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Studying Design Engineers use of Information Systems: Which variables to control for?

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1. Introduction

Information processing in Design has played a major role in the studies of design cognition. If we consider design as a problem solving activity, we must necessarily think of it as an information processing activity (Newell and Simon 1972). For third reason, it is sometimes very difficult to separate the studies that refer specifically to the accessing and processing of information in design from the rest of design research. For instance, Eastman (2001) uses the term “design cognition” to refer to the study of “human information processing in design”, covering a large number of issues such as problem structuring, design representations, sketching, knowledge structure, information accessing and use, etc.

Hertzum *et al* (200) propose that the choices made by designers depend on their understanding of the problem and its context, on their ability to structure both problem and context and consequently, on their success in obtaining proper information about the problem and about the context (Hertzum *et al.* 2000). In a similar fashion, 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 existing knowledge and experience, and from external sources of information. However, designers tend to favor and to rely more on prior knowledge and experience than on external sources of information, either because they are not aware of the information they might need or because they are not motivated to consult the external sources. This lack of awareness (Cross *et al.*, 199; Court, 1997) produces as a result many designs being generated without the benefit of information that does exist and that is available to the designers.

The information seeking behavior of designers, and in particular of engineers, has been studied for at least 30 years, yet the results of these findings do not constitute a consistent body of knowledge (Pinelli, 1991; Pinelli, *et al* 1993). The literature is fragmented and dispersed in a number of publications in different disciplines that have shown interest in the subject. For instance, cognitive neuroscience (Goel and Pirolli, 1992), mechanical engineering (Ullman, 2002; Court, 1997; Court *et al* 1997, 1998), engineering design (Hicks *et al* 2002), new



product development (Szykman *et al*, 2001; Rodgers *et al*, 2001), educational science (de Vries and de Jong, 1997), Knowledge Management Systems (Ahmed *et al*, 2003; Wallace *et al* (2004); Artificial Intelligence (Song *et al*. 2002) and Information Science (Hertzum and Pejtersen, 2000; Fidel & Green, 2003; Majumder, *et al*, 1994) to cite only a few.

All of these studies have concentrated on a limited number of issues: the nature of the problem spaces and the information required to specify them (Goel and Pirolli, 1992), the requests of information by design engineers (Kuffner *et al* 1991), the effect of information technology on new product development (Court, Szykman, *et al*, 2001; Rodgers *et al*, 2001), information sources used by design engineers (Court *et al*, 1998), information management (Majumder *et al*, 2004), documenting the design process (Rittel and Weber, 1973), accessibility of the information (Hertzum *et al*, 2000), the structure and format of the information (de Vries and de Jong, 1997), the information-seeking behavior of design engineers (Pinelli *et al*, 1993; King *et al* 1994) the accessibility of the information (Hertzum *et al*, 2000;), sketching and systems to support sketching (Goldschmidt, 1991; Gross, 1996)

Ullman, Curt and Culley (1998) have studied the information requests of mechanical engineers since the late 80's with the intention of establishing the requirements for the ideal information system for mechanical engineers; and Pahl and Beitz (1984), Rzevski (1985) and Rouse (1986) have tried to determine how to measure the usefulness of information in design engineering.

There is, as it can be seen, an important amount of studies, all of which contribute to further our understanding of information needs of designers. However, as stated above, this research does not yet conform a consistent body of knowledge among other reasons, because all the studies follow different agendas. There is general lack of uniformity in the research methods used and the focus areas. This paper intends to contribute solving this problem, by proposing a set of variables that need to be controlled for when studying engineers and designers use of information.

In this paper, a set of 6 empirical studies on information processing in design are briefly presented. The intention is to summarize the most important issues found to have an impact both on the information intake by the designers and on the research methodology used.

The empirical studies conducted have shown that the main factors affecting the designers' ability to search for, process and apply information to a design task are their cognitive abilities, knowledge base, experience and volition. Specific observations on the effect of the designers' awareness of existing information, reliance on previous knowledge, willingness to use information, ability to transfer knowledge across situations, abilities to properly represent problems and effects of fixation are presented and discussed.

2. Description of the Studies

This paper reports on a series of 6 empirical studies conducted between 2000 and 2004 at the Faculty of Industrial Design Engineering at Delft University of Technology in the Netherlands. The studies tested 89



novice designers, 48 male and 41 female in their last year of the bachelor cycle (23) and in their last year of their master cycle (66). The main purpose of the studies was to set up the basis for the development of information systems to support designers in the conceptual stages of the design process. This required understanding better the way designer enrich their knowledge base, finding what triggers their queries for information and what strategies they use in formulating and understanding design briefs. To achieve these objectives, 6 studies were set up. The following table summarizes them.

	Participants		Level	Task	Time
	M	F			
Study 1	14	9	Last year M.Sc	A flexible workspace	2 days
Study 2	13	10	4 th year	A bicycle rack and a lawn mower	1 day
Study 3	5	4	Last year M.Sc	A flexible workspace	½ day
Studies 4-6	16	18	Last year M.Sc	A telephone for home use	½ day

All the studies except the first one were videotaped and fully transcribed. All designers were interviewed at different stages (see discussion below for more details. See also Refs# for the full description and results of the studies). All the studies were conducted with individual designers, except the second. In this study, it was decided to use teams of three designers since it would make easier the study of the protocols as it is not necessary to frequently remind participants to think out loud (they talk to each other).

For all the studies, an information system was designed. For studies 1, 2, and 3, the information systems consisted of a content management system developed over a LAMP system (Linux, Apache, MySQL and PHP). The information system contained search capabilities, the ability to see related documents and the possibility to share information among the team members.

For studies 4, 5, and 6, the system concentrated on delivering visual information to the designers using a Query by Example (QBE) approach. In such a system, the designer poses a query using images instead of words. The system then compares these images to a collection of 4000 other images of products in a database and delivers the results based on geometrical similarity (Ref.).

The results of these studies can be separated in two main areas: the aspects that make it difficult for the designer to access, process and effectively apply information during the design process. These can be related to the designers themselves (cognitive abilities, knowledge base, experience and volition); or related to characteristics of the information or of the information sources.

3. Impediments to Information Processing in Design related to the designer

The empirical studies mentioned above started from the premise that three factors are the major impediments to information processing. These factors, proposed already by Gestalt psychologists, were *fixation*, *transfer*, and *representation* problems. From the observations made in our studies, it appears that some other aspects such as *awareness*, *confidence* and *volition* also play an important part in the designers' ability to process information.



3.1. Awareness

The designer does not know that he does not know, or does not know that there is information available on a particular topic. The problem of awareness is particularly acute when designers have little experience with the topic. This relationship between information processing and experience is paradoxical. When the designer has little knowledge of the topic, or little experience, his information needs are also lower. Conversely, designers with more experience will have higher information needs. This paradox, studied by Atman (1999), Christiaans (1992) and Rowland (1992) was already described by Erasmus Roterodamus (1469-1536) in his masterpiece *Praise of Folly* (1994).

In the design of the studies, great effort was put into selecting participants that had the same level of education and design experience, and they were questioned about their knowledge of the topic. The intention was to have designers with no previous experience in the field of the design brief. The experimental setting did not allow observation of the effect of awareness, but it is tempting to speculate what the designers might have done differently had they been aware of the existence of information in the system. These results are consistent with previous research. For instance, Ahmed (2003) evaluated 633 queries made by novice engineers to experts in the aerospace industry. They found that in only 35% of the cases were the novice engineers aware of what they needed to know.

3.2. Reliance on Previous knowledge

That the designers rely heavily on their own knowledge (even when almost non-existent) and experience has been widely recognized and discussed in literature. This factor hinders information processing because it is sometimes taken to the point of completely ignoring other external information sources. A more moderate form of this phenomenon is when information is accessed to confirm things the designer already knows. The second and third studies provide several instances of this phenomenon.

3.3. Willingness

This volitional aspect denotes the disposition or reluctance to access and use information sources. Although in our studies designers were not explicitly instructed to use the information system, the fact that they were put in a laboratory with a computer loaded with an information system could have been interpreted as a tacit instruction. It is therefore difficult to say whether or not they would have used the system had there been no implicit expectation. On at least two occasions, however, the designers in the second study mentioned explicitly that they used the system because they had to, and that they would rather have spent their time going out to look at bicycles shops.

3.4. Transfer Capabilities

This is the case when the designer is unable to apply information from previous solutions to the current situation, or is unable to use knowledge or procedures from different domains to solve a (design) problem. This is mentioned by the Gestalt theorists. It was also observable in our studies. For instance, designers of the third study could not understand or apply the information in the documents on personalizing workspaces in



other areas (such as transport and construction) to their office problem. The second study also contains various examples of this phenomenon.

3.5. Fixation

In fixation, the designer shrinks the space in which solutions are sought. When this occurs, not only the scope of the solution space, but also the scope of the information sought, accessed and used is restricted. The results from the first study suggested that fixation could occur in two different modes: one in which the fixating element is an *object* (mental set) and another one in which the fixation element is a *procedure* (functional fixedness). Both have consequences for information processing.

The identified fixating elements, that is, the main factors that can cause the designer to become fixated, are, according to the results of study 1, the initial interpretation of the problem (the early representations), the use of language, and the inappropriate use of sketches. Other researchers have identified precedents or examples as another fixating element. In this form of fixation, designers' concepts mimic features of existing solutions. This has been called "fixation by exemplars". In our studies, we found no reason to believe that accessing documents containing examples of existing solutions had any fixating effect. However, other researchers claim that in certain design situations, such as stereotypical design tasks, designers do tend to become fixated by examples.

When designers adhere to a particular way of working, it is said that the fixation is procedural. If the procedure indicates that the process should start with an analysis of the problem and by collecting as much information as possible about it, the designer will follow this procedure independently of his true needs for information.

Although we could not see any indications of mental set (nor were we looking for it), functional fixedness was evident to some extent, particularly in the third study, where the produce-three-alternatives-using-analysis-first-synthesis-later approach to design that is advocated in the education at IDE in Delft was very clear. Does procedural fixedness or these 'mental set' forms of fixation have any influence on the information seeking behavior of the designers?

The Gestalt psychology suggest that fixation plays an important role in information processing, and that when fixation occurs, providing more information or even removing the fixating elements does not contribute to 'un-fixing' the person. These conclusions were, however, drawn from studies in puzzle solving and have very limited relevance to design. Literature in design does not deal adequately with the relationship between fixation and the designer's ability to access, process and apply information, making this a potential area for further studies.

3.6. Representation Problems

Previous research has suggested that poor or incorrect representations of the problem can lead to inappropriate solutions, or to no solution at all, and that a proper representation of the problem can lead to an



adequate solution more quickly. For instance, the ability to see resemblances between problems, though apparently dissimilar, plays a significant role in some disciplines such as physics, where great effort is put into developing these abilities in students.

An appropriate representation of the problem allows a proper expression of the information needs. For instance, one of the designers in study 3 represented the problem as 'to invent a *system*', and she found it very difficult to articulate what type of information was needed to complete the assignment, and could come with only 3 aspects. In contrast, designer 2 in the same study considered the problem was to re-think the concept of flexibility in offices, and expressed his information needs in terms of 7 aspects including 'corporate culture', 'group behavior' and 'identity'. This representation of the problem and design needs is, in our opinion, a better interpretation of the design brief.

4. Impediments to Information Processing in Design related to the Information Source

Accessibility can be understood as the degree of difficulty in finding and/or getting a piece of information. All research in the field of information access has the objective of reducing this effort and therefore improving accessibility. If the information source is a computer system, which is the case in the studies in this research, the main factors determining the accessibility are availability, means of delivery and cost. Relevance is another factor but will be discussed in a separate section.

4.1. Availability

The impossibility of predicting when a design issue or a design requirement will trigger an information query, and the opportunistic nature of information access in the early stages of the design process, makes availability an important aspect. The design process can be disrupted if the requested information is not available when needed, especially when the designer is *aware* of the existence of the information. For instance, in the second study, which was conducted with design teams, one of the teams thought it would be nice to add wheels to their design, and thought that inline skates' wheels would fit perfectly. However, the information system did not contain this kind of information and they were not allowed to use any other information source, which caused the team to get stuck in the process until they decided to proceed, leaving this aspect of the design unfinished.

4.2. Means of delivery

Information can be delivered by a wide spectrum of media: speech, paper, physical samples, etc. It is acknowledged here that designers use these media profusely, but since one of the purposes of this research was to study what aspects are of importance in developing information systems for designers, it focuses on information delivered by means of a computer system.

In our studies, we found some aspects of the information system that can make it difficult to access and process the information. For instance, if the designer has to put too much effort into using the system, the attention will be shifted from the task to the tool. The main problems associated with the system are the



transparency of the interfaces, *performance*, *format* of presentation and *quality* of the results. Each of these aspects will be discussed later in this paper.

The format in which the information is presented is also considered under this category of impediments. During conceptual design, visual information is preferred over linguistic information for it fits better with the designers' way of thinking. The designer knows, thinks and works in a visual way (Cross, 1984). This claim is supported by our observations. The designers in study 3 said that documents with richer graphical content fitted better their information needs, echoing the comments of the designers in the studies 1 and 2. These results strongly suggest that the development of information systems to support designers during the conceptual stage needs to focus on the visual and the formal instead of on the textual and the factual. This is discussed in greater detail later in this paper.

4.3. Cost

The use of the Internet as an information source has significantly reduced the costs associated with obtaining information, but has brought along other problems, such as how to assess the reliability of the source and the difficulty in finding the precise information needed.

Reliable sources that can be held liable for the information offered are usually not free. What is more, the information needed for a design assignment might require many different sources, such as ergonomic tables, standards and regulations, properties of materials, etc. No single provider can supply all the information needed and it is often necessary to subscribe to different information services, which could be very expensive. For a designer the question of 'how much would it cost me to know this' is balanced with 'how much do I need to know it?' Cost was not investigated in our studies, as we have compiled the information needed for each study and made it freely available to the designers, but it was an aspect often mentioned during the interviews.

5. Variables we need to control for related to de designer

The observations made during the experiments suggest some variables that need to be considered in order to make progress in understanding how designers use information and interact with information systems. The studies in this research focused specifically on some of the variables discussed here. Other variables, however, were not directly investigated but the observations made evident the need for considering them in further studies. Again, these variables can be classified as pertaining to the designer or to the information system itself. Since the ability to process information is a cognitive one, some cognitive variables need to be considered. These variables refer to the designers' *understanding* of the topic to be treated, their *knowledge base* and their *design strategies*, their *information seeking behavior* and their *affective behavior*.

5.1. Knowledge base and experience

The knowledge the designer brings to the situation, be it *domain knowledge*, or knowledge on *procedures*, *methods* and *strategies*, forms what we call *experience*. In our studies, all participants were taken from the same faculty, with about the same (intermediate) level of design experience. In practice, such an homogeneous group could



never be formed. If professional designers had been considered, they would have been from all kind of different backgrounds and would have had different amounts of experience. This would have made for difficulty in comparing the results obtained. The importance of experience in information processing in design is discussed by many researchers. For instance, Rowland (1992) showed that when experts consider a problem as ill-defined and put a lot of effort in using information to structure the problem, novices do not, for they consider the problem sufficiently defined (see also the discussion on *awareness* above). Atman (1999) and Christiaans (1992) arrived at similar conclusions. The implications of these findings are that the issue of information processing is even more significant in professional practice, as experts are more willing to consider more information and to spend more time in structuring the problem than novices.

Experience can also be a reflection of familiarity with the information source and familiarity with the query languages. To control for this aspect, all the information systems used in our studies were web-based, accessible with a standard browser and made use of standard querying interfaces and querying languages such as the ones used in popular search engines (Google, AltaVista, etc.)

5.2. Design strategies

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 sense, one could propose that the tendency to focus on solutions or on problems is situational and idiosyncratic to the designer, but our studies did not provide 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 behavior is inherent to the designer, the situation or to other factors like education and experience?

Our studies did not deliver results on the relation between the strategies used and the information seeking behavior. However, they did show that the strategy chosen by the designers was less important to the quality of the results of the design process than accessing and applying the information that was available to them.

5.3. Information Seeking Behavior

When seeking information, designers display a particular behavior that is reflected in the strategies used and in the interaction with the information systems. The information seeking behavior needs to be described in terms of the *strategies* used to search and use the information (systematic vs. opportunistic), and in terms of the *techniques* used to search (browsing vs. searching).

In our studies, the techniques were used to make inferences about whether the information source was being used for a particular purpose or if the use was more explorative and opportunistic. Opportunistic use of the information was often accompanied by random browsing whereas purposeful, motivated queries were accompanied by structured browsing and use of the search engine.



5.4. Trust and expectations

These are also variables affecting the information seeking behavior of designers. Trust refers to the perceived authoritative nature of the source and can cause the designer to use the information blindly, even when the facts contained are inaccurate. Providing the designers with an information system to perform a task generates high expectations. The designers think they can find all the answers in the system. Sometimes these expectations are not fully met, leading to frustration and loss of motivation.

5.5. affective behavior

These are factors that have an influence in information processing are more personal (and situational). These include *motivation, diligence and thoroughness, resourcefulness and ability to focus on the task*. Motivation, for instance, has been described as a major factor in creativity by researchers like Amabile (1983). She proposed that skills, domain knowledge and creativity cannot compensate for the lack of motivation, but that motivation can compensate for the lack of those skills. Although in our studies affective behavior such as motivation was not the focus, it was observed. All the designers in our studies participated voluntarily and were very excited about testing new systems. Even in those cases where the system crashed and needed to be restarted, the designers were willing to continue (although not without the occasional expression of frustration). In contrast to this, one of the teams on the second found the study so uninteresting that it was difficult to use the data from their session.

6. Research methodology

As it has been discussed previously in this paper, studying information processing in design requires consideration of a large number of factors. First of these are the problems that might hinder information processing both related to the user and to the information source. The previous sections have outlined the variables that, in our view, need to be prioritized in order to improve our understanding of how designers seek, evaluate, process and apply information in early stages of the design process. Some of these variables have been studied and discussed in this research, others are proposed as a result of a critical evaluation of the studies. This section discusses aspects of the data collection, data analysis, experimental setting and research tools used.

6.1. Data Collection

Studying such a complex task requires the development of a research methodology that fits the particular research interests. The methodology used in this research evolved, from the log-files centered approach used in the first two studies, to the more detailed observational techniques used in the last studies.

The first study concentrated on two main aspects: the evaluation of the designers' interpretation of the problem and the quality of their results, and the use of the information system provided. The first aspect was studied using the method proposed by Christiaans (1992) to assess the quality of the results of a design process. A panel of experienced designers and teachers were used to assess the concepts in a number of parameters also defined by Christiaans (1992). This method has been tested in many other studies, among others Dorst (1997) and van der Lucht (2001).



The second aspect was studied using the log files of the information system. The expectation was that by studying how the designers used the information system, inferences on the designers' information seeking behavior could be made. Soon it became evident that the log files could not provide all of the answers. For instance, it was not possible to determine what information was more important or what triggered a query. Log files can reflect, but cannot explain behavior. Although the log files could not provide information about why a document was accessed or how the information was used, they were very useful in reflecting the designers' behavior. For instance, log files provide information on what documents were accessed and in what sequence and whether the designer was browsing in a structured or in a random way. Log files give account of the techniques used (browsing vs. searching) and provide hints about the information seeking strategies (structured vs. opportunistic).

The questions related to *what* triggers a query needed a different approach. In the second study, log files were combined with videotaping of the design sessions. In this study, we decided to use teams instead of individual designers so it was possible to follow the design process by means of the remarks they made when talking to each other. When using teams, the designers need to communicate with the other team mates and in doing so, they account for a great deal of their thoughts, even without asking them explicitly to 'think aloud', as is necessary when using individual designers.

This approach allowed us to determine, by studying the conversations held between the team members, not only why the designers accessed certain documents, but also to determine, partially, how the information was used. In both the first and the second studies the information intake was measured in terms of the amount of documents accessed and the total amount of time spent on the system. Both measures proved to be inappropriate, as they only showed the amount of information accessed but failed to indicate the actual amount of information that was effectively considered and used.

The conclusion was that if you do not ask the designers about *why* they access information, *for what purpose* they use it and *how* they determine what is important, you will never know. In the third study the research method changed. In this study, log files were combined with *in situ* observation of the designer's behavior and with video taped semi-structured interviews before, during and after the information search.

By being in the same place as the designer is, the researcher is able to monitor more carefully the use that the designer makes of the information system, and to observe other indicators of relevance that cannot be logged in a file, such as if the designer makes notes while accessing a document. By duplicating the screen of the designer, it is possible to determine what parts of a document are more important. In the previous studies in which the whole document was considered in the analysis, that level of resolution is too high; sometimes it is only a graph or a paragraph that is interesting to the designer.

Asking the designer for his information needs before the design session and after having read the brief allows the researcher to study the designer's understanding of the problem and their level of awareness. Asking them in every coffee break about what information they have found interesting and what information



will be needed to continue provides information about how information needs are shaped as both the design process and the information seeking process progress.

Lastly, asking the designers specifically about the most relevant documents provides insight into how the information in those documents was used in the design process, and what aspects of those documents were determinant in the designers decision to consider that information.

The combination of methods to study information processing used in the third study allowed triangulation: measuring the same variable (perceived relevance) using different methods from different sources (time spent on the document, adding to personal collection, use of the information in the design process and the designer's own personal accounts).

The approach used in the studies 4, 5 and 6 was a Design-Test-Improve-Test. A research tool was designed with the intention of testing a technological platform. The results of the first tests (study four) were used to draw a list of requirements for a system to handle precedents in design. Study five uses techniques drawn from usability studies to determine what are the main usability problems of the new system developed from the results of study 4.

The sixth study uses protocol analysis to determine which aspects of the visual information are of importance to the designers when collecting images for a particular purpose, e.g., to compose a collage that communicates certain design intent. Protocol analysis proved useful in revealing an important factor, which is the vocabulary designers use to describe the products dealt with (see Ref. for a full account of the studies)

6.2. Experimental Setting

The use of the information systems and the use of accessed information in the design process were the main factors observed throughout the studies. Two factors regarding the experimental setting might have affected the observations and the results of the studies. These are *training* and *instruction*.

The designers in our studies are trained in gathering and analyzing data at certain stages of the design process. Their information seeking behavior thus reflects conditioning factors such as education. In addition, it is possible that the designers use the information system because they have been (tacitly) instructed to do so, or because they feel obliged to given they are provided with a design brief and an information system.

6.3. Research tools

An important aspect of this research is that the information systems used have been developed along with the studies. Although developing them was not the main objective, they gained importance because they allowed the testing of particular concepts and ideas. An example is the possibility of supporting non-linguistic queries in the QBE system developed for studies 4, 5 and 6. In this research, the software developed became part of the research in what it helped shape some of the studies. For instance, the need to allow designers access to the visual database by other means different from the query by example approach motivated the discussion on



design language. The premise was that structuring the visual information in categories that follow their natural way of talking about products would make navigating easier.

This particular tool can be exploited in research in many different ways, for instance, to follow more closely the process of image forming in early stages of the design process. With this tool, it is possible to observe what images the designer uses as positive and negative examples (relevant/irrelevant), as well as what images are actually collected in the collage area. This provides a unique opportunity to see in images how the designer's needs for visual information are shaped by the visual information already accessed.

7. Conclusions

Although there is a significant amount of studies in information processing in engineering design, the differences in the agendas of the researchers and the variety of methods used have prevented the results from becoming a consistent body of knowledge. This paper intends to contribute to the field by proposing a series of variables that need to be controlled for when setting up studies in this area. These are both in relation to certain characteristics of the designer and the design task and to the information sources themselves. Not all the identified issues have been controlled for in our studies, but the analysis of the data has revealed their importance. Further studies are needed to explore the cognitive and volitional aspects of the designers. In the same way, further research is needed to explore different ways of supporting designers' special needs for (visual) information and on developing tools to support complex visual queries.

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