FRAMEWORK OF AWARENESS TO CRITICAL SITUATIONS IN DESIGN AND PRODUCT DEVELOPMENT: A LEAN THINKING APPROACH TO DEAL WITH UNCERTAINTY AND RISK

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ABSTRACT

The present research takes the Lean Thinking perspective adopting the concept of MUDA as a dimension to study designers’ behavior and provides managerial support with a Framework of Awareness to critical situations in the research field of design and product development.

INTRODUCTION

In the past, design awareness was defined as the ability to understand and handle ideas expressed by the means of doing and making (Archer, 1979). Nowadays, design awareness has become a relevant design aptitude in the context of complex and collaborative processes of design and product development. The context of the design activity is profuse in situations that create influences and consequences in designers’ behavior and performance while managing the underlying mechanisms of Value creation. These situations take place due to unforeseen influences and consequences, lack or excess of prevention, a mind frame that does not allow to see further or refuses a sudden aspect. Inherent to the occurrence of downside consequences is the risk to diminish designers’ input of Value for the creation of design results in circumstances comparable to the concept of MUDA. The present research places in perspective the Lean Thinking concept of MUDA (Ohno, 1988; Womack et al, 2003) as a key dimension to study designers’ behavior in such situations and provide managerial support in the research field of design and product development. On a daily basis designers’ have to keep one’s countenance and stand for situations such as, postponement, hindrance and emergency. Occasionally some of these situations lead to valuable inputs essential to the design process, though, designers are not always prepared to attempt and succeed in taking the best from these circumstances. The concept of MUDA is interpreted and defined in the context of this research, as critical situations in designing. Such situations emerge and designers’ behavior is twofold: designers do not grasp a reaction to cope with the difficulties leading to missteps; designers are able to evaluate the dynamics of the situation and make the appropriate decisions to proceed. The first case is our main concern, the second case is our goal: support designers with empirically derived knowledge on adaptive behavior to improve performance towards decision-making in critical situations in design.
As Lean Thinking embodies a motivational approach to keep procedures of value creation at high standard, this research proposes and extends such motivational approach with a framework of awareness to keep designers behavior in high performance.

THEORETICAL FRAMEWORK
From the literature in design research few attempts provide understanding of the sources of fruitless or successful performance in designers’ behavior. Contributions focus on downside aspects of specific issues such as stickiness (Sachs 1999), non-generating alternatives (Gunter and Ehrelenspiegel, 1999), inappropriate focus of attention (Simon 1995) and confirmation bias (Wason, 1960). Design and product development research has paid little attention to these design management issues on an empirical basis. The traditional prescriptive models such as the Basic Design Cycle (Roozenburg and Eekels 1995) but also newer approaches such as the VIP approach (Hekkert and van Dijk 2001, 2011) and other product development structured methods (Cooper, 2008; Ulrich and Eppinger, 2011) do not represent the sources and possible effects of critical situations that designers and developers might have to cope with, as well actions to improve performance.

Taking the Lean Thinking perspective to study designers behavior and performance, was seen as a challenge, similar to identifying the pathologies of designing, its causes, effects, typical behavior and coping measures. For the unacquainted, Lean Thinking (LT) is a domain-independent philosophy based on five principles, namely Value, Value stream, Flow, Pull and Perfection with the purpose of eliminating MUDA in any value creating activity. MUDA, the Japanese word for waste, is defined as ‘specifically any human activity which absorbs resources but creates no value’ (Womack et al, 2003, p. 355). Value is defined at the start of any process and MUDA, if inevitable, is converted into Value. Lean Thinking was initially derived from the manufacturing context (Womack et al, 1991), however its philosophy of guiding principles of behavior has applicability to a large variety of processes, people and organizations (Walton, 1999), with demonstrated practical results. Progress has been made in implementing and raising awareness of LT in several fields of practice and research, and it has been expanded to Lean Product Development (LPD) with contributions on techniques (Karlsson and Åhlström 1996), sub-systems (Liker and Morgan, 2006), principles (Ward, 2007), management domains (Kahn et al, 2006) knowledge domains (León and Farris, 2011), system design framework (Letens at al, 2011) and the Lean Advancement Initiative several contributions (Oehmen et al, 2011). However, a gap in the understanding and linking Lean Thinking and its principles to the creative dimension of design and product development has been identified. Though, as a motivational framework, LT provides concepts, which are relevant to the design activity and to designers’ behavior and performance such as the dimension of Flow (Csikszentmihalyi, 1990). At the same time, designers’ sustainability concerns and talent to create Value from waste, unintentionally makes them Lean Thinking enablers (Oehmen et al, 2012) in a world that disregards and keeps generating MUDA.

Adopting a Lean Thinking perspective does not mean applying its principles to rule or constrain the design activity. This research takes the Lean Thinking concept of MUDA to a higher level of value creation that relates to the search for variables of what is not known, while designing Value. The design process is by nature iterative (Cross and Roozenburg, 1992), designers seize the hints of a design problem and know they cannot arrive at perfection, although by making many essays designers and
developers pursue perfection through iteration processes, correcting all the inaccuracies concerning the final result. From a research implementation point of view, Lean Thinking seemed to be the adequate motivational framework to identify characteristics of less effective designers behavior and coping actions to up-hold performance, assuming first and foremost that design derives from a process where Value is not completely defined in the beginning, once ‘The final outcome of designing has to be assumed before the means of achieving it can be explored.’ (Jones, 1970, p. 10). This unavoidable assumption opened the way for the translation of Lean Thinking into design as an activity that explores Value variants and invariants, where uncertainty, risk and sometimes change play a resilient game. Design is a thought process and some professions take it as its core activity in the reflective practice (Schön, 1983) of the implementation of design. This research supports the premise that design can be studied as a distinct activity that transcends disciplinary boundaries (Cross 1982; Visser 2009). Thus in this context designing is a value creation activity along a purposeful, creative, organized and business oriented process with a dynamic in time. As a process of thought, design entails mental and physical actions that designers have to manage to be able to cope gainfully with the social process of designing in a business context. Designers and developers from different background disciplines specify attributes, properties and qualities towards design solutions and results. Collaborating and sharing the design process become tasks, that ask for management skills, which in turn requires concern with inter-professional collaboration and acquaintance to each other’s criteria of judgment. To each background design discipline particular characteristics have crucial role and influence designers’ approaches. This is supported by the concept of object-worlds (Bucciarelli, 2003), the idea that different participants in design see the object of design differently depending upon their education, background, training, competencies, responsibilities and technical interests. Design involves mental models and a rich set of semantics (Goel, Pirolli, 1992), the materialization of the semantics takes different forms across design disciplines and designers’ approaches. Designers approach influence the teamwork that, similarly to the individual process, involves a shared perceptual act and a cognitive strategy and in addition, a co-development of problem and solution (Cross, 2009). A LT approach to design asks for multidisciplinary investigation. Adopting LT, as theoretical perspective, provided a lens and the opportunity to approach design across its host disciplines (Love, 2002). The benefits of using the LT approach are:

- Lean Thinking as a theoretical background provides a non-discipline-related way to approach design across disciplines.
- The idea of eliminating MUDA along the design process is both specific and common across disciplines and entails situations to be supported.

Lean Thinking is a philosophy of guiding principles of behavior (Walton, 1999) for the business context where aspects such as quality, flow, time and cost play an important role in the creation of value. Such elements are also of major importance for the designing activity, under the pressures of the business context, as design has by far the biggest influence on cost, quality and time-to-market. Although LT focuses on the customer and the producer as value creators, designers also play an important role in the collective effort of value definition, especially in the early phases of design and product development. As a philosophy that has applicability to a large variety of processes, people and organizations, LT ought to be transferable to design. Such task
required a reinterpretation of the Lean Thinking principles, in particular the concept of MUDA in design.

Similar issues have been addressed as critical decisions in risk and uncertainty management approaches to design and product development (Krishnan, Ulrich, 2001; Jerrard and Barnes, 2006; Oehmen and Seering, 2011; Unger and Eppinger, 2011) and in risk management in Lean Product Development (Oehmen and Rebentisch, 2010). In design research, such circumstances have been differently tackled. About forty years ago, John Christopher Jones drew a list of five criteria for design project control from a long list of observations mentioned by many of the design theorists he refers in his seminal book, Design Methods (1970). The first of the five criteria is - the identification and review of critical decisions. Since then other related attempts were made, namely, the concept of critical design moves (Goldschmidt 1996), derived from a study made with teams of product design engineers, the method of critical situations (Frankenberger and Badke-Schaub, 1998) derived from empirical studies in the engineering design practice that depicts mechanisms that lead to success or failure in different types of critical situations. However, research on critical situations misses empirical study of the nature of the phenomenon, its sources and copying measures based across design.

A general framework on the sources of critical situations and crucial actions to uphold performance in design and product development is missing. Though designers and developers might be experienced, they are not always prepared to cope with these situations and its consequential effects such as delays, conflicts but often also successful outcomes. In circumstances of uncertainty and risk, designers and developers can miss orientation and fail to perform effectively. Such situations require the identification of crucial actions and adaptive behavior to cope with downside effects and sense opportunities for constructive outcomes and consequent management implications to designers’ decision-making.

METHODOLOGY AND RESEARCH DESIGN

A Case Study based approach in five design disciplines gives ground to the research. Case studies provide a research environment propitious to gather practical, concrete and context-dependent knowledge essential to gain insight into causal mechanisms, and contextual considerations (Flyvbjerg, 2004). This research entails multiple Case Studies selected to compare clearly different examples, embedded (Yin, 2009) or nested as subunits (Thomas, 2011) to investigate the phenomenon of MUDA in design as the principal unit of analysis.

In this research the case study method is based on periods of observation for the analysis of persons and projects studied holistically and in detail by one or more methods of analysis. From the progressive studies, instances of classes of phenomena provided analytical frames and guidelines to conduct the research to categorization systems (Saldaña, 2009), illuminating the explanations on how to integrate the complementary results in a whole picture of an integrative framework. Multiple cases from different design disciplines were used to strengthen the external validity and enhanced the generalizability (Yin, 2003; Thomas, 2011) of the Framework of Awareness. The careful selection of representative and instrumental case studies per discipline (Silverman, 2005) was based on a variation in cases to obtain information about various situations of MUDA in the design process, complement data and refine results.
Case Studies Selection

The case studies selection was focused on design disciplines, which design processes, go through stages of materialization of ideas with tangible and intangible effects. The research adopted case studies representative of each design discipline that could also have a revelatory character (Thomas, 2011). The case studies are based in four design consultancies established in the following design disciplines, graphic design, architecture, interaction design and mechanical engineering and one group of industrial design graduating students. The selection criteria of the case studies was based on the identification of trustworthy design consultancies known for its reputation, with an organizational structure of 10 people average, where behavioral patterns could be derived from examples of competent performance and led by design experts. Context-dependent knowledge and experience are at the very heart of expert activity (Flyvbjerg, 2004). The well-know experts’ ability to arrive at problem diagnoses and solutions rapidly and intuitively was a central criterion for the selection of design consultancies and its leaders (Dreyfus and Dreyfus, 1986). Other criteria for the selection of design consultancies was to choose design environments where people like to work and feel engaged with, have free choice and freedom to speak so that their reports would be honest. Fulfilling these criteria, the validity of inquiry in the action context was not threatened by defensive routines of including self-censorship and face saving. The selection of the design disciplines was as follows:

**Graphic design** - for being an underlying subject of all the design activities, fast design processes, variant content of its design briefs, easy reproducibility, distribution and diffusion in society. For being a classic design discipline, extremely based on semiotics and communication, stable in its knowledge and processes, therefore an almost independent activity.

**Interaction design** - for being an emergent design discipline, of complex design processes, involving designers from several backgrounds and the assimilation of management tasks. For exploring and adopting the results of technological artisan, for the embryonic processes of reproducibility, for the undeveloped knowledge or knowledge that does not yet exists in a stable and organized structure, an area that brings new and specific design issues.

**Architecture** - for being a classic design discipline that manages the integration of the arts of several design disciplines, taking especially long design processes, long-term achievement of results and less straightforward reproducibility. For being socially representative and having a special focus on authorship and permanence of results. For demanding social reliability, stable knowledge and constant aim to improve people’s life quality.

**Mechanical Engineering** - for being a classic design discipline, fundamental to society and critical to many design activities, for its regulatory nature but also unending aim for discovery, complex design processes, association to science and technology evolution, social reliability, specific methods and design issues, and for the controversy around its aim to simplify people’s life.

**Industrial design** - for replacing engineering in the task of blending science, technology and design, the mass reproducibility, the variant content of its design briefs, the direct concern with the users, usability, social utility and aim to provide better and pleasant experiences, for its multifaceted and sometimes long design processes with connections to many other areas of knowledge.

The design consultancies based on Graphic, Interaction design and Architecture are active in the business environment, the design consultancy based on Mechanical Engineering is based in academic context and works for academic and business
environments. The fifth case study is a graduation project of students in Industrial design engineering. This case was a revelatory Case Study that would tell us how far students are aware and prepared to cope with MUDA in design.

The first Case Study, a Graphic Design atelier, was a pilot study made under exceptional circumstances of collaboration and data collection. This case brought many insights and fine-tuning of the research design. The second Case Study, SME of Interaction Design solutions, brought insight on multidisciplinary and transdisciplinary aspects of innovation processes. The third Case Study, a classic and authorship Architecture office, provided the experience and observation of permanence and adaptive characteristics of a grounded design approach. The fourth Case Study was the challenging observation of a Mechanical Engineering design office based in the academic context that brought into evidence the scientific and instrumental links of design. The fifth Case Study brought insight on Industrial Design students’ awareness to MUDA and the relevance of a related framework in design educational programs. The observation of the case studies in Graphic Design, Interaction Design and Architecture was conducted in Portugal and the case studies in Mechanical Engineering and Industrial Design were conducted in the Netherlands.

Data collection

Data were collected in design environments during continuous periods of observation providing insights into designers’ behavior. The research adopted the following sources of evidence and data collection methods, namely: observations of meetings of selected projects and office daily life; interviews of the organizational team members; design research diary to document the researcher activities and notes of situations of interest; audio recording of interviews and short moments of discussion and audio and video recording of meetings; and visual documentation of results of the design processes, such as sketches, mock-ups, technical drawings, mails, building-prototype and design reports. The individuals were asked to think aloud (Ericsson, Simon, 1993) and verbalize their thoughts and explanations. The researcher role and intervention were based on the techniques of participant observation and interviewing.

Data used in the investigation of MUDA in design are based on the observation and analysis of sequential meetings of projects and interviews as illustrated in Table 2. Data were sequentially collected per case study with data analysis and studies accomplished in between over a period of two years.

Meetings of the Case Studies in Graphic design, Architecture and Mechanical Engineering were audio and video recorded in three sets of 6, 7 and 8 sequential meetings, for the design of a temporary exhibition, interactive design solutions for a permanent exhibition, a train interface and a robot, respectively. The meetings of the Interaction design Case Study were not recorded due to confidentiality issues. However, the meetings were handwritten in the research diary with focus on the identification and transcription of situations of MUDA. A total of 28 meetings went through an iterative process of analysis.

One structured interview of open questions was elaborated in two stages, a first draft based on predetermined list of topics and questions applied in a pilot case, from which in a second stage, the same number of topics were unfolded in groups of open questions. Open questions gives the interviewees the chance to develop their thoughts and discourse about the topics, sometimes leading to very informative and rich moments of conversation.
Table 1. Case Studies Sample and Collected Data

<table>
<thead>
<tr>
<th>Case Studies</th>
<th># Meetings</th>
<th># Interviews</th>
<th>Observation</th>
<th>Types of Informants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphic design SME</td>
<td>6 (12h: 06)</td>
<td>9</td>
<td>6 weeks</td>
<td>Leading designer, producers, graphic designers, editorial designer</td>
</tr>
<tr>
<td>Interaction design SME</td>
<td>7 (10h: 30)</td>
<td>23</td>
<td>4 weeks</td>
<td>Art director, experience designers, illustrator, interaction designers, mechanical engineers and product developers, project managers, CEO, sales, quality, directors of research.</td>
</tr>
<tr>
<td>Architecture SME</td>
<td>7 (12h: 30)</td>
<td>9</td>
<td>5 weeks</td>
<td>Leading architect, proposals, building, aesthetics and detail plan architects.</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>8 (7h: 34)</td>
<td>9</td>
<td>5 month</td>
<td>Mechanical Engineer/ Academic/control design, Aerospace engineer /Academic/ control design/ Electronics engineers: Software, Hardware, and technician.</td>
</tr>
<tr>
<td>Academic consultancy</td>
<td>-</td>
<td>5</td>
<td>14 weeks</td>
<td>Industrial design engineering graduating students</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The interviewees were asked to verbalize any thoughts they would find relevant to explain their answers. Designers from several background and activities answered the structured interview of open questions based on several topics regarding the designing activity such as, motivation, planning, management, teamwork and stakeholders among other aspects. An introduction to the topic of Value is made at the beginning of the interview. The structured interview does not refer the concept of MUDA, LT principles and Lean Thinking. Interviews were audio recorded and transcribed and some were translated from Portuguese to English by a professional service. The most descriptive and informative answers conducted to the selection of five interviews per Case Study for the investigation of MUDA in design.

Data processing

Protocol analysis is one of the four primary techniques currently available for studying designers (Gero, 2010) converting verbal statements to data. The use of verbal protocols (Newell and Simon, 1972) to understand human problem solving became a method that has since been used and developed to understand behavior and is the method currently in use to study designers.

In this research the most important form of designers mental and physical action is talk, which can be recorded, and with some loss of information, transcribed. The separation of talk from action that the transcripts do was compensated with audio and video recordings to assess the mood, context, the objects and matters of conversation and meaning of the utterances. These methods supported the analysis of designers’ verbalizations, when they performed actions such as arguing, justifying, wondering, negotiating, delaying or avoiding some negative steps or promoting positive ones.

The 25 interviews have a total of 42h and 35m of raw data for iterative analysis. The interviews transcripts were imported to Atlas.ti software (www.atlasti.com) workbench for content analysis, coding, clustering and categorization processes. In addition, data from interviews and meetings were analyzed in Excel, Adobe Illustrator and Wolfram Mathematica (www.wolfram.com/mathematica) software for alternative representations to the ones provided by Atlas.ti and Interact software.

The cultural meaning of the statements was many times reviewed according to each design discipline, to the particular characteristics of each design consultancy, to the profile of each designer, and doubts were clarified with them in appropriate occasions. A careful control and mental effort was made to keep the same resolution level of the analysis. It was very important to elaborate a codebook to document and keep
definitions, examples, explanations and criterion in mind to clearly coding the utterances, clustering and categorization tasks (Saldaña, 2009).
Besides other sources of data such as visual documents, the research diary showed to be quite useful in situating the researcher in the timeline of the observation periods and recalling circumstances, ideas, thoughts, descriptions, insights and notes.

**Assessment and measurement issues**
The assessment of *MUDA* in design was focused on the semantic analysis of interviews, design meetings and few research diary descriptions. The analysis of the transcripts of designers’ statements was based on the identification and coding of descriptions of situations where sources of *MUDA* played a positive or negative influence in the design process. Situations of fruitless performance and the identification of competent performance in instances where mistakes are recognized and intervention is requested and taken. The study of these situations in the quantitative dimensions of frequency, incidence, dominant and specific, and in the qualitative dimensions of semantic similarities and differences, such as terminology and representation determined means of comparison for cross-case analysis. Variants and invariants across disciplines derived from the successive studies conducted to the identification of categorization systems and later to the integrative framework. The first coding stage was based on the analysis of prints of the transcripts for a manual and more intuitive assessment. The second coding stage was based on a semantic analysis line by line, identifying verbs, nouns, adjectives, particular terminology, meaning, to get acquainted with the cultural orientation of each interviewee and design office streamline regarding the design discipline and context of practice. The third coding stage was based on the identification of statements that describe the recognition of the situation, its causes, antecedents and consequences. The identification of codes and clusters conducted to the assertion of main axial categories that conducted to a categorization system (Saldaña, 2009). Clustering and systems of categories went through several phases to reducing overlapping.
The interview was a good method to assess a more reflective state of the interviewees, once they talk of what they are doing, have done, or intend to do, and may give reasons for their actions. This reflective talk provides a different window into practical reasoning and interviewees’ discourses on the lessons learnt through years of experience working in several projects. In addition, they report thoughts and concerns not referred while designing. It is assumed that interviewees’ self-reports are reliable, while other source of data, namely meetings gave complementary perspectives. From 582 utterances, two types of critical situations derived from the analysis of designers’ interviews statements:
216 Critical Situations (CS1) – where designers describe how they recognize the situation, explain its causes, its antecedents and consequences leading to positive or negative outcomes but where no solution is provided, only the analysis of the circumstances.
365 Critical Situations (CS2) (Critical situations with crucial actions) – where designers describe how the situation is recognized, identify its antecedents and consequences, anticipate and explain what has to be done to reach an effective result. From this set of Critical Situations (CS2), the analysis identifies: 404 Crucial actions (CA) – where designers anticipate and explain, what has to be done to reach an effective result. The observation and analysis of meetings provided multiple layers of meaning and differing perspectives of the same utterances, circumstances and intervenient. The
analysis of meetings required criteria for selecting utterances namely, utterances comprehensibility, congruence between intervenient intentions and legitimacy of the performed acts. Meetings showed that situations of MUDA are complex to assess. Situations of MUDA occur in instances of evaluation that include multiple aspects of influence in decision-making such as processes inherent to designing as iteration, interdependency and reviewing that can just be empirically assessed through the observation and analysis of meetings. Meetings were first imported to Interact software (www.mangold-international.com) for analysis on the communication between the intervenient, and then mapped in Excel based on design issues prioritized for discussion and their instances of evaluation towards decision-making. Critical design issues conducted to the identification of two types of critical situations in meetings: 35 Long-term Critical Situations (LTCS) - are noticed when a designer recognizes and states that an essential feature it is absent, does not work, or is not assured and immediate solution is not found. Sometimes designers foresee the required long-term measures towards a final decision; 26 Short-term Critical Situations (STCS) - are noticed when a designer recognizes that an essential feature is absent, does not work, or is not assured, and the necessary actions that have to be taken are identified (crucial actions). From this set of Critical Situations (STCS), the analysis identifies: 36 Crucial actions (CA) – are noticed when designers say what has to be done to reach an effective result. Table 2 depicts the data.

**Table 2. Short-term, Long-term and crucial actions across meetings and interviews per Case Study**

<table>
<thead>
<tr>
<th>Case Studies</th>
<th>Total critical situations across the meetings</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>M8</th>
<th>Total</th>
</tr>
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<tr>
<td>Graphic</td>
<td></td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>11</td>
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<tr>
<td>Interaction</td>
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<td>4</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>-</td>
<td>19</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Engineering</td>
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<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>22</td>
</tr>
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<td>Total</td>
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<td>2</td>
<td>3</td>
<td>6</td>
<td>4</td>
<td>9</td>
<td>7</td>
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<table>
<thead>
<tr>
<th>Short-term critical situations</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>M8</th>
<th>Total</th>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>5</td>
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<tr>
<td>Interaction</td>
<td>2</td>
<td>3</td>
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<td>2</td>
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<td>3</td>
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<tr>
<th>Crucial actions in STCS</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>M8</th>
<th>Total</th>
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<td>1</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
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<td>2</td>
<td>-</td>
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<td>0</td>
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<th>Long-term critical situations</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
<th>M8</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphic</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Interaction</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Architecture</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Engineering</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>35</td>
</tr>
</tbody>
</table>

Critical situations across the interviews
The analysis of meetings helped to typify the critical situations in long-term and short term once the recognition of crucial actions is achieved in distinct time span. Protocol analysis studies usually report results from small samples ranging from a few minutes to one or two hours. However, in the practice of design projects last a few weeks or months. Although data from meetings consists of sets of six to eight sequential meetings, located in critical stages of importance to decision-making, critical situations are not so often in the meetings across the four case studies. The study of critical situations would have been difficult with single meetings.

Table 3 illustrates frequency of Short-term and Long-term critical situations across the meetings per case study. The number of critical situations decreases along the meetings in the Graphic design and Architecture Case Studies, and increases in the last meetings of the Interaction design and Engineering Case Studies. The number of Short-term critical situations is low in the meetings of the Graphic design, Architecture and Engineering Case Studies and increases in the meetings of the Interaction design Case Study. The number of Short-term critical situations shows higher incidence in the first meeting across the cases.

The final categorization system of sources of critical situations and crucial actions in design derived from the analysis of meetings and interviews was presented to a panel of evaluation of 32 designers for feedback on a Likert scale based questionnaires. Designers of different backgrounds namely, Industrial Design, Product Design, Rehabilitation Engineering Design, Ceramics Design, Arts, Architecture, Mechanical Engineering, Communication and Graphic Design are Portuguese, Brazilian and Ecuadorean designers aging from 25 to 36.

**Data Analysis**

The progression of studies to identify *MUDA* in design is briefly described and further explained. The 25 selected interviews were analyzed according to the LT nine types of *MUDA* – defects, over processing, waiting, movement, complexity, useless, over production, inventory and transport (Ohno, 1988; Womack et al, 2003) that were categorized in the context of designing. The identification of the behavioral examples to each type resulted in preliminary definitions and a framework to support collecting data along the empirical study (Vieira et al, 2009). First results converged to three main categories namely, cognition, process and decision-making, as streams were *MUDA* could take place. Throughout the observation period the research was open to the recognition of other non-expected *MUDA* situations and other behavioral examples. In this initial stage the LT types of *MUDA* provided a guiding framework in the analysis and clustering of quotes. This approach was helpful for a first screening of categories, helped to identify other sources of categories but it also shed light on semantic overlapping and other limitations:

- The Lean terminology is related to the manufacturing environment. The direct application of MUDA types in the design context would not be suitable as a shared language of communication.
LT defines MUDA types based on what should be avoided (ex. waiting, movement, over processing). However the sources of MUDA in design do not always lead to negative effects but also to positive consequences.

In addition, the analysis of MUDA types showed a prejudice, a negative connotation. For example, when looking for descriptions related to the MUDA of waiting, interviewees did not always regard such situations as unhelpful. Many times, designers refer to situations of waiting as helpful, creating space to think or even a necessary pause to proceed. Some other MUDA types were recognized in the design activity, for example, the MUDA of over processing, defects, useless, movement and complexity. However, the analysis showed that these situations are also essential to forward the design process. Lean Thinking proposes to convert MUDA into Value (Womack, 1996, p.15) what must be distinguished from avoiding MUDA. Thus, review, redrawing and other re-processes of iteration are not excluded from the LT Philosophy. Thus, the system of influence on designers’ behavior that can lead to MUDA situations has a non-absolute negative effect.

After many stages of iterative coding in empirical studies, it was found that in design, the situations of MUDA differ from those of the manufacturing context. While in production the idea of Value relates to the final result of an expected procedure that can be optimized, in design, Value is defined at the same time that resources are absorbed during the creative process. Value complete definition is just accomplished in the end. Thus it is not possible to completely control resources in design, some waste/MUDA is inevitable. At the same, overlapping between the types of MUDA was identified while clustering the codes of designers’ quotes. Other categories were not matching as dimensions for analysis. In addition, the terminology of the initial nine types of MUDA assumes a negative connotation. This was a contradictory aspect to the findings from interviewees’ quotes where potential situations of MUDA had source in actions that went wrong, in other quotes were the actions that would avoid MUDA and uphold performance. A twofold outcome was identified from the same source of action, with a critical aspect of loss of Value, and a crucial aspect of remaining in Flow, or converting MUDA into Value.

From the evidence that the influence of such situations could have a twofold outcome, positive or negative effects, the research adopted an approach to the phenomenon of MUDA as critical situations in design with the same sources of crucial actions to cope with the circumstances. MUDA is in this research seen as sources of critical situations that can limit but can also challenge designers’ behavior and performance. Therefore, the identification of sources of critical situations is in this study the driver for the translation of the Lean Thinking philosophy in design research.

Therefore, the analysis became concentrated on the sources of situations that can bring one of a twofold outcome according to its helpful or not helpful influence. These situations were found to have critical and crucial aspects. A critical aspect that called for the identification of what could go wrong and a crucial aspect that called for the identification of what could be done to get things back on track.

A preliminary categorization system derived from a second round of analysis of the interviews (Vieira et al, 2011). This second attempt led to a third round of more careful analysis of the set of quotes selected from the interviews and definitions were reworked, based on a qualitative assessment of such clusters. From the analysis of the 25 interviews, 582 utterances on designers’ descriptions of situations of MUDA conducted to seven main categories of sources of critical situations and crucial actions in design (Vieira et al, 2012a). As stated by Klaus Krippendorff (2006, p 27) ‘Scientific research is essentially re-search, a repeated search for patterns within
available data.’

The analysis of meetings provided a better understanding of the nature of the activities per categories that led to a third round of analysis of the sets of quotes from the interviews and fine-tuning of the categorization system. Detailed results can be seen in other studies (Vieira et al, 2012b).

Due to the frequent occurrence of MUDA in idea generation, idea solution, and conceptualization phase, the study was initially focused on the analysis of these stages of the design process. However, after some rounds of analysis it became evident that critical situations can occur in any stage with particular incidence at the beginning and end of the design project.

A META-LEVEL BEHAVIOR FRAMEWORK

A Meta-level Behavior Framework derived from data analysis is depicted in Table 3. Main categories represent the sources of critical situations and crucial actions and the second level categories represent the challenges designers face in order to continue, keep flow, and pursue their objectives. The definition of each category is provided.

<table>
<thead>
<tr>
<th>Sources</th>
<th>Challenges</th>
<th>Examples of less successful behavior in critical situations</th>
<th>Examples of successful behavior in crucial actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dosage</td>
<td>Adequacy</td>
<td>Missing criteria</td>
<td>Look for essential criteria</td>
</tr>
<tr>
<td></td>
<td>Balance</td>
<td>Over/under dosage</td>
<td>Make things matching</td>
</tr>
<tr>
<td>Planning</td>
<td>Probability</td>
<td>No risk evaluation</td>
<td>Contingency planning</td>
</tr>
<tr>
<td></td>
<td>Anticipation</td>
<td>No view of the future</td>
<td>Foreseeing opportunities</td>
</tr>
<tr>
<td>Framing</td>
<td>Orientation</td>
<td>Difficulty to choose</td>
<td>Reflected choice</td>
</tr>
<tr>
<td></td>
<td>Focus</td>
<td>Stuckness</td>
<td>Convergence</td>
</tr>
<tr>
<td>Information</td>
<td>Surprise</td>
<td>Missing opportunities</td>
<td>Opportunistic procedure</td>
</tr>
<tr>
<td>Assessment</td>
<td>Knowing</td>
<td>Clients that do not know what they want</td>
<td>Look for information</td>
</tr>
<tr>
<td></td>
<td>Transparency</td>
<td>Difficulty to grasp the features of a problem</td>
<td>Searching for indicators</td>
</tr>
<tr>
<td>Information</td>
<td>Communication</td>
<td>Confirmation bias</td>
<td>Transparent communication</td>
</tr>
<tr>
<td>Transfer</td>
<td>Exchange</td>
<td>“Tunnel view”</td>
<td>Awareness of the need for sharing information</td>
</tr>
<tr>
<td></td>
<td>Documentation</td>
<td>Not keeping record of sub-results</td>
<td>Keeping record of sub-results</td>
</tr>
<tr>
<td>Interdependency</td>
<td>Interfaces</td>
<td>Acting without reference to others involved</td>
<td>Awareness of the different interfaces involved</td>
</tr>
<tr>
<td></td>
<td>Suspension</td>
<td>Missing feeling of competence</td>
<td>Take time for decisions and keep in mind long and short term consequences</td>
</tr>
<tr>
<td>Envision</td>
<td>Open up solutions</td>
<td>Difficulty to think into the future</td>
<td>Generating alternatives</td>
</tr>
<tr>
<td></td>
<td>Representation</td>
<td>Difficulty to represent a concept</td>
<td>Providing clear examples, good graphics and visual proposals</td>
</tr>
</tbody>
</table>

**Dosage** - refers to the need to find adequacy (enough in quantity or good enough in quality for a particular purpose or need) or balance (emotional, economical, aesthetical, or negotiable stability) in the quantity and quality of different activities and measures, in order not to overdo or be underdone.

**Planning** - refers to situations which need an action plan for the future regarding the extent to which results are likely (probability), and the extent to which something is expected or predictable and take action in order to be prepared (anticipation).

**Framing** - refers to situations that hinder or provide orientation (direction to proceed) and focus (concentrating interest, to adapt or adjust so that things can be seen clearly), that need to be framed or reframed.
Information assessment - refers to the awareness of the relevance of a situation that shows the absence or latest information and that relate to: moments of surprise (denoting something made, done, or happened unexpectedly), transparency (difficult to perceive or detect) and knowing (what is known or not about facts, information, and skills acquired by a person through experience or education), which create ambiguity and uncertainty that can hinder the process but can also be beneficial to generate alternatives and overview.

Information transfer – refers to situations where the transference of information requires to deal with different challenges such as: communication (the successful conveying or sharing of information, ideas, feelings, news, through the means of sending or receiving information), exchange (an act of giving or doing something to somebody and receiving something in return) and documentation (the act on recording material that provides official information or evidence or that serves as a record).

Interdependency – refers to situations where the need to establish or undo interdependencies, is made through the creation and recognition of interfaces (a point or moment where two systems, subjects, organizations, etc., meet and interact, such as people, companies, expertise, software, technical limitations) or suspension (the action of suspending someone or something or the temporary prevention of something from continuing or being in force or effect).

Envision - refers to situations that request to start imagining future possibilities regarding the design goal, solution or sub-solutions, taking different perspectives, giving form to mental images or making something visible to the eyes through representation and feasibility assessment. Such situations can hinder or further the design process regarding the extent to which such mental or physical images of solutions are created with flexibility, taking different perspectives, providing a wider ideation space to be unfolded, and solutions to come into view.

All the sources of critical situations can be found in circumstances that make decisions vulnerable that might do not intend side and long-term effects, risk and uncertainty. Therefore, being aware of sources of critical situations and crucial actions to cope with these circumstances is essential for practitioners, students and design teachers.

Results from the Likert scale-based questionnaire show an agreement of 83.8% with the categorization system. Average of the 16 sub-categories is 4.2 (1-5). The average of each of the five categories are over 4 to 4.3. The average of importance attributed to the seven categories is 5.2 (1-6), all the seven categories over 5.

FRAMEWORK OF AWARENESS

The empirical studies accomplished through the perspective of the Lean Thinking philosophy in understanding each of the five design disciplines led to the identification of the following set of characteristics that constitute the Framework of Awareness. Three stages are relevant to the framework of awareness:

- Input- There is an input situation based on a request to discuss a Priority Issue that starts with a question based on a doubt or update request regarding an essential feature.

- Instance of evaluation – There is an instance of evaluation that from the analysis of the request evolves to a point where one of the team collaborators states opposition based on the identification of not-existing, not assured or not working essential features. The discussion involving all the present collaborators is
focused on the opposition and each designer argues his/her point of view based on the set of values inherent to his/her own activity. The identification of the source of the critical situation is spontaneous or based on the proposed categorization system, which can help keeping track and eventually mapping the sources of critical situations. A categorization of challenges defies designers to figure out what can be done and which action should be taken in case a resolution does not arise spontaneously.

- Output - There is an output situation where a team-based decision is made. Two things can happen, a decision based on the agreement of a crucial action to be taken, or a postponed decision based on interdependencies with other design issues, uncertainty or ambiguity among other aspects, that leads to iteration processes.

**Figure 1. Framework of Awareness of Critical Situations and Crucial Actions in Design**

Iteration processes have the capacity to make unnoticed critical issues become apparent and therefore prioritized for discussion. Critical situations brought into description derived from four factors: individual, team, the design subject and external influences.

Critical situations are many times unnoticed or disregarded, therefore, the importance of an enduring awareness. The critical situations fail to be noticed when they were: never experienced, new, assumed as inherently solved, its core issue is not yet unveiled, and when they remain non-transparent.

Critical situations and crucial actions can occur and influence the following views of the design process towards the completeness of the result: goal, direction, ideation, detail, teamwork, planning and conceptualization.
The critical situations are noticed when an element of the team recognizes and states that an essential feature is not: existing, working and assured. The individual starts with a question based on a doubt or update request regarding the essential feature. Critical situations emerge in the design process as a consequence of introduced design issues derived from management demands that relate to: priority and emergency. Although opposition marks the crossroad for the identification of a critical issue, it is not an exclusive characteristic of critical situations. What is specific of critical situations is the recognition of not existing, not working or not assured essential features in the design process.

Crucial actions emerge as a consequence of instances of evaluation of critical design issues where the discussion of opposites leads to a point where actions to be taken are based on common agreement. Such circumstances relate to: opposition, absence of essential features, value judgment (an assessment of something in terms of one’s standards or priorities) and decision-making.

Crucial actions comprise the identification of the inherent challenges to overcome the source of a critical situation as behavior signs to stand up for absent features in instances of value judgment where value is prioritized and drivers for decision-making identified.

**MAPPING THE AWARENESS**

Knowing the incidence of critical situations and crucial actions per category was not sufficient (Vieira et al, 2012b) to understand the mechanisms of influence described. From the analysis of the statements, it was possible to infer the following patterns of sequence:

- Critical situations that are immediately perceived and the crucial action is known have direct solution.
- Critical situations that do not have a successful resolution might lead to other critical situations.
- Crucial actions that are not taken might lead to unsolvable critical situations.
- Crucial actions that are not taken, might be excessive or insufficient can lead to critical situations, that still can be solved.

The representation of these patterns was done through the creation of an axial flow chart that shows the multidimensionality of the variables that constitute the second-level categories of challenges. Such chart derives from a function created in Wolfram Mathematica software for the representation of the data analysis. This chart considers the 16 categories of challenges in axial dimensions with a cycle graph that illustrates in four quadrantes the patterns of sequence in the critical situations.

The up right hand quadrant shows situations where immediate crucial actions are perceived and taken. The up left hand quadrant shows situations where the crucial actions where not taken, are insufficient or excessive. The lower left hand quadrant shows the consequent critical situations.

The lower right hand quadrant shows situations where crucial actions can be taken to cope with the circumstances. As an example, the following image (Figure 2) illustrates the sequences that derived from the critical situations that relate to the category of Information transfer, second level category of Documentation.

In the up right hand quadrant it can be inferred that, Documentation is a crucial action to cope with critical situations which source that relate to Knowledge, Orientation and
Open up solutions, as well Communication is a crucial action to cope with a critical situation regarding Documentation. In the lower left hand quadrant situations where the crucial action of Documentation is not taken, or is insufficient or excessive can lead to critical situations regarding, Focus of attention, Intransparency, Communication and Surprise. In the lower right hand quadrant Adequacy and Orientation are crucial actions to cope with some of these sequences of events. The up left hand quadrant shows what was not done, overload or absent.

Figure 2. Axial flow chart illustrating as sources of critical situations and crucial actions in design as multidimensional variables. The chart refers to the representation of empirically based situations which source relates to the sub-category of Information transfer: Documentation.

To Dorner (1996), ‘The critical variables in a system are those that interact mutually with a large number of other variables in the system. They are, then, the key variables: if we alter them, we exert a major influence on the status of a system.’ This axial flow chart has applicability in design and product development and the utility to provide the mapping critical situations, its sources, patterns of sequence and provide reflection on crucial actions as variables of major influence in designers’ behavior and performance.
MUDA ASPECTS ACROSS THE CASES STUDIES

Case studies of technology-based design approach such as interaction design and mechanical engineering show higher incidence of long-term critical situations, while case studies of rule-based design approach of clear identified tasks and competences as graphic design and architecture show lower incidence, both in meetings and interviews. The innovation-based design approach of the SME of interactive design solutions, a company operating in the emergent discipline of interaction design, which body of knowledge asks for more structure, organization, development and management abilities naturally shows the lowest incidence of short-term critical situations and crucial actions. Thus, this company, although operating in an internal transdisciplinary design environment still needs to reach the level of awareness and managerial aptitude of other cases studies working in internal or external multidisciplinary environments as the engineering and architecture, respectively. This is reflected in the high incidence of crucial actions in the category of Interdependency, sub-category Interfaces, and Framing, sub-categories of Orientation and Focus.

The case study of the Industrial design graduating students, which design approach is rule-based although in a learning environment, shows a balanced number of critical situations and crucial actions, with higher incidence in the same categories, Framing and Interdependency, but also Dosage, in the sub-category of Adequacy and Information assessment, in the sub-category of Knowing. Students show more difficulties in the category of Envision, and low or complete unawareness to critical situations and challenges such as, Transparency, Anticipation, and Suspension, which suggest the usefulness of including the Framework in design education. Table 4 depicts results from the analysis of interviews per categories across case studies in absolute numbers.

| Table 4. Short-term, Long-term and crucial actions across categories from interviews per Case Study |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Categories                      | ST critical situation | CA Crucial action | LT critical situation | Total           |
| Source                          | Challenge        | Adequacy        | Balance          | Probability     |
| Dosage                          |                   |                 |                 |                 |
|                                  |                   |                 |                 |                 |
| Planning                        |                   |                 |                 |                 |
|                                  |                   |                 |                 |                 |
| Framing                         |                   |                 |                 |                 |
|                                  |                   |                 |                 |                 |
| Information Assessment          |                   |                 |                 |                 |
|                                  |                   |                 |                 |                 |
| Information transfer            |                   |                 |                 |                 |
|                                  |                   |                 |                 |                 |
| Interdependency                 |                   |                 |                 |                 |
|                                |                   |                 |                 |                 |
| Envision                        |                   |                 |                 |                 |
|                                |                   |                 |                 |                 |

From the analysis of the statements of short-term critical situations some crucial actions were described as patterns of sequence of two to three actions (as illustrated in Figure 2), therefore the superior number.

The unit of analysis of the research was MUDA in design as critical situations. Diversity in the tasks observed and stated by the informants helped identify a broader set and clusters of sources of critical situations and crucial actions in design and therefore complement the elaboration of the categorization systems.
DISCUSSION

...Adaptation may be quite unconscious and unintended, as in Darwinian evolution, or it may contain large components of conscious intention, as in much human learning and problem-solving.


The present Framework of Awareness contributes to the activation of the individual, team, design and external crucial actions holding value input to cope with critical situation as an adaptive set of principles to apply in any design process model. The Framework, if adopted by design developers, can create a mental state that favors a reflection on the issues to be dealt with. The practice of this mental exercise brings an educational aspect of awareness and adaptive behavior, as invariant characteristics of human realms (Simon, 1990). As a consequence, it can lead to better communication, a more thorough analysis and a more effective design. The importance to depict a framework of awareness in such circumstances can help to reduce lead-time in product design and development, improve performance and above all foster motivation among the design team. Adaptive behavior also creates shared understandings of other collaborators reactions, and values as well of the clients that are usually willing to reflect, discuss and learn from the development of the expected designs. As Francis Bacon phrased “instantia crucis”, crucial instance, which he explained as a metaphor for a crux marking a crossroad (Novum Organum, 1620), Newton and Boyle took up the same metaphor in “experimentum crucis”, crucial experiment, meaning a moment of decision and significance (Romesburg, 2009). For Bacon, finding the essence of a thing was a simple process of reduction through inductive reasoning and listing all the situations where such essence is or is not found. In the present framework, a categorization system of the sources of critical situations leads to the identification of challenges and crucial actions in design that can support designers dealing with crucial instances.

Few research attempts also investigate problematic situations in studies limited to one design discipline. Such attempts elaborate on concepts and empirical studies developed for specific purposes, such as design methods, mapping of design cognition, reducing routine tasks and documentation processes (Table 5).

Table 5. Critical decisions and critical situations in design and product development research

<table>
<thead>
<tr>
<th>Type and source</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical decisions in design methods (Jones, 1970)</td>
<td>'Every decision which carries a high penalty must be identified as early as possible. Such decisions should be taken only tentatively at first and should be reversible if they are later found to conflict with reliable evidence or with informed opinion. Critical decisions include the initial assumptions, the objectives, the choices of models, the choice of strategy and the procedure for changing strategy.' p 57.</td>
</tr>
</tbody>
</table>
| Critical design moves in product design (Goldschmidt 1996) | The meaning of 'move' in designing is akin to its meaning in chess: a design move is a step, an act, an operation, which transforms the design situation relative to the state in which it was prior to that move. We use a binary reply system of 'yes' and 'no' only, and the sole criterion used to determine linkage or its absence is common sense, in the context of the design task. backlinks record the path that led to a move's generation, while forelinks bear evidence to its contribution to the production of further moves. If a high number of links is indicative of productivity, then we should pay special attention to moves that are particularly rich in links, in one direction or the other (and rarely, in both directions). Link-intensive moves are called Critical Moves (CM), and all the Critical Moves of a sequence together describe its critical
Critical situations in engineering design (Frankenberger and Badke-Schaub, 1998)

'where the design process takes a new direction on a conceptual or embodiment design level’ p. 154.
The main purpose was to reduce routine tasks and documentation. This research proposes five general categories based on the identification of tasks and collaboration: goal, conflicts.

The decision perspective in product development (Krishnan and Ulrich, 2001)

"coordinated decision making requires an approach to research that is driven by the intrinsic interdependencies among decisions, rather than being driven by attempts to bridge the extant functional structure of the research community” p.12


The integration of risk management as an intrinsic part of design processes is proposed in the Risk-driven Design framework. The proposal emphasizes that when the design process is driven by the intention to manage risk, known and unknown uncertainties and their effect on the objectives are identified and decision-making then focuses on the most critical uncertainties. The authors argue that if risk management is interpreted as the structured identification and reduction of uncertainty, all product development activities that aim at minimizing uncertainty can be seen as risk treatment measures such as quality management and review processes.

Critical situations in design and product development (Vieira et al 2012b)

The absence of essential aspects of the design process is identified and prioritized for team discussion delaying decision-making in short and long-term.

Crucial actions in design and product development (Vieira et al 2012b)

The identification of the inherent challenges to overcome the source of a critical situation based on team value judgment converges to the identification of an action to be taken for an effective result.

This research proposes a transdisciplinary approach based on the identification of the nature of the actions that can lead to a twofold outcome, a positive or negative influence in the design process and decision-making. The added value of the present trans-disciplinary approach and resulting framework is the relevance given to the influence and interdependency between decisions along the design process. Managing interdependencies among decisions (Krishnan and Ulrich, 2001) has been asserted of major importance in design and product development processes with implications to risk management (Oehmen and Seering, 2011, Bassler et al., 2011). A call for a more humanistic approach towards risk in the area of new product development encompassing a positive attitude towards risk emerged in the last decade. Such approach requires a deeper understanding of design cultures and ability to challenge individuals’ embedded perceptions of risk (Jerrard et al., 2008).

Almost one century after the first known design research attempts (compiled in Pahl et al, 2007), it is still pertinent to understand, externalize and improve effectiveness of the design process. The main reason of concern with more methodical approaches in the design process relates to the need to tackle lots of uncertainties inherent to design tasks. In an attempt to describe the structure of design problems, it has been argued that design problems are possibly undetermined (Dorst, 2005). Intuition still remains an important aspect that persists as an argument against the adoption of systematic design procedures (Alexander, 1964). A widened and integrated design process would be one in which rigidity and flexibility are properly balanced (Jones, 1970). A general working methodology to be widely applicable, asks to be independent of discipline and should not require specific technical knowledge from the user, but support a structured and effective thinking process (Pahl et al, 2007). A principle-based approach as Lean Thinking would still remain systematic but also a flexible approach.
to design. The Framework of Awareness challenges designers and developers to reflect upon their behavior and effective performance in interdependent situations that ask for uncertainty and risk management aptitudes with a principle-based and domain-independent approach.

‘In the middle of difficulty lies opportunity’ (Albert Einstein) is the suggestion of the present framework. Critical situations entail difficulties to which opportunities of resolution must be found. Moderating this basic tenet is the phenomenon that creativity can be enhanced under conditions of optimal frustration, as well as under conditions of difficult but achievable challenge (Boland and Collopy, 2004). The current context of crisis revealed appropriate to assess and derive knowledge from designers’ behavior in the processes of value creation and coping with MUDA situations where designers activate mechanisms that remain hidden in times of normal circumstances (Vieira et al, 2010). Elemental mechanisms of design can best be deciphered under extreme conditions such as missing knowledge, resources and time, circumstances that represent design on the edge of feasibility, where results emerge through essential human understanding (Flusser, 1999).

CONCLUSION
The present research proposes a Framework of Awareness derived from empirical studies and based on the developed categorization systems and interaction modus operandi. This framework intends a twofold contribution:

- Support designers’ identifying and reflecting on the sources of critical situations, challenges and crucial actions to uphold performance towards decision-making.
- Knowledge of the design process and designers behavior across different design disciplines.

Design practice, management, and education are in the scope of this research areas of the design and product development field that can benefit from the present contribution. Creative processes are essential to innovation and context, motivation, time and pressure play essential roles in framing design problems (Root-Bernstein, 2003) leading to different levels of creativity (Taylor, 1959). In the current times of crisis, design mind-set and approach brings different expectations and orientations facing opportunity for intervention and questioning some basic assumptions.

Implications to design management and education
The results derived from the present analysis have implications to design management aiming to support design practitioners improving their performance and facilitate decision-making. The Framework of Awareness provides testing guidelines to intervene and eventually change previously identified less successful patterns of behavior in design. The framework provides a meta analysis to reflect on thinking and acting and on what prevents them from changing. The practice of this behavioral framework involves an internal review so that each designer can become aware of the degree to which usual performed patterns are inconsistent with a less successful process and outcome. The framework might contribute to designers’ professional competence and its acquisition and the redesigning of professional education assuming that competence is based on the ability to develop theories of what to do in new situations and to behave effectively (Argyris et al., 1985).
Research Limitations and Future Research

This research is exploratory and qualitative in nature. While the research proposes the extension of the Lean Thinking philosophy into design taking its principles and concepts as dimensions to new or more integrative directions to design research, it also has its limitations. Although carefully chosen, findings are based on only five case studies. Results provided a transversal explanatory framework and it is likely that some of the findings will generalize or be complemented with further studies based in other design disciplines. Application, corroboration and confirmation of the framework by other researchers with another case studies would provide validation. Research should investigate further the interrelationships and patterns of sequence between the categories.

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