Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 131 (2015) 651 – 660
Procedia Engineering
www.elsevier.com/locate/procedia

World Conference: TRIZ FUTURE, TF 2011-2014

Investigation about the feasibility and impediments of TRIZ application in architectural design process

Sajjad Nazidizaji[a]*, Ana Tome[a], Francisco Regateiro[a]

[a]*Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*

Abstract

Research about new methods in architectural design process can expand design researches. Structured design methods can make design more learnable and teachable. This study is an attempt to draw a framework for research about application of TRIZ theory in architecture in terms of wicked or ill-defined problems.
This investigation reflects the applications of basic concepts and theoretical foundations of TRIZ such as technical systems, ideality, evolution of systems, contradictions, Su-field and ARIZ algorithm in architecture. For spatial configuration, redefining parameters and principles is proposed. We concluded that further concepts of ideality and levels of innovation should be defined specifically for architecture.

Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC

Keywords: TRIZ, architecture, design process, organized creativity, design research, architecture education;

1. Introduction

Creativity is ubiquitous in all areas of science, art, and culture. Since architecture is a combination of art and technology, the study of the creativity subject is somewhat more complex than in other fields. The most influential architects in architectural history did not tend to talk about the design process and idea formation in their minds. Historically, while the discussions and debates about creativity after the destructions by World War II- in order to increase production quantity and quality for nations- had started in the late 1950s, architects were away these meetings

* Corresponding author. Tel.: +351-927-626-665.
E-mail address: sajjad.nazidizaji@ist.utl.pt.

Peer-review under responsibility of the Scientific Committee of TFC 2011, TFC 2012, TFC 2013 and TFC 2014 – GIC
doi:10.1016/j.proeng.2015.12.344

and conferences. So, addressing the issue of creativity in architecture and research about architectural design started later than in other fields [1]. Research on organized and algorithmic methods and creativity in architectural design has been addressed in recent years in some universities around the world. Like in any other field also in architectural process, the more organized process the more teachable and learnable. Furthermore, by making the design process more structured, the evaluation of design will be easier. Considering different interconnected factors influencing the architecture design such as the client, society, culture, space, form, aesthetics and technology, précising definition of the problem in the architecture seems too complex.

Research about the application of TRIZ theory (theory of inventive problem solving method) in the architecture has attracted less attention than in other disciplines. Mann [2] explains the results of training TRIZ to students by four samples of student works. In his earlier research, he was trying to find specified examples for 40 TRIZ principles in architecture [3]. In another research [4], he emphasize more on foundations of TRIZ such as contradiction, Ideality, function and using resources. He also has used four design problems including window, ramp lifetime home and staying warm. He also explained TRIZ theory mainly deals with the topic of evolution [5].

Salamatov [6] outlined five-level innovation in the art. Ruey-Sen [7] has investigated about TRIZ application for the improvement of heat insulation for roof steel plates. The author has tested his theories by experimental method, creating examples and measuring the temperature inside and outside. Kankey [8] has discussed about improving the acoustics in a historic building by using TRIZ. The author has used a theoretical approach to study the subject. Padmanabhan [9] has stated and solved the problem of increasing wind power in buildings using TRIZ Tool in urban areas by an experimental method. Rantanen [10] has tried to explain the concept of accessibility in houses by 40 principle of TRIZ. Other authors have analyzed construction inventive patterns based on TRIZ method [11] and Chang [12] has studied emergent problem-solving in construction with TRIZ. Hamed [13] in his research report has scrutinized key concepts of TRIZ: Contradiction, Resources, Ideality, Patterns of evolution, Innovative principles. He has investigated the design process of some examples such as mosquito trap and an automatic seeding machine. He has studied all mentioned concepts in several design fields [13].

Basically, previous studies conducted in the subject matter of TRIZ application in architecture, are divided into several categories: A - Architectural design; B – Design; C - Design of building components (e.g. doors, windows, ramps); D - Solving specific problems in buildings (e.g. isolation, wind affects, acoustic); E - Devising new methods in the construction process.

The references about the feasibility of TRIZ application's in architecture can be divided into four categories: 1) design process and architectural design methods; 2) TRIZ theory, history, applications and evolution of TRIZ theory; 3) architectural design and TRIZ applications in the arts; 4) evolutionary history of architecture spaces and buildings.

The motivation of this study was examining application of an inventive problem solving method in architectural design and estimates its probable advantages in comparison with other design methods as well as organized architectural design methods. Research about creativity in the field of architecture and architectural design process and methods are relatively new, however, it is a challenging and controversial area. Architectural designers have designed in highly different ways. Even the methods of architectural design throughout history have undergone many variations. The application of a theory that has been produced in other areas in the architecture is highly controversial. Most of the design methods used in architecture were born inside the field. Architecture has its unique features and qualities. Unlike other products, architecture users just do not simply use it, but they live and work inside of it and interact with it. The concept of space in architecture considering its psychological attributes makes it a more complex issue. Form and function are just two needed factors for building among many factors.

This study aims to investigate the feasibility and impediments of TRIZ application in the architectural design process. The few researchers of TRIZ application in architecture have focused on finding case examples for 40 principles instead of dealing with TRIZ theoretical foundations. This work will reflect about some questions: is TRIZ an appropriate approach and method for architectural design or not? What obstacles and problems will occur within the application of this method in architecture? How can the contradiction matrix and engineering parameters and 40 principles be applicable in architecture? Considering the special characteristics of the architectural parameters, are the 39 engineering parameters directly applicable or should be defined and developed architecture-specific parameters? How architectural problems should be considered to be solvable by TRIZ method? How should be considered the concepts of creation, form production, space planning and interaction between different spaces in the process of TRIZ application in architectural design? What would be the advantages of the application of TRIZ method to the architectural design learning? Is application of the TRIZ different in the design of buildings with different functions, such as residential, commercial, educational, health and cultural?

2. Design definitions, design science and architectural design

Many different definitions have been proposed for design. Based on some definitions every kind of human activity is categorized in design. Certain definitions define design as plan, in some others design as the art work and some of the definitions provide an intermediate concept [14], [15].

Some researchers have defined specified boundaries between design and science [16]. “Also design research is not a social science, nor a natural science. It is a philosophical enterprise” [17]. In another study comparing the design process and scientific method has been criticized. “However, it was clear even then that designers could not hope simply to copy the scientists' method, since designers and scientists have radically different interests and goals. As Gregory himself noted, 'the scientific method is a pattern of problem-solving behavior employed in finding out the nature of what exists, whereas the design method is a pattern of behavior employed in inventing things of value which do not yet exist. Science is analytic; design is constructive”[18]. Others emphasize that the process of design is the same whether it deals with the design of a new oil refinery, the construction of a cathedral or the writing of Dante’s Divine Comedy [19].

Despite some similarities in the various fields of engineering and architectural design, there are also obvious differences between them. The main reason for this difference can be searched in the difference between the expected outcomes.

3. Problems and problem solving in architecture

The term problem solving is used in many disciplines, sometimes with different perspectives, and often with different terminologies. For instance, it is a mental process in psychology and a computerized process in computer science. Problems can also be classified into two different types (ill-defined and well-defined) from which appropriate solutions are to be made. Ill-defined problems are those that do not have clear goals or solution paths, while well-defined problems have specific goals and clearly defined solution paths [20]. Planning problems are inherently ill-defined [21].

There is no natural end to the design process. There is no way of deciding beyond doubt when a design problem has been solved. Designers simply stop designing either when they run out of time or when, in their judgment the object is defined. Design problems cannot be comprehensively stated. A design problem can have an inexhaustible number of different possible design solutions. Various design problems have also different generators such as employers, user etc [19].

On the other hand, usually the various components of the design process in architecture cannot be completely separated.That means we cannot design first site plan then form of building then spaces and so on and designers do not proceed in such way. Therefore, prioritizing the various components of the design process is not enough for the design solution. In other words, design process is not just a knowable process, it is a practicable process. The designer, based on the previous knowledge and experience, achieve design skills. Designer experience in the previous project can be effective for the later. Design for industrial building components (including window furniture design) and their relationship to each other can be helpful. For example each of these sub-problems can be solved in several ways.

But ultimately the composition and the choice of which of sub-solutions can be matched with other sub-solutions may be more complicated. By the way design of building components in typical projects usually is not architect responsibility and architect should choose from available designed components in the market. But in more specific projects, the architect also design the components, in some projects architect also design the chair furniture, even the door.definition of design can effect on procedure. For instance in industrial buildings all the components are designed and constructed off-site and are assembled on-site. Defining the architecture components and the factors also can help précising the problems definition.

4. Research approaches and research methods

Design Research emerged as a recognizable field of study in the 1960s, initially marked by a conference on Design methods [22]. The first major design researches started after a decade of Altshuller first book printed in Russia. According to design researchers there are several methods for research in design and particularly about architectural design. These methods include interviews with designers, observations and case studies, protocol studies, reflection and theorizing, simulation trials [23] . However, the term 'design science' is still treated with skepticism. Some do not believe design to be a topic suitable for scientific investigations and point at the differences between design and science. Others point to the fact that the term science is often used to refer to the natural sciences, thus leading to comparisons that fail to recognize the specific characteristics of design and its research [24].

4.1. Research approaches and methods about TRIZ application in architecture

We may find three kinds of approaches to TRIZ application in architecture:

a) Repeat of Altshuler method in architecture

One approach and method for investigation about the application of the TRIZ in architecture is modeling, and re-apply same method that Altshuler applied for evaluation and classification of patents by thousands of hours. Unlike the patents that there are some centers for registration and classification in the most countries, and there is copy right regulation about them, in architecture situation is different. For example in most countries, there is not a specific database of evaluated and ranked architectural designs. basically there are no truly clear criteria for identifying innovative level of architectural designs. Some researches are in progress in this area that shows the level of innovation in the architectural designs is dependent on referee opinion and taste. In architecture, besides the functionality, aesthetic and cultural issues and users` taste strongly affects the design process.

Therefore, the selection of architectural buildings for research will be an extremely challenging issue, unless define criteria for architecture innovation level and select buildings based on these criteria. But it is difficult to find this kind of agreement about criteria between architects. Some of the criteria can be searched in purpose and methodologies of well-known architectural prizes. For example, Pritzker prize that awards each year and is almost the most important international architecture prize, has mentioned its purpose in its website: "To honor a living architect whose built work demonstrates a combination of those qualities of talent, vision, and commitment, which has produced consistent and significant contributions to humanity and the built environment through the art of architecture"[25]. Other international architecture prize, including AIA Gold Medal and RIBA Royal Gold Medal has emphasized too, the contribution to international architecture and humanity affairs. However, in most cases, the details have not been mentioned and referees opinion based on the events and the international priorities in the time of awarding play an essential role.

By the way in lack of registered databases, referring to designs that awarded internationally will be relevant. On the other hand, Unlike the methodology that was used by Altshuler, that was based on patents and intellectual patterns hidden in them, general tendency of design researchers, in recent years, is to inquiry about the mind and how designers think [19],[26],[27]. One of the main design research methods is protocol analysis that is based on monitoring designer's activities during design. Although some researchers have tried to find patterns by typology of existed buildings. One of these approaches is the theory of pattern language by Christopher Alexander [28].

b) Applicability of TRIZ principles in architecture without any changes or modify

Another approach is to use TRIZ in architectural theory without any changes. According to this approach we will try to test if TRIZ is completely applicable to architectural design process. In this approach, we define technical system, concepts of Ideality and contradiction and resources in architecture, and we apply Contradictions and 39 engineering parameters in contradiction matrix and 40 TRIZ principles. Comparison studies can be done between this method and other methods in terms of learning and outcome of design.

c) Mixed approach

Architecture, besides artistic aspect, due to technological characteristic, also can be categorized in the engineering field. Therefore, many of the engineering parameters used in the TRIZ method will be applicable in architecture directly. In this approach, by using case studies concerning different types of functional buildings, we can extract some special parameters for architecture and by the same method we can define contradictions, which in some cases may be specific for architecture.

Finding commonalities and differences between architectural parameters and engineering parameters we can reorganize contradiction matrix and in the same way 40 or more principles usable in architecture. Also in this method, the accuracy and insight into all aspects of architectural design and case samples are needed. Improper definition and use of architectural parameters and commonalities and differences with existed 39 parameters make whole method useless.

5. Buildings as technical systems

Everything that performs a function is a technical system. Any technical system can consist of one or more subsystems [29]. A system is a set of orderly interacting subsystems intended for executing specific functions. It possesses behaviors and properties that cannot be reduced to the behaviors and properties of its separate subsystems [30]. All subsystems are interconnected with each other within the bounds of the higher system. Changes in any one subsystem can produce changes in higher, super systems. When solving a technical problem always consider interactions of the existing technical system with those systems above and below it. In addition, technical systems are like biological systems. They are not immortal. They emerge, ripen to maturity, and die-only to be replaced with new systems [29].

All designed buildings in architecture (e.g. houses, office buildings, hospitals, schools, public buildings, stores, airports) are technical systems that each of them has sub-systems and super-systems. The super-systems of buildings are high-rise towers or neighborhoods. Also neighborhoods are sub-systems from bigger systems such as regions and ultimately city. In a city, changes in one of the regions influence the other regions. This type of perspective can make urban and architecture concepts closer.

Also, every building is composed of different spaces that are sub-systems. Mechanical and electrical installations are other types of house subsystems. Each of subsystems interacts with others but in the architecture, the most complex and important subsystems are spaces and their performance and interrelationships and their interactions with each other and with the physical components of the building.

6. Levels of innovation in architecture

Altshuller defined 5 levels of innovation [29], [31]. He analyzed 14 classes of inventions from 1965 to 1969. He also classified that respectively 32, 45, and 19, below 4 and below 0.3 percent of patents in levels 1 to 5. In architecture Christopher Alexander's that is the creator of pattern language in architecture in his book [32] states that throughout history, people have lived in the houses that they were constructing and renovating houses themselves, they were modifying the problems that had experienced in the previous house. Thus, new houses had a slight modification in comparison with previous one and these patterns were repeating frequently.

Altshuler has presented above mentioned percentages based on statistical and qualitative investigation of patents. Patents usually deal with an engineering problem solving process. In addition to, based on copy rights in the most countries patents are registered in a special organization. As mentioned before, about the architecture such a database is rarely found. But perhaps by investigation about designs that have awarded international prizes, the same 5 levels and percentages are achieved. Many researchers apply the 5 levels of innovation in the same way that Altshuller arranged. Maybe it is reasonable in engineering fields but about artistic, humanities and architecture fields the problems are wicked. This difference is due to the difference of problems nature in engineering, art and architecture. Patents are solving problems that the most people worldwide are dealing with it, but the design in architecture is based on needs and even taste of clients.

In the field of engineering and science, level of innovation can be evaluated by measuring these factors: this solution has solved what kind of problems and what degree of importance and for how many people? In other words, quantitative approach is acceptable.

In architecture determining about innovation level is more complicated. in specifying innovation level, with increasing innovation level, increases using different industries and science area, if the architecture is a domain that inherently uses many different areas of the technology, industry, art even psychology. Even at the simplest level of architectural design, we need to use acoustic, lighting, mechanic, anthropology, psychology and sociology etc.

The definition of architecture has changed significantly before and after modern era. In pre-modern times architect was the designer and builder of the building, there was no artificial light and mechanical installations. The architect's role has changed; in the modern era technology has had a significant impact on the architecture. Modern, postmodern, high tech and echo tech styles have been existed. Many of architectural styles are influenced by philosophical and technological advances.

It is not clear that fundamental changes in architecture must take into account technological progress or philosophical changes and even is the vocabulary of development suitable vocabulary for such changes in architecture or not. By the way, like any other system, in history of architecture, high levels of innovation have been used. Invention of domes to cover spans, Great construction techniques of Pyramids, methods for moving large rocks and lifting them, invention of the wind towers to cool buildings in desert areas, etc.

also vernacular styles of architecture in each country and styles of architecture after the industrial revolution have high levels of innovation. Here we mean the building or architect that was the starter of the style. Although modern architectural styles influenced by the industrial revolution and philosophical movements, but even applying new technology or new philosophy in a building for the first time is a high level of innovation.

7. Law of Ideality in architecture

The concept of Ideality has its root in philosophy, where it refers to the status of ideas and pattern "per se" in metaphysics. The famous German philosopher Immanuel Kant discussed the Ideality of Space and Time [30]. The law of ideality states that any technical system, throughout its lifetime, tends to become more reliable, simple effective – more ideal. Every time we improve a technical system, we nudge that system closer to ideality. It costs less, requires less space, wastes less energy, etc.[29]. The ideal system is the one that has all the useful features and functions of the original system, but has no weight, no volume, requires no labor, no maintenance, consumes no energy. The ideality equation is: $\text{Ideality} = \sum\text{Benefits}/(\sum\text{Costs} + \sum\text{Harm})$ [33].

In TRIZ, Ideality applications include the ideal system, ideal process, ideal resources, ideal solution, ideal method, ideal machine, and ideal substance. Ideality in TRIZ has been described [1-5] in the following way [30]:

"1- The ideal machine has no mass or volume but accomplishes the required work. 2- the ideal method which expends no energy or time but obtains the necessary effect in a self-regulating manner. 3-The ideal process which actually is only the process result without the process itself: momentary obtaining of a result. 4- The ideal substance which is actually no substance (a vacuum), but whose function is performed. 5- The ideal technique which occupies no space, has no weight, requires no labor or maintenance, and delivers benefit without harm, etc., and "does it itself," without any additional energy, mechanisms, cost, or raw materials"

Based on some effective factors in architecture (concept, form, space, aesthetic, view, privacy, accessibility, structure, lighting, heating and cooling, geometry, design process, construction process, materials, energy consumption) Ideal building may be defined as a building that:

The occupied area in the urban area is zero and in the same time limitless interior space. It is beautiful from point of view of people from all over the world. When individuals are inside the building, in all spaces have view to all directions, at the same time there is no view from the outside to inside and creates the highest degree of privacy (or highest degree of control on privacy).

1-Its lifetime is infinite, and it does not require any maintenance and cleaning. Can be adapted for new needs always when is as necessary (maximum flexibility degree). 2-Distance from all parts of the city to this building is zero (highest level of accessibility). 3-Its wall thickness is zero, and at the same time there is no exchange of heat and cold, and sound with outdoor. Its energy consumption is zero. 4-Weight is zero and is resistant against all horizontal forces (the wind and earthquake in any degree). 5-It is compatible with all lifestyles and with all of human culture. 6-Needed time and expenses of design and construction is zero. 7-Ideal architectural form is a form that has infinite interior space, zero lateral area, and by material with zero resistance creates complete resistance against forces. Recent researches and designs are moving toward ideal building. Sustainable architecture, green buildings, smart materials including self-healing and self-cleaning materials,[34] ,the zero-energy buildings [35], intelligent facades, fire-proof materials are in this group. Precise definition of ideality in architecture can present better criteria for referee of architectural projects. Maybe it can be said the more ideal building, the more contribution to architecture.

8. evolution of technical systems

Studies of the history of innovation have shown that many improvements follow similar patterns [36]. In problem solving, knowing the patterns helps you to go from the features of the ideal final result to concrete solutions. In situations where the contradictions are hard to see, understanding the patterns helps you see how the system is evolving. If we see how the system will evolve, we actually know the solution to the problem; in this way, the solution can be developed without contradiction analysis [33].

Like any other system architecture has evolved over thousands of years. Caves, tents, houses dug into the mountains, and skyscrapers show the evolutionary path. The evolution of the architectural space has been from one space as shelter to one multiple functions space. Then evolution of life style made up multi-spaces and multi-functional systems: public and governmental buildings, office buildings, hospitals, terminals, airports and factories, for instance. Before the invention of the drawing representation systems (that occurs during renaissance age) the architect was the foreman supervising the building works. There was no artificial lighting and heating and cooling systems, and traditional architects by their innovation have been solved heating and cooling and lighting problems. We can follow the evolution concept in different aspects of architecture such as material, space, structure, ornaments, and form of building and even in buildings elements such as roof, walls, floors, entrance and windows even in architectural sub-systems and super-systems.

Altshuller [29] established eight patterns and 24 trends of technical systems evolution. Eight patterns are as below: 1-life cycle; 2- dynamization; 3-multiplication cycle; 4-transition from macro to micro level; 5-synchronization; 6-scaling up or down; 7-uneven development of parts; 8-replacement of human.

9. contradictions in architectural problems

Throughout the history of human knowledge, there have been two conceptions concerning the law of development of the universe, the idealistic conception and the materialistic conception, which form two opposite world outlooks. TRIZ ideology is based on two major ideas: Contradiction and Ideality. Contradiction is the basic law of materialist dialectics, whereas ideality is the essence of idealism [30]. One of the early insights of the TRIZ researchers was that solving a problem meant removing a contradiction [36]. The most effective solutions are achieved when an inventor solves a technical problem that contains a contradiction [29]. There is another type of contradiction: physical contradiction –it appears when two opposite properties are required from the same system.

But what kind of contradictions are there in architecture? How can we classify contradictions in architecture? We want a large window to have a better view to the outside and landscape and more natural light, but a large window increase heat exchange with outdoor environment, and this is not desirable. In buildings, depending of the geographic location, light of the west side could be annoying. On the other hand, maybe we need the western side view and maybe there is a beautiful scene there. We want and we do not want this window at the same time.

In terms of accessibility, for occupation less land and have a better accessibility we build a city in height, but we face more risk about forces of wind and earthquake. We want to build a larger house, the bigger house, the more material and more weight. We design bedrooms far from the entrance for privacy, but rooms become less accessible. For easier access to the building, we design entrance in two or three sides, at the same time safety and security decrease.

10. The Su-field and standard solutions

Substance-Field (Su-field) Analysis is a TRIZ analytical tool for modeling problems related to existing technological systems. Every system is created to perform some functions. The desired function is the output from an object or substance (S1), caused by another object (S2) with the help of some means (types of energy, F). The general term, substance has been used in the classical TRIZ literature to refer to some object. Substances are objects of any level of complexity. They can be single items or complex systems. The action or means of accomplishing the action is called a field. Su-field Analysis provides a fast, simple model to use for considering different ideas drawn from the knowledge base [37].

The space concept is nuclear in Architecture. For forming Su-field model in architecture S1 can be first space and S2 can be second space. The spatial system can be understood thermodynamically in terms of exchanges of mass and energy, both internal and with external environment as interact thermally. So, fields types may be classified differently, e.g., mechanical, chemical, electrical, magnetic, and gravitational. The Social Logic of Space theory [38] should be considered in this model in order to describe the structure of the spatial systems, its properties and its relationships with the users groups that inhabit them. Given the complexity of the built environment, it is proposed that in Su-field analysis a space should be considered with all components that contribute to define it.

The 76 standard solutions are useful for level three inventive problems [39]. Level 3 inventions significantly improve existing systems, and represent 18% of the patents. Typically, the 76 standard solutions are used as a step in ARIZ, after the Su-field model has been developed and any constraints on the solution have been identified [40]. By assuming spaces with their formative components and their interactions as substance and field, standard solutions can be applied in spaces designs. After define and clarifying innovation levels in architecture we can specify that in which levels these solutions are more applicable.

11. ARIZ

ARIZ is the central analytical tool of ARIZ. It provides specific sequential steps for developing a solution for complex problems [29]. In the first steps of ARIZ the problem should be analyzed. In the next steps Ideal Final Results (IFR) should be formulated and Su-field model should be used.

In other hand, planning and design problems are wicked problems [21]. There is no definitive formulation of a “wicked problem" and also wicked problems have no stopping rule and solutions to wicked problems are not true-or-false, but good-or-bad. Ideal Final Result (IFR) concept in architecture is controversial. Ideal final result may be different for different people including designers, users and clients.

Comparison of steps of ARIZ algorithm and characteristics of wicked and ill-defined problems, about TRIZ application in architectural design problems are controversial and also based on some authors [21], design problems cannot be solved algorithmically.

12. Conclusion

Efforts to understand the design methodology and even creating new design methods lead to improve outcomes of the design process. Furthermore making the design process more organized makes it more understandable for design students and novice designers and makes the design more learnable and teachable. Scientific research about design is a recent one (1960). For the development of design researches, it is necessary to examine and assess the feasibility of different design methods and problem solving techniques. TRIZ is a problem solving methodology with application in various fields and has been widely studied over the past 20 years. Its applicability in architecture can create new horizons especially for education of design.

This study is an attempt to draw a framework for research about the application of TRIZ in architecture. In this study feasibility of the application of TRIZ in architecture has been studied. This investigation deals with the fundamental concepts and theoretical foundations of TRIZ in architectural design. The obtained results are as follows:

1- Definitions of design should be considered carefully, many different definitions exist for the design, and so for the use of a new method in design, we should have a more specified definition of design. 2-According to some researchers design and planning are wicked or ill-defined problems and for solving these kind of problems one of the important issues are contradictions that are also considered in TRIZ but another main factor in these kind of problems involve stakeholders with different perspectives, and have no "right" or "optimal" solution, that are not considered in TRIZ theory. Problem shaping has a great effect on its solving. 3- To evaluate the applicability of the method in architecture, concepts and components of the architecture and their function should be defined in more specified way. 4- Cultural, psychological and social concepts of the architectural design are the main challenges for TRIZ application in architecture. 5- Architectural buildings are technical systems and the space concept is nuclear in that context. 6- In terms of systems evolution, evolution of architecture because of its technological aspects is similar to other engineering fields, but evolution of spaces and their interaction with users should be considered by further researches and even probable evolution principles should be extracted. 7- Levels of innovation in architecture have not distinct criteria, as well as lack of specified data bases for architectural works is an obstacle for research on case studies; for any use of the TRIZ, innovation levels in architecture must be redefined. 8- Ideality concept in technological aspects of architecture is similar to engineering, but about artistic aspect, ideality has not a specified definition. 9- Contradiction in design of elements and details of architecture are very comparable to engineering problems, thus 39 parameters and 40 principles can be used but for space-use-form design and their interactions, specific parameters for architecture should be redefined. 10- Research methods of design researchers and TRIZ specialists are somewhat different, while most design scholars focus on design thinking and how designers think, creating of TRIZ theory has been based on patents and constructed samples. For creating an effective research method, both perspectives should be considered.11- for using Su-field model, whole space with all elements that form space can be assumed as S1 and S2. 12-characteristics of design wicked problems do not match with ARIZ steps completely.

For future researches, it is proposed that by taking advantage of case studies and design research methods (recurring to interview with designers) focus on innovation levels and ideality. As well as through the aforementioned methods and more samples, commonalities and differences of parameters in architecture and engineering should be extracted. These researches are in progress through defining a PhD thesis about TRIZ application in architecture.

References

[1] Antoniades, A.C., *Poetics of architecture: theory of design*. 1990: Van Nostrand Reinhold.
[2] Mann, D. and C.Ó. Catháin, *Using TRIZ in Architecture: First Steps*. 2005.
[3] Mann, D. and Ó. Catháin, C.,'40 Inventive (Architecture) Principles with Examples'. The TRIZ Journal, 2001.
[4] Mann, D.L. and C.C.Ó. Catháin, *Computer-based TRIZ—Systematic Innovation Methods for Architecture*. 2001, Springer. p. 561-575.
[5] Mann, D. and C.O. Cathain, Systematic Innovation Methods For Architects.
[6] Salamatov, Y., et al., *Triz: the Right Solution at the Right Time: A Guide to Innovative Problem Solving*. 1999: Insytec.
[7] Chiu, R.-S. and S.-T. Cheng, *The Improvement of Heat Insulation for Roof Steel Plates By Triz Application.* Journal of Marine Science and Technology, 2012. **20**(2): p. 15-24.
[8] Kankey, A. and M. Ogot, *Improving the acoustics in a historic building using axiomatic design and TRIZ.* The TRIZ Journal, 2006.
[9] Padmanabhan, K.K., *Study on Increasing Wind Power in buildings using TRIZ Tool in Urban areas.* Energy and Buildings, 2013.
[10] Rantanen, K., *Homes for Strong Families, Children, Seniors and All Others. How Universal Design, Design for All and Forty Principles of TRIZ Enforce Each Other.* TRIZ Journal, May, 2005.
[11] Cheng, S.T., et al. *Analysis of Construction Inventive Patents Based on TRIZ*.
[12] Chang, P.-L., et al., EXPLORING UNDERLYING PATTERNS OF EMERGENT PROBLEM-SOLVING IN CONSTRUCTION WITH TRIZ.
[13] Hamed, H.S., *application of triz theory to solve design problems*. p. 152-152.
[14] Alexander, C., *Notes on the Synthesis of Form*. Vol. 5. 1964: Harvard University Press.
[15] Simon, H.A., *The sciences of the artificial.* Cambridge, MA, 1969.
[16] Farrell, R. and C. Hooker, *The Simon–Kroes model of technical artifacts and the distinction between science and design.* Design Studies, 2012. **33**(5): p. 480-495.
[17] Östman, L.E., *Design theory is a philosophical discipline-Reframing the epistemological issues in design theory.* Design System Evolution–EAD 06 proceedings, 2005.
[18] Cross, N., J. Naughton, and D. Walker, *Design method and scientific method.* Design studies, 1981. **2**(4): p. 195-201.

[19] Lawson, B., *How Designers Think*. 2012: Taylor & Francis.
[20] Schacter, D.L., D.T. Gilbert, and D.M. Wegner, *Introducing psychology*. 2009: Worth Publishers.
[21] Rittel, H.W.J. and M.M. Webber, *Dilemmas in a general theory of planning.* Policy sciences, 1973. **4**(2): p. 155-169.
[22] Bayazit, N., *Investigating design: A review of forty years of design research.* Design Issues, 2004. **20**(1): p. 16-29.
[23] Cross, N., *Natural intelligence in design.* Design Studies, 1999. **20**(1): p. 25-39.
[24] Blessing, L.T.M. and A. Chakrabarti, *DRM, a Design Research Methodology*. 2009: Springer London, Limited.
[25] *The Pritzker Architecture Prize*. [cited 2013 6 May]; Available from: http://www.pritzkerprize.com/.
[26] Lawson, B., *Design in mind*. 1994: Butterworth Architecture London.
[27] Johnson, J., *Designing with the Mind in Mind: Simple Guide to Understanding User Interface Design Rules*. 2010: Elsevier Science.
[28] Alexander, C., S. Ishikawa, and M. Silverstein, *A pattern language: towns, buildings, construction*. Vol. 2. 1977: Oxford University Press, USA.
[29] Al'tsuller, G.S., L. Shulyak, and S. Rodman, *40 Principles: Triz Keys to Innovation*. Triztools, V. 1. 1997: Technical Innovation Ctr.
[30] Savransky, S.D., *Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving*. 2002: Taylor & Francis.
[31] Al'tšuller, G.S., L. Shulyak, and S. Rodman, *The Innovation Algorithm: TRIZ Systematic Innovation and Tecnical Creativity*. 1999: Technical Innovation Ctr.
[32] Alexander, C., *The Timeless Way of Building*. Center for Environmental Structure Series. 1979: Oxford University Press.
[33] Hamed, H.S., *application of triz theory to solve design problems*, 2010. p. 152-152.
[34] Addington, M. and D. Schodek, *Smart Materials and Technologies in Architecture*. 2012: Taylor & Francis.
[35] Attia, S., *A Tool for Design Decision Making Zero Energy Residential Buildings in Hot Humid Climates*. 2012: Presses Universitaires.
[36] Rantanen, K. and E. Domb, *Simplified TRIZ: New Problem Solving Applications for Engineers and Manufacturing Professionals, Second Edition*. 2010: Taylor & Francis.
[37] Terninko, J., A. Zusman, and B. Zlotin, *Step-by-step Triz: Creating Innovative Solution Concepts*. 1996: Responsible Management, Incorporated.
[38] Hillier, B.H., *J. 1984 The Social Logic of Space.* Cambridge University, 1993.
[39] Gasanov, G., et al., *Birth of an invention: a strategy and tactic for solving inventive problems.* Moscow: Interpraks, 1995.
[40] Terninko, J., E. Domb, and J. Miller, *The seventy-six standard solutions, with examples section one.* TRIZ Journal. http://www. triz-journal. com, 2000.