *Time based design actions.*

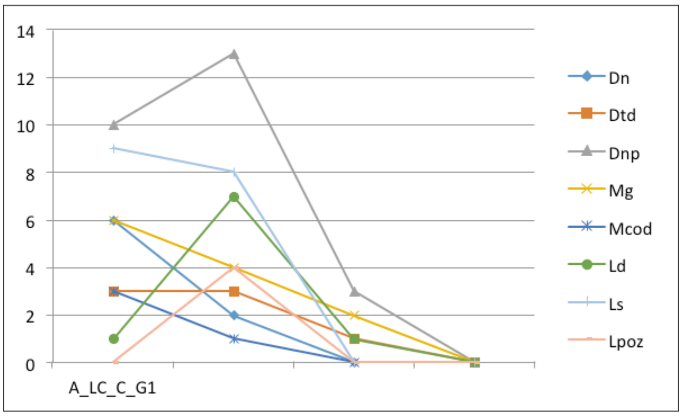
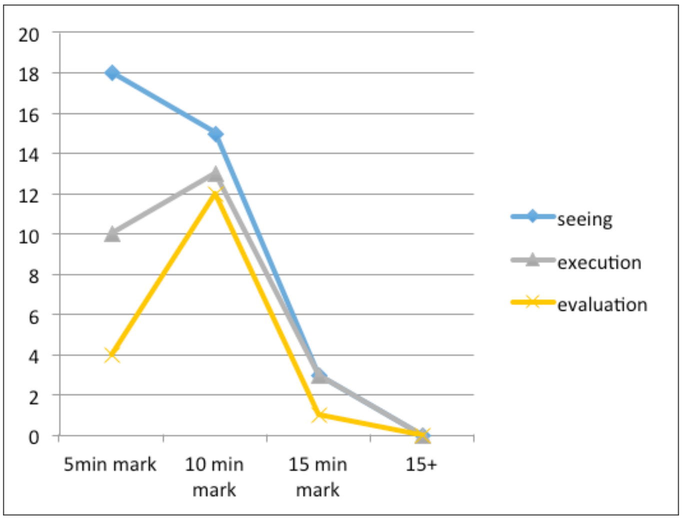


Table 8. *Time based design phases.*



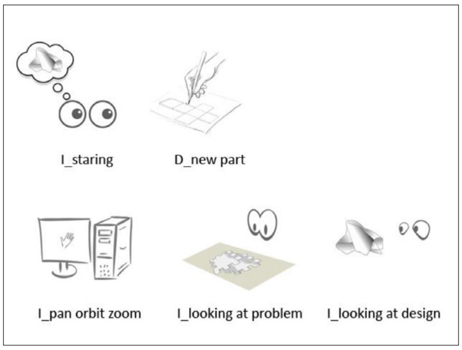


Figure 10. *Action chunk 1 during laser cutter use in non-design task.*

session, allowing the design proposal being viewed as an active image in the mind. All these actions noted suggest that this phase concentrates on synthesis as well as evaluation.

The last five minutes of the session presents a dramatic drop in activity. The actions that are still in process during this part are Dnew parts, Mgesture, Ilooking at the design and Dtracing design. It suggests that there still is an active image of the design in the mind that is being transfered on computer through the help of Dtracing design and Mgesture to keep the internal image alive. And the single instance of Ilooking at the design suggests that act of evaluation is still involved in the process (Table 7).

This design process stars on emphasis on seeing and mid levels of execution accompanied by minor acts of evaluation. The rates of appearance gets closer towards the 10 minute mark; and they all decline almost convergingly towards the 15 minune mark. This design situation creates a process where seeing feeds execution and evaluation accompanies them lineerly (Table 8).

5.4. Laser cutter use in non-design task

This design process consists of 48% of looking acts. These acts consists of staring, looking at the problem, looking at the design and pan, orbit or zoom. 76% of these acts are recorded during the second five minutes of the design process. Drawing acts on the other hand take up the 40% of the design activity, of which 55% takes place in the second five minutes of the process. These numbers show that an increase in the rate of activity takes place during the second half of the design process.

Frequently noted action chunks in this session are Istaring+Dnew_part and Ipan_orbit_zoom+Ilooking_at_problem+ Ilooking_at_design (Figure 10). These chunks suggest that the designer constructs a replica of the problem geometry given in her mind, transfers it on the computer screen for execution and then tries to match her input with the geometry given to make sure that they comply.

The first five minutes of the design process presents us with only 30% of the total activity. Among this, there is the 75% of Istaring signalling us that during the first five minutes the designer has tried to construct the proposal in his mind through attempts to image it internally. Chunks of Istaring+Dnew_part converge to the same point that the designer tries to see in his mind, draws on paper and repeats this chunk for several times during the first five minutes. During this period she also tries to observe the problem to be replicated by Ilooking_at_problem and takes notes regarding the numeric values, Dnumeric, that would be utilized in the construction of the model and also traces parts of the problem Dtrace_problem to better visualize it. In general, this period in the session tries to construct the principles of the geometry asked to be replicated.

In the second five minutes of the session, act of Dnew_parts doubles, Iproblem quadruples and acts of Ipan_orbit_zoom, Idesign and various sorts of Mgesture appear. (Table 9) The increased rate of activity implies that the designer has grasped the principles of construction of the geometry and is working towards production. And the details of the activity reveal that, Ipan_orbit_zoom + I_looking_at_problem + I_looking_at_design chunk, the designer evaluates the drawing she made on the computer and compares it to the geometry given in order to detect any inconsistencies. Appearence of all sorts of Mgesture towards the end of the session signifies an overall evaluation of the completed model through simulation. It acts as a model drawn in the air as the geometry is still only represented on a 2D screen.

Activity level during the first five minutes remain at lower rates, then each phase makes its own peak at the 10 minute mark with the evaluation phase being over-practiced (Table 10). In this process, seeing is minimized as a consequence of the nature of design task given. The designer rather proceeds with attempts to understand the rules of the geometry and applying it, resorting to visualization at a minimum. This signifies that the tool has become transparent through ease of execution.

5. Conclusion

Design process based readings have led to Visser's notion, design one but in different forms (Visser, 2006). When the phases, evaluation, execution and seeing are elaborated through their impact on the design process, a comparison based on design tasks and design tools becomes possible. According to this, based on non-design task situation, the process measured with either

Table 9. *Time based design actions.*

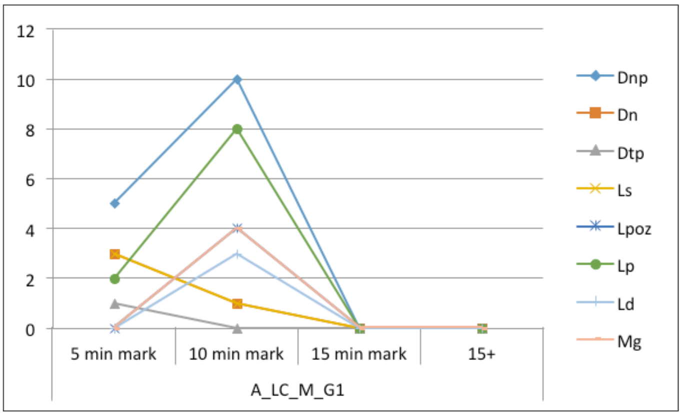
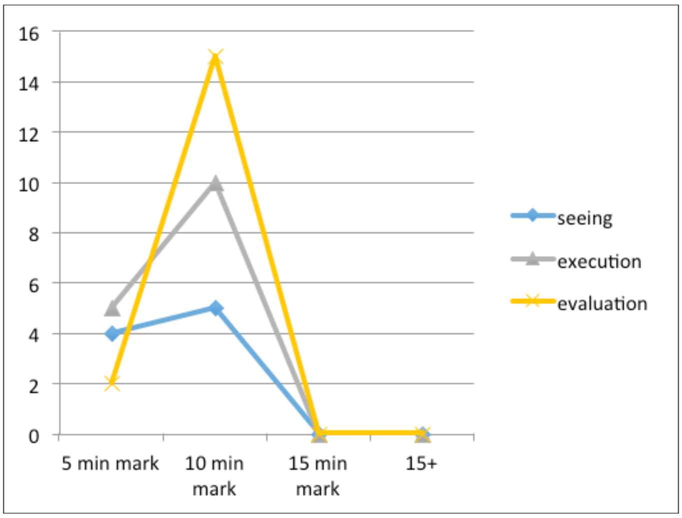


Table 10. *Time based design phases.*



tool has yielded an emphasis on evaluation; therefore we can conclude that the nature of task converges the acts of a designer. On the other hand, the tool combined with the task either becomes transparent as in the case of laser cutter, or becomes overwhelming when the cognitive cost of manual operation is added to evaluation, visualization and execution as in x-acto knife situation. Based on design task situation, evaluation phase is de-emphasized in either case. The tools within design task situation differ in how the designer uses them strategically, such as *seeing by doing* during x-acto knife use or *doing by seeing* during laser cutter use. X-acto knife use for a design situation has yielded an interactive physical model where the designer makes new design decisions as she reacts to her own design moves. On the other hand, laser cutter use during a design task requires the designer to visualize in mind in order to execute, changing the cognitive practices of the designer

Table 11. *Comparing design processes.*

	TASK				
	NON-DESIGN		DESIGN		
X-ACTO KNIFE	EVALUATION 48 % SEEING 26 % EXECUTION 25 %	needs to visualize	EXECUTION 46% SEEING 36% EVALUATION 17%	ease of execution	see or do
LASER CUTTER	EVALUATION 41% EXECUTION 36 % SEEING 21 %	ease of execution	SEEING 45 % EXECUTION 32% EVALUATION 21%	needs to visualize	see or evaluate
	emphasis on evaluation		seeing by doing vs. doing by seeing		

When a comparison is made between design and non-design situations based on use of design tools (Table 11) the analysis shows that seeing and executing, although weighing the same rate, work in reverse timing in the case of x-acto knife use. When use of laser cutter is compared between non-design and design tasks, the role that the evaluation and seeing phases play signals an interchanging importance based on the tool and task combination.

As a result, each design setting has presented similar qualities such as evaluation, seeing and execution phases, independent of certain variables. However, the level at which the previous sections study the sessions reveal that the internal -cognitive- mechanisms that take place and the intensities at which the phases appear, may alter as the variables change such as design tool adopted or design task.

6. Discussion

The study has pursued an investigation at the level of design tools adopted with different types of design tasks, seeking for data that reveal distinct characteristics of design processes in each design situation. According to this, the results suggest that, the nature of design task, whether it is a design or a non-design task, converge the thoughts of a designer into a predictable pattern. The combination of tool and task, may yield a spectrum of unique design situations. Thus, the tool and the task can not be thought independently.

The results have shown that tools have a diverging effect on the proccess as they require different methods for operating and by definition, where Stacey and Lauche (2004) define a method as the way something is done. Each tool, even the ones adopted for same purposes, demand a specific method in order to operate. They bring variety in the way a designer formulates thoughts in order to solve the design problem thus; impact the way the designer thinks and the design process shapes.

Findings of this study will be used as a base for future studies on the strategic use of design variables in design studios focusing on a much smaller scale where cognitive acts are studied. The future studies will look for specific cognitive clues presenting further evidence regarding the ways in which tools bring variety in terms of ways of thinking. Further studies departing from such findings may construct a new pedagogy in design teaching where the instructor decides on a set of cognitive abilities to be practiced implicity by the student through a selection of design tools and related tasks.

References

Asimow, M. (1962). *Introduction to Design.* Prentice Hall.

Best, K. (2006). *Design Management: Managing Design Strategy, Process and Implementation.* Lausanne: AVA Academia.

Blessing, L. (1996). Comparison of design models proposed in prescriptive literature. *Proceedings of COST A3 / COST A4 International research workshop, Social Sciences Series Vol 5.* Lyon.

Broadbent, G., & Ward, A. (1969). *Design Methods in Architecture.* London: Lund Humphries.

Browning, T. R. (2001). Applying the design structure matrix system to decomposition and integration problems: a review and new directions. *IEEE Transactions on Engineering Management, 48*, 292-306.

Clark, A. (2003). *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence.* Cary, NC, USA: Oxford University Press.

Cross, N. (1975). *Man Made Futures: Design and Technology.* Milton Keynes: Open University.

Design Council. (2007). *Eleven lessons: managing design in eleven global companies.* Retrieved May 06, 2016, from www.designcouncil.org.uk

Eckert, C. M., & Clarkson, P. J. (2005). The reality of design. In J. P. Clarkson, & C. M. Eckert, *Design Process Improvement: A review of current practice* (pp. 1-29). London: Springer Science & Business Media.

Fish, J. (2004). Cognitive Catalysis: Sketches for a time-lagged brain. In G. Goldschmidt, & L. W. Porter, *Design Representation.* Stoodleigh, UK: Springer.

Fjeld, M., Lauche, K., Bichsel, M., Vorhorst, F., Krueger, H., & Rauterberg, M. (2002). Physical and virtual tools: activity theory applied to the design groupware. *A Special Issue of Computer Supported Cooperative Work (CSCW): Activity Theory and the Practice of Design, 11*(1-2), 153-180.

Gericke, K., & Blessing, L. (2011). Comparisons of design methodologies and process models across disciplines: a literature review. *International Conference on engineering Design, ICED 11.* Technical University of Denmark.

Goel, V. (1995). *Sketches of Thought.* Cambridge: MIT Press.

Goldschmidt, G. (1991). Dialectics of sketching. *Design Studies, 4*(2), 123-143.

Hayles, K. N. (2012). *How we think.* The University of Chicago Press.

Kuutti, K. (1993). Notes on systems supporting "organizational context" - an activity thory viewpoint. In L. Bannon, & K. Schmidt, *Issues of Supporting Organizational Context in CSCW Systems* (pp. 105-121). Lancester: Lancester University.

Maffin, D. (1998). Engineering Design Models: context, theory and practice. *Journal of Engineering Design, 9*(4), 315-327.

Preston, B. (1998). Cognition and Tool Use. *Mind and Language, 13*(4), 513-547.

Purcell, A. T., & Gero, J. S. (1998). Drawings and the design process. *Design Studies, 19*, 389-430.

RIBA. (2016, May 06). *RIBA Plan of Work 2013.* Retrieved from http://www.ribaplanofwork.com/about/Concept.aspx

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in General Theory of Planning. *Policy Sciences, 4*, 155-169.

Schön, D. (1983). *Reflective Practitioner.* USA : Basic Books Inc.

Simondon, G. (2012). *Being and Technology.* Edinburgh: Edinburgh University Press.

Smedes, T. A. (2005). Technology and Evolution: The Quest for a New Perspective. *Dialog: A Journal of Theology, 44*(4), 354-364.

Stacey, M., & Lauche, K. (2004). Thinking and representing in design. In J. Clarkson, & C. M. Eckert, *Design Preocess Improvement: A review of current practice* (pp. 198-229). London: Springer.

Suwa, M., Gero, J. S., & Purcell, T. (1998). Macroscopic analysis of design processes based on a scheme for codign designers' cognitive actions. *Design Studies, 19*(4), 455-483.Visser, W. (2009). Design: one but in different forms. *Design Studies, 30*, 187-223.

Visser, W. (2009). Design: one, but in different forms. *Design Studies*, 30(3), 187-223.

Volti, R. (1992). *Society & Technological Change.* New York: St. Martin's Press, Inc.

Von Leeuwen, L., Smitsman, A., & von Leeuwen, C. (1994). Affordances perceğtual complexity and the development of tool use. *Journal of Ezperimental Osychology: Human Perception and Performance, 20*(1), 174-191.

Wynn, D., & Clarkson, P. J. (2005). Models of designing. In P. J. Clarkson, & C. M. Eckert, *Design Process Improvement: A review of current practice* (pp. 34-59). London: Springer Science & Business Media.