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Inspiration from Nature in the Training of Structural Design in Architecture

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Abstract

Particular attention to the relationship between architecture and nature, especially in the past three decades, has flourished a very distinctive accomplishments, and yet more useful than the past, in terms of the emergence of new architectural approaches as well as the coordination of new technologies, such as nanotechnology. Structure, as one of the essential components of architecture, is of particular importance. Different and sometimes contradictory approaches to designing structure and architecture, “with” each other or “on” each other, may create different qualities and affect the value of architecture and structure. Relying on the fact that the dialogue between the architect and the designer of the structure is one of the necessities of creating an architectural work, this paper puts a substantial emphasis on the learning of structural sciences by the architects and their mastery in the recognition of structural principles. Furthermore, with a critical look at the adherence of architecture to structure and the key role of naturalism the paper seeks out the origins of this problem in the method of structure training for architects. The pathology of failure to realize the use of nature strategies for the harmony of architecture and structure in the current architecture of Iran is the main research question in this study. This research has been based on three pillars of analysis, assessment and evaluation. In the first step, using a causal-comparative research methodology, the challenges of naturalism in architectural techniques after the industrial revolution are addressed and the position of structure in the naturalistic approach of these styles is evaluated. In the second step, applying interpretive-historical research method, the critics of architecture under discussion are addressed and the achievements of nature in architecture and in particular structure in academic arena are then pointed out. The survey and analysis with the help of SPSS software is the last instrument used for assessment and evaluation in this research. It should be noted that in this survey, the structural and experimental knowledge of the architect in forms, structures and natural structures were considered as the independent variables, whereas the design skills of architect in the harmony of architecture and structure using more naturalist strategies were considered as the dependent variable. Comparison of previous research with the survey indicates that the failure of Iran’s current architecture for the harmony with structure and better exploitation of nature is due to the incorrect reception of the Iranian public architecture in this area, which is often formed in the area of education. Finally, this research accentuates on the purposeful change in teaching method of technical courses to improve the understanding of the behavior and structures by architects. Suggestions to improve such an important phenomenon in professional workspace are also presented.

Keywords: *Harmony of architecture and structure, structural form, naturalistic architecture, naturalistic structures, structural and architectural education.*

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Introduction

Among the architectural approaches in the present era, relationship with nature has been raised as an important argument, and the effect of this has been reflected in the architectural space at different subjective and physical levels; some have focused on nature from the viewpoint of reason and logic; some others have experienced form and space, and emphasized a semantic relationship with nature; still some others have focused on the interconnected relationship of form and function, abandoned forms with free and natural forms. The other group has also sought for apparent relationship with natural elements e.g. water, rain, wind, and sky etc. in reaching issues such as green architecture, sustainable architecture and so on and so forth. However, in this research, the exploitation of the physical properties of natural elements in the transfer of load and structural purposes is an approach part of which, such as “Karbandi” dates back to several hundred years, and part of which, like “Bionic”, is entirely the product of modern research.

Since any comprehensive insight requires the continuity of thought in the past and in the future (Giedion, 1941), for the sake of better understanding, the challenges posed by the application or non-application of nature and the architectural practices derived from these challenges are discussed and what is more discussed is the reference to geometric forms in a group of architectural works where nature has in particular contributed as a platform for the creation of the work as well as an effective context in the process of the development of structural models and their adaptation to the architectural requirements of the building.

Given the samples studied in Iran and the western world, the usefulness and necessity of inspiration from nature in architectural and structural design has proven to be quintessential. The pathology of the failure to realize this important issue in most of

the architectural works of Iran is the main research question addressed in this research.

Research methodology

In this study, in the first step, using an interpretive-historical research method, with an analytical-descriptive and critical expression, the challenges of architecture and nature in the face of contemporary architectural industrialism were discussed. Then, using case studies and hybrid strategy, while conducting a qualitative study of the cases, the important achievements of this paradigm in modern architecture and afterwards were dealt with. In another step, criticizing two examples close to the subject of the present study, by selecting a statistical society different from those of previous studies, by designing two purposive questionnaires in line with the research hypotheses and by specifying the variables, the survey was carried out and it was processed running SPSS software. Finally, by comparing the results of this study with those found in other studies, the relevant pathologies were examined and suggestions for their improvement were introduced.

Research literature

The article “Teachings of Natural Structures, Lessons for Architects” conducted by, Taghizade Azari (2006), while examining and comparing natural samples and man-made structures, considered the use of natural forms and structures as a solution to the effectiveness of structure, performance and aesthetics (Taghizade Azari, 2006). In the article “Difficulties and Complexities in Teaching of Structural Concepts in Architectural Process: A Case Study over Architectural Schools in Iran”, while investigating the ineffectiveness of existing methods and the reasons for it, guidelines based on student participation and the use of scientific opinions to understand the behavior of constructive systems without the need for computational models for structural training were presented (Taghizade Azari, 2015).

The article "Inspiration from Nature for Effective Education of Static Course in Architecture in Iran" by Shahroudi and others, introduced the use of nature patterns as the best way to teach a static course (Shahroudi, Golabchi & Arbabian, 2007). In their article "Evaluating the growing rate of architecture students understanding of the basic structural concepts via natural principles in comparison with other teaching methods", Ansari et al. conducted a survey and practical sample and concluded that those students who learned Static course using natural concepts, were more successful in analyzing structures. Finally, Ansari, Amirkhani and Okhovat, introduced conceptual modeling of nature as the best method for training structures to architects (Ansari, Amirkhani & Okhovat, 2009).

• The Challenges of naturalism in architecture and structure

The advent of the industrial revolution, the tendency toward engineering, and the subsequent separation of architecture and structure led to the approach of architectural ideas to artistic imaginations (Shahroudi, Golabchi & Arbabian, 2007). The result of this was the gap between science and technique, in other words, between architecture and implementation, as if the designs that were done haphazardly, would no longer considered as a basis for modern architecture (Giedion, 1941). Initially, the use of cast and steel in the structure of buildings and subsequent concrete transformed architecture, and the structure of buildings with a very different shape with the various features made the ground for industrial tendencies and especially structuralism in the field of building.

Structuralism means that some of the structural and sustaining factors that hold the building, such as the beam, the pillar and the arc, play a major role in the architectural form, are indicative of most of the modern architectural styles (Mozayeni, 2007). But the challenges created by this approach and the naturalists quickly set new trends in architecture (Fig. 1).

Although the tendency was initially industrial and mechanical, it was not accepted by some of them too. For example, Le Corbusier (who was an advocate of industrial architecture), interconnected modernism modulation as a fundamental geometric principle with logical numbers and meaningful dimensions for body and human movements (Von Meiss, 1990). Continuing with that, Sullivan and Wright turned to natural forms and organic styles (Ghobadian, 2007). Finally, this nature orientation was revealed in architectural sculpture (Fig. 2, 3, 4); (Banimasoud, 2012).

The changes brought about by modern research greatly influenced architectural trends such as naturalism, structuralism, or new trends in sustainability and ecology to revive the early imperfections of modern architecture. This experienced a more profound

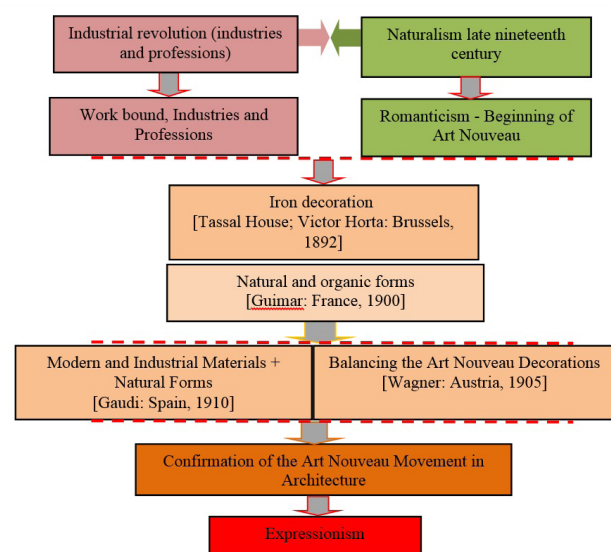


Fig. 1. The influence of industry and naturalism conflict on the rise of art nouveau and expressionism. Source: authors.



Fig. 2. Architectural Sculpture. The Sydney Opera House is likened to sea shellfish and ship sailors. Source: archreport.ir.

growth in the post-modern era, since the need to pay attention to the ecology, inevitably, led man to his nature and his lessons throughout history. In such a situation, it seems that this closeness is much more than what was thought of in post-modern era in such a way that it attracted attention in thoughts such as eco-tech, high-tech, metabolism, organitech, green architecture, dynamic architecture, deconstructive, folding with the themes of indigenous patterns, regionalism, and fractal which was eventually

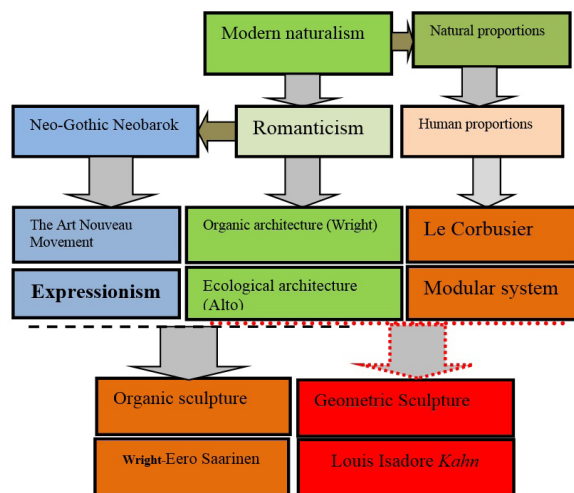


Fig. 3. The relationship between nature and structure and architecture in the early modern trends. Source: authors.

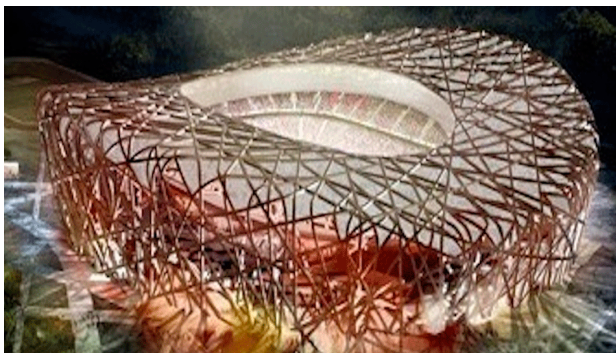


Fig. 4. Bionic Architecture- Olympic Stadium (2008) in Beijing inspired by the bird's nest. Source: Lafafchi, 2013.

flourished in bionic architecture (Rouhizadeh, 2015). The Bionic architecture strives to adapt the nature of the animals to the best of all in terms of the optimal Picture of the building (Portoghesi, 2000). A bulk of the technologies of the second half of the last century can go under the rubric of bionic architecture; inspiration from the role of the flake and the structure of the shark skin in the aircraft “to reduce air friction”, the structure of the lotus hydrophobic nano-species, the structure of the sticky nail of lizard, etc. are examples of such architecture.

In the area of architecture and structure, the Bionic Tower inspired by structural changes in the vegetation, the Montreal Exposition's roof of the strong wings of spider, the Tahoe Woo Station (1989), Lyon City, inspired by the bird's light body, the Beijing Olympic Stadium (2008) inspired from the bird's nest (Fig. 4) and the Kansai airport roof in Japan (1995) inspired by the Eagle skeleton are practical examples of bionic architectural approach. When problems are harder in nature in bionic structural strategies, natural solutions are beautiful, precise, and complicated (Fig. 5). For example, in the structure of the wing of vulture, which must maximize resistance and bearing with the least weight of the structure, the nature solution is extremely interesting and very beautiful in this case; the bone structure forms a spatial and porous network, and thus both the strength and lightness of the structures are being provided. The layer nature of natural structures makes these forms affected by the loadings of the

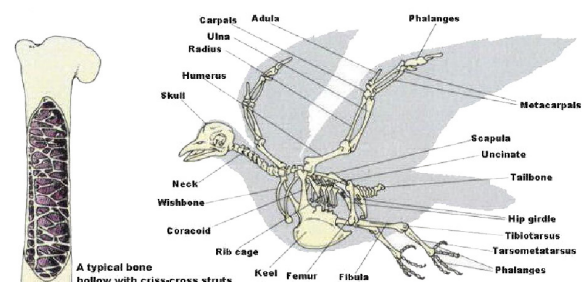


Fig. 5. Bionic Architecture - The structure of the bone of vulture wing (the strength and lightness). This structure was used in the structure of the Kansai International Airport roof. Source: Lafafchi, 2013.

axial shapes, with only tensile or compressive responses (Fig. 6). This natural remedy is also well seen in numerous examples such as wheat stems or trunks of solid trees that are strongly affected by severe winds (Lafafchi & Jahandar, 2013). Tensegrity structure (Fig. 5, 6, 7) is another interesting case in comparison with human skeletal-muscular structure (Golabchi & Khorsand Niko, 2014). Inspiration from nature in trends such as nature-compatible architecture in conjunction with the ecosystem of nature (Kauffman, 1995), metamorphosis (patterned from steep cliffs, often covered with loose or flattened metal plates) (Lynn, 1993) [to formalistic, morphogenetic

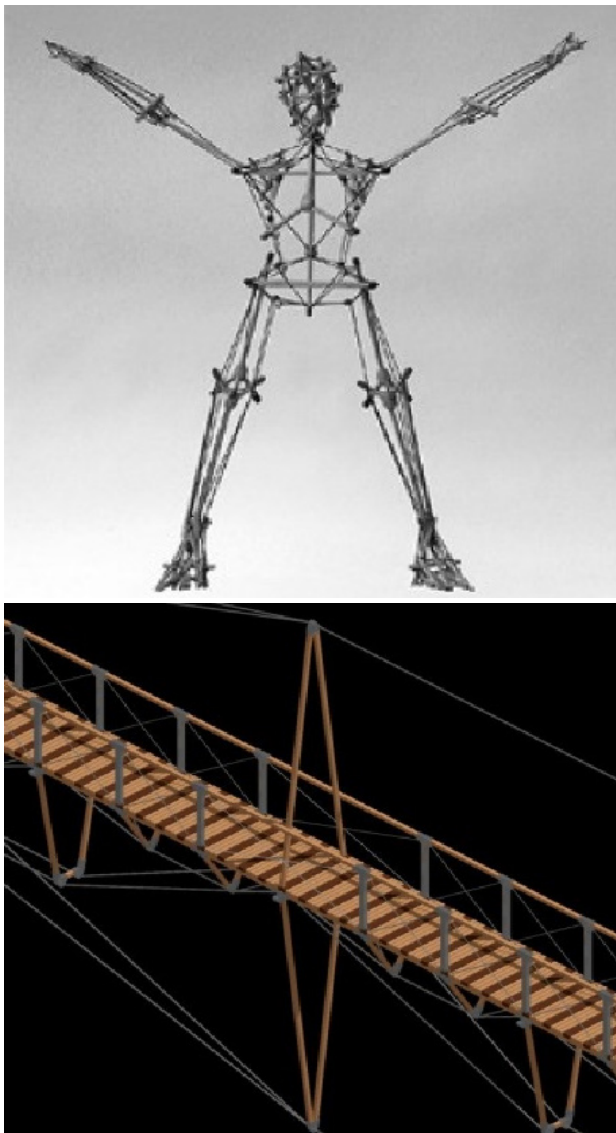


Fig. 6. Comparison of tensegrity structures in a bridge with human skeletal muscular structure. Source: <http://taijiineigong.com/tensegrity-and-taijiqian>.

purposes based on algorithmic structures with biological forms (Stanislav, 2009, and fractal architecture [the peak of nature utilization (Ghobadian, 2007)] experienced new feedbacks (Fig. 8, 9, 10).

The original form of the project has been reconstructed based on the topography of the land.

In summary, attention to the main manifestations of nature has led to the metaphorical-semantic, formal, structural and other metaphorical conceptions, and it can be said that a large number of ideas and concepts of new architecture originate from the attention to the hidden aspects of nature which, in a surprising manner, are revealed through observation and natural reflections (Fig. 11, 12).

The relationship between structure and architecture from the perspective of architects

Structure has always been an essential component of architecture, and as a principle, it is always necessary for man to stamp his architectural structure against destructive loads. But the sense of human beauty always imposes on the structure harder conditions than the conditions of strength and economy (Salvadori, 1995).

Architecture is a logical art and its logic is based on the principles of structure. Understanding architecture without the perception of the sensitivity and response of humans to the material strength, geometry and structures is impossible (Wilson, 1999).

Structure forms the essential part of the form and is like a reinforcement that all non-structural parts depend on it (Macdonald, 1997). Therefore, form is linked to the structure for its continuity and survival, and that an architectural form finds a structural form as well (Salvadori, 1995). In line with this, Pier Luigi Nervi postulates that he was deeply convinced that the apparent appearance of good buildings could not and should not be anything but visual and constructive visualization of an efficient and effective structure. In other words, form of architecture should be necessarily the result of design, not the basis for the design of

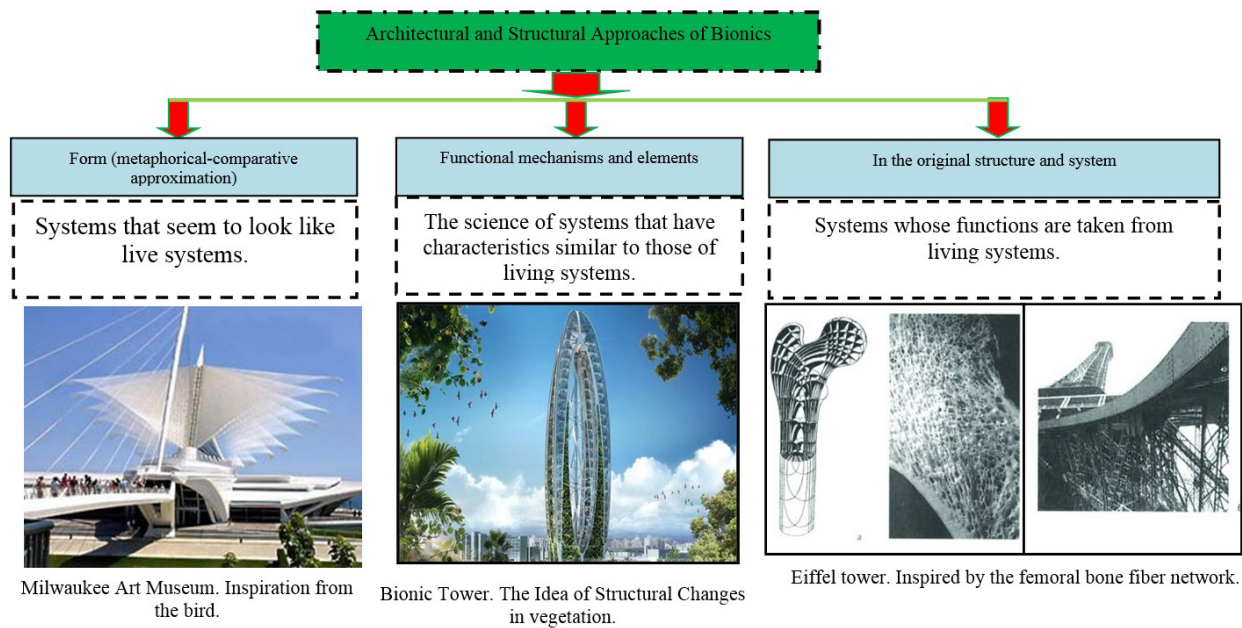


Fig. 7. Architecture and structure interactions with nature in bionics. Source: authors.

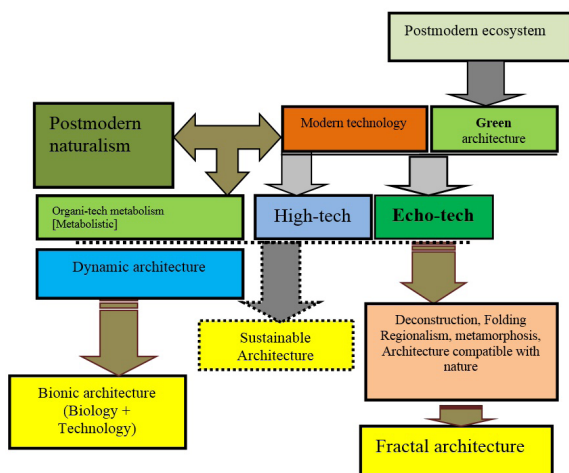


Fig. 8. The relationship between architecture, Technology, and Nature in Postmodern. Source: authors.



Fig. 9. The form of Gallatian Cultural City, Eisenman. Source: www.arcspace.com.

the structure (Charleson, 2005).

The need for the harmony of architecture and structure has long been considered among architects. Marcus Vitruvius for the first time presented an optimal architecture based on three principles of firmitas or stability, utilitas or the proper use, and venustas or beauty. The feasible point of his theory is the priority of having a structure for use and beauty (Capon, 2009).

Gardner argued that architectural and structural interactions were a factor in the success of Gothic architecture, and stated: It must be accepted that the architecture of the Gothic churches, which was mentioned as a modern work, was the product of both theory and technical knowledge (Gardner, 2002).

Viollet-Le-Duc also believed that the beauty of the Gothic churches was due to the fact that even its columns express its structural purpose, and from the perspective that the structures and components of the Gothic architecture are adaptable to the structural architecture of the industrial revolution, they sought to have complex and elegant Gothic architecture (Ibid).

Le-Duc's beliefs about structure as a "formative" were effectively and conclusively sought by Nervi in the 1950s (Charleson, 2005). About the necessity

of the understanding of structural knowledge on the part of architects, he postulates that even when the architects give the final calculations of structures to an expert, they need to be able to create and give the right proportions to it. Only in that context, a structure can have health and possibly beauty together (Salvadori, 1995).



Fig. 10. Inspiration from the form and structure of nature, Doha Education Complex. Source: www.etood.com.

Rob Carrier believes that architecture is determined by the relationships and interactions between structure and form and that form and structures are inextricable. Without structure, there will be no form, so the form associated with the architectural space is also equipped with a structure because the form needs to be constructed for its existence (Shahroudi, Golabchi & Arbabian, 2005).

There is no rationale for architectural brilliance and the non-innovation of engineering, and that structure itself is the basis for creativity (Taghizade Azari, 2015). In this way, the dialogue between the architect and the structural designer is essential; an architect must acquire the necessary structural sciences. It is essential to learn these sciences, especially in the present era, in which structural methods are rapidly developing and have complex behavior; otherwise, the understanding of the features

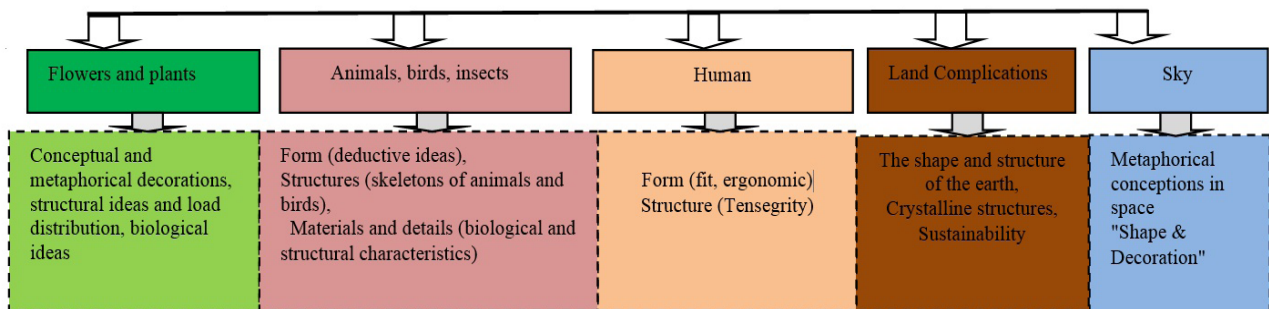


Fig. 11. Overall Patterns of Nature in Architecture and Structures. Source: authors.

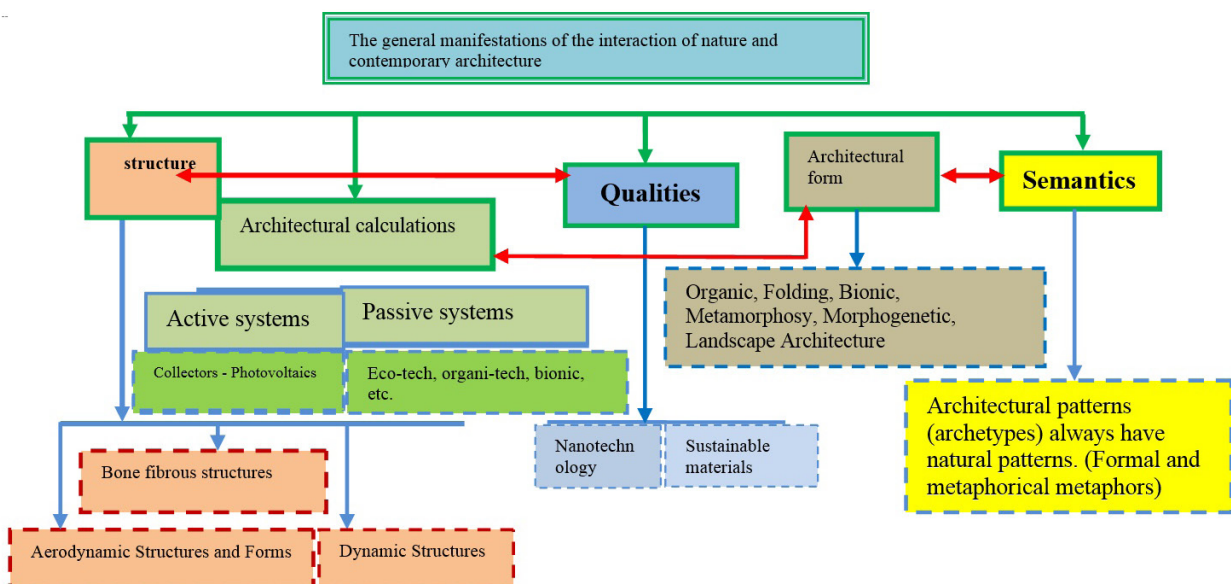


Fig. 12. Effects of inspiration from nature on architecture and structure. Source: authors.

and characteristics of new structures will be impossible, and the architect will be driven out of the contemporary architectural field without the knowledge of the field. (Salvadori, 1995).

From the perspective of Louis Can, today, every architect and every student of architecture is convinced about the importance of structural knowledge, but they consider the acquisition of such science more difficult than what is thought to be. Designing and engineering are intermediaries by which imaginations become reality. About architectural idea, he argues that: "an idea is not an idea unless you know how to make it" (McCleary, 1988). He even considers a structure as valuable, when it plays a role in the creation of space: "A pillar is important because of the role it plays in space, and that is why it serves the space" (Ibid).

• **Structure and architecture, the interaction of naturalism**

Simulation and integration to the environment is one of the important approaches that architects have always been trying to accomplish in architectural designs. Issues such as how to deal with forces, minimization in the use of materials to create the optimal form of structure, the relationship between geometry and structure, the hierarchy of power transmission, etc. exist in nature (Andreas Vesalius, 1543). Alberti considered mathematics to be a common ground in science and art; however, he believed that the artist's ultimate goal, imitation of nature, should be to help with mathematics and use it to create harmony (Capon, 2009). Ruskin compared the beauty of nature with the ugliness of the industrial society, and in this regard, he described the harms from the industry, which damaged open art in art, and rejected the carvings from the industrial era, and expressed the revival of the Gothic (neo-gothic) (Habibi & Maghsoudi, 2002).

Wright, who is basically a naturalist architect, also calls for architectural adherence to structure in an educational and professional arena, and in a speech

in Chicago, addressed the young architects and stated that, "avoid architectural colleges unless you follow structural engineering. Go to workshops to see machines and methods of constructing modern buildings during work" (Mahdavi, 1997). In Waterfall House, he created an indicative sample of the integration of architecture and structure inspiring from nature.

Renzo Piano uses technology in the creation of artistic works, but he has not yet allowed to surrender. He focuses on aspects of humanism in his architectural work. Piano creates structures with a combination of art and technology (Bagha'i, 2009). Santiago Calatrava deals with constructivism to the extent that he states "An artist or architect can tell his message through form and structure over time." His detailed and realistic study shows that he has taken great steps to create harmony between art, engineering and architecture (Golabchi & Khorsand Niko, 2014).

Charles Jencks, in the book entitled *The New Paradigm in Architecture*, states seven trends in contemporary architecture including complexity, inspiration from natural forms, inspiration from structures and data of artificial environments and metropolises, the use of bubble and diamond shapes, the use of indigenous signs and structures, the use of icons related to new cosmology and, ultimately, the creation of vague structures that can be interpreted differently. According to him, these tendencies also include deconstructions. An insight into these tendencies is that they are followed directly or indirectly by inspiration from nature.

• **Inspiration from nature patterns in the design process of structure in the field of education**

In the framework of education, attention has been given to nature both in the West and in Iran. Some samples are discussed here:

Statics course is one of the most basic lessons in the teaching of architectural concepts, which is now presented in most Iranian universities in complex

mathematical form with abstract concepts.

In 1976, the method of teaching theoretical lessons of Statics course at the Faculty of Architecture of the University of California was challenged by students with the theme that static training in terms of methodology was more based on the teaching of the transfer of construct concepts through theoretical courses, this was not an issue for the purpose of educational instruction of architects, even in the absence of empirical and sensory workshops and exercises and did not suffice by making replicas in the lessons of architectural prerequisites, in which creativity and personal experience are involved. Furthermore, presenting their syllabus and sequencing may remain virtually in the early stages of component analysis in terms of the transfer of information and logical concepts “in the same way as in most existing universities,” and that the basic principles will not be transmitted to them, and that they forget what they had acquired too soon (Macdonald, 1997).

The California Statement has been accompanied by changes in the teaching of statics courses at the world's top universities.

1. Using practical equipment and workshop to understand structural concepts without the need for complex mathematical calculations.
2. Using computers and multimedia facilities to understand structural concepts
3. Making replicas on the structures executed in the world for structural concepts
4. Using conceptual modeling and natural structures to teach structural concepts.

In Iran, inspiration from nature to teach statics course has been studied frequently. For example, in a field research (Ansari, Amirkhani & Okhovat, 2009) and in a workshop for one semester to evaluate a more effective way in Static training, three models of “theory training”, “making replicas on projects implemented in the world” and “using conceptual modeling and natural structures for the teaching of structural

concepts” were surveyed. Independent variables of the research were defined based on Bloom Learning Model in the “Cognitive, Emotional, and Psycho-Motion” domains (Bloom, 1967), because in this model, training consists of three areas: scientific and rational perception, sensory relation, and power to use the concepts and knowledge practically.

In order to achieve the desired goal by surveying students and professors on a more appropriate approach, the written answers of the students' end-of-term tests to conceptual questions were analyzed and compared in each of the three groups, and the three patterns were compared (Table 1). In this way, learning the level of learning in the three areas of Bloom model was followed parallel to each other.

The results of Table 1 illustrate the agreement between students and professors and the results obtained from the students' written test of the transfer of concepts through the use of educational models and inspiration from nature as the most effective method in training structural courses for architects. The results of the analysis of variance (ANOVA) also showed that the average of students' responses to questions in inspiration from nature method was significantly more than those in the other two methods. However, based on the findings from the application of theoretical and replica methods, there was no significant difference in the growth of student learning, and the creation

Table 1. Comparison of the views of professors and students regarding the effectiveness of educational methods with the results of written tests. Source: Ansari, Amirkhani & Okhovat, 2009.

Group C- Educational model and inspiration from nature	Group B- Manufacturing of replicas of executive projects	Group A- Theoretical classes	Educational method Sample group
61.1%	43.4%	32.7%	Students' Survey
67.6%	44.1%	41.4%	Professors' survey
76.26%	40.04%	37.5%	Final test results

of the replica of the executive projects, resulted in only the mimics of the appearance of the projects and did not contribute much to the transfer and training of basic concepts (Ansari, Amirkhani & Okhovat, 2009).

In another study conducted by Shahroudi, Golabchi & Arbabian 2007 at the University of Mazandaran, statics course students were divided into two classes for one semester, the first one was trained in a conventional method and the second one selected a subject in nature for studying, analyzing and modeling. The final test questions were divided into two categories, computational and analytical, and the results of the survey report indicated that 70% of all students regarded correct static learning as an important basis for architectural design lessons. 75 percent believe that statics knowledge is involved in the entire design process, but only 20 percent were satisfied with the methods of teaching design process in this course. In response to conceptual questions, on average, students who were trained in nature-oriented method, had a significant difference in the score of 72% versus the average of 22%.

Other achievements of this study are as follows: 75% considered the "use of nature" as very effective in increasing the learning rate of structure. In terms of how to inspire from nature in the training of structures, 83.3% considered "nature analysis" method, 45% "nature Modeling", 37.5% "model testing" and 33.30% the "study" method as a suitable method for inspiration from nature in structural training.

Analysis of the questionnaires and their results

One of the statistics that can be criticized in the second case study is that professional architects and instructors consider the use of nature to be 100% effective in increasing the learning rate of structure, which seems to be due to subjectivity and conclusions in a closed community and it is not definitely generalizable.

What follows from the results of this research is that

the subject matter of structure and the subsequent use of nature in the teaching of structural concepts in the training of architects and in particular the architectural design is not actively pursued. Then, given that the origin of this important matter backs to the graduates and instructors in architecture, one can direct the research toward survey and analysis in this regard. The statistical population of the study consisted of professors (100 faculty members and tutors), architects grades 1 and 2 (about 700 people) and the volunteers of the courses for promotion of engineering system education i.e. a total of about 800 people. In order to achieve the objectives of this study and using Morgan's table, 260 respondents were selected as the study sample

The questionnaire was given to the respondents in two separate sheets and in the setting up of the questionnaire, the structural knowledge of the architect and the experimental knowledge of the architect in natural forms, and structures as independent variables and designing skills of the architect in the field of this research were used as the dependent variable. In the first questionnaire in three packages, each containing several questions of dependent variables without any subjectivity was questioned and in the second questionnaire with the help of illustrations of examples of which the importance of the structure and its natural structures were evident, we again raised the same questions. In the first-type questions containing 6 questions, the role of structure in the process of architectural design was raised, the results of which are presented in Tables 2 and 3.

In the second-type questions which included four questions, the role of nature and the use of its patterns in the formation of the architectural work were questioned (Tables 4 and 5).

In the third-type questions which included four questions, the topic of this research was more emphasized on, and the effectiveness of using nature patterns in structural design was questioned (Tables 6 and 7).

Table 2. Analysis of the role of structures in the formation of architectural work.
First questionnaire. Source: authors.

	Analysis	Number	Percentage	Valid percentage	Total percentage
Valid	Very high	22	6	8.7	8.7
	high	46	12.6	18.1	25.9
	Average	87	23.6	34.3	60.2
	Low	99	27	35	100
	Total	25.4	69.4	100	
Missing	Software	113	30.9		

Tables 3. Analysis of the role of structures in the formation of architectural work.
Second questionnaire. Source: authors.

	Analysis	Number	Percentage	Valid percentage	Total percentage
Valid	Very high	100	27.3	39.5	39.5
	high	109	29.8	43.1	82.6
	Average	40	10.9	15.8	98.4
	Low	4	1.1	1.6	100
	Total	253	69.1	100	
Missing	Software	113	30.9		

Table 4. Analyzing the role of nature and inspiration from its patterns in the formation of architectural work.
First questionnaire. Source: authors.

	Analysis	Number	Percentage	Valid percentage	Total percentage
Valid	Very high	100	27.3	39.5	39.5
	high	109	15.6	43.1	82.6
	Average	40	10.9	15.8	98.4
	Low	4	1.1	1.6	100
	Total	253	69.1	100	
Missing	Software	113	30.9		

Table 5. Analyzing the role of nature and inspiration from its patterns in the formation of architectural work. First questionnaire. Second questionnaire. Source: authors.

	Analysis	Number	Percentage	Valid percentage	Total percentage
Valid	Very high	100	30.6	45	55.8
	high	108	29.5	34.4	90.2
	Average	27	7.4	10.8	10.8
	Low	2	0.5	0.8	100
	Total	249	68	100	
Missing	Software	117	32		

Table 6. Analysis of the role of nature and inspiration from its patterns in the formation of structures; First questionnaire. Source: authors.

	Analysis	Number	Percentage	Valid percentage	Total percentage
Valid	Very high	32	8.7	13.1	13.1
	high	57	15.6	23.3	36.3
	Average	70	9.0	28.6	64.9
	Low	86	0.8	35.1	100
	Total	254	69.9	100	
Missing	Software	112	33.1		

Table 7. Analysis of the role of nature and inspiration from its patterns in the formation of structures; Second questionnaire. Source: authors.

	Analysis	Number	Percentage	Valid percentage	Total percentage
Valid	Very high	127	34.7	49.6	49.6
	high	93	25.4	36.3	85.9
	Average	33	9.0	12.9	98.8
	Low	3	0.8	1.2	100
	Total	256	69.9	100	
Missing	Software	110	30.1		

Analysis and examination of the questionnaires

The results of the three series of questions mentioned in the first questionnaire show that about 73% of architects consider the small contribution of structure to the architect to realize the architectural effect and also about 45% of the architects consider inspiration from nature to form the effective structure form. However, 82.6% think that the use of nature in forms and decorations and the overall architecture is effective. This analytic survey, with the Cronbach alpha coefficient of 0.723 in the first question, which seems more plausible, shows that the present Iranian architects do not have a firm belief in the architect's role in the formation of the original core of the structure, and argue that the role of nature in the formation of architectural works is more appropriate in form and decoration, and that the issue of structure is less important for them; therefore, the results of the survey of the second series of questions did not differ greatly in this regard.

The comparison of the results of the survey in the second questionnaire showed that especially in the discussion of the effectiveness of the role of structure in the formation of architectural effect as well as the role of natural structures in the formation of the structure, the results had a very significant difference with those of the first questionnaire.

Research findings

The summaries and comparison of this research with previous studies provide the following achievements in inspiration from nature in the design of structures in architecture.

• Obstacles and damages

Most Iranian architects do not have a firm belief in the effectiveness of structure in the process of architectural design, so this research at its starting point i.e. the effectiveness of structure in the process of architectural design, suffers from damages let alone the role of nature in this important issue.

In spite of considerable structural exploitations such as Karbandi in the past of Iran, the general perception of architects in inspiration from nature is mostly followed in surfaces and decorations, and this undoubtedly goes back to the field of education as the main reason.

The second survey showed that Iranian architects are keen on exploiting structures based on natural structures, but they do not have much control over their approach.

Given that the challenge posed in the California Statement took 23 years to evolve the structure education in California, this problem, which despite the similar research that has been posed, has still not been resolved in many Iranian architecture colleges.

The origin of transfer, i.e. the dominant graduate architects whether in the field of education (instructors) or in the field of professional activity is problematic, and the current situation is complicated assuming that the subject of education is implemented with all the proposed solutions of previous researches.

• The solutions recommended

Like all previous studies, this research confirmed that the current methodology in training technical courses in Iran for architects in most universities has remained at the first stages of component analysis, and that the basic principles of proper understanding of the structural behavior are not transmitted to them well. Accordingly, changing the content of technical courses and architectural designs from the basic lessons in terms of educational implications seems necessary. Furthermore, an emphasis on the proper understanding of structural behaviors rather than accentuation on abstract and mathematical conventional methods is quintessential. It is evident that this will happen through workshops as well as the use of tools that transfer structural behavior and concepts based on understanding the behavior of structural systems.

Some studies, in addition to suggesting some ways to change the method of architecture training, have

raised content modification, and adding lessons or courses to solve the problem of the separation of structure and architecture [such as the University of Sheffield, UK] (Taghizade Azari, 2015).

Realizing this, in addition to the need to change the method of training, requires the existence of necessary infrastructure in the faculty of architecture, and the multiplicity of architecture colleges without the infrastructure will cause damage to architecture and the failure to address them will result in irreparable losses.

The implementation of this process in one or several universities for one semester does not have any considerable impact; therefore, it is suggested that this change be implemented in a bachelor's degree course from beginning to end in one or more universities, including the subject of this research in all possible courses, and finally, the outputs of the technical design course and its final design be compared.

Considering the challenges posed by the design process in designing an architectural design is undoubtedly the key point of discussion, and therefore the training of instructors of the architectural mastery of the concept of the structure is one of the essential requirements.

The inspiration and learning from nature and the conceptual presentation of structural concepts should not be limited to specific courses of architecture, such as static, and can be considered as a general principle in most architectural lessons in both theoretical and practical aspects.

This study has shown that inspiration from natural patterns, while being the most effective method known in the conveying of structural concepts, is an appropriate axis for creating new architectural approaches in other topics, especially architectural forms and calculations. Undoubtedly, the argumentation of architectural computations in reaching the standards of world-day architecture such as sustainable architecture is not possible without the inspiration from nature. In order to succeed in this, in addition to what was

proposed in the educational system, it is better to focus on specific executive projects where such an objective is more accessible than this, and especially if the issue is addressed in tournaments, the modification will be faster.

Result and discussion

From all four aspects of the study i.e. the study of samples, ideas and views of architects and critics, past surveys and the current survey, one can conclude that the fundamental consideration of a structure in an architectural design process by an architect is an issue that takes architecture from a purely poetic and apparent idea towards a desirable and flawless architecture.

The study and utilization of natural structures in architecture in the form of forms, metaphor and inspiration from the laws of nature in structure discussion can be used in such cases as: the way of coping with forces, the relationship between structures and materials, quantitative use of materials for creating the optimal form of instruments, the relationship between geometry and structure, the power transfer hierarchy, etc. which can be a source for the teaching of the basic concepts of structure.

Initial knowledge or explicit knowledge of design is more or less commonplace in all humans; in other words, the ability to design and even understand different aspects of architectural design, such as aesthetics, structures, facilities, construction sciences, methods of construction, etc. exists in everyone. Therefore, any kind of training in the field of architectural design is in line with the transformation of this basic knowledge into tacit knowledge and skill in the simultaneous creation of architecture, structure, and even other architectural components, and it is better that such process does not put aside its natural base in all its components, because what is important from the analysis of the dominant and permanent effects of architecture is that nature guides have been inseparable in all aspects

of architecture.

Conclusion

As mentioned above, the pathology that can be understood from today's architecture of Iran in terms of integration of structure and architecture in the process of architectural design is a problem that was previously addressed in the Western world and they sought to repair it in two axes of professional workspace and university. The key to this is the success of architects and architectural practices that, while focusing on the structure, have, directly or indirectly, placed nature at the heart of their design.

Undoubtedly, the Iranian educational system needs to be fundamentally revised in method and content structure, but in order to succeed, it is necessary to train and transfer this important issue in the professional field by providing workshops as well as in executive projects through tournaments and so on.

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