DEALING WITH UNCERTAINTY IN DESIGN PRACTICE: ISSUES FOR DESIGNER-CENTERED METHODOLOGY

Jaap Daalhuizen[1], Petra Badke-Schaub[1], and Stephen Batill[2]
(1) Delft University of Technology, NL, (2) University of Notre Dame, USA

ABSTRACT
Design is at the core of successful innovation. While working on innovation projects designers have to deal with the uncertainty associated with complexity, multi-disciplinarity and outcomes that in the early phases are not - and are not supposed to be - foreseeable. Design methodology aims to support the designer by providing structure and thus assist in dealing with uncertainty. However, design methodology often does not provide methodological support that is adaptable to the individual's needs in situations of unusual or high uncertainty, referred to herein as non-routine situations. We define non-routine situations as being associated with levels or types of uncertainty in which the designer does not obviously know how to proceed. In this paper we present the results of a study which addressed the non-routine situations design practitioners encounter in practice, the way they respond to these situations and the role of design methodology.

Keywords: designer-centered methodology, design practice, uncertainty, innovation

1. UNCERTAINTY AS A DETERMINING ELEMENT IN DESIGN

In his influential work 'History of western philosophy' Bertrand Russell defines the main task of contemporary philosophers as follows, "to teach how to live without certainty and yet without being paralyzed by hesitation is perhaps the chief thing that philosophy, in our age, can still do for those who study it" [1]. Design methodology shares this aim and design researchers are in the unique position to study and support people that have the need to 'work with uncertainty without being paralyzed by hesitation'. In the context of this paper, we have a broad understanding of design methodology as the set of any more or less formalized procedures that describe or prescribe (parts of) the act of designing with the aim to support designers. These can range from logical descriptions of new product development processes like the VDI process model for product development [2] to techniques for generating creative ideas like brainstorming [3] or sketching and to CAD systems and optimization algorithms.

Designers have the goal to develop innovative products, services, and experiences. Because the outcomes of innovation processes are supposed to be new, they cannot be predicted during the design process. For this reason a fundamental element in innovation is uncertainty. To be able to deal with this inherent uncertainty, design practitioners rely on knowledge of previous processes that have lead to successful innovation and on their own problem solving abilities. An example of uncertainty inherent in design is found in a number of empirical studies on designing that have shown that problem definition and problem understanding co-evolve with the development of solutions [5], [6] and [7]. This co-evolution of problem and solution means that designers can encounter situations during a project where they do not know obviously how to proceed. For example, a new insight into the problem might require the practitioner to frame it differently, and force him to develop or adopt another, more appropriate procedure. This aspect of designing has been most notably addressed by Donald Schön [6], [8]. He found that practitioners display reflective behavior to be able to deal with the uncertainty in the problems they encounter. To date, very little design research has focused on this issue. An exception is research into design expertise [9], [10] which gives insight into how experts deal with complexity and ambiguity in design projects. Other important elements of actual design practice that also contribute to uncertainty, such as collaboration and communication in

multidisciplinary teams, became issues for design research in the 90's, however these studies are not theory-based and consist mainly of descriptive case studies. There are some exceptions like the study of modeling design practice by a collaboration of German engineers and psychologists [11]. Also some insights from industry have been published in non-academic literature [12] giving a broader picture of the range of issues that make up the practice of design. However, very little is understood about how designers respond to situations of uncertainty and how design methodology can assist them in these situations.

1.1. Non-routine situations

In this study we define non-routine situations as those situations associated with levels or types of uncertainty in which the designer does not obviously know how to proceed. These situations are characterized by an increased perception of uncertainty (Figure 1). As a consequence the designer will feel less confident about procedures or skills that are already known to him. He will be prone to reflect on the situation and either decide to develop or adopt a new procedure or apply a known procedure and find out if it works for the unfamiliar situation through trial and error.
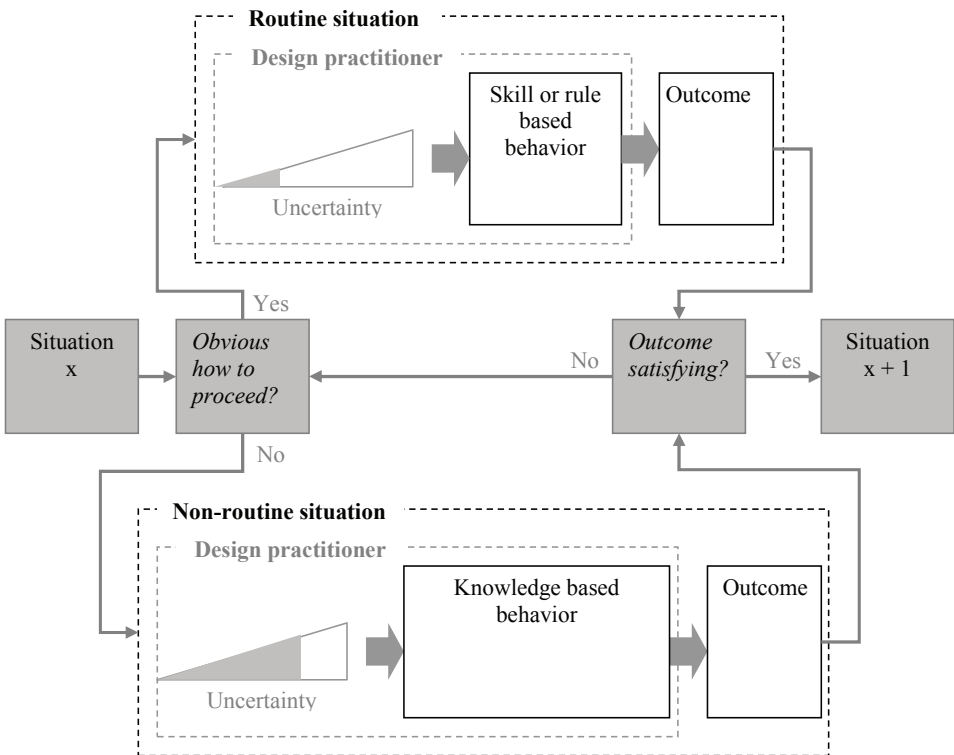

Figure 1. Distinguishing between routine & non-routine situations and the relationship with levels of performance.

Human behavior in routine and non-routine situations has been studied by Rasmussen and others who identified different levels of abstraction in human information processing from studies of nuclear power plan operators [13]. Their model identifies three levels of performance as skill-based, rule-based and knowledge-based [14] on which cognitive processing activities happen on an increasingly abstract and mental-effort intensive levels. Although the model primarily provides insight in the behavior of plant operators that interact with a control room interface, we believe the model provides useful insights in the behavior of designers as well. It can give insight into the ways in which designers respond to uncertain, situations and the role design methodology can or should play to assist designers in dealing with them. In routine situations, designers will either directly release a pre-set response, called skill-based behavior. Or when features of a familiar situation are recognized, they

make shortcuts within the model called rule-based behavior. These types of behavior are indicative to the descriptions of expert behavior described by Lawson [15]. In non-routine situations designers go through several steps to make a decision and define a course of action. As a consequence of the frequent occurrence of non-routine situations in design processes, it is expected that the designer often performs on a knowledge-based level. In these situations, the designer will have to focus his attention on the situation and analyze and develop an understanding of the situation at an increasingly abstract level in order to develop an appropriate course of action. Because uncertainty plays a major role in design, we expect that for some non-routine situations the designer may anticipate the need to adopt or develop new procedures.

1.2. Designer-centered methodology

"At Bell Labs, which is the fountainhead of innovation, as soon as an innovation is completed and ready, the organization officially announces it obsolete." [16] This quote makes clear that the relevance of knowledge is changing very quickly. Though this is true in most fields, it is particularly true in disciplines such as medicine and engineering. Knowing that knowledge in certain fields may have a half-life of 2 to 3 years means on one hand that we need to learn continuously and on the other hand, the way to cope with new situations, i.e. the methodology used to understand and address new situations, is becoming more important. Design methods aim to serve as a means of process support independent from the particular person and product. However, designers are different in terms of knowledge, experience and skills; also each task is different in terms of complexity, resolution level etc., and every project is in a different context. The process the designer should follow may be explicitly prescribed in a given method, however the characteristics of the individual designer, such as experience, that influence the choice as well as the use of methods are not considered. This is also true for characteristics of the specific task and project context such as the organizational environment, time constraints, financial constraints, and constraints associated with multiple projects that must be treated simultaneously. These are elements which – especially in combination - can contribute to an increase in the level of uncertainty that is experienced by a designer, and need to be addressed by design methodology. Furthermore the designer must feel the need to use the particular method; therefore the benefit must be recognized very quickly to convince the designer that the method will not add more uncertainty. Thus, *designer-centered methodology* should focus on the designer by reducing both motivational resistance and uncertainty. We argue that if design methodology is to support designers appropriately, it must enable the designer to choose an appropriate method in a particular situation given a set of characteristics specific to that interaction between the designer and the situation.

1.3. Contents and goals of the study

This paper presents the first phase of a larger research project related to how designers behave during innovation processes, and how they deal with the inherent uncertainties in them. The project is aimed to contribute to the development of designer-centered methodology. In this context, the overall aim is both to create a better understanding of the designers' behavior in situations of uncertainty and to develop a web-based, interactive system that assists designers to deal with uncertainty in innovation processes. As a first step, it is imperative to study how designers currently recognize uncertainty and how they cope with it. This study focuses on the non-routine situations that designers encounter in practice and the ways designers deal with the uncertainties associated with them. It is intended to provide a starting point for further research into this topic. The two main questions that this study addressed were: "What kind of situations do designers consider as situations of high uncertainty?" and "How do designers respond in order to deal with these uncertainties?"

2. INVESTIGATION

2.1. Research method

In six different design companies, located in the USA and the Netherlands, 16 design practitioners were interviewed. The data was collected through open-ended, semi-structured interviews [17]. The interviews were designed to address three themes. In the first theme participants were asked to recall non-routine situations in which they felt 'inefficient or ineffective' or 'out of their routine' during specific projects and to talk about the factors that brought about these situations in-depth. In the second theme participants were asked to reflect upon how they dealt with these situations. Their

answers included both procedures that they developed personally and the use of known design methods. The third theme focused on issues associated with using new or unfamiliar methodologies in non-routine situations. During the interviews some probing was used to elicit in-depth reflections. The sample was heterogeneous in terms of experience-level, expertise and working-domain. The experience-level ranged from 1 to 30 years of working experience. The expertise-domains ranged from new business development to developing manufacturing strategies to project management. The working-domain ranged from product design to user research to mechanical engineering. The data was analyzed according to the 'Framework' method [18]. The method guided the data analysis through five stages:

- Familiarization with the body of data gathered leading to the identification of key ideas and recurrent themes.
- Abstraction and conceptualization of the data and development of a thematic framework.
- Indexing of the data through the application of the thematic framework to the data.
- Charting the indexed data according to the themes of the framework.
- Mapping and interpreting of the data resulting in a set of patterns and connections that are supported by the data.

3. MAIN FINDINGS

In the following section we first describe the different types of non-routine situations that were identified by the designers. We also present an overview of the responses that were described by the designers to deal with those situations. We then present an overview of the issues that were used to characterize the non-routine situations, and to choose an appropriate response. Although we were not able to correlate non-routine situations to specific characteristics and related responses in the whole dataset in this study, we do present an example of a designer that reflects upon a specific situation in which these relationships were described.
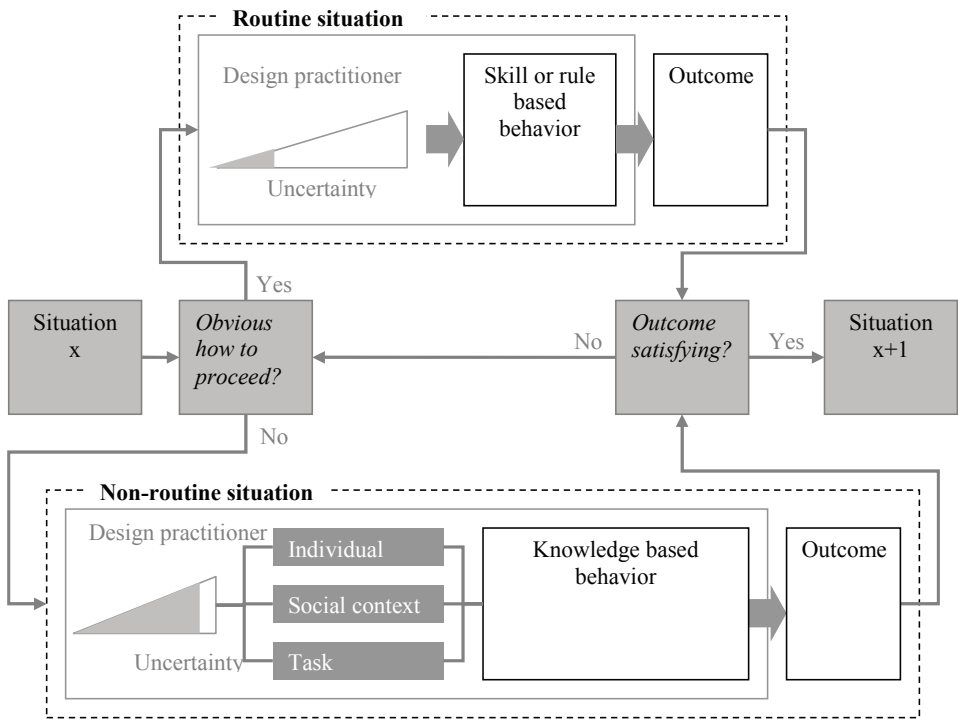

Figure 3. Sources of uncertainty leading to non-routine situations and knowledge based action

3.1. Sources of uncertainty

First we analyzed the perceived sources of uncertainty in non-routine situations. Each of the non-routine situations was attributed to one of the following categories: (1) uncertainty attributed to the individual herself, (2) uncertainty attributed to the social context in which the project was being conducted, or (3) uncertainty attributed to the some element of the design task. Although uncertainty will always be present in design, it becomes problematic when it increases to a level that is uncomfortable or adversely affects the behavior or performance of the individual designer and when it prevents him from proceeding towards his goals. In those situations it will either lead design practitioners to reflect on the situation and develop new or untried responses or lead them to apply a known procedure in spite of the unfamiliarity of the situation. This is illustrated in Figure 3.

Uncertainty attributed to the individual

The performance of designers is governed by their abilities and experience. Uncertainty attributed to the individual is caused by the absence of having the required knowledge, rules or skills to proceed in a way that is appropriate for the problem at hand. In these situations, uncertainty is perceived to be associated with the person herself.

Uncertainty attributed to the social context

When working with others, the individual designer needs to exchange information and make collaborative decisions. Uncertainty attributed to working with others is caused by the absence of necessary information exchange or collaborative action necessary to proceed in a way that is appropriate for the problem at hand. In these situations, uncertainty is perceived to be associated with the interaction between the designer and other team members and issues like trust and shared understanding play a crucial role.

Uncertainty attributed to the task

Uncertainty attributed to the task is caused by a lack of understanding and current status or the complexity of the task necessary to proceed in a way that is appropriate for the problem at hand. In these situations uncertainty is perceived to be associated with the task itself.

3.2. Non-routine situations

Analysis of the frequency of occurrence of non-routine situations revealed that designers encounter a variety of situations that can be categorized according to the three sources of uncertainty as shown in figure 4. The data indicated that 46.3 % (n = 54) of the non-routine situations were attributed to the task and that 46.3 % were attributed to the social context and only 7.4 % of the situations were attributed to their own ability or behavior.

Figure 4 shows that most non-routine situations attributed to the task were characterized as being caused by changes in the understanding of the problem during the process, such as a sudden change in the design brief or a new interpretation of the task. As a result of these changes it was not appropriate to continue with the same course of action. The designer's appreciation of the task shifted and she needed to develop or introduce a new way of approaching the problem. Also many non-routine situations occurred because the designer was operating on a strategic level. This required analysis of strategic issues and development of strategic propositions besides working on the design of the product itself. In these cases different issues needed to be analyzed, and results needed to be articulated in a language appropriate for a strategic decision making.

Designers attributed significantly fewer non-routine situations to their own personal ability or behavior compared to the task or social context. Situations that were related to the individual were problems with the transition from analysis to synthesis during the design process, to an escalation of commitment to a sub-optimal solution or to improper framing of the assignment. Non-routine situations that were attributed to the social context were mostly characterized as being related to interfacing with others. In these situations the designer and the others, i.e. clients, users, colleagues etc., did not have a similar understanding of the issue at hand. The result may be a conflict between the designer and the client or an improper understanding of the design task within a design team.

In summary, we found that most of the reported causes for the occurrence of non-routine situations were attributed to either the task or the social context. This is important because it implies that designers usually attribute the occurrence of a non-routine situation to something or someone outside themselves. A second observation is that the variety of non-routine situations is broader than is usually addressed in the design methodology literature.
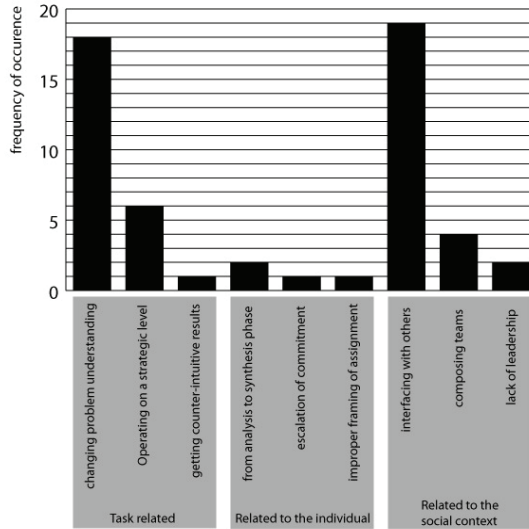

Figure 4. Frequency of types of non-routine situations related to the three sources of uncertainty (n=54)

3.3. Responses to non-routine situations

The next issue considered in this study was related to questions about the responses of the designers when dealing with high levels of uncertainty. The interviews indicated that design practitioners usually have a broad set of courses-of-action, or strategies, at their disposal to apply in different non-routine situations. The 16 participants mentioned 80 strategies that were part of their collective repertoire. The self-reported strategies were grouped by this study into 9 different categories and are presented in figure 5 indicating their frequency of occurrence during the interviews.
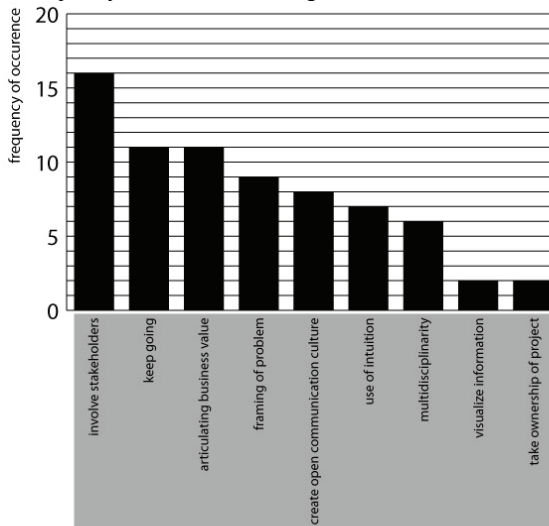

Figure 5. Frequency of different types of responses (n=80)

This figure illustrates the responses of the designers to the multitude of non-routine situations they encounter. We briefly describe the different responses that were mentioned by the designers.

Involve stakeholders
Many situations include working and communicating with multiple stakeholders that have different backgrounds. This often causes communication problems due to large cognitive distance between the mental models of these stakeholders and thus the design problem is understood in very different ways. In these cases designers try to involve the stakeholders throughout the process to increase common understanding of both the problem and the design process and decrease this cognitive distance. When the cognitive distance reaches an optimum, the different stakeholders can even contribute in a fruitful way to the innovation performance of the team [20].

Keep going
Designers encounter many situations in which they perceive that the goals are ill-defined and the solution space is very large. These can induce a strong feeling of ambiguity and cause the designer to hesitate and "get stuck". In these cases designers invoke a range of strategies, such as involving colleagues, building a physical model, keeping a positive or playful attitude, and these activities or actions provide immediate courses of action in spite of a high level of ambiguity. Some of these involve the application of previously used, formal design methods.

Articulating business value
Many of the non-routine situations occur when designers work on a strategic level. In these cases the client requires an understanding of the potential business value of the solution, even while it is being developed and impossible to predict. These situations require designers to present their solutions in a business context. Designers try to articulate the relationship between their understanding of the problem and the solution they developed. In this way they express the strategic value of the solutions they are developing

Framing of problem
Design problems are often complex and ambiguous and resist a comprehensive understanding. This can cause vague descriptions of the problem and goals in a design brief, and lead to miscommunication and even failure. Designers try to frame the problem explicitly, sometimes even together with the client, by creating a shared frame of reference. By agreeing that the frame of reference is the defined starting point of a project, it provides a basis for communication and decision making throughout a project.

Create open communication culture
Design projects are often multidisciplinary, have ill-defined goals, happen under time pressure, have no right or wrong answers, etc. This causes situations in which the information available is often wrong, conflicting, excessive or inadequate. To enable the effective evaluation of information designers try to create a culture in which all involved with the project have the feeling they can communicate freely without being judged or criticized.

Use of intuition
Many situations require understanding or decision making without a complete understanding of the design problem. This might for example be due to time pressure or to incomplete or ambiguous information. In these cases designers try to find familiar patterns and intuitively frame the problem or make a decision. This type of response is inherent in designing [21] and the use of intuition often leads to a change in the understanding of the problem.

Multidisciplinarity
Many design problems are very complex due to their multifaceted nature. They are for example complicated due to issues related to user behavior, to competing technologies, to sustainability issues, etc. In these situations designers try to gain a more complete understanding of the problem by working in multidisciplinary teams.

Visualize information

Design problems and also solutions can often not be described in explicit ways, written or verbal during the process. This might lead to communication problems with various stakeholders. The response to deal with that problem is to present information visually; either to describe a problem or to present a solution. This has the aim to create shared understanding between the stakeholders and enables more effective communication.

Take ownership of project

Some design projects are worked on by teams that lack a hierarchical structure. This might be beneficial for an open-team climate but it can cause situations in which no one takes responsibility for the whole of a project. In these cases designers try to take ownership of a project and introduce a coherent structure.

3.4. Issues related to the choice of individual strategies

Appreciating that designers described a variety of responses to deal with non-routine situations, we do not yet understand the factors that designers use to characterize non-routine situations and how those factors influence their choice of a specific responses in given situation. Using the information from the interviews, we attempted to correlate the non-routine situations, their characteristics and related responses, but we were not able to reveal these connections. We can however present an overview of the factors that were used by the participants to characterize non-routine situations or motivate a choice for specific responses.

The issues are again categorized according to the task, the individual and the social context. Table 1 on the last page of the paper shows the summary, their frequency of occurrence and a brief description of each of the issues. The overview is not an exhaustive list, but it does help illustrate the relative importance of issues that were identified. We can see that time pressure plays a major role in the task domain. This means that when choosing an appropriate response for a step or phase in a project the perceived time pressure often is a crucial issue that is taken into account. In the domain of the individual designer, there is a more evenly distributed set of issues that influence the choice of an appropriate response. For example level of experience, having a strong individual design philosophy and a methodological background are all issues that were reported as an influence the choice for an appropriate response. Last, in the social context domain, we see that the culture of a company, the habits, and the structure of an organization in which a designer works are by far the most influential for the choice for appropriate strategies.

In most cases it appears as if it is a combination of these issues that will characterize the situation at hand and lead a designer to respond in a certain way. Although a thorough analysis of these 'patterns' were not within the scope of this study, the next section does describe an example of how such patterns occur in practice.

3.5. An example in dealing with uncertainty

To illustrate how uncertainty affects the design process and results in the designer invoking appropriate strategies, we describe an example of a connected pattern taken from one of the interviews. The example describes the response of one of the participants that resulted from his experience in dealing with the uncertainty associated with the social context of design – a problematic client- designer interface. In the interview he talked about what previously had been a non-routine situation for him, and the responses he developed after encountering it more often. He recognizes the situation and how and why he deals with this situation in a certain way.

Client-Designer interface: Framing the problem and involving the client

A frequently occurring situation is when designers meet with clients. This can be in a kick-off meeting where the client presents a problem and designers create a plan based on their understanding of the problem. It can also be when designers present their concepts to the client at some point during the project. Often in these situations there is a lack of common understanding, causing problematic communication. In the following example a designer reflects upon how and why he deals with a specific situation in the way he does (see figure 7).

The designer is an experienced designer and owner of a design firm. He describes that explicitly and collaboratively framing an assignment at the start of a project has become very important in his practice in order to deal with issues associated with designer-client communication. He starts with explaining the influence of his educational background on the way he approaches design in general:

> "I am educated as a mechanical engineer, so I am able to translate abstract ideas into working objects… And I think this relationship between idea and object is the most important thing you can imagine"

He then goes on to tell that he has basic design principles that influence his choice for specific ways to approach problems:

> "I fully agree with the methodology I use, but of course this methodology is based on basic assumptions… and if other tools are in conflict with these two basic assumptions… then I ditch those tools of course…"

His choice to create an abstract frame of reference (before any concrete solutions are created) is related to his background as a mechanical engineer; he is able, and prefers, to relate abstract ideas to working objects:

> "So first you create a frame of reference, and if you agreed upon this frame of reference, so this is what we call context then… then everything is related to this context, so your judgment is not an absolute judgment, but a relative judgment. And because it is relative, you can have communication with the client"

The response clearly has the goal to create a shared understanding of the problem at hand to enable discussion and collaborative decision making. The designer explains that this is necessary because every design project is complex and nobody knows what will be the outcome of the project. Because of this, they have to involve the client in the design process:

> "Every project has its own complexity… so there are not more or less difficult projects" and "we ourselves don't know at forehand what comes out… so we have to give the client some grip, and the grip is in the process steps as such, that's the only thing we can give them"

He then explains briefly what is avoided by paying attention to a proper framing of the assignment:

> "Because it is not anymore about: ok, I like this color, and because I am a designer and I have a lot of success this color we choose. No this color has meaning in relation to the context I have defined over there… and we have agreed upon this context."

Also some of the consequences of this response are explained:

> "so what we do, with the client… we first work together in creating this context, and then we have to say 'ok do you agree on this context?'. And if we agree on it, then it is the frame of reference, and this creates a lot of clearness in the rest of the process. So when we present something, clients never say 'Oh, what's that?' because we can explain it exactly where it comes from."

> "and in the end we always put too much time in the project… so we always say, ok put in 20 percent more time in the project because then in the end we have a better result. And a better result is really important to get the next assignment, so it's more like an acquisition tool."
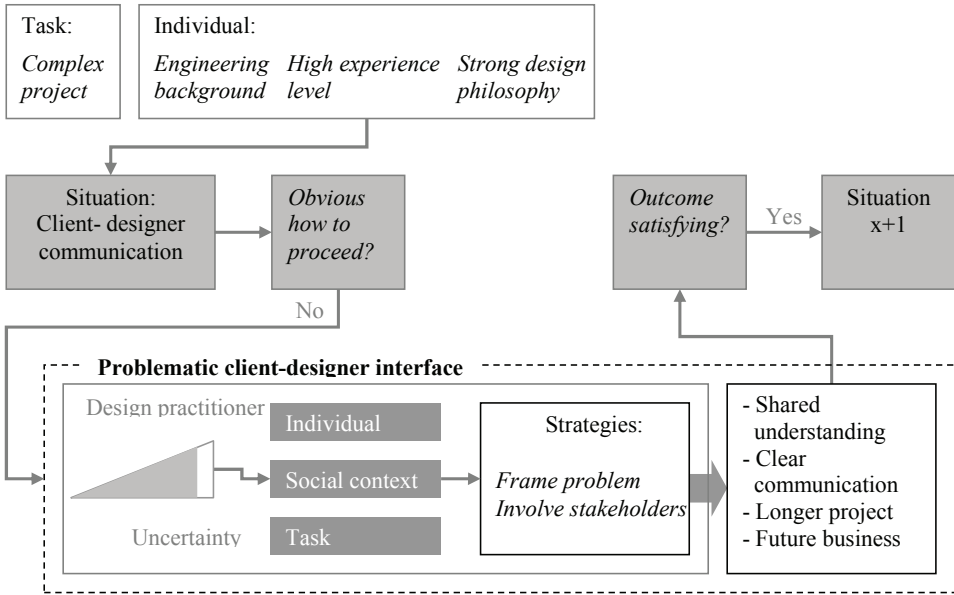
Figure 7. Example of a pattern that describes a non-routine situation, its characteristics, the response of a designer and the consequences of that response.

4. CONCLUSIONS

Restating the basic assumption in this study, design problems are ill-defined and designing is an activity which requires dealing with uncertainty. As design methodology is aimed to support the designer the questions exists how design methodology can support the designer to deal with uncertainty? To answer this question it is necessary to know which kind of uncertainty is perceived by the designer and what are chosen responses to deal with these uncertainties. Thus, the major concern of this study was to find out how uncertainty is perceived by the designer, when uncertainty leads to non-routine situations and how designer respond to these.

Sixteen designers were interviewed in six different design companies in the Netherlands and the USA. Three main elements were analyzed: 1) sources of uncertainty in non-routine situations, 2) responses of designers to deal with non-routine situations and 3) factors that are used to characterize non-routine situations and the relationship of these factors to specific responses in specific non-routine situations.

A key outcome of this study is that designers mainly attribute the occurrence of non-routine situations to sources outside themselves. They most frequently refer to characteristics of the task and of the social context as sources of uncertainty. The interviews also indicated that designers have a broad variety of the responses at their disposal to deal with non-routine situations which differs from individual to individual, and from project to project. Issues which are relevant to choice of a specific response were mainly time-pressure and organizational culture. Another result from the study is the apparent absence of the use of new methods in response to non-routine situations. When the participants were asked how they dealt with non-routine situations, many different responses were mentioned. However, the use of a new method was not part of their suite of responses!

These results are a first step towards an improved understanding of the behavior of designers when facing non-routine situations. Through this understanding more appropriate ways of assisting designers can be developed as we continue to explore how design methods can support designers in dealing with uncertainty. Two particular aspects are important. First, there is a need for research to explore the relationship between the designer's perceived source of uncertainty and the way in which a specific design method might allow for an effective response to that situation. A framework is needed

to analyze specific non-routine situations and characterize them according to the immediate needs of the designer. Second, there is a need to encourage the designer to take a more comprehensive look at non-routine situations by reflecting on his own contribution to the situation. This limited study implies that designers focus primarily on issues related to the task and to the social context. If one could enable designers to reflect more effectively on the determining factors in non-routine situations, it may be possible to provide them with design methodologies that would support them in more appropriate ways. As stated earlier, a promising approach seems to be to develop a web-based, interactive system which integrates the findings of this and future studies into designer-centered design methodology. Such a system would have as its objectives: 1) stimulate designers to reflect upon non-routine situations and motivate them to use appropriate methodologies, 2) enable the designer to quickly find an appropriate methodology, 3) and stimulate discussion about design methodology within a web-based community of designers and researchers.

ACKNOWLEDGEMENTS

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Table 1. Frequency of occurrence of the characteristics of the task, the individual and the social context that were used to describe non-routine situations and appropriate responses

Issue	f	Description
Task		
Time pressure	10	Estimated effort that is needed, and the difficulty of the task in relation to the time available
Complexity	5	Amount and inter-relatedness of factors that need to be solved in an integrated way
Client relationship	3	Type of relationship that exists with a client that provides the task (e.g. long term relationship based on trust and positive experiences)
Phase of the project	3	Phase in which the project is insofar as they may require different type of activities
Newness of the domain	2	Familiarity with the task domain
Fuzziness of the task	1	Degree in which the task is described in abstract and open terms
Budget	1	Estimated effort that is needed related to the budget that is available for the task
Individual		
Experience	6	Perceived level of experience of the designer related to the domain of the task
Design principles	5	Degree in which a designer has personal principles or philosophies about how to design
Methodological background	5	Level at which the designer's education involved instruction of design through methods
Perfectionism	4	Designer's focus on producing optimal results
Curiosity	3	The designers' tendency to search for and understand issues related to design projects
Engineering background	1	Educational background in engineering
Innate abilities	1	Perceived availability of innate design abilities
Social context		
Company culture	15	Level to which the culture of the company influences the way of working
Team culture	3	Level to which the culture of the design team influences the way of working
User involvement	3	Direct involvement of users in the design process and its influence on the way of working
Client demands	1	Level to which demands from the client influence the way of working