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Architects and Engineers Differences: A comparison between problem solving performances of architects and engineers in the ideation phase of an analogy-based design

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Abstract

This study examines how analogy affects problem-solving in ideation phase of design among architects and engineers. For this purpose, a design problem was given to master and Ph.D. students of engineering and architecture. They were given two optional analogy sources to choose and be inspired by one. From the analysis of design sessions, using different coding groups and the application of the Protocol analysis, the following results were achieved. Choosing different analogies would cause application of different levels of abstraction by designers in design, considering their discipline. Also, choosing between two analogies would affect mainly the behaviour of engineers in the problem space. For architects choosing between different analogies do not affect their problem solving or structuring so much but it affects their problem space monitoring mainly. Finally, architects benefit from analogy mostly for problem solving.

Keywords: *analogy, Ideation, Problem Solving, Engineering, Architecture.*

1. INTRODUCTION

Design has important contributions in different disciplines. There exist some commonalities and differences between various design disciplines. Architecture and engineering are among disciplines that involve design in their domain [1-2]. As the design projects are getting more trans-disciplinary with more collaboration of architects with engineers [3], there is a need to know more about the commonalities and differences between their design performances [4]. Also, considering analogy as a means of fostering creativity [5], it is important to know how different disciplines may benefit from analogy in design problem-solving.

The design is a cognitive activity that can be seen as a type of problem-solving [1-2]. According to General theory of problem-solving, which was firstly defined for moving problems, any problem consists of three components including data, goal, and operators. Data are pieces of information that describe the problem. The goal is the desirable state and operator are the activities toward the goal state [6]. Finding a solution starts from problem state, which transfers problem state using operators to the goal state [7-8]. There are two types of problems as well- defined and ill-defined problems [9-10]. Well-defined problems are the ones with clearly defined existed and desired situation, which can be solved through an algorithmic solution. In comparison, ill-defined problems are complex and not clearly defined problems that involve creative solutions. Design problems have little information about the problem and even less about the goal or solution and almost no information about the transformation phases based on their nature. So, they need structuring, which is a process of using the supply of knowledge (external information) to compensate the missing information and completing the problem state [11]. Consequently, design is defined as a ill-structured problem [12-14]. Knowledge and information are used for two purposes; i.e., structuring the problem and solving the problem. from a cognitive science point of view, problem solving is an information processing activity and problem solvers are as an information processing system [14].

Today, there is a high need for designing in multidisciplinary teams to meet different needs more efficiently and to achieve the systematic design. In construction projects also there is a need for more

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corporation of different disciplines mainly architecture and engineering. Thus, it is very important to find out how information is processed during a design activity to help understand more about design and how designers think to have more efficient design results [3-4]. Architects and engineers deal with complicated information related to the range of abstraction levels involved in the design [15].

As an ill-structured problem, design needs creativity to find solutions. Analogybased designs play important roles in problem solving and generation of creative ideas [16-18]. In addition, the analogy is a key factor to enhance creativity because it helps to conceptual change, which is essential for creativity [16]. Therefore, analogies are useful in the design process and help to foster the creativity. Accordingly, analogies have a crucial role in different design disciplines. For a more useful application of analogies in design teams with different disciplines and achieving a more concrete design concept and solution, it is important to know how different disciplines use analogies and whether there are differences in the application, types, and process of applying analogies. The main goal of the present work is to investigate the differences between engineers and architects in the application of analogy in concept generation phase of design.

2. ANALOGY

Analogy lies at the center of the human cognition [19]. As a cognitive process, analogy transfers meaning or information from a source domain to a target domain. In cognitive sciences, there are two types of analogies: surface features analogies and generative analogies. The former is a kind of analogy that is based on surface features, but the latter includes structural and conceptual analogies, which help inference from the source domain to target domain [20]. Also as they help to create patterns regardless of the elements that create them, we can consider another group as the structure. It helps to create concepts that are abstracted from patterns [19].

Using an analogy based on the multi-constraint theory, Thagard and Holyoak introduced three main constraints including similarity, structure, and purpose, which can guide the analogical thinking and lead the designer to a coherent result [21]. Gross proposed an approach to create information for computational aid in creative architectural design using drawing analogies. Drawing analogies are visual references (analogies), which are indexed as a function and form in conceptual design [22].

We concluded from these studies that there are different analogy types that can be defined at different levels of abstraction as form, structure, function, and concept as shown in Fig. 1. We considered two analogies (i.e., Eye and tree) for designers to choose one and be inspired from for their ideation. This choice was made in order to find more about the level of analogy abstraction. The eye is an analogy that is more dominant in its form while tree can be more dominant with its structure. The two analogies were given to evoke either a superficial or a generative aspect of analogy in designer’s mind. Also, designers were asked to mention their reasons for choosing one of the analogies in order to find about the retrieval data from memory at the beginning point of design where thinking process did not affect the designer's mind.

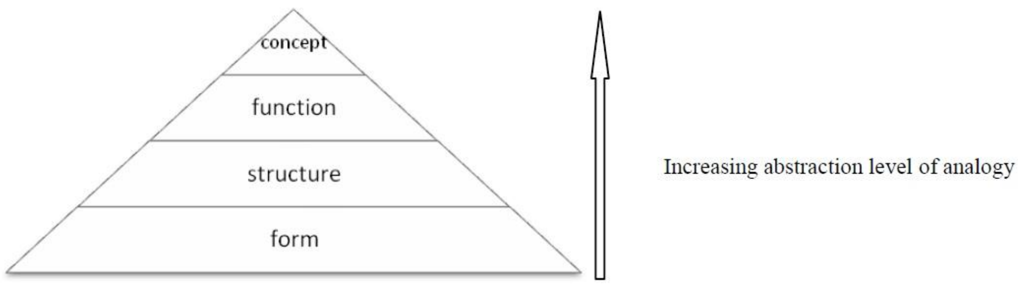

Fig. 1: Levels of order or systematicity of hierarchies in the application of analogies

2.1. Analogy and problem solving

Analogies would provide new insight into problems. Even analogies may find new aspects and cause the emergence of new solutions [21, 23]. Hey et al. discuss how analogies and metaphors help to solve design problems. They concluded that for design problems metaphors help to structure and to define the problem through understanding the needs and attributes while analogies help to problem-solve through mapping the causal structure of source (of inspiration) domain to target (problem to be solved). The mapping can be in functional, geometrical, or configurative aspects of the two domains.

Finally, they concluded that analogies can be used for concept generation in design [24]. Christensen found three functions for analogies as problem identifying, problem-solving, and explaining concept analogies. While problem identifying analogies are mainly within domain analogies, explaining concepts are between domain and problem solving a mixture of the two. Analogizing uses almost equal number of within and between domain analogies in engineering design. Also, it was found that using sketches increases between domain analogies [16]. Indurkhya discussed different uses of analogy and their role in cognition [25]. Linsey et al. concluded that the level of abstraction for representation of prior knowledge and design problem affects the ability of people to retrieve and use analogous solutions. Also, the stated that having a proper functional model of the problem affects the ability to find and use an analogy [26].

According to the mentioned works, it is important to find how applying an analogy may affect the problem space and its operations.

Bonnardel conducted two studies in creative professional space to find the role of analogy in creativity and found the nature of sources of information in analogical reasoning. He found the high level and inter-domain analogies help the creation of new ideas. Then, he classified the cognitive constraints as external (prescribed) and internal (designer expertise) [27]. Ball et al. studied the application of analogical reasoning according to the designer expertise and realized that skilled designers use schema-driven analogy while unskilled use case-driven analogy [28]. Ball studied the nature of spontaneous analogical reasoning related to novices and experts in design activity and found that spontaneous analogizing is dominating in both novice and experts practices.

Also, experts show more schema-driven analogizing while novices do more case driven.

Most of the case driven analogizing used surface level analogies in target problem [Ibid]. Casakin investigated how experts and novices apply visual analogy in Architectural design. He claimed that experts retrieve analogise from between-domain while novices retrieve from within-domain and between-domain. Also, he reported that novices in contrast to experts produce many solutions with fewer constraints [17].

Although many studies have been done considering the application of analogies in design disciplines, there exist few studies to compare architecture and engineering disciplines function during ideation phase of design. Also, there is no clear study to compare designers' behaviour in the problem space in analogy-based design. If we give designers with different educational background (architecture and engineering) a design problem with two predefined analogy to choose, when they should rely on their memory and self-information, what would be the differences? Whether choosing different predefined analogies make any differences in the abstraction level that designers involve during design?

The questions to be answered in this research include: What are the differences between Architects and Engineers on their problem space operators when they choose different analogies? Do Architects and Engineers differ at the abstraction level at which they utilize the analogy in design?

It seems there are differences between Architects and Engineers when they choose different analogies to be inspired. They may prefer to choose different analogies as they have different information processing methods. Engineers mostly focus on structuring the problem, while architects mainly concentrate on solving the problem [10, 29]. Considering analogy abstraction levels, it is possible that choosing different analogies would affect using different abstraction levels of analogy during problemsolving of design. Moreover, it would cause Architects and Engineers apply different levels of analogy abstraction.

2.2. Comparing design disciplines

Cognitive processes have similarities and differences in different design disciplines. Differences between design disciplines have been studied in limited studies. Comparison of design problem space in three disciplines of architectural design, mechanical engineering design, and educational design with non-design problem space represents the fixed and specific features of the design problem regardless of the discipline field [3]. Architectural studies relate to several key issues that include: architectural presentation, strategic behaviour, and creativity and innovation. Each major theme is covered by many topics and subcategories. Some of the prominent differences that distinguish architectural design from other areas of design are strong presentations, the untapped use of innovative rivals, non-standard problem mix design, and complexity management strategies [3]. Design thinking of architecture students is compared with industrial design at the undergraduate and doctoral level of design. However, there is a difference between undergraduate students in architecture and industrial design, but the most important difference between the PhD. students and the two undergraduates. The results of the study question the conventional design methods in design thinking, because it limits the creative framework of the mind [3]. The Understanding of the designers of design for engineering and non-engineering disciplines and impact of this understanding on their design behaviour is investigated, which has led to the presentation of six views of design. The matters and processes of design in three different domains (architectural design, software design, and mechanical design) are compared with the case study. The design matters are intended function, expected behaviour, obtained behaviour, structure representation and design requirements, and processes are defined as frameworks, analyzes, configuration, evaluations, documentation, and re-framing. Design processes are achieved from changes to design matters, in which processes are dependent on the matters. The framework of the problem is defined as the transformation of design requirements into functions and functions to the expected behaviours. The configuration is the transformation of the expected behaviour into a structure or form. Analysis is the extraction process of the structure from the behaviour and the evaluation is the comparison process between expected behaviour and obtained behaviour. Documentation is the process of converting matters into presentable and displayable documents. Three re-categorization processes are also introduced for reviewing and presenting new structures, behaviours and functions. The study shows that different design disciplines are comparable with the design ontology approach and thus the design processes in different domains can be compared. Different areas of design work in processes differently [3]. A comparison between architects, industrial designers, and electronics engineers has shown that architects have more variety in architectural design presentations than engineers. They also produce more malicious options, and more often than engineers are involved in fake production strategies in creative design [35-36].

Comparison of the understanding of the design between two disciplines of mechanical design and industrial design in the conceptual phase of design is done which is based on the ontological model of function-behaviour-structure. The focus of the cognitive effort of the designers on the argument about the design issue or the design solution has been examined. The goal of the research was to know whether the epistemology of design critique is compatible with the design process. The results have shown that design review and critiques sessions emphasize design solutions more than design sessions. Industrial designers are less focused on the solution than mechanical engineers [3]. Engineers are compared with industrial designers regarding the application of design heuristics, which explains the effect of design heuristics on the production of diverse, functional and creative concepts. There are also differences in the heuristics that apply to the production of various options [3]. The application of design heuristics in collaborative design ideation of the engineers (mechanical) with industrial designers has been investigated. The role of heuristics has been identified in creating solutions and defining new issues. Also, the application of a heuristic often leads designers to a different part of the problem space and facilitates the inclusion of other heuristics [3]. A review of the common design ideas of engineering design and marketing professionals has shown that the use of design heuristics produces a more diverse concept [3,33].

To find out how different design disciplines especially Architects and Engineers benefits from analogies at first phase of design, we examined candidates at a high level of education from Engineering and Architecture discipline by giving them a design problem with no familiar solution and two familiar choices as analogies to be inspired by.

Their design thinking and behaviour were then analyzed to achieve the results.

3. RESEARCH METHOD

3.1. Participants

Designers were chosen from master and Ph.D. students of different disciplines of Engineering related to design and Architecture. Among seven Engineering candidates, three were structural Engineering PhD. students, one mechanical Engineering PhD., one master and one bachelor of Mechanical Engineering, and finally one master student of Industrial Engineering. Also, three master students of Architecture and three professional with master degree (one instructor) were among the Architecture candidates for the task.

3.2. Design task and procedures

To find how Engineering and Architectural designers use an analogy (a biologic analogy) for solving design problems and generating design concepts, a design task was defined. The task was to design a façade for the house of philosophy, where philosophers can gather and talk about philosophy and make more communications with each other. Also, two optional analogies from biology were suggested to designers to be inspired by as Eye and tree. These two analogies were chosen because the eye can be referred to as seeing as a function and also its beauty aspects. Besides, the tree is most dominant for its appearance features and structure. Designers were asked to say about the reason why they choose eye or tree. Then, it was investigated which levels of analogy was applied in reasoning during the design process and finally which one was mainly applied to design idea creation.

3.3. Data collection

The candidates were given the design task in the description and the way they should do the task. They were provided with notepapers. They should first decide to choose between two fixed concepts as Eye or Tree to be inspired and then they must explain their reasons for why they chose one of the two and what the benefits for choosing that analogy are. Next, they began to design with the chosen analogy and inspired from it during the design and explicate their thoughts about how they benefit from that analogy. Each designer was recorded separately. The whole process was videotaped and recorded as their drawings and writings were collected at the end of their session. The time given for the conceptual phase to produce concepts of the design was in average 30 ± 10 min according to candidate's decision for finishing the design. All videotapes were transcribed and analyzed according to coding provided.

3.4. Coding schemes

Coding was prepared based on the literature review. The data can be coded according to designer source of knowledge, level of analogy abstraction (form, structure, function, concept) [24, 41-44], and how data are used for problem space state as problem structuring (adding the knowledge needed to structure the problem), problem-solving (improving the design specification), and monitoring (review of subject or comment upon the problem-solving process) the problem [30]. The coding is for problem state is illustrated in Fig. 2. Finally the information is processed for each participant; the frequency of every category code was calculated. Then, the percentage of every frequency in each transcript was calculated.

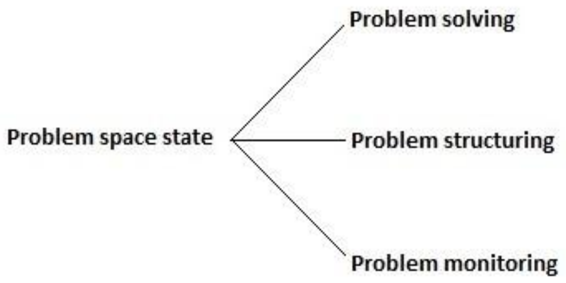

Fig. 2 Problem space state in design including problem structuring, problem-solving, and monitoring the process

As there were two categories of coding, each transcript was coded two times. The first category involves designers' operation in the problem space. The problem space operators consist of problem structuring (which is crucial in design problems as they are ill-defined and lose information), problem-solving (searching alternatives and solutions), and monitoring (review the problem and monitor the design process) [30].

The second category was the abstraction level of analogy that designers benefit to deal with the problem.

The four analogy levels include form, function, structure, and concept [21]. According to function-behaviour-structure model Gero [45] and the principle of “form follows function” [46], the form is the lowest level of order than structure and function. Form refers to the shape, but the structure is a deeper aspect that refers to relation and hierarchy of the components in the object. So, the structure is at a deeper level of order in comparison to forming. Also, the function has a higher order than structure because it refers to the function of the object as its goal to provide something. The concept is the goal of the designer so it is the highest level of order.

Each transcript was also coded for the abstraction level of analogy. The first coding was to find the level of analogies that help to reason and think through the design process. Also, the whole transcript was coded to find the level of analogy in design outputs. And third, the coding was for answering the question that why designer chooses Eye or Tree to see what level of abstraction of the analogies first catch the designers’ Eyes.

So, there are two groups of Architects and Engineers with a subject of design that is to be inspired by choosing between two analogies as eye and tree. Fig. 3, gives a brief of the two main coding scheme of the study.

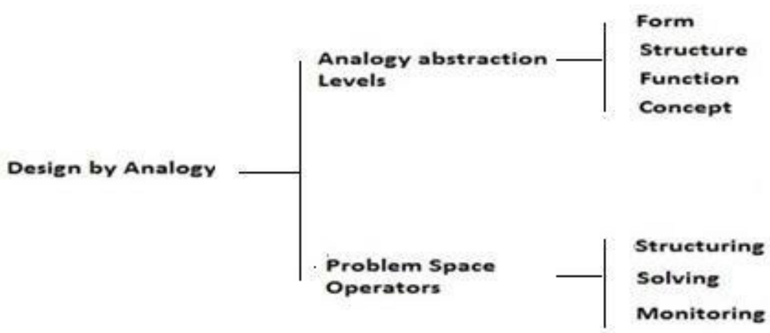

Fig. 3 Research design diagram introducing dependent variables

4. RESULTS

The frequency of every category codes was calculated for each participant and then the percentage of every frequency in each transcript was calculated. Then, considering two choices for inspiration (two optional analogies as eye or tree) and two groups of expertise as Architecture students and Engineering students, different ANOVA tests were conducted for each coding group. The independent variables are field of education and the chosen analogy (eye or tree) as shown in Fig. 4.

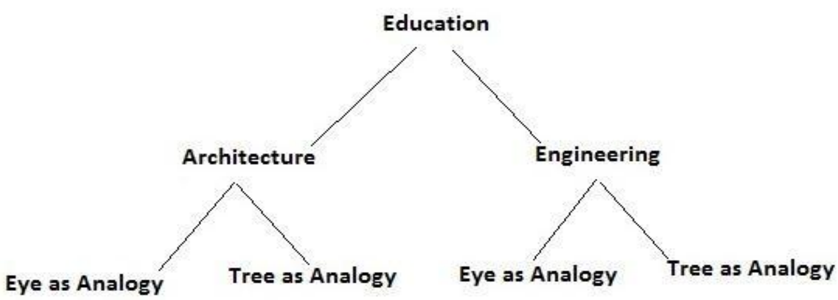

Fig. 4 Independent variables are defined as field of education and the chosen analogy (eye or tree)

4.1. Problem space operators

According to our first hypothesis for design problem-solving, problem state would be different considering choosing different analogies. Also, they benefit from analogies for different operators in the problem space. The coding for this hypothesis was through transcript statements. To test this hypothesis, the discipline of designer and the chosen analogy were consider as independent variables and designer's behaviour in the problem space as dependant variables. ANOVA repeated measure analysis shows that the discipline of designers as architecture and engineering affects designers' behaviour in the problem space. The ANOVA result F (2.29, 18.34) =13.51, p= 0.000 shows that there is significant difference between different problem space operators. This difference would be confirmed when considering the designer's discipline of design with the test result, F(2.29, 18.34)=3.83, p= 0.036. Descriptive statistics in Fig. 5 reflects that Architects benefit from analogies mostly for problem-solving (Total Mean=40.23, SD=10.56) while engineers benefit from analogies mostly for structuring the design problem (Total Mean=37.04, SD=20.36). Also, analogies help Architects to monitor the problem space more than Engineers.

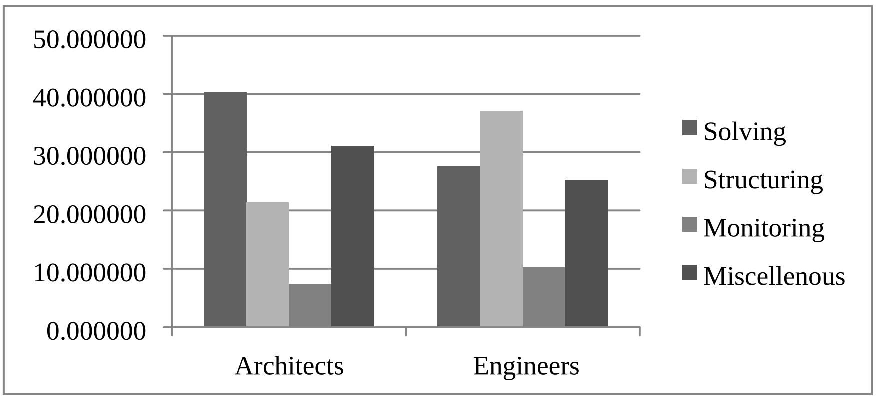

Fig. 5 Total mean for architects and engineers considering problem space operators

The test results for the problem space operators considering different analogies as eye and tree without designers' discipline was F(2.29, 18.34)=3.73, p= 0.039. Comparing total means of problem space operators for different chosen analogies as eye and tree Fig. 6 shows that designers mostly benefit from eye analogy for structuring the problem, while they benefit from tree analogy mainly for solving the problem. Also, using different analogies cause different proportions between solving and structuring the problem. For eye analogy, designer's difference in structuring and solving is much less than for tree analogy. This means different analogies affect designers' problem structuring and solving performances.

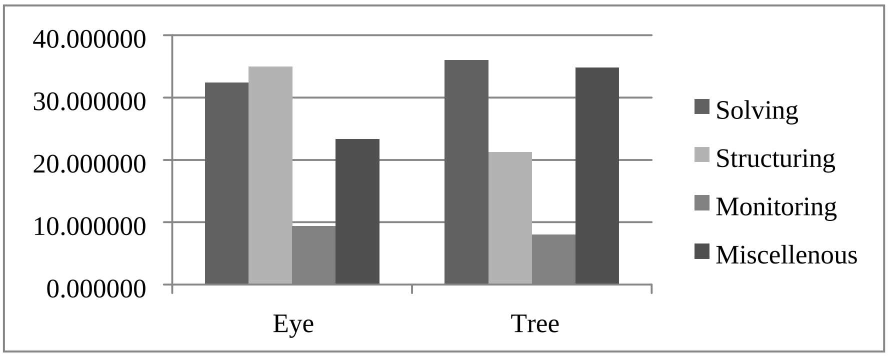

Fig. 6 Total means for predefined analogies as eye and tree considering problem space operators

Architects and Engineers behavior in the problem space is compared considering choosing different analogies. The test indicates F (2.29, 18.34) =5.14, p= 0.014, which means that problem space operators would differ more when imposing the designers' discipline and the chosen analogies. Choosing different analogies as eye or tree causes different problem structuring and solving for the Engineers, according to descriptive statistics in Fig. 7.

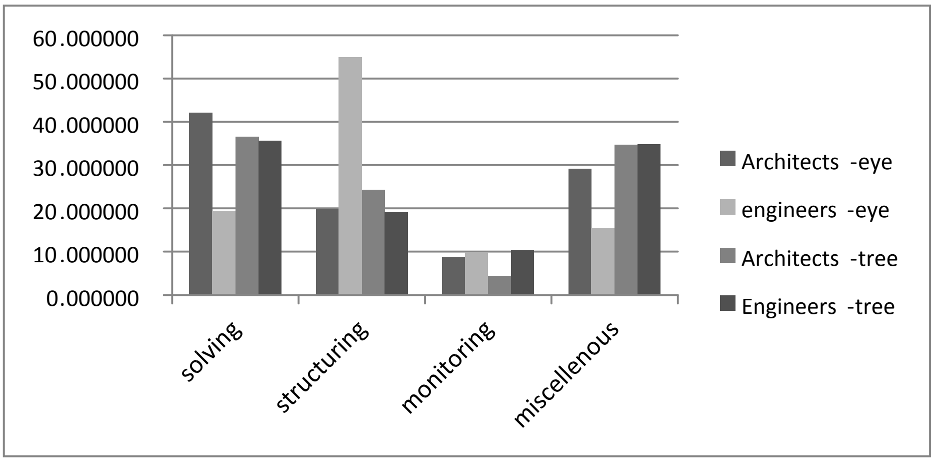

Fig. 7 Comparing means for architects and engineers with chosen analogies as eye and tree in the problem space

In comparison, Architects behave not much different when using different analogies in the problem space. Choosing different analogies do not affect engineers monitoring the problem space in a noticeable way. While for architects using different analogies makes noticeable difference in monitoring the problem.

4.2. Level of analogy abstract results

The other hypothesis states that different analogies may impose different levels of abstraction in design ideation. And it will affect architects and engineers differently by using different levels of analogy abstraction. For this hypothesis, coding was done at the statement level. The MANOVA test with dependent variables being abstraction levels of analogies and independent variables being designer's discipline (architecture and engineering) and chosen analogies (Eye, Tree), resulted in $F(1, 8)=26.9$, $p=0.001$, suggesting that there is significant difference between architects and engineers in applying different levels of abstraction. The test results also indicates that there is significant difference between four abstraction levels as form, structure, function and concept, $F(4, 32)=296.07$, $p=0.000$. Comparing the total mean for Architects and Engineers at different levels of abstraction using the descriptive statistics Fig. 8, indicates that architects have greater means at form and concept levels while Engineers show a greater total mean at form and function levels. Architects have greater means in all of the abstraction levels, comparing to engineers.

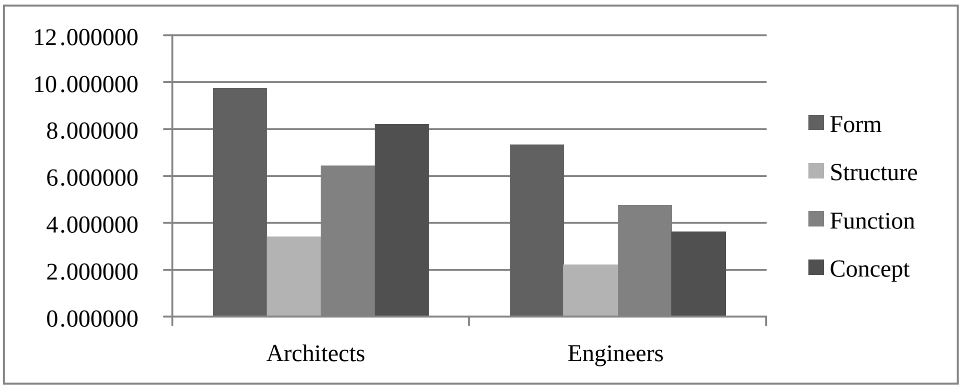

Fig. 8 Architects' and engineers' mean for different abstraction levels of analogy

Designers mainly benefit from eye analogy in form level, while they benefit the tree analogy mostly in concept level Fig. 9. Architects and engineers noticed to eye different abstraction levels with the same order in form and function levels and with contrast in structure and concept levels. The tree analogy makes completely different set of levels for different analogies.

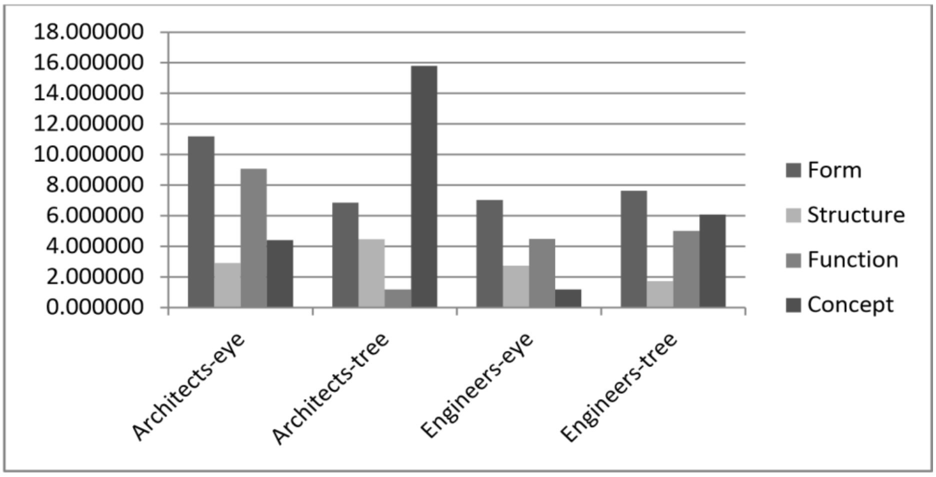

Fig. 9 Architects' and engineers' means for different abstraction levels of two chosen analogies

As illustrated in Fig. 10, eye analogy mainly arise the form and then function levels in designers' minds, while tree analogy awoke concept and then form levels.

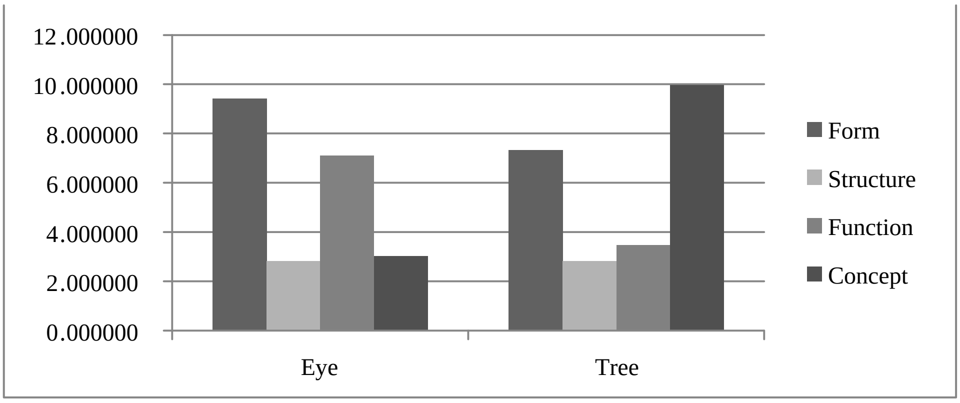

Fig. 10 Total mean for eye and tree analogies at different abstraction levels

5. DISCUSSION

There were two questions to be answered in this study. The first was: What are the differences between Architects and Engineers on their problem space operators when they choose different analogies?

Architects benefit from analogies mostly for problem-solving while Engineers benefit from analogies mostly for structuring the design problem. Also, analogies help Architects to monitor the problem space more than Engineers.

Designers mostly benefit from eye analogy for structuring the problem, while they benefit from tree analogy mainly for solving the problem. Also, using different analogies cause different proportions between solving and structuring the problem. For eye analogy, designer's difference in structuring and solving is much less than for tree analogy. This means different analogies affect designers' problem structuring and solving performances in different ways.

Architects and Engineers behavior in the problem space is compared considering choosing different analogies. Problem space operators would differ more when imposing the designers' discipline and the chosen analogies. Choosing different analogies as Eye or Tree causes different problem structuring and solving for the Engineers. In comparison, Architects do not behave much different when using different analogies in the problem space. It means that choosing different analogies makes no much difference in structuring and solving the problem for the architects. While choosing different analogies affect engineers' solving and structuring the problem much more. This different behavior regarding different analogies is related to the way architects and engineers benefit from the analogies in design. Since engineers more benefit apply analogies for structuring the problem and because different analogies can generate different information for different aspects of the problems so engineers behave much differently regarding using different analogies to structure hence to solve the problem. But because architects use analogies mostly for solving the problems, choosing different problems do not affect their function in the problem space so much.

Choosing different analogies do not affect engineers monitoring the problem space in a noticeable way. While for architects using different analogies makes noticeable difference in monitoring the problem. It shows engineers have independent criteria from analogies for their monitoring of the problem space which means they have more fixed and determined criteria than architects. Using analogy helps architects mainly for solving the problems. And the second question was: Do Architects and Engineers differ at the abstraction level at which they utilize the analogy in design?

Comparing the Architects and Engineers using different levels of abstraction of analogies indicates that architects apply more the form and concept levels while Engineers apply form and function levels. But they apply the form and concept levels mainly or tree analogy.

Designers mainly benefit from eye analogy in form level, while they benefit the tree analogy mostly in concept level. So, different analogies would take the notice on special levels of abstraction. Different analogies can make different structural mappings in different levels of abstraction in designers' minds.

Eye analogy mainly excites the form and then function levels in designers' minds, while tree analogy awoke concept and then form levels. So designers would consider special abstraction levels in different analogies regardless of their design disciplines.

Architects and engineers noticed to eye more in form and then function levels. So, eye as an analogy would be considered in form and function level. But architects pay more attention to concept than structure level in contrast to engineers when they choose eye for inspiration. The tree analogy makes different set of levels for inspiration as an analogy. Architects consider tree as an analogy mostly in the concept and then form level, but engineers noticed to tree mainly in the form and then concept level. When choosing tree for inspiration architects consider the structure level than function in contrast to engineers. The difference between architects and engineers are in the abstraction levels of analogies regardless of the type of analogy. It means the order of applying different abstraction levels of the analogies is different for architects and engineers.

The whole transcript were coded two times for the level of analogy that helped the design output to be evolved and shaped and the reason of designer for the choice of analogy, The information is presented in Table 1.

Table 1 Results for three coding sets: choice reasoning analogy level, reference of reasoning, and design output analogy level

Eye	**Choice reasoning analogy level**	**Design output analogy level**	**Eye**	**Choice reasoning analogy level**	**Design output analogy level**
Arch 1	Concept	Concept structure	Eng 1	Function concept	Structure form
Arch 2	Concept	Concept function	Eng 2	Structure	Function
Arch 3	Concept	Form	Eng 3	Function	Form
Arch 4	Concept function	Form concept	Tree	Choice reasoning analogy level	Design output analogy level
Tree	Choice reasoning analogy level	Design output analogy level	Eng 1	Function	Function
Arch 1	Concept	Form	Eng 2	Function	Form
Arch 2	Function concept	Concept structure	Eng 3	Function concept	Form

Two third of the Architects chose Eye to be inspired by, mostly inspire at concept level and all of them mentioned their reason for choosing Eye at concept level.

In contrast, for choosing Tree analogy, there was an equal inspiration for concept and form and their reasons also were at the concept level.

Engineers have chosen two analogies in equal numbers. For Eye analogy, they are inspired by most levels of form, function, and structure, but the reason behind their choice was mainly a function of the Eye. For Tree analogy, they were inspired mostly in form but their reason behind their choice is function. Statistical test declares no significant differences between architects and engineers in this level of coding.

6. CONCLUSION

In this study, we investigate the difference between Architects and Engineers in choosing and applying two different analogies in ideation phase of design. They have to choose one analogy among two to be inspired by for design ideation. In this study the different behaviour of architects and engineers in the problem space considering choosing different analogies in an analogy-based design has been investigated.

Also, designers' behaviour toward applying different abstraction levels of the chosen analogy in ideation is studied. Results show that giving analogies for inspiration without any provision and information about them, affect designers’ operation in the problem space. Designers' discipline makes differences in using different levels of abstraction of the chosen analogy referred by the designer.

– Choosing different analogies mainly differs in engineers' problem solving and structuring, while for architects it mainly affects their problem space monitoring. So choosing analogy can help engineers benefit analogies in different ways. Architects benefit from analogies mostly for problem-solving. Engineers have more fixed and determined criteria than architects. But architects benefit from analogies for monitoring the problem space and different analogies affect their monitoring.

– Analogies have various abstraction levels for designers to be inspired. Different analogies can make different structural mappings in different levels of abstraction in designers' minds. Designers would consider special abstraction levels in different analogies regardless of their design disciplines. The order of applying different abstraction levels of the analogies is different for architects and engineers.

The study addresses the educational aspects of multi-disciplinary fields related to architectural design. It helps to know more about designers' behaviour in the analogybased designs such as bio-inspired design in design teams or multi-disciplinary design subjects where architects and engineers works together. Applying analogy-based design in education can help architecture students to find more solutions. Also it can help to find educational solution for better function of architects in multidisciplinary design teams with engineers.

This study is done with architecture and engineering participants with no or little professional experience. We should be cautious to generalize the results of the study to the professional or expert designers.

For future studies, it is suggested to search what causes that architects and engineers refer to the abstraction levels of analogies in different orders when ideating in design problems and whether it affects their behaviour in the problem space or not. Also whether they refer to special abstraction levels of the analogies regarding their discipline or not, and if the answer is positive, what causes this difference.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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