Problem Structuring and Information Access in Design

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In order to design proper information systems for designers, it is important to understand how they enrich their knowledge base during the design process, what triggers their queries for information, what strategies they use and what factors influence their behaviour in relation to information seeking. Exploring these questions requires a closer look into the design process and the factors that influence information intake. Taking Newell and Simon's (1972) theory of human problem solving, we discuss different aspects of the design process that are relevant to information access during the early stages of this process, and we discuss the implications of such aspects in the design of information systems to support designers.

Design is primarily a problem solving activity, (but not a common one) because of the special nature of the problems it solves. Classical literature on cognitive science considers human problem solving as an information processing activity, and problem solvers as information processing systems. Newell and Simon proposed that an information processing system (ISP) is a relatively unconstrained physical symbol manipulator that is provided with memory (long term, short term and external), a processor, sensory receptors and motor effectors. There are, of course, more sophisticated accounts of human information processing in literature, but the premises and descriptions provided by Newell and Simon's theory suffice for the purposes of this work.

In the paradigm of design as a rational activity that follows Simon's views (Dorst 1997), it is proposed that design is a process of searching for a solution in a certain problem space, that is, a metaphorical space in which the problem solving activities take place. According to Newell and Simon's theory, such a space should contain complete information about the initial state of the task (problem), information about the transformation function to move from the problem state to the solution, and information about the goal.
However, because of the very nature of design problems, there is very often very little information about the problem, even less information about the goal (solution) and absolutely no information about the transformation function. This means that design problems require a lot of structuring. Problem structuring is a process of drawing upon knowledge [or external information] to compensate for missing information and using it to construct the problem space (Simon 1972, 1973).

This is not significantly different from what is proposed in the paradigm of design as a reflective practice. Schön proposed that a designer would frame a problematic design situation by setting its boundaries, selecting particular things and relations for attention, and imposing on the situation a coherence that guides subsequent *moves*. He called it problem setting.

> "The competent practitioners bring available knowledge [and information] to bear on practice situation" (Schön1987, p. 34).

This is not to say that information is taken into the process exclusively with the objective of structuring the problem. During problem solving information is also required, but the nature and the objectives of the information required in both problem structuring and problem solving, is very different. Our focus is on information requests and processing for problem structuring purposes. Problem structuring occurs mainly in the beginning of the design process but also reoccurs periodically as the design activity progresses. This makes for difficulty differentiating between problem solving and problem structuring, as it is not always clear whether designers are talking about the problem or about the solution. Our empirical studies (Christiaans 1992, Christiaans and Restrepo 2001, Restrepo and Christiaans 2003) showed that there are differences in the way designers approach the design assignments, describing it sometimes in terms of abstract relations and concepts (problem oriented) or descriptions of the possible solutions (object or solution oriented). These differences seem to influence the information seeking-behaviour of designers, their tendency to become fixated as well as the output of the design process. This will be illustrated later in this paper.

Problem/solution focusing strategies have been acknowledged in different models of the design process produced by studies on design cognition. For instance, architectural models propose that designers need to generate a solution before they start talking about the problem (Darke 1979). Models produced by research on software design propose that the software designer first negotiates the structure of the problem (Guindon 1990), and models of design engineering propose that the synthesis of a solution follows the analysis of the problem (Pahl and Beitz 1984, Roozenburg and Eekels 1995). This does not imply that strategy is something discipline specific. In fact, industrial design engineers seem to display a combination of these strategies.

Several accounts have been given for this behaviour by several researchers. For instance, Thomas and Carroll (1979) and Lawson (1979) suggested that it is a behaviour that develops with education; Lloyd and Scott (1994) suggested that experience is the variable that determines whether the designer will emphasize the problem or the solution; Christiaans (1992), Dorst (1997), and Christiaans and Restrepo (2001) found that even with homogeneous group of designers, with almost the same experience and/or education, differences were observable. It was suggested in these studies that the preference in the conceptual stage of the design process for either focusing on problems or on solutions has an idiosyncratic character.

However, more important than recognizing the problem or solution focusing behaviour of designers is discussing what consequences it has on the design process and on the results. This paper discusses such consequences, particularly focusing on the information-seeking behavior of the designers during the problem structuring phases and the implication on the design of information systems for designer

1. What is a Design Problem?

During the last four decades problem solving has been a field of continuous research. However, much of the research on problem solving has been carried out, for practical reasons, on well-structured, semantically impoverished tasks, having well-defined goals, initial states and transformation functions (Goel and Pirolli 1992). Examples of this research are cryptarithmetic, logic, puzzle solving and physics problems in the classroom.

Design is a unique type of problem solving. It is the maximum expression of human intelligence and the prototypical case of cognition, as it requires devising future states of the world (goals), recognizing current ones (initial states) and finding paths to bridge both (transformation functions). Moreover, it requires the generation of external representations of such states and paths (Restrepo et al 2000). These characteristics make design a very attractive subject of study in cognitive psychology. Alexander (1964) and Archer (1969) observed that design is an activity that requires both logic and creativity. The idea of the design methodology movement that appeared in the 60's, partially as a response to the demands of the industry and the military, and partially because of the advent of cognitive psychology, was to create systematic methods and tools to better conduct the logical analysis in order to unload the designer to engage in the creative aspects of the problem solving (Cross 1984).

Research in different design disciplines started to produce models, concentrating on different aspects of the design process (Lloyd and Scott 1994). For instance, design engineering provided models that rely upon the premise that analysis of problems precedes synthesis of solutions (Cross 1989; Jones 1963; Pahl and Beitz 1984; Roozenburg and Eekels 1995). Architectural models proposed that solution concepts precede problem structuring; and models derived from computer science showed the designer negotiating the structure of the problems (Guindon 1990).

However, as Goel and Pirolli (1992) noted, this research suffers from the difficulty that it either

> "tends to concentrate on the analysis of discipline–specific design domains and shies away from cross–disciplinary generalizations, or

> the term design has been applied to an increasingly large set of activities that begins to drain its substance".

Such tasks that include learning (Perkins 1986), communication (Thomas 1978), letter writing, naming and scheduling (Thomas and Carroll 1979) etc. have all been called design activities. Other tasks less dissimilar but still not completely comparable to design, like music composition and painting, have also been called design.

The criticisms of Goel and Pirolli are based on their view that design characterizations are not necessarily discipline-specific nor is design an ubiquitous activity.

> "There is no more reason to construe every cognitive activity as a design activity than there is reason to construe every cognitive activity as a game–playing activity or a natural language–generation activity."

Hence, although various design professions differ in aspects such as the nature of the artefacts designed, they certainly share common issues that identify them as design professions, and that make them different from non-design professions like medicine and law. Such common issues refer to the similarity in the structure of the problems they solve and in the process of solving them. Based on these common features, several researchers concluded that

> "the logical nature of the act of designing is largely independent of the character of the thing designed" Archer (1969).

Design problems in general can be characterized as not being subject to systematisation, incomplete, and vague. Reitman (1964) pointed out that design problems (and some other open-ended real life problems) are radically under-specified. He noted that there is a lack of information in each of the three components of design problems. The start state is incompletely specified, the goal state is specified to an even lesser extent and the transformation function from the start to the end is completely unspecified.

Simon (1973) referred to these problems as ill-defined or ill-structured problems and Rittel and Webber as wicked and tamed problems (1973). In design, problems are wicked, in the sense that a design problem and its solution are linked in such a way that in order to think about the problem the designer needs to refer to a solution. Furthermore, there is not an absolute way to tell when the problem has been solved because the referents for such a judgment are dynamic and arbitrary. Tamed problems (like math problems), as opposed to wicked problems, have a mission that is clear, as it is also clear when the problem has been solved. However, it is important to note that the fact that design problems are radically undetermined does not mean that they are completely undetermined. There are still some unchangeable constraints the designer has to learn to live with.

2. Problem and Solution Focusing

Several design protocol studies have observed that designers jump to solutions or partial solutions before they have a full formulation of the problem. Cross (2001) proposes that

> "this is a reflection of the fact that designers are solution-led, not problem-led; for designers, it is the evaluation of the solution what is important, not the analysis of the problem" (p.82)

This is quite a radical view, as there are significant differences in the way designers formulate and solve their problems. In some cases, they generate conjectures about possible (partial) solutions and use these conjectures as a way of exploring and define the problem and the solution together (Kolodner and Wills 1996; Cross 2001; Suwa and Gero 2000). This is what Lawson (1979) called "analysis through synthesis".

Education, experience and personal preferences such as idiosyncrasy and tolerance to uncertainty have been given as explanations for the tendency to focus on problems or on solutions. Thomas and Carroll (1979), for instance, studied several problem-solving tasks, including design problems. What they observed was that designers tend to treat all problems as though they were ill-defined. They do so by changing the problems' constraints and goals. They behave in this way even in those cases in which the problems might have been treated as well-defined. The implication, conclude Thomas and Carroll, is that "designers will be designers even if they can be problem solvers".

Lawson's (1979) observations on problem-solving behaviour suggested that focusing on either the problem or the solution is a learned behaviour. He compared scientists with architects. Whilst the scientists were trying to discover the structure of the problem, the architects were generating solutions, until one proved satisfactory. The scientists presented a problem oriented strategy and the architects a solution-oriented one. He then compared first year students of science and architecture and did not find the same differences.

Lloyd and Scott (1994) in a protocol study of experienced engineers found that the tendency to focus on the problem or on the solution appears to be a function of the level and type of previous experience. Designers with more experience of the type of problem studied tended to focus more on solutions (generative reasoning) and designers with less experience tended to use more problem analysis (deductive reasoning). They concluded,

> "It is only when designers have specific experience of the design problem that they start to approach design tasks through solutions".

Cross et al. (1994), based on a study by Christiaans (1992) on differences between novice and intermediate design students, reported that students of both levels of experience display different behaviour regarding information gathering and problem formulation strategies. The more successful students changed very rapidly from gathering information to reflecting upon it and using it to structure the problem "building a structured representation of requirements, constraints, etc."

The less successful students asked for large amounts of information, but for them, "gathering data was sometimes just a substitute for any design work". Interestingly, they found that the ability to gather information and use it to structure the problem did not depend on the level of experience or education of the designers, as some senior students also were trapped into information gathering for problem structuring. Instead, they suggested that the need to gather information (to structure the design problem) is related to the (in)ability of the designer to cope with uncertainty.

In two studies with senior design students, all with the same level of experience, we observed differences in the way designers formulated the design problem (Christiaans and Restrepo 2001). Being asked to formulate the problem in their own words, after having read the brief, some of them formulated it in terms of abstract relations and concepts (problem oriented) whereas others did it in terms of physical objects (object or solution oriented). This first formulation of the problem is referred to as *early representations*. These differences in the production of early representations were later replicated in another study with senior and intermediate design students (Restrepo and Christiaans 2003).

Simon (1973) argues that the ill- or well-definedness of a problem is not intrinsic to the problem, rather, these attributes can only be endowed by observing the relationship between the problem solver, his available knowledge and the problem to be solved. In the same line, one could propose that the tendency to focus on solutions or on problems is situational and idiosyncratic to the designer, but we have no evidence for this. Design studies have been concentrated so far on multiple designers in the same design situation. What would be the result of longitudinal studies creating situations where we can observe whether the behaviour is inherent to the designer, the situation or to other factors like education and experience? The reasons for focusing on either problems or solutions are far from clear. There is no one cause for this behaviour, instead, it seems to be caused by a combination of factors. However, the choice of either strategy has a great influence on the way the designer structures the problem (type of information accessed, requirements or design issues generated, etc.) and on the outcome of the design process. This will be discussed in the next sections.

3. Problem Structuring and the Generation of Design Requirements

Design is a discursive activity. Designers propose *design issues*, reflect upon and discuss them and for each issue propose answers (also called positions). For each position, they discuss the pros and cons and finally a decision is made about which position to accept (Rittel 1972). This is what Schön called "design moves" (1983).

Issues can be requirements (new goals), specifications, ideas, etc. posed during the design process and can contribute either to further structure the problem or to solve it. However, problem structuring is not a clearly distinguishable phase of the design process, but instead an activity that reoccurs regularly. This makes the distinction between problem structuring and problem solving rather difficult to make.

Problem structuring begins with an interpretation of the problem situation. Darke (1979) proposed that designers interpret the design situation through images of the possible solutions and called these preconceptions "the primary generator of design". She stated,

> "These preconceptions seem to act as points of departure in the development of a design concept. When confronted with a new design situation, the designer imposes images of possible solutions to it. These images provide a means for the designer to analyse and structure the design situation, thus directing the actual development of the product form."

However, not all designers proceed in the same way. These primary generators Darke is referring to do not have to be images of the (possible) solutions. They could also be abstract relations describing the design situation. In our empirical studies, we called the representation of these first interpretations "early representations". These early representations have a great influence on how the process continues. A way to make the early representations explicit is to let designers write down their interpretation of the design assignment after a first short reading of the brief. In our studies, these early representations could be categorized as referencing either the problem or the solution. Compare, for instance, these early representations: *"In current offices there is a need for flexibility…"* or *"Make more flexible the physical workplace."* with*: "…to construct a workstation" or "Design a product solving the problem of the need for flexibility in office spaces"*. The first two express the problem in more abstract relations whereas the latter two refer to possible solutions (Christiaans and Restrepo 2001).

This does not necessarily mean that those designers that produced an object (solution) oriented early representation did not do any problem structuring at all. In fact, in both cases these early representations played a very important role in the problem structuring, *conditioning* the extent to which designers consulted external sources of information, the type of information they accessed and the type and level of specificity of the design requirements produced.

During problem structuring, designers add constraints or re-formulate the problem in terms of the envisioned solution. This should come as no surprise, as the designer naturally interprets the problem situation through personal experience and biases. Reformulation of the problem can be done, for example, by changing the requirements or by manipulating the client's expectations. Designers do this for several reasons. For instance, the designer can foresee, through his experience, that the goal set by the client will not produce the expected outcomes (in terms of functionality, e.g.); he can then feel professionally obliged to point it out to the client. Another reason to change the problem situation, more human and frivolous, is to make it fit more closely into his expertise, knowledge and experience (Akin 1978; Ullman et al 1988; Goel and Pirolli 1992).

This manipulation of the design situation is possible because, in opposition to well-structured problems, the constraints of design problems are arbitrary and non-logical. Design constraints are either nomological (expressing basic physical laws of nature) or political, social, legal, economical technical etc. The latter constitute norms and conventions and can be negotiated whereas the former cannot. Even though nomological constraints restrict the possible solutions, they are non-constitutive of the design task. Moreover, the needs, intentions and requirements of the client and the solution itself are two different conceptual worlds (Meijers 2000) than can be manipulated separately.

Requirements are used to specify the design assignment (defining the problem space) and to describe and explore aspects of the desired solution (exploring the solution space) and are therefore an important aspect of problem structuring. They are either given or dynamically generated during the design process and are used by designers to express what they consider the most important aspects of the given assignment.

This creation of design requirements *on the fly* seems to be triggered by prior knowledge or by knowledge acquired during the design process by interacting with the designed object (Schön 1983) or with external sources of information.

In our empirical studies, we observed that the very nature of the constraints or requirements generated vary significantly depending on whether the designer takes a problem or a solution oriented approach. These differences are mainly expressed in the type of requirements and in the level of specificity. In fact, it is sometimes difficult to see whether a particular design issue is a design requirement (how the solution *should* *be* like) or a design specification (what the solution *is*). Take, for instance, these two examples taken from the first 30 minutes of our protocols: *"it is desirable that different types of products can be attached to the bike"* and *"The click mechanism should be safe for hands and fingers"* (Restrepo and Christiaans 2003). The former is a requirement that applies to a wide range of possible solutions and the latter seems more like an extra condition to an already devised solution.

Another important observed difference is *timing*. We observed that problem-oriented designers produced their requirements throughout the entire session, whereas solution oriented designers specified their solution at the very beginning of the session. These reveal a completely different approach to design requirements. While some of them generated most of their requirements as their concept developed, others did so almost exclusively during the browsing of the available information system. Some designers used the identified design issues to guide their use of the information system, and to generate their design requirements whereas others used the information on the system to generate the design issues.

This can be interpreted in different ways. First, the need to completely specify the situation in terms of requirements (or better, in terms of descriptions of a solution) very early in the process can reveal either a difficulty to cope with uncertainty, a strong commitment to an early concept or both. This strong commitment to a concept is called *fixation,* and is described as the negative effect of an early commitment to a design (Purcell and Gero 1996; Purcell et al 1993) or as a blind adherence to a set of ideas or concepts limiting the output of conceptual design (Jansson and Smith 1991; Smith et al 1993; Christiaans and van Andel 1993). This phenomenon could also be observed in the distance between the proposed concepts (final results of the study) and the early representations. For those designers with solution oriented approaches the distance was minimal, that is, the proposed concepts resembled to a great extent the early representations generated. This raises interesting questions about the role these early representations play in the proneness to become fixated. However, this phenomenon does not necessarily have to be seen negatively. It could be, for instance, a matter of efficiency, or a result of the time pressure given for the assignment, but we have no evidence for this.

4. Information access

As it has been stated previously in this paper, one of the cornerstones of problem structuring is information access. Choices made by the designers depend on their understanding of the problem and its context, on their ability to structure that problem and that context and consequently, their success in obtaining proper information about the problem and the context (Song, Dong and Agogino 2002).

This is not to say that information access is not important during problem solving, the difference is made because the type of information and the support required for problem structuring and problem solving is different. The type of information accessed during problem solving is often more related to materials, manufacturing conditions, etc. During problem structuring information accessed referred more to users, the company and the environment in which the product is used. Information for problem structuring requires much more active interpretation and manipulation before it can be used by the designer.

Eastman (2001) proposes that a designer's conception of a design and its context is built up over time, using information from the designer's already gained knowledge and experience, and from external sources of information. These external sources can be other designs (examples), the design brief, the client, or encoded sources like books, drawings, pictures, etc. But another source also applies, that is, the information generated (inferred) during the design process (Ullman et al 1988).

Designers rely heavily on prior knowledge and experience. Several empirical studies in the field of information processing in engineering reveal that one of the most prominent reasons designers have not to use other sources of information is that they are not considered accessible. This lack of awareness (Cross, Christiaans and Dorst 1992; Court 1997) produces as a result many designs being generated without the benefit of information that does exist.

Accessibility is a subjective measure of the effort that a designer needs to make in order to access such an information source. There are many factors affecting the accessibility of an information source, like familiarity to the source, quality of the results, format, right level of detail, etc. (Fidel and Green 2003, Choi and Rasmussen 2002).

The selection of an information source will depend on the type of activity the designer is performing. For instance, designers will consult more books and manuals when they need specific *data* about properties of materials, tolerances, etc. whereas when negotiating the structure of the problem humans will be the most consulted, if not the only ones (Fidel and Green 2003). The reasons for this is that humans are considered more accessible, but also because humans are able to translate their knowledge in terms that fit more closely the requirements of the person asking.

Research in the field of information access by designers and engineers has the objective of improving access to information. Access to information will be improved if the information provided is deemed by the user as relevant, for relevance is not a property of the information itself, but an attribute endowed by the user in a certain situation. Relevance is therefore a product of the interaction between the designer and the information source. A document, for instance, will be considered relevant if it closely fits the designer's expectations, that is, if the information it contains is what the designer expected it would contain. Improving the relevance of the information retrieved by a system will improve its accessibility.

Designing information systems for designers requires therefore a means to foretell in advance whether a document retrieved by the system will be deemed as relevant by the user. This is an active field of research in computer science and information management. Of particular interest is the design of information systems to support the designer during conceptual design, phase in which problem structuring is the most prominent activity. In order to do that, we need a better understanding of the structure of the problem and solution spaces, as well as of the process of structuring problems, as it will allow further insight into the process followed by designers (Eastman 2001).

5. Discussion

The primary objective of our research is to devise ways to provide support to the designer during early stages of the design process. Of particular interest is the interaction with information sources. This enterprise requires us to have a better understanding of what motivates information access, what use accessed information will be given and what factors influence both accessing and using the retrieved information.

A number of reasons have been found to be the triggers of information requests, the need to structure the design problem being the most remarkable and interesting one. Problem structuring is a process of drawing upon knowledge and (external) information to give structure to the problem space. The need to structure the design problem has its roots in the very nature of the design problems, for the design problems have unique characteristics that make them require specific structuring processes to be solved. Understanding this process of problem structuring could provide further insight into the process followed by the designers and therefore provide the necessary conceptual knowledge for the design of information systems to support this task.

The process of problem structuring is made visible in the design issues posed by the designers. One type of issues that is generated refers to design requirements and constraints. The relation between the generation of design requirements and information access was one of the most interesting findings in our studies. For some designers the discovered design issues, and the generated design requirements was the driving force for their use of the information system provided. For some others, it was the information accessed what motivated the generation of new design issues and requirements.

As it has been shown throughout the paper, designers often follow either a problem-oriented or a solution-oriented approach. We do not know, however, whether these approaches originate in experience, education, the design situation, idiosyncratic reasons or a combination of these. What we do know is that the selection of either approach has a very strong conditioning effect on the way designers structure the problem and therefore on the way they interact with information sources. Our observations show that a strong solution oriented approach could mean that information consulted from (new) external sources will never become knowledge (internally processed) and thus will never be applied to the current design situation. Nevertheless, if the designer interprets the design problem in a more abstract way (problem oriented) such interpretation could elicit willingness to access and process more external information. But the opposite could also happen. That is, if access to information is stimulated, this can elicit willingness to better structure the problem space. Preliminary results of our studies suggest that problem oriented designers produce results that are assessed higher in terms of creativity. This relation could have its roots on the fact that those designers did a better job of structuring the problem.

Another factor that influences the access and use of information sources is the perceived accessibility of the source and the perceived relevance of the information accessed. Even when information exists and is relevant, it would not be used if its source were perceived as inaccessible. These are good reasons to make information tools more accessible to designers and, why not, fun to use!

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