
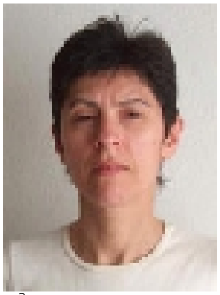


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Levels of innovation in architectural design

Abstract

There are different methods for evaluation of architectural design. Novelty, utility and contribution to the society are relevant concerns to be considered in such methods. Most of methods, do not address novelty sufficiently.
In TRIZ theory (Theory of inventive problem solving) in order to describe novelty, five levels of innovation have been defined. These levels have been recognized by investigation on thousands of registered patents. Levels have been defined based on the quantity and quality of contradictions that have been solved in patents. Also the theory has considered required domains of technology and knowledge and required number of trial and error for solving problems in each level.
This study aims to investigate about adaptability of these five levels to evaluation of architectural design projects. Several aspects and approaches including FPM (function/principle/market) model, level model for art, system changes, solved contradiction and required knowledge were compared.
In conclusion a formula for calculating levels of innovation in architectural projects was proposed. The proposed formula comprehensively measures the innovation levels of building system and subsystems.
Keywords: Design evaluation, levels of innovation, TRIZ, architectural design.

1. Introduction

Architectural designs are judged and evaluated in schools, professional offices and international competitions. Also users after construction of design, assess the design quality related to their needs. As Chupin (2011) states judgment and evaluation of design is a discipline's tradition. There is hardly a design that does not undergo a process of judgment. Beside the need for evaluation of design projects in architectural competitions and educational environments, according to Sarkar and Chakrabarti (2011) assessing creativity and innovation helps to identify innovative designers and products and improve both of them. Based on US Patent and Trademark Office (USPTO, 2014) and World Intellectual Property Organization (WIPO, 2014), a patent should meet three requirements: novelty, utility and non-obviousness.

. International prizes for architecture do not clarify the criteria for recognition of novelty degree. Pritzker prize that awards each year and is almost the most important international architecture prize, has mentioned its purpose in its website (Pritzker, 2014) "To honour a living architect whose built work demonstrates a combination of those qualities of talent, vision, and commitment, this has produced consistent and significant contributions to humanity and the built environment through the art of architecture." In other international architecture prize, including AIA Gold Medal and RIBA Royal Gold Medal have emphasized on a contribution to international architecture and humanity affairs. Contribution to the society is the most important factor in all prizes. Majority of prizes, in their criteria do not clarify idea of novelty.

In design research literature, Sarkar and Chakrabarti (2011) develop individual methods for assessing novelty and usefulness of products, and then combine these into a method for assessing creativity of products. Chupin (2011) by exploring the hypothesis of a fundamental analogy between designing and judging, seeks to contribute to the theoretical modelling of architectural judgment. The method name is judgment by design. He points out wickedness of design problems as an impediment of design evaluation. In other hand, Afacan and Erbug (2009) provides a definition of a universal usability that is applicable in architectural context. Their study highlights how heuristic evaluation as usability evaluation can feed into current building design practice to conform to universal design principles. They use seven universal design principles provided by the Centre for Universal Design: 1. equitable use; 2. flexibility in use; 3. simple and intuitive use; 4. perceptible information; 5. tolerance for error; 6. low physical efforts; 7. size and space for approach and use. De

Wit and Augenbroe (2002) analyse uncertainty in building design evaluation. They believe that a design evolution involves a chain of design decisions.
In point of view of TRIZ (theory of inventive problem solving) created by Altshuller and Shapiro (1956) the innovative solutions and designs are those which solve a contradiction(KORNER, 2006). One of the first attempts for recognizing of level or degree of innovations was by Altshuller and Shapiro (1956). Altshuller defined five levels of innovation by investigation of thousands of patents. Degree of inventiveness, required domains of technology and knowledge and required number of trial and errors for each level and the type of contradictions that is solved in each level, have been considered in Altshuller work. He believed that he could help anyone to develop inventions in levels 2, 3 and 4.
According to Savransky (2002) level 5 solutions require recognition of a new natural effect or human needs, based on innovation levels notion, he also believes that approximately 95 percent of problems in any fields, have already been solved in other fields. Access to application of these typical solutions, decrease the time duration between inventions, in result problem solving and design process would be more efficient. Five Levels of innovation will be explained sufficiently in next sections.
Different authors has called five levels of innovation by different names: "five levels of creativity"(Altshuller et al., 1999), "five levels of inventions" (Altshuller, 2003 (in Russian)), "five levels of solutions" (Rantanen, 1997) , "5 levels of innovations", "five levels of problems" (Altshuller and Williams, 1984) and "five levels of inventiveness" (Souchkov, 2007). However, the words creativity, innovation, problems and solutions are not synonym. Souchkov (2007) presents new classification for five levels of solutions. His classification is based on Function, Principle, and Market. Also the idea of function/principle/market will be clarified in next sections.
Aim of this study is investigation about adaptability of these five levels to architectural design project. Acknowledgement of levels of architectural design innovation during design process can improve outcomes, and can provide some guideline for refereeing of projects and predict future innovative projects. For clarification of subject, we have provided definition of some concepts such as TRIZ, contradiction and technical systems.

2. A brief about TRIZ

TRIZ is a knowledge-based systematic methodology of inventive problem solving (Savransky, 2002).TRIZ rests on the idea that the system evolutions and invention process are not by random, they can be predictable and follow certain patterns and trends (Eversheim, 2008). The TRIZ has been defined in different ways as a toolkit, a methodology, a science and a philosophy (Barry et al., 2008). The fundamental concepts of TRIZ are technical systems, levels of innovation, law of ideality, contradictions, evolution of technical systems, and the main tools of TRIZ are its 40 principles, Su-filed model (standards), ARIZ (Algorithm to solve inventive problems) (Altshuller et al., 1997). Two main needed concepts of TRIZ for our discussion are clarified as below.

2.1. Technical Systems

Everything that fulfils a function is a technical system. Any technical system can consist of one or more subsystems. All sub-systems have interaction with each other and with system; any change in every sub-system can make changes in main system. (Altshuller et al., 1997). According to above mentioned definition, all designed buildings in architecture are technical systems that each of them has sub-systems and super-systems. The super-systems of buildings are neighborhoods, regions and cities. Different sub-systems of building are spaces, structure, installations, architectural elements, furniture, and network of users' sub-systems. These are just some examples of sub-systems. A lot of sub-systems can be defined in buildings.

2.2. Contradiction

The core concept of TRIZ is notion of contradiction (Rousselot et al., 2012). Resolving the contradiction, solve the problem (Ilevbare et al., 2013). Two main types of contradictions are technical and physical contradictions. Technical contradiction arise when improving one characteristic of system deteriorate another characteristics of system. For example, the bigger, more powerful engine proposed for a car to increase its speed would contribute more weight to the car, which in turn limits how fast it can travel; therefore TRIZ possesses considerable advantage over other methods negating the desired benefit of increased speed.

Physical contradiction arises when there are contradictory requirements for the same condition in system. For example, the bigger the window, the better the view. In contrary, by increasing the area of window, the consumption of energy will get higher. We want window big and small at the same time. Normally, resolving physical contradictions are more difficult than technical contradictions.

3. Levels of innovation and TRIZ theory

For the first time Altshuller and Shapiro (1956) applied ranking idea, in the area of inventiveness and innovation. They started TRIZ (theory of inventive problem solving) by ranking of thousands of patents (Savransky, 2002). They recognized five levels of inventiveness (Altshuller et al., 1999). The levels of innovation were distinguished based on some criteria as below.
"• Problem difficulty D, or the number of trial and errors required to guarantee a solution of a certain level
• Difference between an earlier known prototype and the new solution", and
• "Distance" knowledge from the inventor's field used for the new solution" (Savransky, 2002)
The main significance of the levels classification was being the first successful effort laid on empirical investigations on case patents to clarify the differences between types of problems and solutions. This contributes a major value to nature of systematic innovation (Souchkov, 2007).
According to Altshuller respectively 32, 45, 19, below 4%, below 0.3 % of designs are at levels 1 to 5 (Altshuller et al., 1997).
One another question is: does the distribution of inventiveness at levels change over time? Altshuller studied patents again in 1982 (published in the former USSR), from three patent classes. The distributions were a little different to the study of patents during years 1965-1969. The results: first level - 39 %, second level - 55 %, and third level - 16 %. Inventions of fourth and fifth level weren´t found at all. The change, perhaps, can be explained by the statistical variation between samples. Or maybe the distribution really changes. More research is needed to answer to this question" (Rantanen, 1997).

3.1. Level 1: Regular or the Standard Solution

Solving problems at level 1 includes routine design problems, can be solved by a few attempts or trial and error (1 to 10 trial and error). According to Altshuller, 32 percent of patents are classified at level one. He analyzed 14 classes of inventions from 1965 to 1969 (Altshuller et al., 1999). The solutions in this level represent small changes in earlier prototypes without its essential variations.
From TRIZ point of view, level 1 is not invention (Savransky, 2002). According to Souchkov (2007) solving problem in level 1 does not eliminate any contradiction. There is a logarithmic relationship between difficulty of problem and level of solution. "The level of a problem can be estimated as lg (D), where lg is the decimal logarithm and D

is the difficulty of the problem .Unfortunately, for many technical tasks it is hard to determine the difficulty D of the problem itself" (Savransky, 2002). For example in level one, the most number of trial and errors or difficulty D of problem is 10 that (lg10=1).

3.2. Level 2: Improvement or Change of a System

At level 2 inventions, the changing of earlier prototype is qualitatively and not substantially. 45 percent of inventions are in this group. The approximate needed number of trial and errors is 10 to 100 (Savransky, 2002). Normally problems are solved by applying uncommon methods from the same area. Level 2 solutions are a small improvement of previous existed systems or prototypes. Souchkov (2007) believes that, at level 2, there are technical contradictions to be solved.

3.3. Level 3: Invention inside Paradigm or Solution across Industries

19 percent of inventions are classified at level 3 (Altshuller et al., 1999). At level 3 a fundamental improvement and essential change in relation with earlier system or prototype. For achieving this level, we need hundreds (100 to 1000) trial and errors. Level 3 inventions significantly improve existing techniques (Savransky, 2002). Level 3 include removal of a major contradiction mostly physical contradiction (Souchkov, 2007). At this level inventor utilize the methods or knowledge from other disciplines or different industries.

3.4. Level 4: Breakthrough outside paradigm or solution across sciences

At level 4, a radical change happens in previous prototype, a new idea that has no common point with previous systems. Less than 4 percent of inventions are classified at level 4. Thousands (1000 to 10,000) trial and error is needed for achieving the results. Required knowledge should be obtained and applied from different areas of science. Level 4 solutions are breakthrough lie outside of paradigms across engineering fields (Savransky, 2002). For instance, "mechanical" problems are solved with knowledge of chemistry.

3.5. Level 5: Discovery

Less than 0.3 percent of inventions are distributed at level 5. The inventive situation is a complex network of difficult problems (Souchkov, 2007). "Level 5 solutions exist outside the confines of contemporary scientific knowledge and usually stand between science and engineering" (Savransky, 2002). The numbers of trials and errors are almost unlimited. This type of invention causes of existence of a completely new system, which is accompanied by inventions of lower levels over time. A new area of technology is created. When level five once occurred, this new discovery is applied in one of 4 smaller levels. TABLE 1 summarizes the different aspects of innovation levels from TRIZ points of view.

TABLE 1: Levels of Inventiveness

Level	Degree of inventiveness	% of solutions	required knowledge	Approximate # of trial and error
1	Simple improvement of a technical system	32%	Personal knowledge	1 to 10
2	Resolution of technical contradiction	45%	Knowledge from different areas within an industry	10 to100
3	Resolution of physical contradiction	19%	Knowledge within different other industries	100 to1000
4	New technology breakthrough solution	Below 4%	Knowledge from different field of science	1000 to10,000
5	Discovery of new phenomena	Below 0.3%	All that is knowable	10,000 to1,00,000 and more

4. Levels of innovation in art

Salamatov et al. (1999) outlined five-level innovation in the art that is shown in theTable2. He classified artistic works from paintings, music, literature and cinematography based on novelty of expressive meaning.

TABLE 2. Five levels of innovation in art from (Salamatov et al., 1999)

level	Degree of inventiveness	Examples from different arts			
		Painting	Music	literature	Cinematography
1	Duplication of ready-made expressive means, sometimes to the point of sheer Plagiarism**.**	Examples are so abundant that it would be unfair to speak of a single specimen: 90% of music, literature, cinematography etc. utilize hackneyed devices, reiterate patterns of mass culture			
2	Wide use of well-known expressive means**.**	picture by G. Griva, "Zane" depicting a girl with a rabbit in her hands.	Tchaikovsky uses trepak dance in his "The Nutcracker" to invigorate the scene.	novel by J. Verne "Matiash Shandor**."**	"Front Line in My Father`s Yard**."**

3	Inventing a particular expressive means or novel application of an old means**.**	to show the "glowing" face of a lady, A. Renoir in "Portrait of Actress Jeanne Samari**"**	M. Musorgsky introduces the vigorous Russian dance trepak in dismal "Songs and Dances of Death**"**	to overcome rhythmical monotony, A.Pushkin combines several meters into one stanza in his "Eugene Onegin**."**	a typical way to show the death of a hero is through close up on his writhing figure. By contrast, in the film "Here Fly the Cranes**"**
4	inventing a new type of expressive means, which quite often leads to a new Subgenre**.**	profile portraits (Russian artists of the 17th century), historical landscape (A. Vasnetsov)	new method of transition (Mozart), choral symphony (Beethoven)	poems of everyday life (A.S. Pushkin "Count Nulin"), social fiction (H. Wells)	Soliloquy (A. Dovzhenko). Third level. Inventing a particular expressive means or novel application of an old means**.**
5	Inventing a new genre or even a new form of art**.**	the portrait, engravings (A. Durer), the landscape (P. Bruegel)	at the end of the16th century the genres of oratorio (G.F. Handel),	the poem, science fiction (J. Verne)**.**	the comedy, western**,** musical**.**

5. Levels of innovation in contemporary architecture

Architecture has artistic, social and technological aspects. In artistic and social aspects, we can apply Salamatov et al. (1999) levels of innovation.

The innovation patterns are different before and after industrial revolution. Traditional architects before industrial revolution were designer, planner and constructor of buildings. Alexander (1979) that is the creator of pattern language theory in architecture believed that throughout history, people have lived in the houses that they were constructing and renovating houses themselves, they were solving the problems that had experienced in the previous house and modifying the solutions. Therefore, new houses had a slight modification in comparison with previous one and these patterns were repeating frequently. In TRIZ language, many of these kinds of constructions can be classified at level 2 of innovation. However many of innovative discoveries such as domes, vaults, and arches can be classified in highest levels of innovation.

During last century architecture was affected by new movements in philosophy, art and technology. Different styles were created including early modernism, futurism, constructivism, international style and 20th late-century styles including high-tech, echo-tech, post-modern, neo modern, neo classic, deconstructivism (Macdonald et al., 2012). Majority of styles were started by design of a building by an innovative architect mostly in international competitions. According to Salamatov et al. (1999) inventing a new genre is classified at level 5 and inventing a new type of expressive means, which quite often leads to a new subgenre is at level 4. Based on this definition, launched projects of the majority of above mentioned contemporary styles can be classified at levels 4 and 5. Also Other styles such as blobitecture and novelty architecture can classified at lower levels (level 2 or 3). The majority of other design projects are at level 1.

6. FPM (Function/Principle/Market) model in innovation levels

Souchkov (2007) defined a different classification of five levels. He used 3 main ideas including function, principle and market. He defined the concepts as below:

1. *Function:* every man-made system is designed to perform a specified purpose, which is prepared by a determined main function in the system. Namely, to perform the purpose of medical inquiry, experts a matching system which accomplish the function "to see through a human body" Functions can be typical or very specific, and normally high-level inventions enable fulfill of general functions that guarantee applicability of these inventions across broad range of challenges and problems.
2. *Principle:* This is an essential scientific phenomenon, effect or principle that enables delivery of the function. For example, x-ray emissions form the function of "seeing through a human body".
3. *Market:* the functions of any man-made system are delivered within a specified context, which satisfies certain type of needs in a particular market. Namely, x-ray imaging device is applied for medical market; simultaneously it may also be applied in security systems market. Principles in different markets may deliver different functions. (Souchkov, 2007)

Then he defined the five levels of innovation based on function/principle/market
"Level 5: Discovering a New Principle
Level 4: Creating a Radically New Function/Principle Combination
Level 3: Extending a Known Function/Principle Combination to a New Market
Level 2: Qualitative Improvement of the Existing Function/Principle/Market Combination
Level 1: Quantitative Improvement of the Existing Function/Principle/Market Combination"

6.1. FPM model in architecture and building design

In architecture domain, some functions of buildings are based on user needs. Easy accessibility of buildings and spaces, thermal and acoustic comfort are examples of user needs. Considering interdisciplinary nature of architecture, usually applied principles in architecture are from other fields of science, engineering and technology. Every function may use several principles. Also Functions can be divided into system functions and subsystem functions. System functions are the functions of whole building and sub-system functions are the functions of the minor parts of buildings. Sub-systems in buildings have been clarified in technical systems section.

For instance for solving acoustical problems of a space (or satisfying acoustic comfort needs of users), architects apply geometrical principal's also acoustic materials (absorptive and diffusive materials or sound absorb and diffuse principles), or for accessibility function, architect may use geometrical principles. In our discussion market is architecture. For improving aerodynamics of high-rise buildings, material science principles, structural principles and geometrical improvement principles are used.

By definition of Souchkov (2007), there is no level 5 innovation in architecture, because the majority of applied principles are outside of architecture domain and Discovering new principle does not occur in architectural domain. For lower levels, we have illustrated some examples by using FPM model as below.

Floating cities (Figure 1) function by applying naval architecture principles, is a radically new function/principle and can be classified at level 4. Entering by a digital password is a known function/principle in other fields; application of this FP for the market of architecture to open doors can be classified at level 3. Using folded furniture for decreasing needed space for furnishing, is a qualitative improvement of existed function/ principle and can be classified at level 2. For function of heating and cooling, the mechanical engineering principles are used. Improvement of quantity of consumed energy by air conditioning system is an innovation at level 1.

For understanding of FPM model in architecture, we need to have a better understanding of functions and principles. Some of the functions of buildings can be divided at: a) spatial functions including interactions among spaces and interactions of space with users such as accessibility; b) environmental factors function such as energy, natural light, heating and cooling, acoustic functions, wind and aerodynamic; c) structural functions. Applied principles in architectural design can be from a wide range of technology, and science including social science. For more clarification, some principles that have been applied in recent and probable future designs, have been pointed out.

6.2. Some principles for increase the level of architecture innovation

6.2.1. Bionic: Bionics is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology. According to TRIZ view, applied knowledge in bionic architecture (biology) is from different field of science and consequently designed buildings can be classified at level 4, in case of satisfying other criteria's. Turning torso tower by Santiago Calatrava, arc of world by Greg Lynn and bionic tower are samples of bionic architecture (Figure 2).

6.2.2. Information technology and computation: Digital architecture, digital morphogenesis, building information modeling, optimization algorithms and building management system are examples of using IT in buildings or design process. In TRIZ, level 3 innovations benefits from knowledge within different other industries. Based on case, the applied FP can be classified by FPM model (Figure 3).

6.2.3. Material science: has developed nano and smart materials for use in buildings. Research about applying these materials in architecture have been focused in recent years, Smart materials can revolutionize the form and application of buildings. Applying developed material science in architecture can classified as level 4.

6.2.4. Advanced geometries: Architectural geometry is an area which uses applied geometry in architectural design, manufacture and analysis process (Pottmann, 2007). Differential geometry, topology, fractal geometry and cellular automata are the branches of geometry that has increasing influences on architectural design. Using advanced geometries as principle outside architecture can increase the level of innovation in architectural design.

6.2.5. Robotic: Robotics is the branch of technology that deals with the design, construction, operation, and application of robots. The idea of design of dynamic towers (Figure 4) can be attributed to robotic. The Dynamic Tower is a planned 420-metre (1,378 ft), 80-floor moving skyscraper in Dubai, United Arab Emirates, designed by architect David Fisher (bbcnews, 2008).

Robotic as a principle outside of architecture domain can facilitate and enrich architectural functions in buildings. Considering that robotic is “Knowledge within different other industries”, applying robotic principles in architectural buildings function can be classified at level 3.

Figure 1: Floating cities, www.gizmag.com Figure 2: Bionic Tower , aedesign.wordpress.com

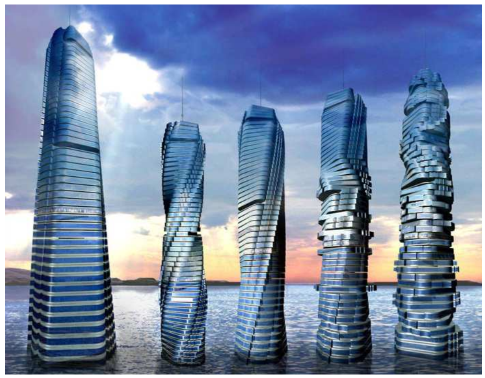

Figure 3: A sample of parametric design, http://www.evolo.us/ Figure 4: Dynamic tower, simoncpage.co.uk

7. Discussion

Due to mutual effects of system and sub-systems on each other, levels of innovation in architecture should be considered for system and subsystems. Meanwhile degree of artistic innovation of design should be under attention. Different aspects of a design may have different levels of innovation. TABLE 2 represents a comparison among system change, FPM model, art model and required knowledge at different levels. For a better understanding of levels of innovation in architectural design, understanding of design problems and contradiction is vital. Also recognizing functions of systems and sub-systems in architecture and applicable principles from different area is necessary. Majority of items in different columns at one level are

dependent to each other. For example, at level 3, when in a design a physical contradiction is solved, normally a fundamental change has been happened in comparison with previous design prototypes, also a known function/principle combination have been used and knowledge within different other industries have been applied. In fact in this kind of view to levels of innovation, novelty and utility has been considered because solving contradictions increase utility of design.
This formula is proposed for a comprehensive measuring of levels that involves system and sub-systems.

$$LOI\ of\ buildings = \frac{1}{\alpha + \beta + \gamma} * \left(\alpha * \ LOI\ of\ TS + \beta * LOI\ of\ AS + (\frac{\gamma}{n}) \sum_{i=1}^{n} LOI\ of\ SS_i \right)$$

Where
LOI is level of innovation
TS is technological aspect of building as system
AS is artistic aspect of building
SS is subsystem and n is number of considered sub-systems
α, β,γ coefficient of different aspects that can be specified by designers or experts

TABLE 2: Comparing different aspects of levels of innovation

	Degree of Inventiveness	System Change	FPM Model	Model for Art	Required Knowledge
Level 1	Simple improvement of a technical system	A little change in previous prototype	Quantitative Improvement of the Existing FPM Combination	duplication of ready-made expressive means, .	Personal knowledge
Level 2	Resolution of technical contradiction	Qualitative change	Qualitative Improvement of the Existing FPM Combination	Wide use of well-known expressive .means	Knowledge from different areas within an industry
Level 3	Resolution of physical contradiction	Fundamental change	Known FP Combination to a New Market	Inventing a particular expressive means or novel application of an old means .	Knowledge within different other industries

Level 4	New technology breakthrough solution	Radical change	New FM Combination	inventing a new type of expressive means, which quite often leads to a new .Subgenre	Knowledge from different field of science
Level 5	Discovery of new phenomena	New phenomena	New Principle	Inventing a new genre or even a new .form of art	All that is knowable

8. Conclusion

Aim of this study was recognizing levels of innovation in architectural building design. The idea of innovation levels extracted from TRIZ theory and also developed ideas such as function/principle/ market model and levels in art were discussed. According to technical system definition, an architectural building is a system with many various types of subsystems. Also architecture has artistic, social and technological aspects. Degree of innovation should be considered and calculated at different aspects and both system and sub-systems. A formula was proposed for calculation of degree of innovation for buildings. Recognition innovation levels in design can improve future design and designers and is a way to predict possible future inventive designs. Lack of researches about the subject in art and architecture were the limitations of research. For future studies, finding numeric degree of innovation of buildings by case studies and comparison of it with designer's idea about inventive designs is proposed.

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