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FROM FUNCTION TO CONTEXT TO FORM: SUPPORTING THE CONSTRUCTION OF THE PRODUCT IMAGE

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1 Introduction

In design, the form creation process involves imagining, seeing and drawing in the early stages of the design process. Translating the vague and imprecise initial ideas into sketches demands significant ability, and requires the designer shifting focus from the product's function to its context of use to the actual form the product will have. To represent these foci, designers make use of collages, mood boards and other visual aids to communicate their ideas for which images of existing products (precedents) are a welcomed aid. Searching for them, however, is difficult, because it requires either exhaustive browsing or verbalization of the ideas to be able to use the existing search engines.

This paper presents an approach that uses images as query seeds instead of keywords (like current search engines) called Query by Example (QBE). This approach is tested through an empirical study and shows that the QBE approach is a significant step into helping designers satisfy their visual information needs. It also shows that, as designers change their focus from function to context to form, their way of expressing their information needs changes and therefore the systems to support them must adapt to this behavior.

2 Precedents in Design

In thinking of a solution to a problem, the designer has a vague image of the form that will embody the solution. Creating collages, sketches and other types of (external) visual representations are used to help in shaping and establishing this image. When making collages, for instance, the designer needs just one image that represents a concept, but often he does not know himself what image it will be. On many occasions, designers simply flick through magazines or image databases: as one of the designers that participated in our studies said, *"searching for something you cannot describe"*, trying to find the precedent that carries the kind of knowledge needed to formalize the idea. This visual thinking and visualization of ideas is a process that is inherent to conceptualizing solutions in form and material [10], [7], [19]. At this stage of the design process, visual information is preferred over linguistic information for it fits better the designers' way of thinking. The designer knows, thinks and works in a visual way [5].

Using images of existing products, as well as physical samples, is a common way of exploring possible solutions. Precedents, being solutions to previous similar problems, provide the designer with the frames of reference for the generation and development of new product forms, and using them is an important aspect of design practice [13]. In fact, many design studios have their own repository of samples of materials, physical objects, videos, glossy magazines, etc. Designers actively use these elements as sources of knowledge, to generate an image of the possible solution space, to get an impression of modes, styles, trends, applications of materials and production/assembly techniques, or just as sources of inspiration[2], [16].

These collections of precedents form a domain-specific knowledge base that aids the designer in the form creation process in a way different from formal rationality. Formal rationality proposes that knowledge can be put into a collection of abstract, generally applicable principles as in, for example, mathematics and physics. In these disciplines, knowing certain abstract rules that can be applied to a great number of different situations eliminates the need for learning how to resolve every imaginable situation (which would be impractical, if not impossible). This is the reasoning that inspired Altschuller's theory of technical problem solving TRIZ [1]. Knowledge, however, comprises more than generally applicable rules. It can also consist of concrete, specific experiences. Generally applicable rules suit domains with well-defined problems. In creative design, where problems are ill-defined, such general rules are either not always applicable, or completely non-existent. Instead, transfer of knowledge is based on cases [20], making precedents very important in design education.

In design education, precedents are used in a number of different ways. For instance, to illustrate the results of using certain materials or manufacturing processes, to compare differences in styles or design movements or to discuss the effects of changing the spatial relations among components, to monitor trends, or as sources of knowledge and inspiration [19], [2].

All the knowledge encoded in these precedents is decoded and transferred by the designer to the current situation. Kuhn [9] called this process 'thinking from exemplars'. However, in spite of being critical to design, the process of transferring knowledge from precedents to current design situations is still poorly understood and poorly supported.

Several researchers have considered the issue and tried out alternative solutions (for a complete review see [16]). However, most of the systems developed require the addition of metadata to the images in the form of 'design stories' [13], [2], affective associations [13], requirements [6], icons [21], [3] or sketches [8], [22]; or need to be classified within a predetermined structure to browse through [11], [4], [18]. These approaches have some serious drawbacks.

The first drawback is a practical one. To be useful, a database with precedents has to have a significant amount of images. Describing and indexing each image is a time consuming, labor intensive, expensive task. The second drawback is related to the way images are understood and interpreted. Attribution of meaning is very personal, subjective and situational and can hardly be determined beforehand by the editor of a collection.

These shortcomings could very well be the reason why none of these initiatives have left the research environment to become a successful commercial product. The high costs associated with the indexing of the data and the amount of maintenance required to keep it up to date, are major obstacles for the assimilation of these technologies in industry.

The filtering approach used by most of these systems can be sufficient if the designer has a good idea of what to search for (a keyword is usually necessary) and if the search criteria are well defined. However, information needs cannot always be expressed in such a straightforward manner.

In addition to their use as a means to explore possible solutions, as a source of knowledge and as a source of inspiration, precedents are used as referents in the codification of messages that have to be transmitted by a product. For instance, if a designer intends to design a product that looks sturdy, sportive or elegant to a certain social group, salient characteristics of other products that are considered sturdy, sportive or elegant by that social group serve as a starting point for the exploration of new forms. This exercise requires not only a good understanding of the codes to be used, but also access to a large number of referents (e.g. products containing those codes). In this case, the filtering approach is no longer adequate. The reason is that images (or what they represent) do not have an intrinsic, fixed meaning that can be completely captured in words by the editor of an image collection. Instead, as will be discussed throughout this paper, the meaning of an image is characterized by three factors: It is contextual, it is differential and it is situational [17].

These characteristics of attribution meaning are not reflected in the design of current systems to support the handling and usage of design precedents, as most of them are based on the addition of metadata such as descriptions, icons or sketches. In all these approaches, the data must be described beforehand by either the designers themselves or by editors of a collection of precedents, and with few exceptions, the collections must be queried using keywords.

In order to use a keyword based system to search for precedents, it is necessary to have a good idea of what is being sought, as it is also necessary to have a good idea of how the information has been represented in the collection. Due to the vagueness of the ideas early in the process, it is difficult to express information needs in the form of keywords.

An additional difficulty is that in the design process, the designer shifts focus constantly, from considering aspects of the problem to considering aspects of the solutions and between the different issues that need to be considered. Aspects such as the target group, the context in which the product is going to be used and ultimately the form that will embody the solution are considered. Are the information needs of the designers expressed in the same way as they shift focus?

This paper intends to answer this question by allowing designers performing a design task to search for visual information using exclusively images as seeds for their queries instead of using keywords. This approach, called query by example (QBE) was implemented in a system that will be described in the next section.

2.1 Developing a system to handle design precedents

A review of the current research on information systems to support the use of precedents in design has demonstrated the difficulties inherent to the process of describing and representing precedents adequately. Subjectivity, inflexibility, high maintenance costs and the dependence of expert knowledge are amongst the problems mentioned.

A system that does not require a previous description of the data it contains (metadata) would need to be aware of the *content* of the information it processes. Recognizing the content and retrieving text documents based on content and not on metadata is a most demanding task. But if the document is an image, then we are referring to one of the most formidable challenges of modern computer science: Content Based Image Retrieval Systems (CBIRS) [12]

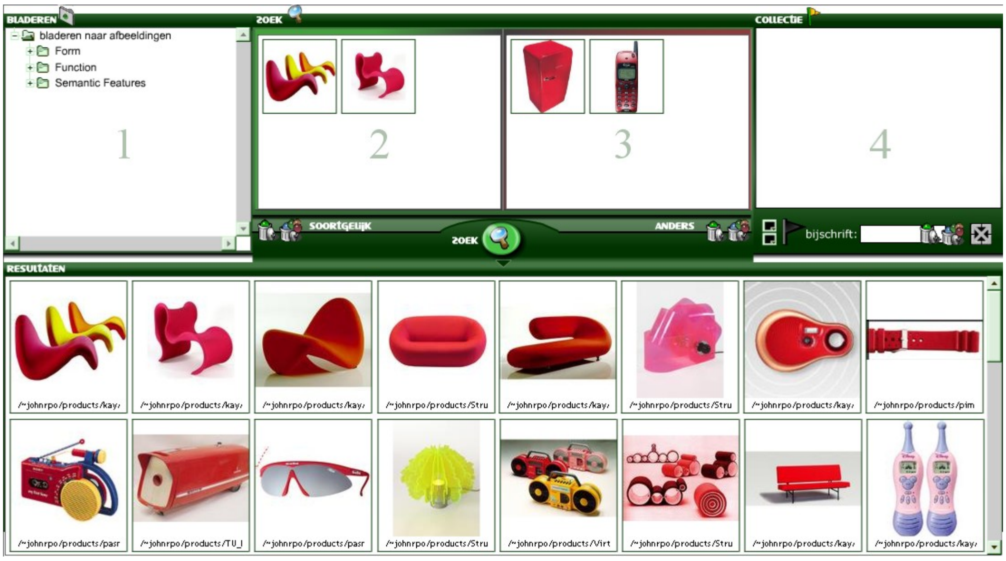

Figure 1 Screenshot of a Query by Example system. In area 2, the user drags the images to be used as examples (should look like this) and area 3 is used for counter examples (should not look like this). The results are ordered by similarity. Area 1 is used to allow the user to browse through a set of examples of products that will serve as seeds for the query. Pressing the search button with an empty query returns a random set of images.

In a CBIRS, the system automatically creates a low level representation of the images it contains. This representation is based exclusively on properties of the image, such as color, texture, shape, spatial relationships, etc. However, the system cannot map this low level representation to the full semantics of the image. Even recognizing that the image contains a TV, a car or a phone, i.e., recognizing a small part of the semantics, is still an unresolved problem.

If CBIRS are still so immature, how can they contribute to the issue of indexing and retrieving precedents in design? The answer is twofold. First, CBIRS allow the automatic creation of a low level representation of the image that is used for indexing purposes. Second, this representation, being based exclusively on properties of the image, is culturally independent and does not represent any particular point of view. In a CBIRS, the search is done using a seed that, in contrast with other systems, is not based on language. If a user needs an image, all that is required is to feed the system with an image that resembles what the user is looking for. This approach is called query by example (QBE).

An Example of this approach is presented in Figure 1. If the designer wants to retrieve products with a certain character, it is enough giving the system examples of products with the character required. The search occurs in an interactive process in which the user gives to the system examples and counterexamples. In this case, the user gave the system two chairs as positive examples and two other cubic looking products as counterexamples. The results, based exclusively on appearance, are not necessarily chairs, but do share characteristics that could be interpreted by the designer as he pleases, for instance, as organic, or as friendly or as modern, etc. The actual interpretation of the images is done during the use of the system, not before, for there are no humanly added descriptions attached to the images.

The interface is divided in five areas. In the first area the user can browse through a pre-view of the collection. The intention is to allow the user get a first impression of the types of images that are in the collection. Since there are no means to search by keyword, it is sometimes difficult to find this first *seed* that is needed to start the query. This area intends to facilitate this process.

The second area is where the user drags and drops the images that contain the characteristics sought (positive feed back) and the third area is where images with undesired characteristics are dragged and dropped. Once the query is composed, pressing search (zoek, in the example), delivers the results.

There is a fourth area where the user can compose a collage. There, images can be put in any order, can be tagged, described and saved. The fifth area, which corresponds to the lower part of the screen, is where the results of the search are presented.

Attribution of meaning attributed emerges in an interactive process of searching and giving feed back. It was also proposed that the meaning of an image is differential. That is, meaning become more evident by comparing it with other images that share common characteristics.

This was reflected in the design of the interface by putting the search areas next to each other (areas 2 and 3 in Figure 1). In the example shown, the intention of the user is to find images that look like the ones in area 2. Putting the area where images that will receive negative feed back next to the images with the desires characteristics emphasizes the differences. In this case, the organic character is emphasized as opposed to the geometric, cube-like appearance of the images used as counterexamples. The query is then based on the distance between the positive and the negative images. In the same order of ideas, the results are better evaluated when both the query (positive and negative images) and the results of the query are visible at the same time.

Eliminating the human mediated process of classifying, describing and indexing images allows the organization of vast amount of precedents. In our test, we indexed over 40,000 images in about 12 hours which is the time our computer (a Pentium III 1.5 GHz with 1GB RAM) needed to create an index based on the low-level representations of the images. However, during the tests with designers we used only a subset of 4,000 photographs of products. The system has been tested in a series of empirical studies, one of which is reported in the next section.

3 The Study

3.1 Participants

The participants in this study were 10 senior students from the faculty of Industrial Design Engineering (IDE) at Delft University of Technology (7 female 70%, 3 male 30%) that participated voluntarily from a group of students who were contacted by e-mail. They were invited to our laboratory, one at a time, to work on a small design assignment and to and to hold an interview.

3.2 The Design Assignment

In order to test how different designers would use the system to collect visual information, they were asked to design a product. The assignment was formulated as the design of a telephone for young, highly educated people living in west Europe. The target group and the conditions were further explained by a text of about 300 words. This text indicated that the people in the target group have a lot of high tech equipment in their work environment and that for the house, they would like something more sober, elegant yet modern.

The participants were asked to compose a collage that expressed the character they wanted to give to their product. No further instructions were given, so they had the freedom to compose a collage that illustrated the target group, which served a starting point for an exploration of form, color, materials, or whatever other use they could think for a collage. They were asked to collect at least ten images, with no maximum limit. For the task of collecting images, they were given 30 minutes.

3.3 Procedure

The study was conducted in one and a half hour sessions. Each participant spent 30 minutes working on the assignment. There was a 30 minutes interview and the other half an hour was spent in introducing the study and training the participant in the use of the system. The participants were invited, one at a time, to our laboratory. A computer was set up with the software, a table with sketching material (markers, paper, etc) and video camera that was used to tape all activities. The camera was aimed at the computer screen and recorded the remarks of the participants.

The session started with a short introduction in which the participants were informed about the activities. Then, each participant received a short demonstration of how to use the system. Following this they were given a small training assignment. They were asked to make a collection of five images that they considered related to each other in whatever way. They were also asked what the relation was. In this way, the participant was forced to think about certain criteria to use in the searches. For instance, they could search products with the same geometry, the same color, the same function, etc. (this was not suggested during the experiment, and is mentioned here for illustration purposes only). For this task, the participants had 10 minutes.

After this training, the assignment was given and they started working. For the collection of images to compose the collage the participants were allowed 30 minutes. During this time, they could make notes and sketches. They were also asked to indicate why they decided to give positive or negative feedback to particular images or why they wanted to add them to their personal collections. These protocols were later used to determine what criteria they used to judge the images. Each time the participant performed an action, the action and the time stamp was noted in a log book. This logbook was used later to search the tapes for those segments of particular interest.

Finally, all the participants were interviewed. The participants were asked questions about three images selected randomly from the ones they collected in the collection area. In some cases, it was necessary to show them the video tapes so they could see themselves and reflect on their actions. All the protocols were fully transcribed.

3.4 Results

From Function to Context to Form: The Construction of the Product Image

The protocols provided an insight into the rationale behind the designers' choices of visual information, and showed the path followed in selecting the images for the collage. All the participants started by browsing through the database and of these, six started looking for telephones. They asked questions such as *"what type of mobile phone would he have"* (participant 5); *"I am going to start collecting telephones"* (participant 4); *"I'll start browsing by function, […] telephones for domestic use"*. Participant 7 did it differently, *"I am going to start with something different, with sports"*. The other participant that did it different was number 6, whom started browsing by form, but very soon after switched to function and started looking for telephones. After having explored the images on telephones, a big change in strategy can be seen.

In all cases, the designers talked about the users, describing them in terms of the products they would or would not have. For instance, participant one selected a *"sofa that is a little bit straight, and this lamp, because I do not think that this gentleman would have a pink lamp"* Participant 5 added an Audi saying *"Yep, they drive an Audi… or a Scooter? No, definitively an Audi"* and immediately after added a Scooter in the negative feedback area. Participant 2 mentioned that she would start looking at *"status symbols"*. In general, the most added products were Rolex, B&O, and 'high-tech' products. Others such as the Barcelona Chair, the Porsche designed kitchen appliances and several Macintosh products were also used to describe what the user would possess and therefore considered for the composition of the collage. *"He drinks espresso"* said participant 5 before adding an espresso machine.

Some other products that were put in the negative feedback area had the intention of eliminating what the designers considered users in the given target group would not have. For instance, participant 1 tried a search on a mobile phone. One of the results was a calculator. She removed the calculator and added later instead a PDA mentioning that *"a PDA would represent better the user in this target group"*. Participant 6 said that *"he would not have an agenda but a palmtop"*. Participants 1 and 5 used an Iron as negative feedback because such a user *"would not have an iron"*; *"I do not think he would have this lady shaver"* (participant 6).

Products were used not only to describe the user in the target group, but also to describe the context in which the telephone to be designed would be used. Six of the nine participants mentioned explicitly that they selected particular pieces of furniture because they imagined the living room of the potential user having these products. Plasma televisions, B&O stereos and halogen lamps were common in the collages: *"B&O products come very close to the atmosphere"* (participant 5).

After considering users and contexts, the tendency of the users is to describe the form the product would have. This is done mostly with the help of new images found in the database and almost always using keywords extracted from the text of the design brief. Examples of what participants said are *"I am looking for masculine forms with high tech details. Masculine is squared"* (participant 4); *"I am looking for squared things, I find that masculine"* (participant 2); *"I can find very little good, hard forms, rectangular and sharp, just cubic like shapes"* (participant 9). Participant 5 said *"I throw asymmetric out because I find it too female and not straight enough*". *"It has to be streamlined, but not too much that it becomes organic, I do not find that high-tech"* (participant 6).

Other aspects than form were also used to describe the character they were looking for. For instance, materials, textures and colors. Participant 8 mentioned *"I have a high tech aluminum in my head"* and participant 4 mentioned *"black and metallic products are very common amongst men in west Europe"*.

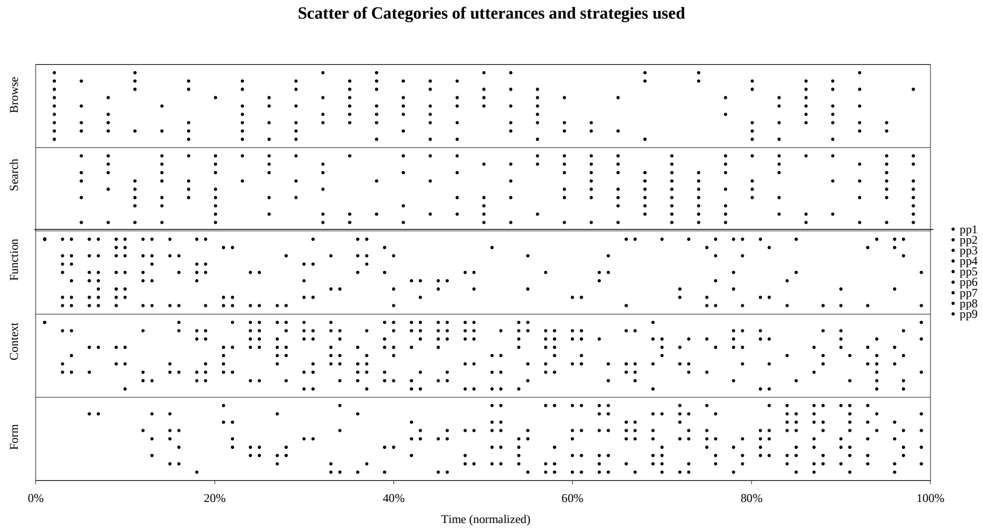

Figure 2 The utterances of the participants refer to function, context or form. The scatter shows what the user considered at a certain time. Time has been normalized, as there are slight differences in the total time spent by all participants.

This path of moving from function to context to from is not linear or sequential, as shown in Figure 2. This figure is a scatter of the designer's behavior. To construct this figure, the total time spent by the designers was normalized, as there are small differences in the time participants used the database. Every 30 seconds we placed a dot in one of the three categories depending on the last utterance of every designer for that timeslot. Every 60 seconds a dot was placed on search/browse depending on the last action.

The scatter reveals interesting aspects of the designers' tendency to focus first, during roughly 20% of the time, on function. This browsing on function becomes less prevalent as other aspects are explored. Between 20% and 80% in the timeline, the focus is on aspects of the user or aspects of the context of use. Interestingly, as the designer progresses in this activity, more and more remarks related to form are made. The last 15% of the time is mostly spent discussing aspects of the form.

Strategies Followed: Searching vs. Browsing

At a first glance, the distinction between searching and browsing does not follow a particular pattern. Designers started browsing and moved to searching at various points but continued to come back to the browsing area. However, when correlating the strategy to the categories they were looking for, the relation becomes clearer. In the first minutes, the dominant activity is browsing. This occurs because of the *zero page* problem that has already been described in the previous sections. Not having a first seed with which to start the search, browsing is the only alternative.

The dominant category in these first minutes is function. Very soon after browsing, users find themselves navigating through household and office products, using those as *seeds* for searching. Later in the process, as the focus shifted from function to context, the search engine did not produce satisfactory results. The designers kept coming back to the browsing area as they got frustrated by the inability of the system to recognize their intentions. For instance, one designer posed a query with a B&O stereo, a Rolex and an Audi, expecting to get more of these *“status symbols”* (participant 2). As it has been discussed before, only queries with products that share geometrical features can be retrieved, as the semantics of the images cannot be automatically inferred.

Towards the end, when form was more important that other aspects, users started to use the search capabilities again. However, every time it did not deliver the expected results, they went back to browsing, but with less time spent, as results based on form-based queries are more accurate. However, if searching did not deliver the expected results, they went back to browsing. This behavior can be the result of conditioning by experience: all the computer based collections used previously by the participants (such as stock photo collections) allowed only browsing or keyword searching.

3.5 General Discussion

One of the aspects that were considered in our studies was the design vocabulary used by the participants to express what they were looking for. This was surprisingly limited. Whether this is a consequence of a real lack of design vocabulary or a difficulty in verbalizing their ideas was not investigated. It was clear, however, that should the system have used keywords for a search, the entire process would have been less rich in results. Searching by keywords requires having a clear idea of what is being sought and of how the information in the database was represented and indexed. Due to the ill-defined character of the design tasks, and the vagueness of the initial ideas, this clarity is rare at this point in the design process.

Providing a non-linguistic means of searching was welcomed by the designers. The ability of the system to look for images that look alike allowed the designers to study examples they would not have considered otherwise. One of the participants expressed it as *“when you are looking for telephones, the chances of finding, say, a PDA that inspires you, are very small”*.

The system allows designers to refine their idea by letting them explore a wide variety of products that, though different in function, share other characteristics. The fact that a search for chairs, as in Figure 1, produced also other images that are not chairs is more to the advantage of the user than a flaw in the system. This type of result stimulates other creative processes, like lateral thinking.

Recall and Precision: Quality of the Results of a Query

In most computer systems, as in for example mathematical software, the quality of the output generated by the computer, measured in terms of predictability of the results, is very important. That is, the results should be constant, consequent, predictable and always the same for the same operation. Contrastingly, in the case of systems to support creative processes, the way the user’s thinking is influenced is far more important than the actual output. It is for this reason that the results of a query in our system do not have to be perfect (and cannot be, because perfect image recognition is still impossible) as long as the response is *consequent* with the user’s intentions. It is this *consequence* what defines the *relevance* of the results.

The designer’s willingness to use a computer system (for finding design precedents or other type of information) is largely determined by the perceived relevance of the results it produces. 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 system. An image, 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.

Visual information is useful if it is delivered in such a way that the designers understand the rationale behind the choices made by the software. This rationale was not always understood by the designers. For instance, a user wanted to search household products by using a phone and a sofa. This is not an irrational way of thinking, but since the system uses only common geometrical features in these images, the results were not what the user expected.

The designers also wanted to decide what criteria to search for. For instance, they would have liked to search e.g., based only on geometry (ignoring color, texture, etc.). They also wanted to be able to search by product type. In the beginning, when the image of what to look for is still vague, when the designer does not know what to search for, searching by similarity was very useful. However, when the designer does know what he wants, this approach is difficult to use.

One of the most requested features in the software was the ability to select the search criteria. For instance, the users would have liked to search e.g., based only on geometry (ignoring color, texture, etc.), or based only on spatial distribution. They also wanted to be able to search by product type. This request has to do with the willingness to understand the criteria used by the system to calculate the results.

Giving examples is a very coarse way of posing a query. The reason is that the user might not be interested in all the characteristics of the given example, but only on a few ones, like the geometry, or the texture, or only a part of the image (the buttons used in that radio, the frame of that bicycle or the screen of that lamp), therefore the importance of allowing the user to select the criteria applied during the search. This imperfect method is nonetheless, very appropriate when the user is still at the stage in which an idea of what is needed is not yet completely formed. However, as the user progresses in the image forming process, the need for specific examples appears. At this point, the precision of a text-based search was often requested.

4 Conclusion

Responding to the first question proposed in this paper, many different approaches were reviewed. Text-based searching based on pre-determined descriptions, querying by icons, sketches or just browsing through pre-established structures were common strategies, all of which had significant shortcomings: the impracticality of needing an editor to describe every image or the impossibility of using these descriptions due to the contextual, differential and situational character of meaning attribution. This paper proposed an approach that, based on image recognition techniques, provides a means for automatically indexing large image collections, and a way to search through them in a non-linguistic way.

While our tests showed the potential of this approach, they also made evident other difficulties. When the search criteria is vague, the system provides an ideal way to help the designer formalize ideas; but when the designer knows clearly what he wants, searching using images is less appropriate.

Eliminating the human mediated process of classifying, describing and indexing images allows the organization of vast amount of precedents. In our laboratory, we indexed over 40,000 images in about 12 hours (which is the time the computer needs to create an index based on the low-level representations of the images). However, during the tests with designers we used only a subset of 4,000 photographs of products.

This paper has shown that representing precedents using language, icons, sketches are all approaches with disadvantages. To be able automatically to index and retrieve images using a QBE approach, the images must be represented using low-level image representations. Whilst this approach delivers usable results, it also has, as has been shown throughout this paper, difficulties and disadvantages. These observations make it questionable whether there is a *right way* to represent and index precedents in a meaningful way.

Humans have great ability to recognize if two things are related to each other. For instance, if one takes a vacuum cleaner, an iron and a toaster, it is easy to say that they are all electric household appliances, and that 'iron' is more related to 'toaster' than to say, 'scooter'. This was demonstrated by the user that expected to find household products by giving the system a sofa and a phone. Organizing precedents in a way that allows this ability to be exploited seems to be the next step. This idea has been implemented in a prototype that is currently being tested. Preliminary results show that this is a significant improvement over the system developed for this research.

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