Chaabi, M. Chougui, A. (2021). Visual Analogy as a Cognitive Strategy in the Architectural Design Process: expert versus novice performance. *International Online Journal of Education and Teaching (IOJET), 8*(3). 1348-1368

Received : 06.03.2021
Revised version received : 06.04.2021
Accepted : 15.04.2021

VISUAL ANALOGY AS A COGNITIVE STRATEGY IN THE ARCHITECTURAL DESIGN PROCESS: EXPERT VERSUS NOVICE PERFORMANCE

Research article

Mouloud Chaabi https://orcid.org/0000-0002-3000-4163
Ferhat Abbas University, Algeria
mouloud_archi@yahoo.fr

Ali Chougui
Ferhat Abbas University, Algeria
Ali_chougui@yahoo.fr

Mouloud Chaabi holds : A Master degrée from Washington Unversity, USA, and a Ph.D in architecture from University, Setif 1, Algeria. His research interests include approaches and techniques of teaching in using technology of the information and communication.

Ali Chougui holds : A Master degrée from IIT, USA, and a Ph.D in architecture from University, Setif 1, Algeria. His research interests include approaches and techniques of teaching a project of architecture in using analogy.

VISUAL ANALOGY AS A COGNITIVE STRATEGY IN THE ARCHITECTURAL DESIGN PROCESS: EXPERT VERSUS NOVICE PERFORMANCE

Mouloud Chaabi
mouloud_archi@yahoo.fr

Ali Chougui
Ali_chougui@yahoo.fr

Abstract

This study examined the use of analogy in architectural design. Its main goal was to provide an understanding of how experts and novices alike used visual analog thinking to generate satisfactory solutions during their design process. A series of controlled experiments were conducted in order to examine how this cognitive strategy contributes to improving the resolution of design problems in each group of participants. Students and architects were asked to solve a set of unusual design problems. They were stimulated by exposure to visual images, and were given explicit instructions for using the analogy. The results showed that novices and experts were able to reason by visual analogy and used deep analogies. It was found out that the experts identified and recovered analogies from out-of-domain images. Novices, however, identified a large number of out-of-domain images, but recovered the analogies of out-of-domain and out-domain images to the same extent. Novices, unlike experts, did not add constraints to the initial design problem, but produced a large number of solutions. These results were found significant implications for the teaching of architectural projects.

Key Words: Visual analogy, experts, novices, cognitive strategy, architectural project.

1. Introduction

What are the differences between the performance of experts and novices in the field of architectural design? How can we help designers solve unusual design problems while using familiar knowledge structures? The production of an unlimited number of unexpected solutions that differ significantly from previous designs is a feature of non-routine design. Researchers as examples of unusual major problems (Gero and Maher 1993) describe problems in architectural design. In design, visual analogy is a powerful problem-solving strategy that can help explain new and unusual problems in terms of familiar ones. While there is some evidence that designers find it difficult to spontaneously use this strategy, references to using the analogy are mostly anecdotal. Additionally, differences in expertise on the use of visual analogy in design have rarely been reported.

The main objective of this study is to provide empirical evidence regarding the differences and similarities in the performance of expert and novice designer architects, when they use visual images in their analogue reasoning process. The qualitative and quantitative results of

the use of visual analogy during the design process are presented after a brief review of the literature.

2. Analogical reasoning

Thinking in terms of analogy involves the transfer of prior knowledge from a familiar situation (called sources) to a situation that needs to be clarified (called target) (Gentner 1983; Novick 1988; Vosniadou 1989). Identifying and looking for some resemblance between potential relationships in the target and known relationships in the source makes it possible to understand the new situation from a familiar situation. Gentner's (1983) Structure-Mapping theory supports the view that an analogy can be characterised as the application of a system of major structural relations from a source, to the resolution of d 'a new target problem. Another theory, more pragmatic proposed by Gick and Holyoak (1980), as well as by Holyoak (1990), argue that analogue mapping is triggered when a source analogy presents a solution procedure that seems to be more efficient than an inference rule.

The selection of a source match is a consequence of rule activity to solve the target problem. In this theory, structural principles are considered secondary, and mapping is driven by the importance of attributes in relation to the objectives to be achieved. Thus, the targets of the target largely control the mapping process. The main processes of analogical reasoning consist of: (i) identification and research; (ii) Mapping and transfer. These are described as follows:

i) Identification and research: designer subjects identify and represent the target situation according to various characteristics that may contain abstract principles of the solution. These activities provide memory reclamation tips, which are useful for accessing important knowledge about known situations. A number of experiments have been conducted to study the recovery process through the hint / no hint paradigm. These included providing sources with instructions, keywords, or visual tips such as diagrams hosting a solution principle similar to the target problem. Gick and Holyoak (1980) argued that when designers are not explicitly asked to relate a visual source to the problem, they tend to fail in retrieving and applying analogue principles. Weisberg and Alba (1982) found that the mechanical use of an index should not be assumed. They argued that clues can only be useful when the design subjects have enough expertise and knowledge to relate the cognitive moment to the problem in question.

ii) And transfer: When a potential source analogy is retrieved, designers establish correspondences between objects and between relational structures in objects, in source and target situations (e.g., Novick and Holyoak 1991; Sternberg and Ketron 1982; Vosniadou and Ortony 1989) and they try to see how an analogue principle can be transferred. This process is considered to be of utmost importance to the process of analogical reasoning. A successful mapping increases the possibility of a successful transfer of a solution principle from the source to the target.

2.1 The classification of analogies

According to theorists like Gentner (1983), Rips (1989), Smith (1990) and Vosniadou (1989), an analogy can be classified as surface analogy and deep (structural) analogy. Surface analogies relate to easily accessible or superficial concepts of the properties of objects. Researchers such as Gentner (1989) and Keane (1988) have argued that although these types of analogies are easy to create, under normal circumstances they cannot guarantee the transfer of structural relationships between source and source. Target. Structural analogies, on the other hand, involve a system of higher-order relationships that are based on the deep

properties of a familiar situation. These types of analogies have a strong influence on the quality of the solution.

An analogy can be drawn between two different fields, each encompassing different knowledge, but with a common shared correlation based on similar structural aspects. This type of analogy is called "out-of-domain', where the source and the target problem belong to different and distant domains. In cases where the source and the target are integrated in the same or very close domain, the analogy is called "of the domain". The level of difficulty of accessing and transferring an analogy x depends largely on the distance or proximity between the target and the source (Johnson-Laird 1989). The use of in-domain and out-of-domain visual images can influence the quality of an analogy. Non-domain analogies are based on structural commonalities and are therefore more difficult to access. However, when accessed, they are believed to lead to a successful analogy (Vosniadou 1989). Dejong (1989) asserted that domain analogies are mainly based on surface similarities and are therefore easier to establish. Vosniadou (1989) asserted that successful analogical reasoning can be used between two elements belonging to the same domain, provided that it involves the transfer of an explanatory structure from one element to another. The use of in-domain and out-of-domain visual images will be explored later in the context of expertise in design problem solving.

2.2 Visual Thinking in Architectural Design

Beyond the anecdotal examples illustrated in the Most cognitive science research has focused on the fields of vision and visual perception (e.g., Beveride and Parkins 1987; Gick and Holyoak 1983), but studies of visual analogy have rarely attracted the attention of researchers. Visual thinking and visual analogy have always been considered important aids in problem solving (e.g, Goldschmidt 1995). In design activities, where visual thinking is widely used, designers are frequently assisted by visual stimuli such as visual images. Designers' reference to visual images explains why visual analogy is an appropriate strategy for improving the resolution of architectural design problems (Goldschmidt 1994; 1995; 1999).design literature, recent work provides empirical evidence for the role of visual analogy in design (e.g., Verstijnen et al. 1999; Casakin and Goldschmidt 1999; 2000; and Casakin 2002). These empirical studies indicate that the use of visual analogy improves the quality of design solutions. In most cases, the instructions for using the analogy are considered an important success factor. The failure or success of using the analogy is assessed by the quality of the design solutions obtained. However, aspects related to the use of visual analogy during the architectural design process have remained unexplored.

2.3. The role of knowledge

Experience and knowledge in a particular field are fundamental requirements for developing expertise. Knowledge helps to find solutions to problems that gradually become familiar (Dominowski 1995). With reference to the unconventional use of knowledge, Akin (1990) emphasises the relevant role of productive thinking in creative problem-solving activities, such as architectural design. Like Wertheimer (1959/1982), he further differentiates the reproductive and productive uses of knowledge. The first involves a new problematic situation that can be resolved by recalling and using previous knowledge, while the second involves a change in the perception and representation of the new problem in question. Researchers like Glaser (1989), Medin and Ross (1990) or Newell and Simon (1972) assert that the differences in skills between novices and experts depend on the nature of the representation of the problem in question. Experts, who have more developed and integrated knowledge structures, are likely to focus on relevant aspects; in contrast, novices who have a lower level of developed knowledge tends to represent problems by focusing on

irrelevant characteristics. The question of the representation of knowledge has been studied in a number of fields such as chess games (e.g. Chase and Simon, 1973), physics (Bransford et al. 1989; Chi, Feltovich and Glasser 1981; Schiano et al. all 1989 ;), medicine (Patel and Groen, 1991) and computer science (Davies et al. 1995). Research results in these fields show that experts tend to encode and represent information through domain knowledge in a more extensive and meaningful way than novices, thus affecting the retrieval of qualitative and relevant information in the field. Solution of the problem.

2.4. The use of analogy by experts and novices:

The level of expertise has been observed to have an effect on the use of analogy (e.g., Collins and Burstein 1989; Goldman 1982; Vosniadou 1989). Daimler et al. (1993) claimed that this is partly due to the way designers represent knowledge. Experience in a particular field allows the generation of abstract representations of problems and increases the probability of structural mapping from source to target. Difficulties in spontaneous access and use of analogy are associated with the level of expertise in several studies (Gick and Holyoak 1980; Needham and Begg 1981; Phye 1989). As a result, novices often fail to recognise how new problems can be viewed in terms of old problems, and lack sufficient skills to benefit from explicit instructions on using the analogy.

Novice (1988) claimed that while experts tend to draw successful analogies based on structural similarities, novices tend to retrieve surface features from available sources, which in most cases leads to analogies. Unsuccessful. But if the source shares structural similarities with the target problem, experts are more likely to use the analogy more spontaneously than novices. Ross and Kennedy (1990), on the other hand, have demonstrated that surface features provide a means by which novices can establish relationships between problems of a particular type and can form generalisations of that type of problem. Blessings and Ross (1996) studied how experienced designers use surface features while solving problems. Through a series of experiments, these theorists have shown that there are important correlations between problems with similar deep structures and their surface characteristics. They claimed that while experts often focus on the deep structure of a problem, they also use surface features to access a source problem. Relying on surface features to access a source problem can be seen as a useful heuristic that can lead to the establishment of a successful analogy.

3. Empirical research: Objectives and hypotheses

The use of visual analogies by novice and expert designers during the architectural design process has been addressed through empirical research.We have asserted that most of the references on the use of analogy in architectural design are anecdotal. Therefore, one of the objectives of this work is to provide empirical evidence on the use of visual analogy in solving architectural design problems. The main goal of empirical research is to analyze whether novice designers, compared to experts, use visual analogue reasoning to solve design problems, and how they go about it during the design process. According to Johnson-Laird (1989), the degree of complexity in accessing an analogy depends, to a large extent, on the distance or proximity between the target and the source. Since domain analogies are easier to access, our first hypothesis is that novices tend to identify and recover analogue principles from visual images belonging to the same domain of the problem (sources of the domain). On the other hand, experts tend to do the same for visual images belonging to a remote domain (non-domain sources). Our second hypothesis concerns expertise and the use of analogy. Researchers such as Gentner (1989), Holyaok and Thagard (1989) and Keane (1988) have argued that while novices tend to draw surface analogies, which are based on accessible characteristics of sources, experts are able to 'establish structural analogies, which usually

lead to positive results. In the second hypothesis, we have proposed that novices, unlike experts, are unable to draw deep analogies between the visual sources provided and the target problem. It is assumed that expert architects, unlike novice students, are given specific instructions for reasoning by analogy.

Understanding design problems is a crucial part of solving them. Designers have to deal seriously with problems that are ill-defined, under-specified, and have significant implicit constraints (Simon 1981). The architectural design is to some extent driven by the constraints imposed on the project problem. It is quite common that in order to solve an architectural project design problem, designers activate a large number of constraints. The addition of constraints can be guided by established principles and guidelines, by individual preferences or by cognitive strategies such as analogy (Eckersley et al. 1999). While deepening their understanding of the project problem in question, expert architects devote considerable and greater effort than novices. They try to bring together all of the available constraints placed on the project, which helps narrow the range of possible design solutions to explore. In our research we want to test the effect of the use of visual analogy on the generation of constraints and the production of alternative solutions in the two participating groups. We hypothesised that experts, unlike novices, add new constraints to the problem in question, but create a small number of alternative solutions.

3.1. The Experience: Test Groups

Twenty-six architectural designers took part in the experiment carried out as part of this research. The first group of participants included eleven architects who had a minimum of seven years of experience. The second group consisted of fifteen students of architecture, third, fourth and fifth years. Participants had to solve an architectural design problem; they were given a board on which a collection of visual images was presented. They were informed that some of the pictorial elements made available to them could be considered as potential sources of analogy. The painting included 12 images from the architectural domain, as well as 12 images outside the architectural domain.

Participants were asked to identify relevant visual sources and use the analogy to solve the assigned design problem. The results obtained by the group of novices (students) were compared with those obtained by the group of experts (architects). The three different project design problems in the experiment are:

(i) a primary school; (ii) a mountain chalet; and (iii) housing. The first problem concerns the design of a school of 12 classrooms organised in a compact way and distributed on a single floor with facilities for students and teachers. Each classroom should have one of its sides facing an interior courtyard. The design should allow contemporary quality education for students aged 6 to 12. The second problem is to design a mountain chalet on a panoramic plot of 30 square metres. The chalet must be divided into two parts: one part must have maximum contact with the ground, while the other must have minimum contact with the ground. The third problem is to design and organize a set of 28 typical duplex apartments compactly organised around interior patios and arranged to minimize exposure to the outdoors. The arrangement of the housing also had to respect the orthogonal geometry.

3.2 The protocol

3.3. Assessment The experiments were carried out in a research laboratory, and in the architects' offices, during individual design sessions. Participants had about twenty minutes to solve the design problem. They were asked to verbally express their thoughts, as the design session was videotaped. Written and oral expressions as well as recorded sketches were used

to analyze the protocols produced during each design session. Before starting the design activity, participants were allowed to ask questions of the interviewer. The investigator did not intervene during the remainder of the experiment. Since in some cases participants solved two project problems, the number of statistical entries exceeded the number of participants. In total, the number of issues resolved by the expert group was 18, and the number of issues resolved by the novice group was 24.

In order to test the impact of the level of expertise on reasoning by analogy, a number of dependent variables were analyzed from the protocols produced by the participants during each design session. These consist of identifying visual images, retrieving visual images, using analogue principles, adding additional constraints and producing alternative design solutions.

a- The identification of visual images: each visual image identified by the participant from the set of images provided is marked with a value of 1 point and classified according to the categories identified within the domain and outside -field. For example, looking at alternative visual images, the participant commented: “I see the image of plant anatomy and the DNA molecule double helix of living organisms, of the tree…” (See figures 1c and 1g), "and I also visualize the image of the house of the casbah organised around a patio…" (See Fig. 1 (a)). Consequently, 2 points were awarded to the category “images identified outside the domain” and 1 point was awarded to the category “images identified from the domain”.

b- Recovery of visual images: visual images, which are considered as analogue sources, are marked with a value of 1 point and classified according to the categories recovered within the domain or outside the domain. For example, when the participant says: “I think the picture of the tree and the plant leaf can be of some help in organizing the classrooms…” (See Fig. 1 (c)) 1 point a was awarded to the “images retrieved from outside the domain” category, and 0 points to the “images retrieved from the domain” category.

c-The use of analogue principles: if the participants succeed in solving the design problem, they are considered to have used a deep analogy. On the other hand, if they fail to come up with a - successful solution, they are believed to have drawn a surface analogy. Three jury members with at least 7 years of professional experience in the field of architecture evaluated the quality of the projects produced. To do this, the jury established a scale of points from 1 (minimum) to 5 (maximum). As there is no clear definition that distinguishes successful solutions from unsuccessful solutions, in a comparison between the two groups of participants, The solutions considered being successful, when they are awarded more than 3 points and in another comparison, they are awarded more than 4 points.

d- Addition of constraints: a value of 1 point was attributed when the participants considered more constraints than those initially required in the design problem, and a value of 0 point when no additional constraint was added to the problem. For example, if the participant says: “I would like to add a playground to the housing problem” 1 point has been awarded for the category “adding constraints” (see section 4.2).

e- Alternative design solutions: a value of 1 point was assigned when participants proposed more than one design solution, and a value of 0 point was assigned to participants who proposed only one solution.

4. Statistical analysis

The data obtained from the experiments were subjected to the "chi-Square test" (x2) for statistical analyzes. For statistical analysis purposes, the three design issues (“school”, “housing” and “mountain lodge”) were grouped into each group of participants.

4.1. The results

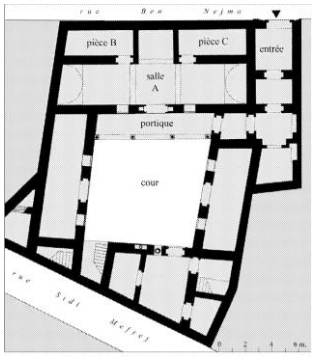
In this section, we explain two individual design problem-solving sessions, each presented by a novice designer and another expert, in which visual analogy was used. In the first case, we show an example of an unsuccessful problem-solving attempt in which a female student failed to use visual analogy to solve a design problem. In the second case, we describe an example in which an experienced architect successfully used visual analogy. The two participants had to solve the housing problem.

4.2 Unsuccessful attempt by the novice

The participant in this experiment was a student who first looked at the visual images and identified an image inside the estate, the plan of a house with a patio (interior courtyard) shown in Figure 1 (a). While inspecting this image, she tried to see how it might help meet the project requirements of a "compact courtyard housing organization". She commented:

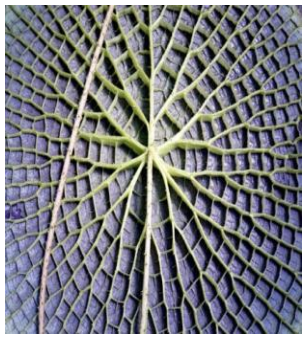
-"[The visual image belonging to the] plan of a house with a patio is an example of a compact organization of a number of similar dwellings…. Anyway, the internal perimeter is quite large… This is because [the units] are arranged in a grouped organization around an inner courtyard, which are exposed to this [internal] side, and to this side. [External]… "

Subsequently, the student attempted to establish a correspondence with the problem of the project and to produce a sketch, which is shown in figure 2. However, instead of abstracting the visual source in order to establish a structural analogy with the problem, she reproduced a copy of the image of the plan of the house with patio.



- a) Plan of a house on the courtyard (patio) of the Kasbah of Algiers

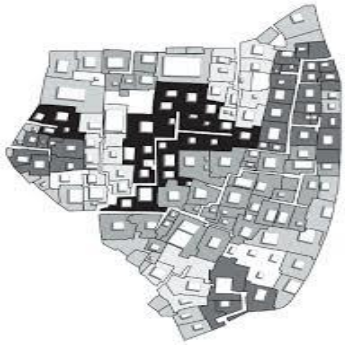
- b) advertising panel on the traditional city; c) plant anatomy under the microscope;



- c) plant anatomy under the microscope;

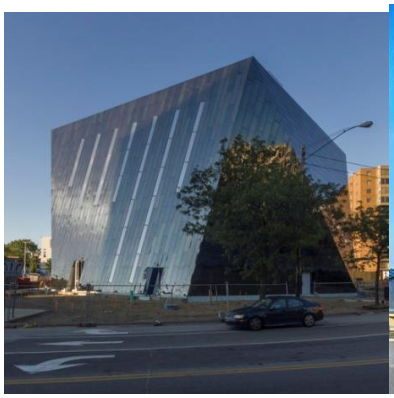
- d) drawing of tree without leaves;

-e) calculating machine;



- f) plan of a casbah;

- g) Double helix of DNA molecule of Living orgasnisms



- h) Cleveland Museum of Contemporary Art by Farshid Moussavi 2012

i) TGV station at Lyon airport France, Santiago Calatrava 1989-92

Figure 1: It shows the images taken into account when solving the "housing" problem

The student was not happy with her plan and decided not to refine it further. She continued to observe the given visual images and discovered an out-of-domain source of architecture representing plant anatomy as shown in Figure 1 (c).

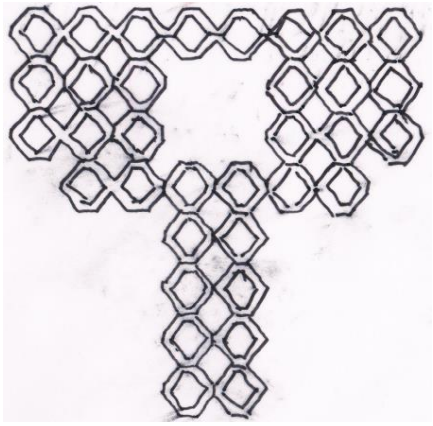


Figure 2: first sketch produced by the novice designer

However, while exploring this visual image, the student focused on surface characteristics such as the link between the image of a plant anatomy seen through a microscope, or the three-dimensional organization of the diagram:

-“In the visual image of this type of structure, there are geometric shapes like clusters that are linked to each other by connectors ... the organization [of the diagram] is three-dimensional but not linear .... "

In order to try to establish correspondences between the visual source and the target, the novice designer made a second sketch, in which she reproduced a copy of the model of the plant anatomy, as shown in figure 3.

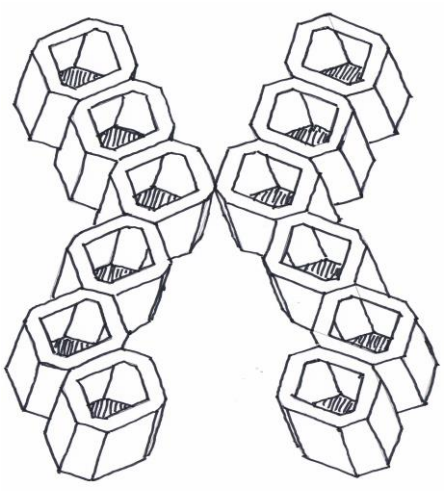


Figure 3: Second sketch produced by the novice designer

However, she was not able to abstract it further, and so she failed to find a structural principle and draw an analogy to the problem.

She wrote: "In principle, this type of organization deals with the principle of compact organization, but the links between the units are more problematic ... I do not see anything else ..."

Her attempts to uncover a potential analogue source continued: she focused on an out-of-domain image of architecture that is a tree, shown in Figure 1 (c). However, again, the novice student reclaimed the surface analogue aspects such as the idea of a cluster organization that did not help her find a successful organizing principle that could meet the requirements of the project. Its results are shown in Figure 4 below.

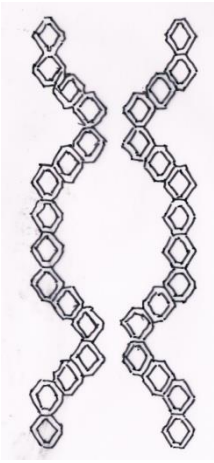


Figure 4: Third sketch produced by the novice designer

The novice student wrote: "Maybe I can consider the tree principle ... where the organization seems to be very efficient ... I should probably consider a cluster organization of units like these. ... "

His latest proposed project sketch did not meet the requirements for minimal outdoor exposure. His lack of expertise played a role in his inability to represent an abstraction from visual sources and draw a deep analogy to the target (Marchant et al. 1993). Instead, she

made near exact copies of the sources provided and focused on surface properties, which did not lead to any successful solutions.

4.3 Successful attempt by an expert

The expert architect began the design session by scanning almost exclusively off-domain visual images. These were selected because they shared a common principle: all adopt the concept of repetitiveness. The visual images he was referring to are shown in Figure 1:

The expert architect wrote: “Now I have to look for a common principle that can help me solve the design problem… there is definitely a [principle] of repetitiveness in most [visual images] that make them work. … And… repetitiveness, it seems to me that this is the common principle. The repetitiveness of the calculating machine, ... just the distribution of clusters that make up the anatomy of the plant leaf, in everything else there is a kind of repetitiveness, in the rooms around the courtyard of the house of the Kasbah ... ... the repetitiveness of the clusters in the plant leaf, ... the repetitiveness of the courses in the district of the Kasbah ... it is the constant, the repetition of the branches of the tree… ”.

The architect succeeded in establishing a structural correspondence between the visual sources and the problem in question, and began to draw. His first sketch, illustrated in figure 5, he seems to be influenced by the structural principle of "repetitiveness" adopted by the visual images identified.

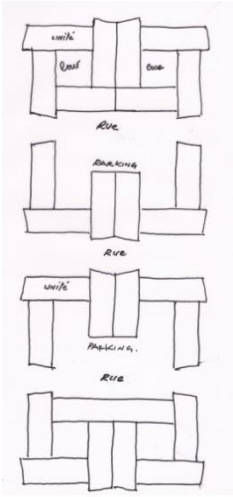


Figure 5: First sketch made by the expert designer

By making his first sketch, the experienced designer succeeded in activating his memory and recovering knowledge related to the organization of the house on the courtyard, a typological dwelling that embraces the structural principle of “density” and “compactness” between units. With reference to the phenomenon of memory activation, Anderson (1983) provided a theory based on research mechanisms. His approach to information processing has focused on the notion of semantic networks, which is linked to the principle of symbolic association in memory. In the case of the architect participating in this experience, his associative structures enabled him to recover a design principle from an image of the field of architecture, which enabled him to meet the requirement of the relative project. To "the compact organization of housing". He commented:

"Obviously there are other ways of creating the twenty eight apartments, even in an urban setting, but I don't think anything can be as dense and compact as houses organised around a courtyard and arranged one beside the street. The other repeatedly" Vosniadou (1989) argued that a domain-analogy can be drawn between a source and a problem if it embraces the transfer of an explanatory structure. She added that belonging to the same or a different domain is not a defining characteristic of the quality of an analogy. The defining characteristic of analogical reasoning is the resemblance in the underlying structure. Thus, a structural resemblance can be established between objects belonging to different conceptual domains and between objects belonging to similar domains. In the current example, we consider that the analogue principle that the participant recovered from memory, although belonging to an image of the architectural domain such as the dwelling with patio, embraces an explanatory structure, which helped him to solve successfully the design problem.

During the design and compact organization of housing, the participant decided to add additional constraints to those required in the original objectives, such as a few streets, alleys and a common playground. Subsequently, the expert architect made a second sketch, in which he developed a prototype of a housing unit, with its internal functional organization, as shown in Figure 6.

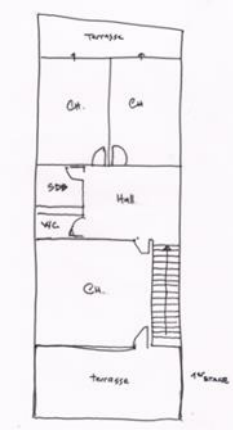


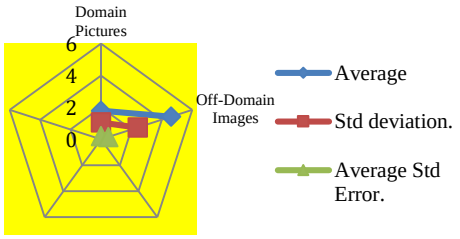
Fig. 6: *sketch made by the expert designer*

He wrote: "There are eight compact apartments in each block… There should be two main streets and one side lane. Maybe we can add a shared playground… well, the apartment should be 80 square metres… it looks like it must be so tight and compact. Maybe this ... can be an example of a prototypical apartment. "

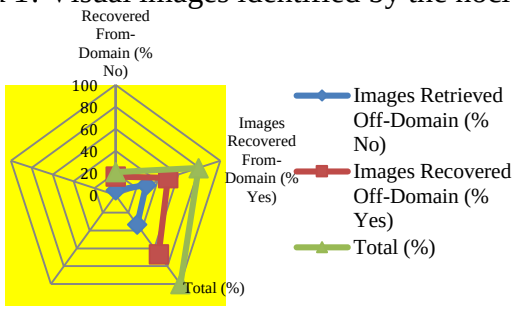
The designer was able to organise the twenty-eight housing units into two compact blocks of eight apartments and two compact blocks of six repeating apartments, and afterwards he refined one of them see figure 6. The experiment ended. With a positive result that fully satisfied the requirements of the project.

The hypothesis that novices identify and retrieve analogies from images belonging to the same area of the design problem has not been confirmed. The results show significantly that the number of visual images outside the architectural domain on which this group of participants relied was greater than that of the images from the domain, see graph 1 ($t = -4.813$; $df = 23$; $p < 0.001$). On the other hand, no significant difference between the two types of visual images was found in the retrieval process, as shown in graph 2. The novices

retrieved analogue principles from images of an out - domain as many as visual images from the same domain of the architecture (x2 = 0.505; df = 1; p ~ 0.477).

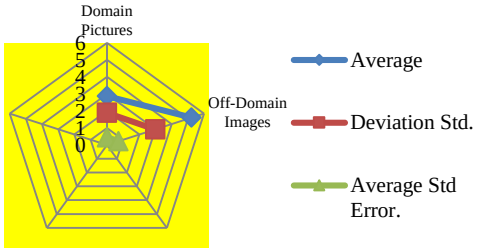


Graph 1: Visual images identified by the nocives

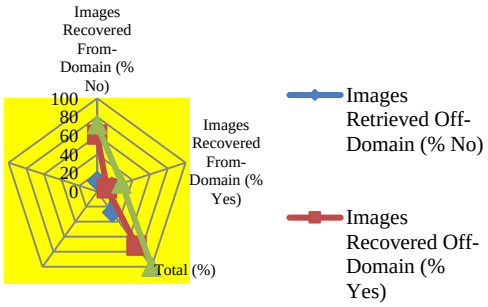


Graph 2: Visual images recovered by the novices

The hypothesis that experts identify and recover the analogies of visual images belonging to a different area of the design problem has been fully confirmed. The results obtained in this group reveal a significant difference in the use of out-of-domain images compared to inside-domain images (t = -3.108; df = 16; p <.007) in the identification process. , and (x2 = 3.58; df = 1; p <0.058) in the recovery process, as shown in graphs 3 and 4.

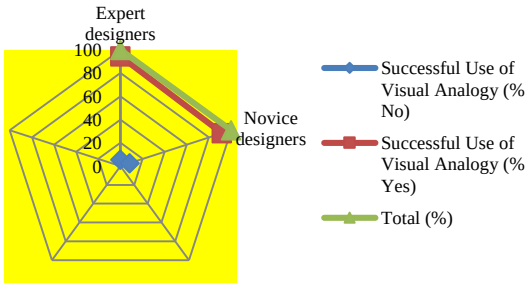


Graph 3: Visual images identified by experts

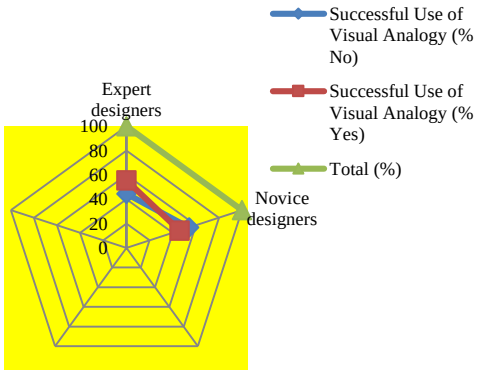


Graph 4: Visual images recovered by experts

The hypothesis that novices, unlike experts, are not able to draw successful analogies from the given visual sources has not been confirmed. Novices and experts have succeeded in drawing deep analogies in almost all observed cases. The results showed that there is no statistical difference between the two groups of participants. As shown in Graph 5, for a comparison between successful design solutions from novices and those from experts who scored 3 or more points, we found (x2 = .120; df = 1; p ~ 729). Similar results were found for a comparison between successful solutions from novices and experts who scored more than 4 points (x2 = 0.389; df = 1; p ~ 0.533) (graph 6).

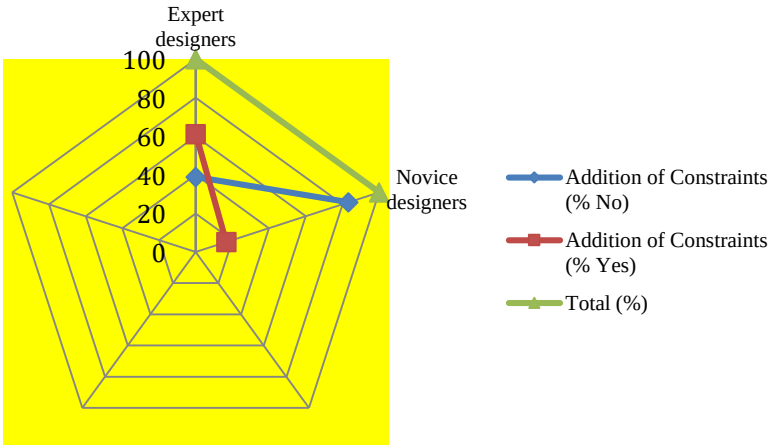


Graph 5: Establish a successful analogy between the visual sources and the target (solutions obtaining 3 points or more).

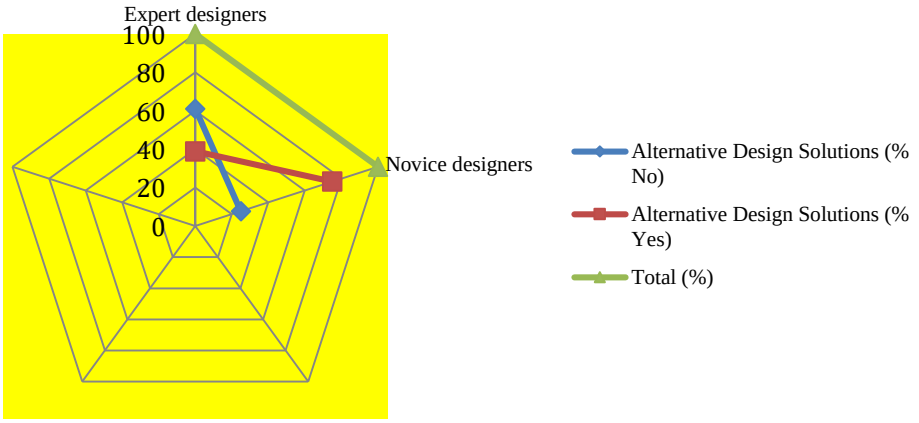


Graph 6: Establish a successful analogy between the visual sources and the target (Solutions obtaining a score out of 4 points).

The hypothesis that experts, unlike novices, add additional constraints to the design, and produce a number of alternative solutions has been completely confirmed. Regarding "the addition of new constraints", a significant difference was observed between the groups. The results, as presented in graph 7, show that the expert group overtook the novice group ($x2 = 8.84$; $df = 1$; $p < .003$). Furthermore, as shown in Graph 8, experts, unlike novices, significantly generated a number of alternative design solutions ($x2 = 5.56$; $df = 1$; $p < 0.018$).



Graph 7: Addition of new constraints to the design problem



Graph 8: production of alternative design solutions

5. Conclusions

The results obtained from the experiments validate the hypothesis that experts identify and recover analogies from visual images belonging to a different domain of the project problem. However, the hypothesis that novices identify and recover analogies from images belonging to the same domain of the project problem has not been validated. The observation that the two groups of participants identify the images outside the domain of architecture is particularly remarkable for novices who, contrary to our hypotheses, were able to base themselves on a large number of images outside the domain of architecture. . According to Dejong (1989), out-of-domain images contain structural similarities, which are believed to lead to successful analogies, but are more difficult to access. It has also been observed that experts are likely to recover a large number of visual images outside the domain of architecture. We postulate that due to their strong and well-organised knowledge structures (e.g., Gero 2002), images from the architectural domain played an irrelevant role in their design process. However, novices were able to retrieve analogies from out-of-domain images as many times as from out-of-domain images. The large, detailed and heterogeneous collection of graphic material made available in the experiment can have a positive effect in overcoming the difficulties of accessing images outside the architectural domain.

The hypothesis that novices, unlike experts, are not able to draw successful analogies from the visual sources provided has not been confirmed. It was observed that both groups of participants are able to retrieve deep principles from the available visual sources and create successful analogies. These results contrast with Gick and Holyoak (1980), Novick (1988) and Phye (1989) who asserted that novices often have difficulty spontaneously accessing and using relevant analogies. We propose that the instructions for using the analogy, as well as the large collection of visual images inside and outside the architectural realm available to participants, play a role in this cognitive moment. .

The hypothesis that experts, unlike novices, add new constraints to the design and create a number of alternative solutions has been fully confirmed. In the novice group, it was verified that the availability of visual sources has no effect on adding new constraints to the problem in question. Their solutions tend to be schematic, characterised by a low level of

detail. However, the use of visual analogy helps novices broaden their explorations into "the spatial problem" (Newell and Simon 1972) and improves the generation of different solutions. On the other hand, we find that although the experts added constraints to the original problem, they did not produce alternative project solutions.
Experienced architects, who developed knowledge structures, were able to direct their research efforts towards fertile metaphorical “conceptual spaces” where effective solutions could be found. These results correspond to Eckersley et al. (1999) and to the study carried out on the differences in expertise between chess players (Chase and Simon 1973). In the above study, it was observed that while striving to find a suitable solution, novice gamers carried out exhaustive research through relevant and irrelevant knowledge embraced in "the space problem". The master players have, however, demonstrated their awareness of these narrow areas in which their exploration efforts could lead to more promising results.

The results of this study have important implications for the teaching of the architectural project and for the development of design skills. It is believed that in the architectural project design workshop, learning from novice students to use in-domain and off-domain visual sources in particular can significantly contribute to better understanding how to identify, retrieve and apply analogue reasoning spontaneously in specific design tasks.

References

Anderson, J. (1983) A spreading activation theory of memory, Journal of Verbal Learning and Verbal Behavior, 22, pp 261-295.

Akin, O. (1990) Necessary conditions for design expertise and creativity, Design Studies, 7 (2), pp 107-113.

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

Bransford, J., Franks, J., Vye, N. and Sherwood, R. (1989) New approaches to instruction: because wisdom can't be told in Vosniadou, S. and Ortony, A. (eds) Similarity and analogical reasoning, pp 470-497, Cambridge University Press, Cambridge.

Casakin, H. and Goldschmidt, G. (1999) Expertise and the Use of Analogy and Visual Displays: Implications for Design Education, Design Studies, 20 (2), pp 153-175.

Casakin, H. and Goldschmidt, G. (2000) Reasoning by Visual Analogy in Design Problem-Solving: The Role of Guidance, Environment and Planning B: Planning and Design, 27, pp 105-119.

Casakin, H. (2002) Well-Defined vs. Ill-Defined Design Problem Solving: The Use of Visual Analogy, in Common Ground Proceedings of The Design Research Society International, Stoke on Trent, pp 202-216.

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

Chase, W. G. and Simon, H. A. (1973) Perception in chess, Cognitive Psychology, 4, pp 55-81.

Chi, M. T. H., Feltovich, P. J. and Glasser, R. (1981) Categorization and representation of physics problems by experts and novices, Cognitive Science, 5, pp 121-152.

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

Davies, S. P., Gilmore, D. J. and Green, T. R. (1995) Are objects that important? Effects of expertise and familiarity on classification of object-oriented code, Human-Computer Interaction, 10, pp 227-248.

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

Dominowski, R. (1995). Productive Problem Solving, in R. Finke, T. Ward, and S. Smith (1995). The creative cognition approach, 73-95. Cambridge, MA: MIT Press.

Eckert, C., Stacey, M. and Wiley, J (1999). Expertise and designer burnout. International conference on engineering design, ICED, Munich.

Glaser, R. (1989) Expertise and Learning: How do we think about instructional processes now that we have discovered knowledge structures?, in D Klahr & K Kotovsky (eds) Complex information processing: the impact of Herbert A Simon, pp 269-282, Erlbaum, Hillsdale, NJ.

Gentner, D. (1983) Structure-mapping: a theoretical framework for analogy, Cognitive Science, 7, pp 155-170.

Gero, J. and Maher, M. L. (1993) Modeling creativity and knowledge-based creative design, in Gero, J. and Maher. M. L. (Eds), pp 1-7, Lawrence Erlbaum Associates, Hillsdale, NJ.

Gero, J. and Kavakly, M. (2002) Strategic knowledge differences between an expert and a novice, in Pre-proceedings of Human behavior in design, Schloss Hohenkammer, no pp number.

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

Goldman, S., Pellegrino, J., Parseghian, P. and Sallis, R. (1982) Developmental and individual differences in verbal analogical reasoning, Society for Research in Child Development, 53, pp 550-559.

Goldschmidt, G. (1994). Visual analogy in design, in Trappl, R. (ed) Cybernetics and Systems ’94, pp 507-514, World Scientific, Singapore.

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

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

Holyoak, K. (1990) Problem-solving, in Osherson D.N. and Smith E.E. (Eds) Thinking: An invitation to cognitive science, vol 3, pp 117-146. MIT Press, Cambridge, MA

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

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

Medin, D. and Ross, B. (1990) Cognitive psychology, Harcourt Brace Pub,NY.

Needham, D. and Begg, I. (1991) Problem-oriented training promotes spontaneous analogical transfer: memory-oriented training promotes memory for training, Memory and Cognition, 19 (6), pp 543-557.

Newell, A. and Simon, H. (1972) Human problem solving, Englewood Cliffs, Prentice Hall, NJ.

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

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

Patel, V. L. and Groen G J. (1991) The general and specific nature of medical expertise: a critical look, in Ericsson, K. A., Smith, J. (eds) Studies of Expertise: Prospects and limits, Cambridge University Press, Cambridge, MA.

Phye, G. (1989) Schemata training and transfer of an intellectual skill, Journal of Education Psychology, 81 (3), pp 347-352.

Schiano, D., Cooper, Glaser, R. and Zhang, H. (1989) Highs are to lows as experts are to novices: Individual differences in the representation and solution of standardized figural analogies, Human Performance, 2 (4), pp225-248.

Simon, H.A. (1981) The Sciences of the Artificial, MIT Press, Cambridge MA, 2nd ed.

Sternberg, R. and Ketron, J. (1982) Selection and implementation of strategies in reasoning by analogy, Journal of Educational Psychology, 74, (3), pp 399-413.

Verstijnen, I., Wagemans, A., Heylighen, A., and Neuckermans, H. (1999) Sketching, Visual Analogies and Domain-Expertise, in Proceedings of 4th Design Thinking Research Symposium: Design Representation, 77, Cambridge, MA, pp II.71-II.

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

Vosniadou, S. and Ortony, A. (1989) Similarity and analogical reasoning: A synthesis, in Vosniadou, S. and Ortony, A. (eds) Similarity and analogical reasoning, pp 1-17, Cambridge University Press, Cambridge.

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

Wertheimer, M. (1959/1982) Productive thinking, Harper & Row, NY.