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DESIGN AIDED BY VISUAL DISPLAYS: A COGNITIVE APPROACH

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The use of visual displays is seen as a supportive tool for solving design problems. Throughout the design process, and particularly in the early stages of the process, designers are exposed to vast collections of visual displays. These are external representations, i.e., pictures, diagrams, or sketches, which provide designers with helpful explicit and non-explicit references. Despite the importance of this pictorial material, only a small number of researchers have dealt with the spontaneous use of visual displays as an aid in design problem solving when no instruction to use analogy is given. Furthermore, no studies have been conducted to examine whether visual displays play a more significant role in solving ill-defined or well-defined design problems. The main goal of this work is to empirically research the use of visual displays in these two problem contexts by studying the design process of groups of designers with different levels of expertise. Findings showed that both experts and novices profited from the use of visual displays in ill-defined design problem solving, resulting in a significant enhancement of the quality of design solutions. Additional results showed that visual displays did aid experts, but not novices, to improve their performance in solving well-defined design problems. These findings may have consequences for design education. It is suggested that practicing with a large number of within-domain visual displays (which belong to the same or very close realm of the problem) and a large collection of between-domain visual sources (which belong to a different or remote realm of the problem) can help designers in general, and novices in particular, to spontaneously retrieve meaningful information and to enhance their design abilities.

INTRODUCTION

Problem solving can be classified according to well-defined and ill-defined types (e.g., Gero and Maher, 1993; Goel, 1995; Medin and Ross, 1990; Reitman, 1964; Rittel and Melving, 1984; Simon, 1984). One of the characteristics of well-defined problem solving is that it involves fully specified initial requirements, unambiguous goals, and a limited number of solutions, which can be reached through a known algorithm. Consequently, well-defined or well-structured problems can be solved in a routine way. Ill-defined problem solving, on the other hand, can be defined as involving the existence of partially specified initial requirements, ambiguous goals, and a large number of ambiguous solutions that cannot be found by a defined set of operators or algorithms. Therefore, ill-defined problems relate to the production of unexpected and novel solutions that cannot be solved in a routine way (e.g., Suwa, *et al.*, 1999). Design problems are regarded as major cases in point that can be defined by these features and are therefore considered as ill-defined or wicked problems (e.g., Cuff, 1992; Goel, 1995). Designers make frequent use of visual reasoning, particularly when engaged with the production and refinement of forms. In the design domain, visual reasoning entails the interaction between internal and external visual representations. Some of the external representations are presented through the production of sketches, and others by the visual information that the designer frequently inspects and uses during the design task.

One of the ways that designers apply visual representations to their design problems is by reasoning through analogy. An analogy involves the mapping and transfer of structural information from a familiar problem to a problem that needs explanation. The degree of usefulness of an analogy is generally established through the way relevant domain knowledge is accessed and transferred. This, to a large extent, depends on the skillfulness and the level of expertise of the problem solver (e.g., Collins and Burstein, 1989; Novick, 1988). Findings obtained from a number of studies on cognitive development and expertise (e.g., Brown, 1989; Vosniadou, 1989) demonstrated that analogical reasoning skills between older and younger children are different and that experts represent problems differently than novices. A strong correlation was found between the level of expertise and the way the subjects represent problems. This aspect was recognized in a number of studies as one that plays a significant role in the use of analogy (e.g., Clement, 1994; Daheler and Chen, 1993; Gentner, 1983; Marchant, *et al.*, 1993). Experience in a certain domain endows subjects with more integrated knowledge structures. The existence of strong and developed knowledge structures enables the experienced designer to concentrate on relevant aspects of the problem. These facilitate the generation of abstract problem representations and increase the chances of deep mappings of essential information from source to target.

Despite the beneficial assistance offered by visual representations, almost no empirical studies have been carried out in order to investigate their use in design.

Visual Reasoning in Design Problem Solving

Most studies on visual thinking have concentrated on art products in particular, rather than on aspects related to processes that lead to them (Arnheim, 1969). Moreover, investigations conducted in cognitive science have focused on vision and visual perception; however, with few exceptions, visual cognition has received much less consideration. Research on internal visual representation in problem solving can be considered an exception to the rule (e.g., Arnheim, 1969; Finke, *et al.*, 1995; Wertheimer, 1959/1982). Finke (1990) studied how human beings manipulate mental images when carrying out creative thinking tasks. He proposed that visual imagery entails not only recalling visual information but also allows the transformation of forms into new objects. Since design deals with the production and refinement of pictorial representations with the aim of generating new forms, it is proposed that designers make frequent use of visual thinking. Goldschmidt (1991, 1992, 1994a, 1994b) argued that forms are not stored in the mind before they are externalized on paper. On the contrary, design forms are generated and transformed through an interactive process in which an interplay between internal visual representations (imagery) and external visual representations (sketches, drawings, pictures, images, objects) takes place (Goldschmidt, 1995; Portugali and

Casakin, 2002). Goldschmidt (1995) noted that visual displays contain information that is represented pictorially, as required in the design process, and this new graphic information can contribute to the restructuring of the problem representation. Visual representations may include helpful hints that can help to trigger and develop this interplay process. In his pioneer work on design as reflection in action, Schon (1983) also referred to a conversation between the designer and his/her materials. The designer "talks" to the external representations and these "talk back" to the designer's internal representations.

Important scientific discoveries and inventions are accredited to the use of internal representations through visual imagery in different fields. There are a number of frequently cited examples of well-known scientists, such as Einstein, Kekule, or Crick and Watson, who achieved important break-throughs thanks to the manipulation of internal visual displays. The Maison de Verre constitutes an example provided in the design literature of the use of internal visual displays as major references. The building program incorporated both a house and a gynecological practice. Purportedly, the woman's body and its sexuality served as an imagistic source to Pierre Chareau when designing the house. Through the use of a translucent glass-facade, the architect succeeded in connecting artistic and sexual creativity. Additional examples of the use of external visual displays in the design domain are provided in the following section.

Design Assisted by External Visual Representations

Depending on the relationship between a visual display and the problem to be solved, visual representations can be classified according to within-domain and between-domain categories (e.g., Casakin, 2004; Vosniadou, 1989). In cases where a visual display and the problem at hand share the same realm or a similar area of interest, the visual representation is called a within-domain display. The use of typological knowledge referring to a specific domain, such as, for example, a dwelling, is a pertinent example in the field of architecture. A characteristic of the use of within-domain displays is that it enables the understanding of visual information according to relevant, well-structured knowledge. In architecture, the use of within-domain displays is considered to be a helpful tool for the analysis and solving of a variety of design problems (e.g., Lawrence, 1994; Schneekloth and Franck, 1994). In the early stages of the design process, the information included in within-domain displays can facilitate the transformation of ill-defined problems into well-defined ones (Simon, 1981). This typological knowledge can further help a designer to understand new or very complex objects in the form of more typical and simple ones.

When a visual display and the problem belong to two distant realms or two different areas of interest, the visual representation is called a between-domain display. The Heinz-Galinzki School designed by Zvi Hecker is an example of the use of a between-domain display, where the spiral of movement through the building (through snake-like corridors), together with the building's rooms, mirrors the image and the geometry of a sunflower. Another example is Christian de Portzamparc's Cite de la Musique at La Vilette, where the building simulates the rhythm and intensity of Paris. The building refers to an image of the pedestrian alleyways encountered in central Paris. Utzon's use of the image of a vessel while designing the roof of the Opera of Sydney is yet another example. Since Utzon was particularly interested in studying the relationship of the building with the sea, it is not surprising that the form of a vessel influenced the image of the building. The New National Science and Technology Center of Amsterdam designed by Renzo Piano constitutes an additional case of design based on the use of visual displays as major sources of inspiration. The building's monumental form is a clear reference to numerous nautical shapes, particularly with the prow of a "great supertanker" rising up from the city's docklands.

Despite the extensive use of visual displays in design practice, almost no empirical studies have been carried out in order to examine how visual displays are utilized in design. Moreover, no work has addressed questions such as "what is the effect of using pictorial information to improve the quality of design solutions?"

Visual Analogical Reasoning in Design

When dealing with design problems, designers frequently reason by analogy. The use of analogy is concerned with the transfer of known relations from a familiar situation (termed the source) to potential relations to an unknown situation (termed the target). Abstract relationships are mapped and transferred from the source to the target in order to explain what the possible relations that are lacking in the target are (e.g., Dejong, 1989). Thus, an analogy can be the way that A relates to B, as C relates to D. When establishing such relationships, the A, B, and C terms are frequently specified, but the D term needs to be established (Pierce and Gholson, 1994). In problem-solving tasks, reasoning by analogy enables the transfer of a solution principle from a known problem to a new problem that needs to be solved (e.g., Reed, 1991).

Several studies have been conducted on the use of visual analogy in problem solving (e.g., Antonietti, 1991; Bean, *et al.*, 1990; Beveridge and Parkins, 1987; Gick and Holyoak, 1983). However, the study of visual analogy has still not been awarded enough attention from the domain of cognitive sciences, and its contribution to design has not been fully assessed. Since designers are in the habit of making recurrent use of visual displays, visual analogy is regarded as a valuable strategy for enhancing design quality. During the past decade, some theoretical works (e.g., Goldschmidt, 1994a,b; 1995; 1999) and several empirical studies (e.g., Verstijnen, *et al.*, 1999) have dealt with the use of visual analogy in design. Additional empirical investigations were performed regarding the use of visual analogy in design problem solving (e.g., Casakin, 2002; Casakin and Goldschmidt, 1999, 2000). In these studies, a number of experiments were carried out in which subjects were explicitly instructed to use analogy while solving ill-defined and well-defined problems. However, to date, no empirical work has focused on the spontaneous use of visual displays in both design contexts when no explicit instructions to use analogy are given.

Using Visual Displays in Design, Guided by Analogy

The degree of difficulty in establishing an analogy is mainly determined by how remote the source is from the target (also called "metaphorical distance" between the source and the target), as well as by the manner in which a target situation is represented and a visual display is accessed. The use of within-domain displays and between-domain displays may have significantly different effects on the access and transfer of knowledge (e.g., Johnson-Laird, 1989). It is said that within-domain displays lead to analogies that are easy to establish because they are mainly supported by surface similarities (e.g., Gentner, 1989; Holyoak and Thagard, 1989; Keane, 1988). Surface similarities, however, do not ensure a transfer of structural relations. In contrast, between-domain displays are difficult to access, since they are frequently based on deep similarities. However, after they are accessed, they may guarantee a transfer of structural relations to the problem at hand (e.g., Dejong, 1989; Vosniadou, 1989).

The identification and representation of a target situation according to certain features can endow the problem solver with memory retrieval hints, which are useful to access relevant knowledge included in the visual sources. Poor results of analogical use of visual displays in problem solving are related to the identification of superficial attributes rather than deep ones. Studies carried out by Novick (1988), Novick and Holyoak (1991), and Reeves and Weisberg (1993) demonstrated that a typical case of failure is the consequence of the inability to make abstractions and establish deep analogies between the available sources and the problem. A number of investigations have studied the role of instructions to use analogy in problem solving. Catrambone, *et al.* (1995) argued that although analogy can be a helpful mechanism, which can be utilized in problem solving, it is essential to provide powerful hints that direct attention to potential sources. On the other hand, Weisberg and Alba (1982) found that the successful use of hints is related to the level of expertise that subjects may possess. Thus, novices, as compared to experts, may benefit to a lesser extent from instructions to use analogy. Gick and Holyoak (1980, 1983), who investigated the effect of guidance through visual diagrams as major analogical sources, observed that the successful use of analogy was related to explicit instructions given to relate a visual display to the problem at hand. This study will focus on the use of visual displays in design problem solving without providing guidance to utilize analogy.

OBJECTIVE AND HYPOTHESES

The objective of the present study is to examine dissimilarities between experts and novices in the use of visual displays when solving well-defined and ill-defined design problems. Verifying to what extent the use of visual displays contributes to the enhancement of the quality of design solutions in the early stages of the design process is a major challenge. The main goal is to determine whether subjects are by themselves capable of establishing an analogical relationship between the assigned visual sources and the problem at hand, although no specific instructions to use analogy are given.

In previous studies, Casakin and Goldschmidt (1999, 2000) showed that both experts and novices benefited from the successful use of visual analogy in ill-defined problem solving. When specific instructions to use analogy were given, subjects significantly improved the quality of their design solutions. Considering these findings, the first hypothesis of the current research states that when no explicit instructions to use analogy are provided, both experts and novices will still benefit from the use of visual displays in the ill-defined context. Casakin (2002) also demonstrated that when given specific instructions to use visual analogy, novices benefited from the use of visual analogy in well-defined design problem solving. In contrast, instructions given to experts to use visual analogy did not improve their performance in the well-defined context. It was claimed that rather than using visual analogy when solving well-defined problems, experts may prefer to activate familiar algorithms or solution principles.

The second hypothesis of this research proposes that when no explicit instructions to use analogy are provided, the availability of visual displays will assist neither experts nor novices to improve their achievements in solving well-defined problems. It is posited that without instructions, novices do not possess the cognitive structures required to retrieve the appropriate solution principle from the available visual displays. On the other hand, it is argued that because experts benefit from such developed skills, the visual displays cannot help them any further.

METHOD

Subjects

A total of 53 architectural designers with different levels of expertise comprised the subjects that participated in well-defined problem solving. They were divided into three groups as follows: 16 architects, 17 advanced students, and 20 beginner students. Additionally, 63 architectural designers were divided into groups of 17 architects, 22 advanced students, and 24 beginner students, which participated in the ill-defined problem solving. All subjects volunteered their time to participate in the experiment, although neither course credit nor payment was given to them.

Experimental Conditions

Two experimental conditions were implemented to validate the research hypotheses:

- Test condition: *Solving design problems with visual displays*
  Subjects were provided with general instructions and a description of the design problem. They were also given a board with an assortment of visual displays including images from the architectural domain as well as from remote domains. However, they were not explicitly required to use these visual displays while generating design solutions.

- Control condition: *Solving design problems without the aid of visual displays*
  The same instructions and design requirements were assigned to subjects possessing the same level of design expertise as in the previous experimental condition. However, no visual aid was provided in this experimental condition.

The well-defined design problems presented in the experiments consisted of (1) the staircases and (2) the parking garage. The ill-defined design problem experiments were (1) the prison, (2) the dwellings, and (3) the viewing terrace. Since it was uncertain if subjects, novices in particular, would be able to deal with the complexity of the proposed non-routine problems, for the purposes of this study an extra problem was considered in the ill-defined problem experiment.

Procedure

One subject at a time participated in each design session. Subjects were given instructions and a description of major design needs and requirements. Participants were then given approximately 20 minutes to solve the design task and explain their solution. They were asked to think aloud while solving the problem, and the sessions were video recorded. During the task, interactions between the subject and the experimenter were avoided. Although a board of visual displays was provided to the subjects, they were not required to use them. Several participants solved more than one design problem under the test or control condition; therefore, the number of statistical "entries" as presented below was greater than the number of subjects. Nevertheless, it should be noted that in all these cases, design tasks assigned in the control condition (no visual displays provided) were solved before design tasks in the test condition (visual displays provided).

Equipment and Materials

Each subject was exposed to a 1 m x 0.7 m board upon which a rich collection of visual displays was depicted. Sheets of A3-size paper and felt pens were provided to each participant. The assortment of images varied according to the problem to be solved. The panels included 24 displays classified into 12 pictures from the architectural design domain (within-domain sources) and another 12 pictures from other remote domains (between-domain sources).

QUALITATIVE STUDY OF THE USE OF VISUAL DISPLAYS

In this section, we will illustrate two individual design problem sessions obtained from the analysis of the protocols produced by two novice designers. The underlying rationale is to show what the effect of a collection of visual displays in well-defined and ill-defined problems is. In the ill-defined context, one successful example in which a novice designer was aided by the use of visual displays is shown. The task consisted of a schematic design of a 30 m^2 viewing terrace situated at the top of a 16 m high precipice. The subject was requested to split the viewing terrace into two different areas. One part was to have maximal contact with the ground and the other to have minimal contact with it. In the well-defined context, one unsuccessful example is presented in which a novice designer was not aided by the use of visual displays. This is done through a problem in which the subject was requested to place two staircases in a restricted internal core area of an office building of four floors. A corridor around the perimeter of the offices, which connects the staircases with the offices and a waiting area of 25 m^2, was also required in the same zone. The constraint that was to be overcome was the apparent lack of room for all the required elements in the area allocated.

The examples illustrated below are intended to provide a better comprehension of the experimental task and to enhance the understanding of the results. These reflect major findings obtained from quantitative analyses described below.

Qualitative Study of the Use of Visual Displays in Ill-Defined Problem Solving: Successful Example by a Novice

The novice designer commences the design process by analyzing the initial requirements and then starts looking at the visual displays. At the outset he comments:

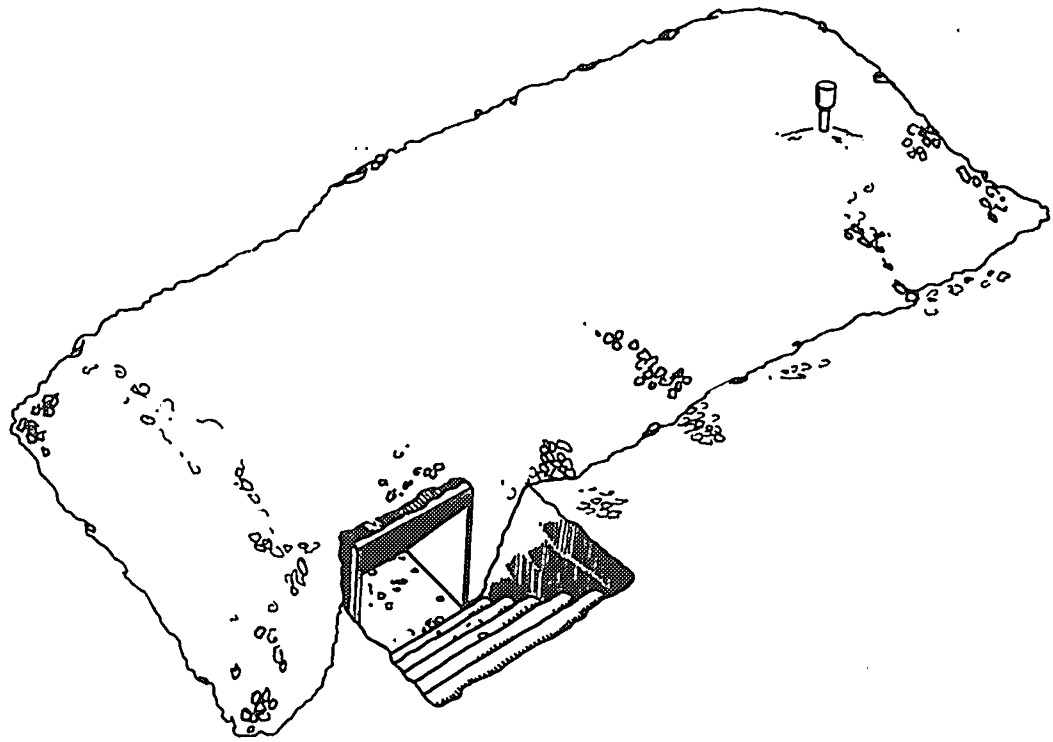

FIGURE 1. Example of available visual displays inspected by the novice designer for the "viewing terrace" problem: The shelter.

Two main areas should be designed ... one area should have maximum contact with the ground, and the other area should have minimum contact. Well let's look at the panel with the figures ... .

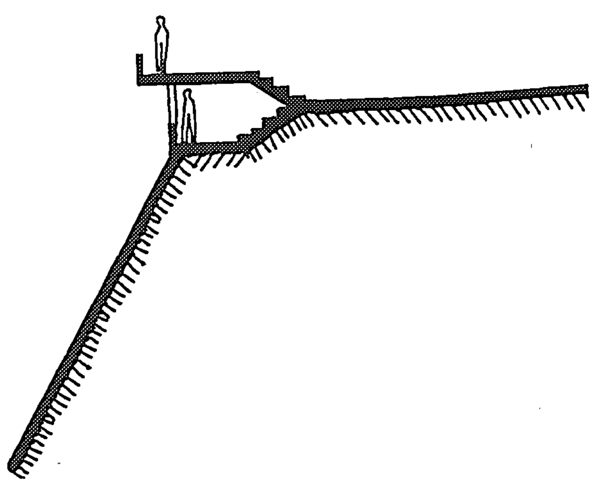

FIGURE 2. First sketch produced by the novice designer for the "viewing terrace" problem.

Although the subject does not mention any visual display in particular, he notes that some information included in the panel relates to the design problem. Afterwards, he mentions the structural principle of "excavation into the precipice," which he manages to retrieve from the collection of visual displays. This principle relates to some of the available visual displays, such as the shelter (see Figure 1). In the next step, the designer begins to sketch the first part of his solution:

Hmm, let's look at the visual displays ... . Well ... I can see some examples from the panel that relate to the idea of excavation. Perhaps the idea of maximum contact [with the ground] means something related to an excavation into a mountain.

The subject produces a section including a part of the viewing terrace excavated into the 15 m precipice (see Figure 2). At this stage of the design process, the novice designer is able to establish a deep

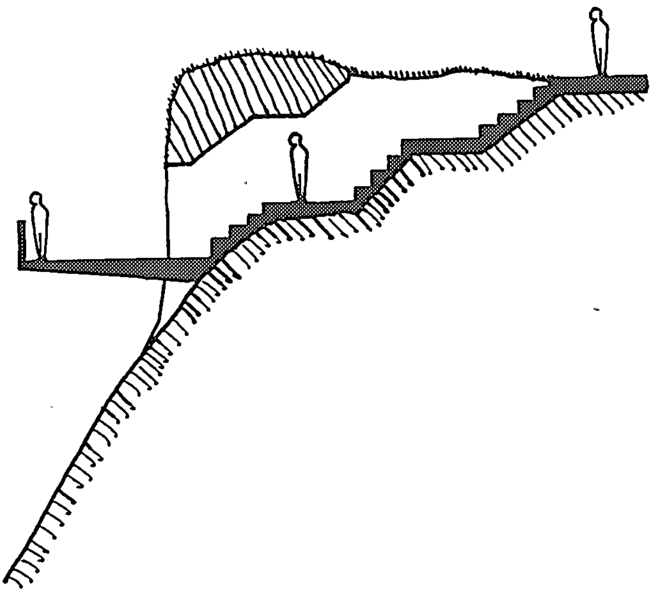

FIGURE 3. Second sketch produced by the novice designer for the "viewing terrace" problem.

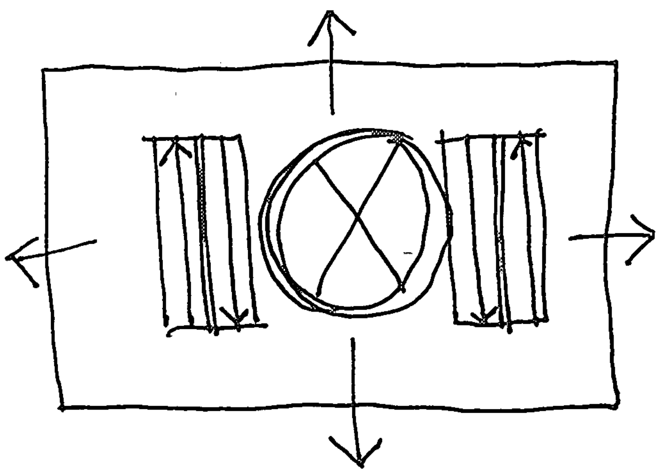

FIGURE 4. First sketch produced by the novice designer for the "staircases" problem.

structural analogy between some visual displays and the problem at hand. In order to meet the additional design constraints, he continues developing his sketch.

On the other hand, I have to consider another possibility of minimum contact [with the ground]. I am trying to think about an area of the viewing terrace that could come out of the precipice.

The subject completes the design, adding a sort of protruding platform in the upper part of the precipice. The novice designer, however, is not completely satisfied with this solution and continues exploring alternative solutions. He says:

Well, the question is how to relate the two still unconnected parts of the viewing terrace in such a way that they could be seen as an integrated space.

He produces another section in which he manages to relate the two sectors of the viewing terrace, with minimum and maximum contact with the ground, into a more integrated design (see Figure 3). The novice designer was able to comply with the design requirements through a successful design solution. Although no instructions to use analogy were given, success is attributed to his ability to identify and retrieve a deep analog, such as the "principle of excavation," from the visual displays, map it, and finally transfer it to the problem at hand.

Qualitative Study of the Use of Visual Displays in Well-Defined Problem Solving: Unsuccessful Example by a Novice

The subject starts the design session by analyzing some of the design constraints, which involve the location of two staircases and a waiting area within an allocated area of an office building of four floors. While drawing his first sketch (see Figure 4), he exclaims:

These are the staircases that should be located in the allocated space. Half of the staircases go down, and the other half goes up. Therefore, within this central space I have to arrange a waiting-room and two staircases each of which are about 4.50 x 3.50 [meters] ... .

The subject continues to process the design requirements while producing a second sketch, in which he begins to consider the position of the entrance of each of the rooms surrounding the central space (see Figure 5). This aspect is irrelevant to the solution of the problem.

But first I want to see where I have to locate the doors ... that are the entrances [to the rooms]. Here there is an entrance, and another two entrances here, and here ... . It seems that the staircases should be located in the transversal direction [of the central space] so as to let the entrances be connected with the central space. The waiting room should not be used as a path ... .

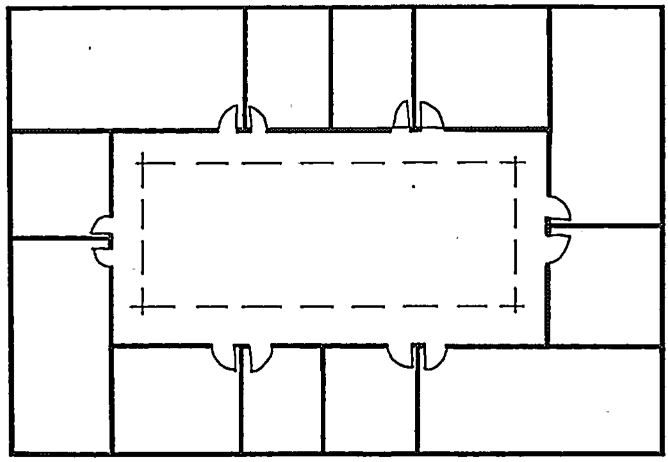

FIGURE 5. Second sketch produced by the novice designer for the "staircases" problem.

The subject returns to the essence of the problem, and in order to analyze the exact location of the two staircases in the central space, he produces a third sketch, through which he studies the relationships among the staircases, the waiting room, and the corridor. The novice designer checks out the possibility of locating the staircases within the allocated area by taking into account the exact dimensions of each of the requested elements (see Figure 6). While sketching he comments:

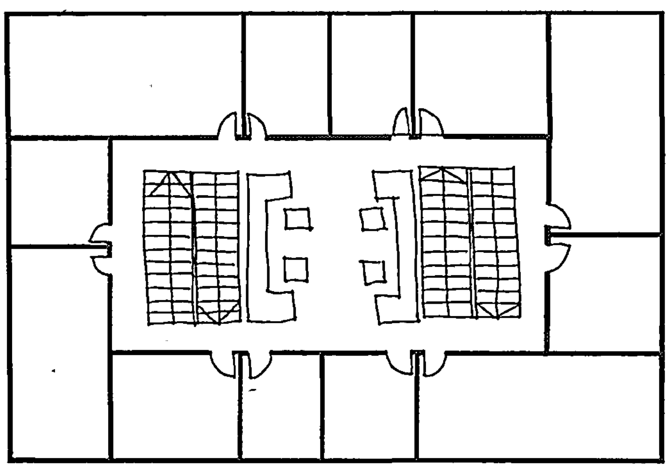

FIGURE 6. Third sketch produced by the novice designer for the "staircases" problem.

We need a corridor that is 1.00 m wide and [a central space that is] 4.5 m wide, which is exactly the length required for the staircases. So I can locate the two staircases ... each facing towards the transversal direction but located in opposite extremes. Mmm ... well in the remaining space I can arrange the waiting room and by so doing meet the design goals. This seems to be the best solution, because otherwise I must place the staircases in the middle of the space and two small waiting rooms in the extremes ... .

Since the provided solution consisted of a waiting room area of 22.5 m², the novice designer failed to comply with the requirement for an area of 25 m² initially specified. One of the reasons for this failure can be attributed to his inability to perceive and manipulate three-dimensional elements in space. Plan views represented almost all of his sketches, but no section drawings were made. Another possible reason for the unsuccessful solution was his incapacity to access and retrieve deep analogical principles from some available visual displays and establish analogy with the problem. For example, the "DNA molecule" pictorial representation provided in the panel included the analogical principle of two intertwined helicoidal elements. This visual source, together with an example of a successful

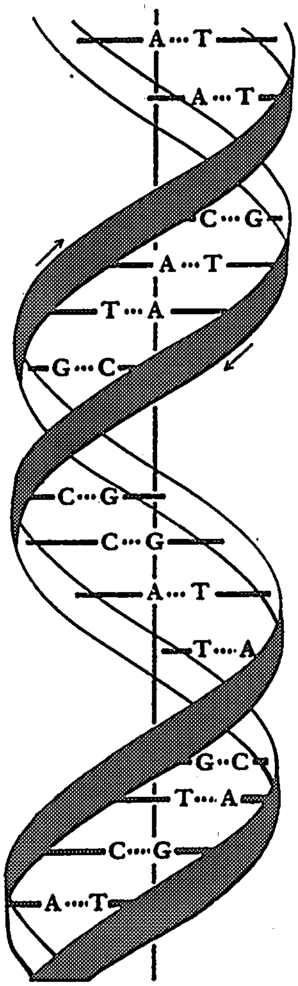

FIGURE 7A. The DNA molecule visual source.

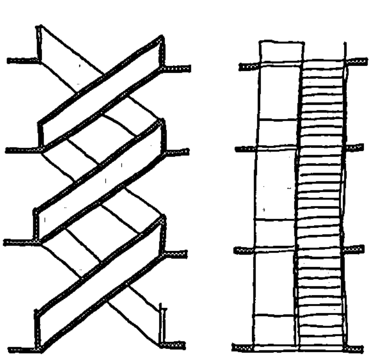

FIGURE 7B. The target solution.

FIGURES 7A-B. Example of a successful design solution obtained by analogical reasoning.

solution, is illustrated in Figures 7A-B. In the design shown in Figure 7B, the two staircases are arranged by superposing one on the other, and as a result, enough room is available for designing the 25 m² waiting room.

QUANTITATIVE STUDY OF THE USE OF VISUAL DISPLAYS

In this section, we will present statistical results pertaining to the use of visual displays in the different groups of subjects that took part in the empirical tasks. The individual role played by novice and expert designers was compared in both the test and control experimental conditions. According to the hypotheses stated above, it is predicted that in the ill-defined context, the quality of the design solutions produced by expert and novice designers who use visual displays would be higher than the outcomes of the group of designers that were not provided with any visual materials to solve the problems. In the well-defined context, no differences in the quality of the design solutions were expected between novices and experts who are provided with visual displays and those that did not receive any visual materials to solve the problems.

Scoring

A characteristic of well-defined problem solving is that it is concerned with the production of a limited number of possible solutions that can be reached through a routine process. In the well-defined problems presented in our experiment, only one possible design solution is considered to be successful. Therefore, a scale of 0 and 1 points was determined in order to assess the design solutions. Zero points were assigned when the solution did not meet design requirements, and one point when the solution was considered to be correct. Ill-defined problem solving, on the other hand, relates to the production of a large number of ambiguous design solutions that cannot be solved in a routine way. In order to evaluate the quality of this type of design solution, a scale from 1 to 5 points was established. A score of 1 or 2 points was assigned when the design solution did not satisfy the design requirements. A score of 3 to 5 points was assigned when the design solution met with the design requirements.

Three judges, who were unaware of the experimental conditions, scored solutions independently. All of them were experienced architects with at least seven years of professional experience who volunteered their time. A Scale Reliability Analysis was used to assess scores assigned by the judges by calculating the coefficient alpha. This test showed a high degree of agreement among the three judges in the assessment of the design solutions. The coefficient alpha reliability was approximately .97 for all design solutions.

TABLE 1. Experimental conditions for the three independent subject groups in the ill-defined problems: Mean and standard deviation.

Design Solution		Beginner Students	Advanced Students	Architects
Visual displays provided	Mean	2.621	2.939	3.236
	Standard deviation	.758	1.029	.740
Visual displays not provided	Mean	2.227	2.580	2.809
	Standard deviation	.689	.797	.822

Statistical Analysis Methods

Scores assigned by the judges in the ill-defined design problems were analyzed through T-tests. Differences between groups were considered as significant at a level of 90% ($p < 0.1$). The scores assigned in the well-defined problems were submitted to Fischer Exact Tests. Since this study focuses on a comparison between the different type of design problems, for statistical analysis considerations the three ill-defined problems ("the dwellings," "the prison," and "the viewing terrace") were grouped together in one set of design problems, and the two well-defined problems ("the staircases" and "the parking garage") were considered in another set of design problems.

Quantitative Study of the Use of Visual Displays in Ill-Defined Problems

The individual role played by novice and expert designers was compared in the test and control experimental conditions. In the test condition, 63 solutions were obtained (19 by architects, 22 by advanced designers, and 22 by beginner designers). In the control condition, 68 solutions were obtained (21 by architects, 25 by advanced designers, and 22 by beginner designers).

The hypothesis that the use of visual displays in ill-defined problems aids experts and novices was fully confirmed. Results demonstrate that the provision of visual displays assisted both expert and novice designers, as predicted ($t = -1.80$, M.D = .393, $p < .039$ for beginning students; $t = -1.35$, M.D = .359, $p < .092$ for advanced students; and $t = -1.72$, M.D = .427, $p < .046$ for architects) (see Table 1).

Quantitative Study of the Use of Visual Displays in Well-Defined Problems

The performance by novice and expert designers was compared in the test and control experimental conditions. In the test condition, 35 solutions were obtained (11 by architects, 12 by advanced designers, and 12 by beginner designers). In the control condition, 37 solutions were obtained (11 by architects, 13 by advanced designers, and 13 by beginner designers).

The hypothesis that when no explicit instructions to use analogy are given, the availability of visual displays will neither assist experts nor novices, was partially confirmed. It was found that although the provision of visual displays did not assist novices, experts managed to successfully solve design problems, as shown in Table 2 (phi = .138, $p < .469$ for beginner students; phi = .080, $p < .541$ for advanced students; and phi = .378, $p < .091$ for architects).

DISCUSSION AND CONCLUSIONS

The results of the present study verified that the use of visual displays played a different role in ill-defined problem solving (where unexpected analogical relations between visual sources and the design problem can be found), as compared with well-defined problem solving (where a unique, specific analogical relation can be established). Results fully validated the working hypothesis, which states that the availability of visual displays in ill-defined problems aids both experts and novices. It was

TABLE 2. Experimental conditions for the three independent subject groups in the well-defined problems: Percentages of success and failure.

Design Solution		Beginner Students		Advanced Students		Architects	
		Yes	No	Yes	No	Yes	No
Visual displays provided	Frequency	2	10	2	10	6	5
	Row %	16.67	83.33	16.67	83.33	54.55	45.45
	Col %	66.67	45.45	40.00	50.00	75.00	35.71
Visual displays not provided	Frequency	1	12	3	10	2	9
	Row %	7.69	92.31	23.08	76.92	18.18	81.82
	Col %	33.33	54.55	60.00	50.00	25.00	64.29

found that experienced architects and novice students possessed the cognitive ability to use visual displays in order to enhance the quality of their design solutions. Although no instruction to establish analogy was provided, novices managed to make abstractions from the visual sources, retrieve analogical principles, and apply them to the ill-defined problems. In a number of studies, Gick and Holyoak (1983) and Reeves and Weisberg (1993) found that the processes of abstraction and mapping are rarely carried out from a single visual source. When this happens, it generally implies that a focus is placed on surface and irrelevant features of the image, which usually leads to an unsuccessful solution. It is proposed that the availability of a rich collection of visual displays helped novices and experts to search for a number of unconventional and unpredictable design solutions and to enhance the quality of their design solutions. The large set of between-domain and within-domain images may have contributed to the retrieval of deep relations between clue-harboring images and the design target. It is suggested that the creation of relevant knowledge structures through the use of visual displays can afford a fundamental tool to help develop expertise in design problem solving. This has important consequences for design education since students, who lack expertise, are not always aware of the usefulness of visual representations in the design process. Training and practicing in the use of within-domain and between-domain visual displays can assist them to master this strategy. The quality of the design solutions generated by both groups of subjects through the use of visual displays in ill-defined problem solving, however, was found to be poorer than in a previous study carried out by Casakin and Goldschmidt (1999, 2000), in which subjects were provided with visual displays and also instructed to use visual analogy. Although the use of visual displays contributes to the enhancement of ill-defined problem solving, instruction to use analogy has an important role to play in further improving the quality of the design solutions. Practicing in the explicit use of analogy through a trial and feedback method can help students gain a better understanding of how meaningful knowledge structures can be retrieved from visual displays and transferred to the problem at hand. Designers who become familiar with this strategy can progressively learn to use analogy, even when no explicit instructions are provided.

The hypothesis that the use of visual displays in well-defined problems would neither aid experts nor novices was partially confirmed by additional findings obtained in the experiment. It was observed that although the provision of visual displays did not help novices, experts were able to enhance the quality of their design solutions.

Coincidently with results obtained from the study carried out by Gick and Holyoak (1983), with no instructions, inexperienced students who generally lack problem-solving algorithms encountered difficulties in identifying a single solution principle from the available visual sources and establishing high-level relations with the well-defined problem. They were also unable to apply routine processes to succeed in solving the problem. Results from this experiment differ from those of the study conducted by Casakin (2004) in which the quality of novices' design solutions was enhanced as a consequence of instructions to use visual analogy. It is concluded that without instructions, novices remain unable to retrieve an analogical principle and apply it to a well-defined problem. For novice designers who lack experience, finding a finite number of possible solutions is an unfamiliar and non-routine process. A main challenge for design education will be to train students to use visual analogy in order to help them turn an unknown problem into a routine one. In addition, it was found that the group of experts managed to access the available visual displays and use them to improve their performance in the well-defined problems. Like in the ill-defined context, we found experienced designers to have strong enough knowledge structures that enable them to spontaneously retrieve design principles from visual sources, even when no instructions to reason by analogy are provided. Even if experts had retrieved familiar algorithms from their memories, no differences were detected with the experimental condition in which no visual displays were provided. It is therefore posited that although architects are able to potentially retrieve existing algorithms, master routine processes, or adapt solutions to new problems, the use of visual displays as potential analogs might be an alternative or complementary strategy for well-defined design problem solving.

REFERENCES

Antonietti A (1991) Effects of partial analogies on solving an ill-defined problem. *Psychological Reports* 68:947-960.

Arnheim R (1969) *Visual thinking.* Berkeley: University of California Press.

Bean T, Searles D, Singer H, Cowen S (1990) Learning concepts from biology text through pictorial analogies and an analogical study guide. *The Journal of Educational Research* 83(4):233-237.

Beveridge M, Parkins E (1987) Visual representation in analogical problem solving. *Memory and Cognition* 15(3):230-237.

Brown A (1989) Analogical learning and transfer: What develops? In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning.* Cambridge: Cambridge University Press, pp. 369-411.

Casakin H (2002) Well-defined vs. ill-defined design problem solving: The use of visual analogy. In D Durling and J Shackleton (Eds.), *Common ground proceedings of the Design Research Society International.* Stoke on Trent: Staffordshire University Press, pp. 202-216.

Casakin H (2004) Visual analogy as a cognitive strategy in the design process: Expert versus novice performance. *Journal of Design Research* 4(2).

Casakin H, Goldschmidt G (1999) Expertise and the use of analogy and visual displays: Implications for design education. *Design Studies* 20(2):153-175.

Casakin H, Goldschmidt G (2000) Reasoning by visual analogy in design problem solving: The role of guidance. *Environment and Planning B: Planning and Design* 27:105-119.

Catrambone R, Jones C, Jonides J, Seifert C (1995) Reasoning about curvilinear motion: Using principles of analogy. *Memory and Cognition* 23(3):368-373.

Clement C (1994) Effect of structural embedding on analogical transfer: Manifest versus latent analogs. *American Journal of Psychology* 107(1):1-38.

Collins A, Burstein M (1989) Afterword: A framework for a theory of comparison and mapping. In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning.* Cambridge: Cambridge University Press, pp. 546-565.

Cuff D (1992) *Architecture: The story of a practice.* Cambridge: MIT Press.

Daheler M, Chen Z (1993) Protagonist, theme, and goal object: Effects of surface features on analogical transfer. *Cognitive Development* B(2):211-229.

Dejong G (1989) The role of explanation in analogy; Or, the curse of an alluring name. In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning*. Cambridge: Cambridge University Press, pp. 346-365.

Finke R (1990) *Creative imagery: Discoveries and inventions in visualization*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Finke R, Ward T, Smith S (1995) *The creative cognition approach*. Cambridge: MIT Press.

Gentner D (1983) Structure-mapping: A theoretical framework for analogy. *Cognitive Science* 7:155-170.

Gentner D (1989) The mechanisms of analogical learning. In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning*. Cambridge: Cambridge University Press, pp. 199-239.

Gero J, Maher M (1993) *Modeling creativity and knowledge-based creative design*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Gick M, Holyoak K (1980) Analogical problem-solving. *Cognitive Psychology* 12:306-355.

Gick M, Holyoak K (1983) Schema induction and analogical transfer. *Cognitive Psychology* 15:1-38.

Goel V (1995) *Sketches of thought*. Cambridge: MIT Press.

Goldschmidt G (1991) The dialectics of sketching. *Creativity Research Journal* 4(2):123-143.

Goldschmidt G (1992) Serial sketching: Visual problem solving in designing. *Cybernetics and Systems* 23:191-219.

Goldschmidt G (1994a) Visual analogy in design. In R Trappl (Ed.), *Cybernetics and systems '94*. Singapore: World Scientific, pp. 507-514.

Goldschmidt G (1994b) On visual design thinking: The vis kids of architecture. *Design Studies* 15(2): 158-174.

Goldschmidt G (1995) Visual displays for design: Imagery, analogy and databases of visual images. In A Koutamanis, H Timmermans, and I Vermeulen (Eds.), *Visual databases in architecture*. Aldershot: Avebury, pp. 53-74.

Goldschmidt G (1999) Visual analogy: A strategy for design reasoning and learning. In C Eastman, W McCracken, and W Newstetter (Eds.), *Design knowing and learning: Cognition in design education*. New York: Elsevier, pp. 199-219.

Holyoak K, Thagard P (1989) A computational model of analogical problem-solving. In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning*. Cambridge: Cambridge University Press, pp. 242-265.

Holyoak K, Thagard P (1994) *Mental leaps: Analogy in creative thought*. Cambridge: MIT Press.

Johnson-Laird P (1989) Analogy and the exercise of creativity. In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning*. Cambridge: Cambridge University Press, pp. 313-331.

Keane M (1988) *Analogical problem-solving*. Chichester: Ellis Horwood Ltd. and John Wiley & Sons (Ellis Horwood Series in Cognitive Science).

Lawrence R (1994) Type as analytical tool: Reinterpretation and application. In L Schneekloth and K Franck (Eds.), *Ordering space: Types in architecture and design*. New York: Van Nostrand Reinhold, pp. 271-287.

Marchant G, Robinson J, Anderson U, Schadewald M (1993) The use of analogy in legal argument: Problem similarity, precedent and expertise. *Organizational Behaviour and Human Decision Processes* 55:95-119.

Medin D, Ross B (1990) *Cognitive psychology*. New York: Harcourt Brace College Publishers.

Novick L (1988) Analogical transfer, problem similarity, and expertise. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 14(3):510-520.

Novick L, Holyoak K (1991) Mathematical problem-solving by analogy. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 17(3):398-415.

Pierce A, Gholson B (1994) Surface similarity and relational similarity in the development of analogical problem-solving: Isomorphic and non-isomorphic transfer. *Developmental Psychology* 14(3):724-737.

Portugali J, Casakin H (2002) SIRN (Synergetic Inter-Representation Networks): An approach to design. In D Durling and J Shackleton (Eds.), *Common ground proceedings of the Design Research Society International*. Stoke on Trent: Staffordshire University Press, pp. 884-902.

Reed S (1991) *Cognition*. Monterey, CA: Brooks/Cole Pub.

Reeves L, Weisberg R (1993) On the concrete nature of human thinking: Content and context in analogical transfer. *Educational Psychology* 13(3/4):245-259.

Reitman W (1964) Heuristic decision procedures, open constraints, and the structure of ill-defined problems. In M Shelly and G Bryan (Eds.), *Human judgment and optimality*. New York: John Wiley & Sons, pp. 282-315.

Rittel H, Melving W (1984) Planning problems are wicked problems. In N Cross (Ed.), *Developments in design methodology*. New York: John Wiley & Sons, pp. 123-143.

Schneekloth L, Franck K (1994) Type: Prison or promise? In L Schneekloth and K Franck (Eds.), *Ordering space: Types in architecture and design*. New York: Van Nostrand Reinhold, pp. 15-38.

Schon D (1983) *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Simon H (1981) *The sciences of the artificial*. Cambridge: MIT Press.

Simon H (1984) The structure of ill-structured problems. In N Cross (Ed.), *Developments in design methodology*. New York: John Wiley & Sons, pp. 145-165.

Suwa M, Gero J, Purcell T (1999) Unexpected discoveries and s-inventions of design requirements: A key to creative designs. In JS Gero and ML Maher (Eds.), *Computational models of creative design IV*. Sydney: Key Centre of Design Computing and Cognition, University of Sydney, Australia, pp. 539-567.

Verstijnen I, Wagemans A, Heylighen A, Neuckermans H (1999) Sketching, visual analogies and domain-expertise. In G Goldschmidt and W Porter (Eds.), *Proceedings of 4th design thinking research symposium: Design representation*. Cambridge: MIT Press, pp. II.71-II.77.

Vosniadou S (1989) Analogical reasoning as a mechanism in knowledge acquisition: A developmental perspective. In S Vosniadou and A Ortony (Eds.), *Similarity and analogical reasoning*. Cambridge: Cambridge University Press, pp. 413-437.

Weisberg R, Alba J (1982) Problem-solving is not like perception: More on Gestalt theory. *Journal of Experimental Psychology* 111(3):326-330.

Wertheimer M (1959/1982) *Productive thinking*. New York: Harper & Row.

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