Chapter 2

Ambiguity, Risk and Change in Designing: A Micro-level Description for a Property-based Approach

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2.1 Introduction

The purpose of this study is to know if risk takes place in designing and if so, to provide an understanding of risk underlying mechanisms and its influence in the design process. The study is a starting point to investigate the interplay and causal networks of ambiguity, risk and change (ARC) as properties of variables of design issues introduced in circumstances that ask for evaluation and decision, and that have the potential to increase or decrease uncertainty towards completion.

This paper presents the ARC hypotheses to explore the interplay between the three proposed properties of design issues variables. The investigation is based on the analysis of a set of meetings for the design of a robot developed at a Mechanical Engineering design consultancy. The approach has its application in the semantic analysis of the transcripts of thought sequences obtained from verbal reports. A closer look is given to critical design issues that emerged at the first meeting and how they evolved throughout the meetings.

A property-based approach underlines the investigation of ambiguity, risk and change as properties of variables and their influence towards the completion of design issues at design meetings. The study contributes with preliminary results that show interdependency between the properties. A domain-independent and property-based approach is proposed to assess risk in designing.

The leitmotif of the present study is the investigation of risk in designing. Design is, in this research, a cognitive process extensive to all the fields of human action that can be acquired and embedded through personal development and experience (Vieira, 2013). Risk in designing remains unspecified. Attempts to approach risk in design have recently established the basis for further research (Jerrard and Barnes 2006; Oehmen, 2010), though we still do not know what risk is and how it evolves in design. Besides not knowing what risk in design is, it is also not known where risk starts or where it ends. Risk perception is innate to thought with plausible influence in design as a cognitive process.

Although it is still not possible to fully assess how designers think and act while designing (Gero, 2010), the sharing of risk perception occurs when the important meaning and associated essential issues are communicated (Jerrard *et al.*, 2007). The implicit process of risk perception becomes explicit when the perceived risk is verbalized, shared with the design team and discussed in instances of evaluation that ask for decisions (Jerrard and Barnes, 2006). The study of the underlying mechanisms of risk in design is therefore dependent on the analysis of other underlying processes, such as valuation and decision-making towards the design completion.

This paper attempts to illustrate the understanding of how risk takes place in designing and is based on the analysis and mapping of selected moments from sequential meetings for the design of a robot, developed in a design consultancy specialising in mechanical engineering. Interdependent relations of risk with other properties of variables of design issues are hypothesized and investigated. The following section explains the theoretical background and illustrates the hypotheses.

2.2 Theoretical Foundations

Research in engineering design has placed more attention towards the investigation of risk in project management and product development. Structured methodologies for better planning and control of stable environments have been applied in order to transform the product development process into a more predictable activity, such as the stage-gate model (Cooper, 1995; 2008). Although with the focus on downside aspects the knowledge of risk in project management is well established.

The numerous technical methods for handling risk and uncertainty that are available to project managers, do not seem to fit designers' needs when it comes down to less instrumental design approaches and a more connected performance. Recent studies assert that in current practices risk management processes still tend to be treated as separate tasks of project management approaches (Oehmen and Rebentisch, 2010).

From the many definitions of risk that can be found in project management and product development literature, one particular definition is appropriate to the context of this study, 'Risks are defined within complex and dynamic causal networks' (Oehmen *et al.*, 2009). Studying risk in design requires the investigation of the causes, effects and underlying mechanisms of risk in order to provide awareness and strategic principles for risk management.

The integration of risk management as an intrinsic part of design processes is laid out in the Risk-driven Design framework (RdD) (Oehmen and Seering, 2011). This proposal emphasises that, when the design process is driven by the intention to manage risk, and known and unknown uncertainties and their effect on the objectives have been identified, then decision-making focuses on the most critical uncertainties. The RdD framework shows that if risk management is interpreted as the structured identification and reduction of uncertainty, all product development activities that aim at minimising uncertainty can be seen as risk treatment measures, such as quality management and review processes (Bassler, 2011).

The same reasoning can be extended to design, assuming that risk perception and the reduction of uncertainty are implicit processes always at the background of designers thought. Therefore, the understanding of risk in design requires the analysis of the verbalizations of perceived risk, its causes, antecedents, effects, consequences and influence in decision-making. The shared perception of risk has been hypothesised as a non-linear process and individual risk perception as value-laden (Jerrard and Barnes, 2006). A more complete understanding of risk in design may derive from the investigation of iteration processes (Cross and Roozenburg, 1992; Unger and Eppinger, 2011).

Designing relates to the search for variables that relate to what is not known (Gero, 1998) and designers are likely to take risks. The environments of greater uncertainty are those in which designers face a greater number of unknowns within the variables. Such environments seem to be appropriate to investigate the extension of risk effects in design, and provide a more complete understanding of risk in general.

From previous studies, results from the analysis of design meetings show interdependency between variables of design issues with influence in decision-making as one of the mechanisms of iteration in design (Vieira, 2013). When design issues are brought into discussion, some have an immediate resolution; others go through iteration processes of discussion and decision-making leading towards completion. On a macro-level, design *'fundamental issues are a topic or problem for debate and discussion, not particularly, nor uniquely related to any specific design task, design or design situation'* (Gero, 2010). On a micro-level, design issues are specifically related to the design subject context, and explicit verbalized in team.

Design issues are comprised of constants and variables and evolve through a process of the reduction of uncertainty towards completion. Variables are based on knowns and unknowns (Knight, 1921; Loch *et al.*, 2006) and evolve through evaluation processes and interdependency within other design issues. The underlying processes for completion of design issues are plausibly intertwined with risk perception and evaluation; consequently, the study of risk in design asks for the analysis of the processes of evaluation and decision-making towards the completion of risk-design issues variables. Such variables are context sensitive, can bring change and have variant meaning and intonation according to the design situation (Gero, 1998). These variables are the subject of a designers' evaluation that might change, not just their own values, but also situational relationships. Attempts for the understanding of change in engineering design processes unfold in complementary perspectives (Jarratt *et al.*, 2011). A call has been made to develop tools and knowledge to help understand and improve change processes.

From the literature, risk is recognized in two ways: a perceived risk that leads to the identification of an effect; or an identified effect with influence in the design outcome. Whether the effect is immediately or later identified, both influence decision-making and the design trajectory. The perceived risks are not clearly known. There is uncertainty underlying their perception. A risk effect clearly identified might have some space for uncertainty if its consequences are not fully considered.

This investigation explores the proposition that risk possibly derives from ambiguity. Identifying and solving ambiguity is to make the unknowns known, reducing uncertainty and setting the path for a decision. The definition of ambiguity is twofold: uncertainty or inexactness of meaning in language; or lack of decisiveness or commitment, resulting from a failure to chose between alternatives (New Oxford American Dictionary). Consequently, ambiguity is about unknown knowledge or unclear information and relates to knowledge assessment and decision-making. In other words, variables of design issues have, most likely, the property of ambiguity until they become known.

In this process of clarification, risk can emerge with a perceived effect on the design outcome and eventually lead to change, or change might be introduced and influence all that was done before, eventually bringing new risk and ambiguity. The term property is defined as an attribute, quality, or characteristic of something (New Oxford American Dictionary).

In the process of designing, attributes and qualities are specified to the formulation of ideas and solutions (Vieira, 2013). It is supposed that a set of temporary or permanent properties of design issues variables and constants influence the design trajectory towards its completion. From this set of properties, evidence from a causal network between risk, ambiguity and change emerged from the observation and analysis of designers' verbal reports.

The present study hypothesizes ARC as properties of design issues variables introduced in circumstances that ask for evaluation and decision, as a starting point to further investigation on the interplay between these properties.

2.2.1 The ARC Hypotheses

The study attempts to build on two hypotheses that can bring new insights and directions to research the causal networks of risk in design. The hypotheses are further explained and illustrated. The hypothesis H1 holds the following statement:

H1: Ambiguity, risk and change are properties of design issues variables.

The investigation of H1 aims to clarify if risk takes place when the design team discusses incomplete design issues and their causal networks, looking for a plausible explanation of when risks start and when it ends. The identification of variables of design issues under risk and ambiguity and what changes and effects can take place is proposed through the semantic analysis and coding of segments of designers' verbal intervention in meetings.

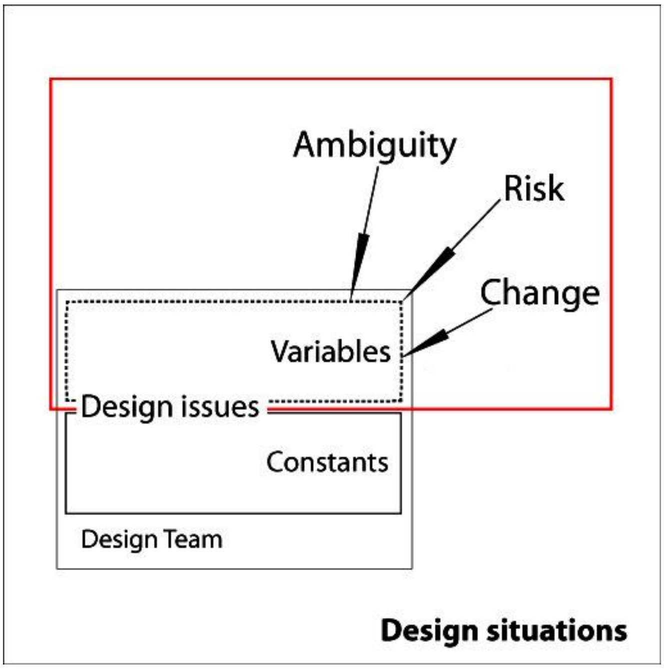

Figure 2.1. Illustration of the hypothesis 1: ambiguity, risk and change are properties of design issues variables

The hypothesis 2 sets out the following statement:

> *H2: Ambiguity, risk and change are properties of variables that influence design issues constants.*

The investigation of H2 aims to explore how far the properties that influence the variables also influence design issues constants and have the potential to increase or decrease uncertainty towards the design completion.

Two perspectives of the interplay of ambiguity, risk and change as properties of variables are proposed:

- Ambiguity, risk and change have independent influence in the design issues variables with or without a resultant interdependency (H1).
- A direct interdependency between the three properties might emerge from ambiguity of the perception and identification of a risk, and therefore, to change (H2).

The present paper intends to present the ARC hypotheses and to investigate the phenomena based on the microanalysis of a piece of data, and further directions for researching risk in design and the hypotheses corroboration.

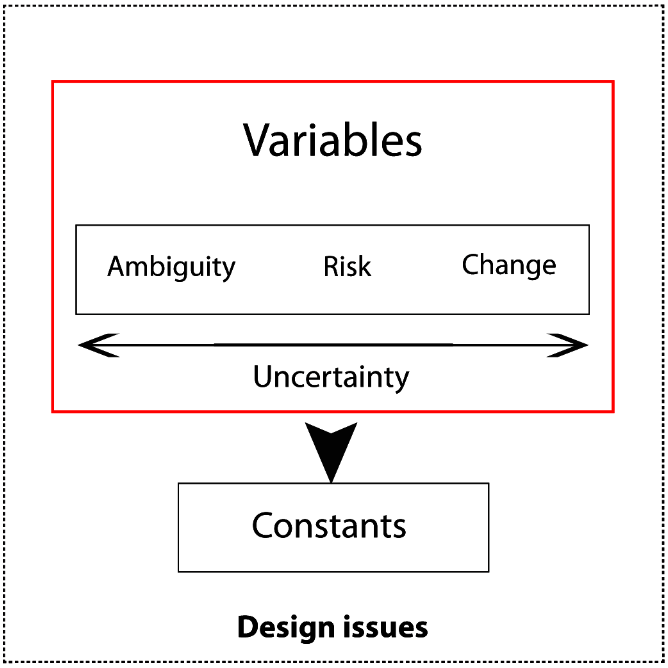

Figure 2.2. Illustration of the hypothesis 2: ambiguity, risk and change as properties of variables have influence in design issues constants

2.3 Research Methods

Studying risk in designing requires the analysis of designers' verbal reports in evaluation and decision-making processes in real life design environments, as the appropriate settings to assess designing activities with all the influences of the social and business context.

This research takes a different look at a piece of data previously analysed under the scope of prioritized design issues and their iteration, interdependency and decision-making processes at design meetings (Vieira, 2013) and under the scope of the Function Behavior Structure ontology (Gero *et al.*, 2013).

From these results, a closer look has been taken at the analysis of critical design issues, where the absence of essential aspects of the design process are identified and prioritised for discussion, thereby delaying decision-making. The study identified the sources of the absence of essentials in circumstances where risk and uncertainty are perceived on a base level.

Insights from these studies based on data gathered from several design disciplines brought into perspective that: change could be introduced in actions that relate to envisioning, rethinking direction and the focus of the design process; ambiguity could be introduced in circumstances that relate to information assessment and information transfer; ambiguity and change could bring consequent downside and upside risk effects. Critical design issues represent the basic level of influential situations in design where risk is perceived and therefore the first stage to investigate the ARC hypotheses. Studies of other types of design issues may bring further insight into other levels and mechanisms of risk causal networks and risk management in design.

For the purpose of this study, the analysis focus is the assessment of variables of critical design issues, and how far ambiguity, risk and change emerge and evolve as properties of the variables. The data consists of audio and video recordings of sequential design meetings referring to a design project, a robot developed in a mechanical engineering design consultancy. Previous results show that a higher incidence of critical situations occurs at the first meeting (Vieira, 2013). In these circumstances, the design team experiences opposition, at least from one of the collaborators awareness of the absence of essential issues. Table 2.1 illustrates the characteristics and details of the project and the first meeting.

Table 2.1. Overview of the design project and details of meeting one

Source of data	**Project**
Discipline	**Engineering design**
Design	Robot
Meetings	8
Observation	5 month
Meeting	1
Duration	01h 06 m
Topic	Detailed discussion of specifications and solutions
Team members	Leading Engineering researcher
	Electronics Engineer
	Software Engineer
	Technician

2.4 Data Analysis

The investigation of the hypotheses is based on the semantic analysis and coding segments of transcripts of verbal reports from moments of discussion of critical design issues that emerged in the first meeting of the design project. The analysis is based on verbalizations that relate to: risk perception or risk effect; risk interplay with ambiguity and change; variation of uncertainty underlying the three properties; and implications to decision-making. The paper reports a closer look at the analysis of four critical design issues, namely: a software, the space box for components, a demo experiment, and the Inertial Measurement Unit (IMU) specifications. Table 2.2 shows the design issues iteration across the meetings.

Table 2.2. Design issues frequency and iteration across the meetings

Design issues	Frequency per meeting								Total Frequency	Total Iteration
	1	2	3	4	5	6	7	8		
Software	1	1	-	-	-	-	-	-	2	1
Space box for components	1	2	-	3	-	-	-	-	6	5
Demo experiment	1	-	-	-	-	-	-	-	1	-
IMU specifications	1	2	3	1	-	-	3	-	10	9

The semantic analysis of the transcripts is based on the lines of each intervenient per segment of discussion. The segment lines were mapped out by the identification of verbalizations that relate to each one of the proposed properties – ambiguity (A), risk (R) and change (Ch) - underlying uncertainty (U), upside (↑) and downside (↓) effects of risk, decisions (D) on actions (∏) to take, solutions (3), conversion into design issues constants (¬C) or influence on variables (¬V). Table 2.3 illustrates the mapping across the segment lines of each of the four design issues. Due to the extension of the mapping two of the design issues are partially illustrated. The table shows the mapping of the initial segments where the absent feature is identified and the last segments where the problem is solved. Number one (1) represents the presence of the properties in the segment lines, while zero (0) means its resolution. A description of each of the four design issues based on the identification of ambiguity, risk, change, variables and constants is provided.

The software was malfunctioning due to a bug. A risk related to time lost emerged. The engineers knew that once the bug was known (ambiguity) an optimization procedure became necessary to overcome the problem. Meanwhile, other bugs could arise (perceived risk effect). It was found that the software had an untrustworthy compiler (variable), which was changed by an official package (change as replacement) that made the software function again (constant).

The design issue of the space box emerged when one of the collaborators had doubts about there not being sufficient space (perceived risk) to place the unknown (ambiguity) components and cables (variables) in a previously defined box (constant). This was a long-term issue that after some iteration was solved at meeting 4, but many times the need was raised to change for a box with more appropriate dimensions.

The demo experiment relates to the use of some robot components to demonstrate to the students an experiment that failed (risk). One of the connections failed because two pins were bent (involuntary change), presumably by the students (perceived risk). This accident triggered a mini capacitor from the bent pins (ambiguity), which was an unfilled need for a component that, in case it worked, would save time looking for another capacitor, and change the scheduled activities (risk upside effect).

The IMU specifications needed considerable iteration to be solved. It was a fairly interdependent issue that asked for clarification and many decisions to be arrived at. The space box and the IMU design issues have respectively 58 and 53 segment lines of evaluation at meetings. The discussion of these design issues evolved through the different intervenient speeds of perception, with many doubts to clarify, and information and knowledge to assess.

Table 2.3. Mapping of the moments of discussion per design issue according to the verbalized segment line (SL), Ambiguity (A), Risk (R), Change (Ch), Decision (D), Action (∏), solution (3), Risk upside effect (↑), Risk downside effect (↓), Uncertainty (U), conversion into design issues constants (¬C), influence of design issues variables (¬V)

	Software				Space box for components				Demo experiment				IMU specifications			
SL	A	R	Ch	D	A	R	Ch	D	A	R	Ch	D	A	R	Ch	D
1	1	-	-	-	1	1↓			1	-	-	-	1	1↓		
	U				U	U			U				U	U		
2	0	1↓	-	-	0			∏	0	1↓	1	-		1↓		
		U						U						U		
3	1	1↓	-	-	1				1	-	-	-	1			
	U	U			U				U				U			
4	1	1↓	1	∏	0			∏	0	1↓	1	-	0	0		
	U	U	U	U						U						
5	0	0	1	∏	1	1			0	-	-	-	1			
			U	U	U	U							U			
6	0	0	1	∏	0			∏	1	1↑	1	∏	0	1↑		
			U	U				U	U	U	U	U				
7	1	1↓	-	∏	1				1	¬V						∏
	U	U		U	U				U							3
8	0	0	1					∏	0	1↓		∏	1			
			¬C	3				U		U			U			
9					1	1↓			0	1↓		∏				∏
					U	U						3				U
48					1								1			∏
					U								U			
49								∏					0			∏
								U								
50					1								1	1↓		
					U								U	U		
51								∏					0			∏
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53					0											∏
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54					1											
					U											
55					0											
56					1	1↑										
					U	U										
57								∏								
								U								
58								∏								
								3								

2.5 Results

Results from the investigation of risk in designing derived from the semantic analysis and coding of a total of 128 segment lines. The paper reports four sets of results relating to: risk awareness and proposed definition of risk in design, ARC properties interplay, uncertainty underlying the properties, and convertibility of constants and variables, further explained.

2.5.1 Risk in Designing

Three stages of risk awareness were identified: perceived risk, risk effect, risk worth. Verbalizations on risk relate to: time lost, probability of downside and upside risk effects, awareness of inadequate characteristics (of objects, such as volume, space and a person’s ability), suspension of expected connections (such as power or interfaces), unexpected opportunity, anticipation of preventive measures, synchronization issues and flow lost. n the three stages of risk awareness, whether risk is, perceived, an identified effect, or an opportunity, it can influence the initial variable under discussion, another variable within the same design issue, or a variable of another, but interdependent, design issue.

A preliminary conclusion can be stated: risk in designing is a property of a variable with a perceived or identified effect that can have situational relationships of expected or unexpected risk effects in other variables within a single design issue or interdependent design issues.

2.5.2 Risk, Ambiguity and Change: Properties Interplay

Perceived risk is preceded by the recognition of ambiguity. Ambiguity leads to several effects that are underlined by uncertainty, such as vagueness, abstruseness, doubt, formal dubiety, ambivalence, equivocation and double meaning, all having implications to the decision-making. Clearly identified risk effect is preceded by ambiguity clarification. The verbalization of risk worth can be preceded by a recognized ambiguity or ambiguity clarification. If the expected risk worth is successful it becomes an effective risk. Risk worth can be dependent on an expected change. Expected change depends on decisions of actions, reduction of ambiguity and identification of solutions. Whether change is voluntary or involuntary, four types of change were identified: change as replacement (a better alternative), change as modification (adjustment), change as transformation (conceptual change, process change) and change as regeneration (renewal). Clarification of ambiguity and accomplished change convert design issues variables into constants.

In circumstances where the influence and effect of risk reaches its utmost extent, a pattern of interplay settles ambiguity as the point where perceived risk starts and change becomes the ultimate risk effect. This corroborates hypothesis 2 and is illustrated in the examples from Table 2.3, namely in the segment lines: SL

4 of the software design issue; SL 6 of the Demo experience design issue. In both situations, uncertainty underlies the sequence, further confirmed or not in other segment lines.

From the analysis of this piece of data there was no evidence of independent influence regarding the properties of risk and change (H1), except for ambiguity. Other studies based on the analysis of various types of design issues across design disciplines might bring evidence of such circumstances.

2.5.3 Uncertainty Underlying Properties

Ambiguity is underlined by uncertainty. Ambiguity goes through a process of reduction until it is null and void, as knowledge is clarified and commitment to decisions is attained. Uncertainty has a dual state: you have it or you don't. Uncertainty is zero when ambiguity is zero, when risk is effective and when change is effective too. A perceived risk, an expected risk effect, expected risk worth or an expected change are always underlined by uncertainty and dependent on actions, reduction of ambiguity, decisions and solutions to know the extent of its influence.

2.5.4 Convertibility of Constants and Variables in Design

In the process of reduction of uncertainty, effective risks and changes can influence not only the variables, but also design issues constants and therefore the overall design trajectory. When the uncertainty underlying a design issue variable is reduced to zero the variable becomes a constant (see Table 2.3, Software, SL 8). However, risk and change of a variable can influence other variables (see Table 2.3, Demo experience, SL 7) and constants within a single design issue. A variable that became a constant can have as a consequence the conversion of a constant into a variable within the same or an interdependent design issue. The reduction of ambiguity evolves through the characteristic of convertibility between variables and constants (examples: Space box and IMU design issues where several stages of ambiguity reduction were mapped out).

2.6 Discussion

This study contributes to the investigation of causes, effects and underlying mechanisms of risk in design with consequences and influence to decision-making and attempts to provide awareness and strategic principles for risk management. Therefore, the present paper sets a proposal of a property-based approach for the analysis of risk causal networks with application in research and practice of design. The approach entails three layers of analysis, namely: analysis of design issues, constants and variables (knowns and unknowns), and assessment of ambiguity; types of design issues and assessment of perceived risk and its effects; assessment of the influence and types of change in the design process and decision-making. This proposal supports the notion that reduction of ambiguity and stages of uncertainty, risks worthiness, effects and consequential change are achieved through iteration processes of incremental learning in time.

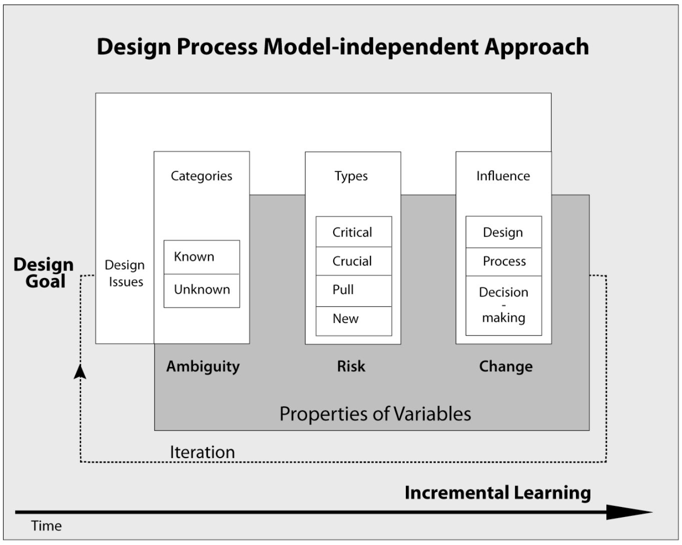

Figure 2.3. Illustration of the property-based approach

The approach is a property-based instrument that can fit different design and product development methodologies, as 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) among other design approaches, product development structured methods (Cooper, 2008; Ulrich and Eppinger 2011), and reflective models of the design practice (Schön, 1983; 1988), with application in research, industry, and practice of design. It has the utility to help in identifying what ambiguity, risk and change are, and how they evolve in design. This study aims to understand and proposes guidelines for researching risk in design, for example, how the joint use of this analysis can be useful in a stage gate process model (Cooper, 1995; 2008).

2.7 Conclusions and Research Implications

Evaluation and decision-making processes, as well as design issues variables and constants interdependency are relevant to the management of ambiguity, risk and change in design. The properties of variables influence the evolution of iteration processes towards the design completion within a time-related dimension suitable to each business context. The management of such processes influences the expected design outcome. The foreseen use of the present property-based approach is twofold:

- An instrumental approach for the analysis and understanding of risk causal networks in research in design across disciplines.
- A domain-independent approach to risk management for identification of causal networks of risk in the different practice design of design host disciplines.

Further studies can attain the consolidation of the approach with potential benefits at other development stages. More advanced studies might provide further knowledge on how to manage the three properties in highly complex and innovative design processes. Such achievements will be particularly relevant to improve awareness in the current economic context.

Further research might bring insights: on other influential properties of design trajectories; on variants and invariants of the causal networks of risk in design across its host disciplines (Love, 2002) through studies based on multidisciplinary and transdisciplinary design environments (Vieira, 2014); on implications to design management with improved methods to cope with ambiguity, risk and change; contribute to structuring the knowledge of design (Visser, 2009) as a discipline (Archer, 1979) with influential mechanisms of risk in design.

2.8 Acknowledgements

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