Application of TRIZ in building industry: study of current situation

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Abstract

This article is focused on literature review in the area of TRIZ application in building industry. TRIZ is the Russian acronym for the Theory of Inventive Problem Solving which can be presented as a methodology for problem-solving, ideas-generating and forecasting in innovation, based on logic and data. The theory has been widely used in many fields since early 2000s when innovation became an integral part of the modern World. Despite that, the analysis showed that the number of publications related to application of TRIZ in construction is less than 2% out of all TRIZ-related studies in the SCOPUS database. The paper is organized in the following order: introduction into the topic, the principle of obtaining the dataset for the review, Short description of TRIZ and its possible application in construction, discussion of demand of innovation in building industry and the main body consisting of TRIZ in Development of Construction Techniques and Technologies, TRIZ in Design of New Structures and Construction Materials and TRIZ in Construction Project Management and Value Engineering. The work ends with conclusion, suggestion for future work and acknowledgment. Overall, 28 scientific works regarding application of TRIZ in building industry were discovered and reviewed in this paper. The study reveals that TRIZ usage in construction is still quite limited. The further research will adapt classic TRIZ tools for construction engineering and management and provide a number of specific case studies.

1. Introduction

Construction engineering and construction management are professional disciplines within building industry which deal with design, overall planning, construction and management of infrastructures (buildings, bridges, utilities, etc.). To succeed in those aspects construction specialists have to always find new solutions and ideas, solve technical and technological issues which may appear in every single project’s stage during both design and construction. Thanks to bright innovative ideas and solutions, which enable the scientists and engineers to evolve construction materials, technologies, design techniques, etc., the World nowadays has such truly astonishing structures as the Dubai’s Burj Khalifa (the tallest man-made structure in the world, standing at 829.8 m), the Sidu River Bridge in China (the bridge with the biggest drop distance from the bridge deck to the ground level which is nearly 500m high and crosses a mountain belt), the incredible Milau Viaduct in France (the world’s tallest bridge with one mast reaching 343 meters above the base of the structure), the China’s Jinping-I Dam (the tallest dam 305m high), the Capital Gate tower (the World’s furthest leaning skyscraper in Abu Dhabi that was built to lean 18°) and a few others. Moreover, there are quite simple structures differing by the way they were built. For instance, a Chinese construction company used a Modular method and became the world's fastest builder after erecting a 57-storey skyscraper in 19 working days in central China [1]. The method enables the builders to assemble the prefabricated blocks (modules) instead of building brick by brick.

In the modern professional world engineers and managers must have a universal intellectual set of tools that would enable them to find the right ideas in a well-structured methodological way avoiding consideration of knowingly false solutions leading to waste of time, missed deadlines, planned budgets, etc. Since the risk of failure in construction is higher than in many other industries [2] it is not acceptable to use trial-and-error approach (especially for large-scale projects) to find ideas and solutions for the development and improvement of design procedures, structures and...
construction techniques. At the same time, there is the Theory of inventive problems solving (TRIZ) which includes a practical methodology, tool sets, a knowledge base, and model-based technology for generating new ideas and solutions for problem solving [3]-[5]. According to ETRIA (the European TRIZ association) Worldwide survey performed in 2009 [6], only 3.5% of construction professionals are devoted to the TRIZ, which means that TRIZ remains marginal in the building industry. This paper presents scientific indexed literature review to a) identify existing innovative approaches based on TRIZ tools which find their application in design and construction and help solving ongoing issues, b) justify relevance of further study of TRIZ application in building industry and, finally, develop a set of key objectives to be later investigated.

2. Creating the dataset

The review is based on papers indexed by SCOPUS mostly database. In order to create the set of articles to be reviewed, two searches were performed: (1) the search query “TRIZ” and “Construction” in Title or Abstract or Keywords and (2) “TRIZ” and “Building” in Title or Abstract or Keywords. The terms “Construction” and “Building” were selected as they are most commonly used in the studied field while “TRIZ” as generally accepted abbreviation for the Theory of Inventive Problem Solving. The former case resulted in 83 papers while the latter in 57 ones. However, reading the papers filtered out the irrelevant texts that reduced the quantity to only 18 and 6 industry-related articles respectively with 2 of them being in both lists. Thus, the dataset consists of 22 articles selected from the SCOPUS database. It is just 2% of the 1389 articles retrieved by “TRIZ” in Title or Abstract or Keywords search. Quick analysis shows that 9 of articles are cited more than once. Most of the works originated from the PRC during the last decade. As the amount of retrieved papers is small, the Google finder was used to extend the list of reviewed papers. The search query “TRIZ” and “Construction” and “Building” forwarded us to such sources as ScienceDirect, Elsevier and Springer where 6 more industry-related papers were obtained. All bibliographic information is given as it was seen in May 2015. Thus, 28 works regarding application of TRIZ in construction were discovered and reviewed in this paper, some of which are available in abstracts only. The review showed that those articles are mostly dedicated to:

- Development of Construction Techniques and Technologies
- Design of New Structures and Construction Materials
- Construction Project Management and Value Engineering

3. Demand of Innovation in Construction

First, we need to comment the demand for innovation in construction in general. According to [8] innovation can be defined as “the successful exploitation of new ideas. However, ongoing research [2], [9]-[12] and statistical data [6], [8] show that construction lags behind many other industrial sectors (such as IT, computers, software, automotive industry, electronics, mechanical engineering, etc.) in terms of efficiency and productivity due to mostly lack of realizations of new ideas.

For instance, U. Kulatunga et al. demonstrate [2] that construction is behind other industrial sectors due to, in particular, lack of innovations. At the same time modern construction companies are keen on innovations to be competitive on the market, which is why engineers and managers innovate when technology can be modified easily. On the other hand, construction industry is also known for its conservatism and professionals tend to use an accepted industry practice and norms in fulfilling client’s need.

The study [11] by S. Asad et al. also shows the importance of innovations for construction organizations. The authors even claim that construction innovations can become a fourth dimension in the future along with the traditional dimensions of cost, quality and time. Only in that case such organizations would be able to take advantage of changes in market economy. The study [13] additionally explains that successful building products must be innovative to become competitive on the market in terms of cost, time and performance efficiency. Besides, the survey performed by the Chartered Institute of Building (UK) [8] discovered that 100% of respondents felt that innovation is important for the future of construction.

To sum up, there is plenty of research, surveys and literature regarding innovation in construction and almost all of them state that innovations are vital in construction sector but the question is how to become innovative. Z. Ding and J. Ma [14] describe that using TRIZ can accelerate technical innovations in construction process. On the other hand, the report [6] shows the statistical data related to distribution of TRIZ use in industrial sectors which demonstrate that TRIZ is not widely used in civil engineering and building industry. The other work [15] by D. M. Conall and Ó. Catháin explains again that construction specialists in most cases do not use systematic or formal design methods and this situation leads to a number of drawbacks (for instance, it takes a long time to find a solution; waiting for inspiration; designers cannot proceed in a logical manner, etc.). To avoid such minuses a systematic innovation approach was suggested, which came out of TRIZ. The approach is based on five principles called “pillars” which are function, contradiction, resources, ideality and interfaces.

Furthermore, Y. Mohamed and S. AbouRizk [16]-[18] noticed that there is lack of structured theory for managing innovation improvement in the construction industry. Innovation is an integral part of improvement of construction techniques but, however, most approaches are based on the trial-and-error method. The studies present a few number of cases to show results of TRIZ application in tunnel construction. All case studies were taken from real life situations and it was well proven that TRIZ tools help to achieve innovative conceptual solution in a methodological way avoiding consideration of irrelevant results.
Ding Z. et al. [10] particularly suggest the design framework of the technology innovation platform based on TRIZ by taking advantage of available patent knowledge in the construction industry. Based on extracted construction patent knowledge, the development of construction technology innovation platform allows a heuristic environment to help the industry improve the capacity and efficiency by motivating knowledge worker’s innovative thinking.

Therefore, it can be concluded that innovation must be of high demand in the construction industry but, at the same time, construction is considered slower in technology innovation in the past decades partially due to the characteristics of the industry. The literature review clearly states that it is necessary to extend application of innovations in construction and determine an optimal approach for ideas generation to be applied in a real practice.

4. TRIZ in Development of Construction Techniques and Technologies

A small amount of research has been done regarding the development of construction techniques and technologies using TRIZ. For instance, the article [19] describes step-by-step analysis of formwork technology development from the TRIZ point of view. The 40 inventive principles are used for formwork patents investigation. Based on 176 Taiwan patents analysis from years 1975 to 2005 there were extracted top 5 inventive principles which were most frequently used in the formwork patents. The principles are: (1) prior action, (2) Combining, (3) Segmentation, (4) Cushion in advance and (5) Mediator. Some examples of each of them are given in the work to show the formwork technology development. To predict future development trends, the contradiction matrix was used, which led to determination of future innovation trends of formwork engineering. Among those trends are the following inventive principles: Inversion, Segmentation, Transformation of properties, Replacement of mechanical system and Extraction. Finally, it was concluded that TRIZ provides a systematic approach for technology research, and construction technologies can be analyzed with TRIZ.

Yu W.-D. and Wu C.-M. also state that construction technologies are little comparable to other industries due to lack of innovation tools [20], [21]. They proposed to use a Systematic Technology Innovation Procedure (STIP) for fast innovation in construction technologies. The STIP approach is also based on patent analysis, TRIZ and Computer Aided Invention (CAI) tools. STIP consist of (1) a problem description scheme, (2) a systematic procedure of technology innovation and (3) a set of criteria for technology evaluation. STIP principal scheme is: PROBLEM->DEFINITION->ANALYSIS->SOLUTION (using TRIZ)->APPROVAL->INNOVATIVE TECHNOLOGY. A case study of STIP application in searching an innovative solution for leaking pipes surrounded with reinforced concrete (RC) is provided as an example.

Furthermore, the same authors developed their research in [22]. They explained that technology innovation has been an important source of competitiveness for individual construction firms and provide long term benefits for the industry. In this research they proposed a new integrative “Model Used for the Generation of Innovative Construction Alternatives” (MUGICA) based on the formerly developed STIP and the “Model for Automated Generation of Innovative Alternatives” (MAGIA) to tackle both the systematic and automated requirements of construction technology innovation. The testing result showed that the proposed MUGICA was able to improve both the efficiency and effectiveness of construction technology innovation compared to previous approaches.

According to Keşvær Coşkuna and M. Cem Altun [23] in-situ construction techniques have distinct characteristics such as unique production, partial lack of industrialization, standardization and quality control, location of construction process, local techniques related to construction culture. Those characteristics are mostly reducing “productivity”. There are several innovation models for improving the “quality” in the construction process. The authors found out that TRIZ could be used to improve the quality of in-situ construction techniques. However, it was discovered that improvements are needed to the “analysis of the problem” and “evaluating proposed solutions” steps of the TRIZ approach. According to the comprehensive investigation of other improvement methods, the Six Sigma approach was found to be effective in overcoming the uncertainties in TRIZ. In the paper a conceptual model for improving in-situ construction techniques is proposed by using the TRIZ approach, the Six Sigma approach and statistical tools. It was demonstrated that the integration of TRIZ and Six Sigma approaches is considerably more effective. The same authors evolved their research in [24] and also investigated the applicability of the TRIZ tools on in-situ construction technologies. Improving the quality of the construction technique for wood joint fixing is defined as a problem to be tackled. The problem was solved with TRIZ method considering “construction time” and “strength” criteria. For the assessment of the method, construction process observation and compressive strength tests were carried out.

Lin Y.H. and Lee P.C. presented a modified TRIZ model called TRIZ-AHP-G model which combines with Analytic Hierarchy Process (AHP) and grey relational analysis [25]. The use of TRIZ-AHP-G model was illustrated by two examples, the pre-stressed concrete and the shoring system. The results of both examples demonstrated the effectiveness of this proposed model, which can effectively measure the importance of criteria associated with innovating products based on expert knowledge.

5. TRIZ in Design of New Structures and Construction Materials

TRIZ has also shown its potential in design of new structures and construction materials. One of such examples is...
an integrated innovation method combining TRIZ, Technology Acceptance Method (TAM-approach for product demand analysis) and Quality Function Deployment (QFD - transforms customer or market demands into design requirements) suggested in the work [26] by Y. Luo et al. The approach helps to solve main contradiction problems from the product demand analysis to its design, production and application. An example for design of new wall material using integrated method was given in the paper. The core part of the method is identification and solving contradictions in customer demand and quality control during design and production procedures using different TRIZ tools. As for building façade solutions, Chen Z. et al. proposed in [27] a TRIZ based management process model for selecting the most appropriate solutions of building façades. To set up the model, environmental values of building façades were analyzed with respect to their life-cycle performance and impacts.

Besides that, TRIZ can be applied in finding inventive ways to upgrade heat insulation of external building structures. R. Sen Chiu and S. T. Cheng [28] describe how solar reflectance of heat-proof paint was improved by applying TRIZ contradiction. The parameters which were discovered to be improved are the following: temperature, harmful elements on objects, adaptability, stability of objects and brightness. To solve those five contradictions, four inventive principles (transformation of the physical and chemical states of an object, segmentation, changing the color and flexible membranes or thin film) were singled out in TRIZ. A number of heat resistance tests were performed, which led to successful development of new paint that upgrades the solar reflectance and heat insulation of the plate paint and, thus, saves over 24% of electricity for internal air conditioning.

The other study [29] by D. Lee and S. Shin shows how TRIZ can be used when it is required to evaluate bearing steel diagrid structures of free-shaped tall buildings to resolve such issues as the concentration of stress at the ends of the tube contacted to cap plates. Stress concentrations among node rib, cap plate and tube result in collapses of tubes before tubes arrive to yielding stress state. This occurs despite using cap plates, like as changing thickness and extended length. In addition, an extended cap plate may cause interference in building construction. In this study a DSDI TRIZ procedure was mainly applied in order to develop the details of diagrid structures. The DSDI (for “Define”, “Solve”, “Design”, and “Implement”) approach was introduced by a POSCO steel company in 2008 [30]. In the “Define” stage it is required to define the above-mentioned problem of the existing diagrid detail. It was found that stresses by high performance steel tube with tensile stress of 800 MPa have to be bigger than stresses by given forces at the zone of the tube in which the tube contacts the cap plate in order to avoid collapse. Inventive ideas were evaluated by solving the problem that exists in the operating zone. Since the diameter and thickness of each tube are constant for the purpose of economy, they could not be considered to be design variables in the operating zone. Cap plate and node rib are design variables and can be modified to improve the existing diagrid details. To solve the problem and generate inventive ideas the authors considered a multi-screen thinking method, a resource analysis and interaction matrix. To resolve technical and physical contradictions, separation in space and based upon condition were applied to idea generation. As a result, the cap plate was modified to both enlarge the contact area between a tube and a cap plate and reduce the interference that results from length extensions of a cap plate. Therefore, original flat cap plates were developed to be either concave or convex shaped plates. The “Design and Implement” stages of DSDI TRIZ procedures measure the idea generation results by using measurable tools such as structural analyses or experiments. In the particular case the researchers applied ABAQUS to investigate structural behaviors of the invention results. A convex diagrid was evaluated as being an improvement on the current best solution. TRIZ applications shown in this study verify that TRIZ is a strong idea generation tool for conceptual design to improve current steel-framed products such as diagrid structures in tall buildings. Another research related to TRIZ usage in steel bearing structures design was presented by D. Lee and S. Shin in [31] where they suggested developing an advance in the frame modules and frame structures used to truss structures. The DSDI approach was also used to verify that the advanced product secures structural safety and is of optimized size.

Craig et al. suggested applying so-called BioTRIZ approach for radiative cooling of buildings [32]. BioTRIZ is a combination of TRIZ and Biomimetics - methodology for using Principles of Nature in problem solving and design. BioTRIZ matrix was applied in order to design roofs for buildings in hot climates that get free cooling through radiant coupling with the sky. The chosen solution is to replace the standard insulation component with an open cell honeycomb. The vertical cells allow longwave radiation to pass, while stopping convection.

6. TRIZ in Construction Project Management and Value Engineering

The key target of Construction Project Management (CPM) is satisfaction of a customer, codes and regulations to deliver a qualitative, safe, secure and financially effective project that meets the designed time schedule and budget. Hence, in order to achieve those goals specialists have been applying various techniques to managing a complex construction process. Since the level of competitiveness and complication of projects have been increasing, the majority of such techniques cannot be considered beneficial nowadays. Several papers were discovered during literature review regarding the above mentioned subtopic. For instance, Cabrera B. R. and Li G.J. [33] suggest more effective construction process via application the key TRIZ tool such as the contradiction matrix in order to develop innovative solutions to the most complex issues. As a practical example, the case study based on application of TRIZ tools in a highway construction was discussed. The abovementioned tools assist optimization of
working method for soil grading and compacting. However, the authors noticed that the innovative solution, after some time of testing, would possibly create new issues which should be further reevaluated with the help of TRIZ techniques and common practice. Moreover, the authors concluded that all project’s participants have to always accurately investigate and discuss created inventive solutions before applying them into practice. H. Cui [34] presented conflict resolution methods for construction projects from the standpoint of TRIZ. Based on the review of the article abstract, the main TRIZ tools used were: the ideal final result (IFR), Substance-Field (Su-Field) analysis, 76 standards, separation principles, contradiction matrix and 40 inventive principles. Case studies of key conflicts limiting the IFR were discussed in details. Additionally, a few specific solutions for the physical and technical contradictions in the construction projects were presented with the illustration of conflict resolutions as a case. Chang P.-L. et al. [35] developed and tested a preliminary Model of Engineering Problem Solver (MEPS) based on TRIZ to explore the underlying patterns of problem solving for emergent construction problems. MEPS consists of 15 identified management parameters, a contradiction matrix and 16 problem-solving principles. Their work received further development in [36] where a General Construction Problem-Solving Model (GCPM) was presented. The proposed GCPM integrates Construction Project Management Body of Knowledge (CPMBOK), TRIZ and Data Mining (DM), so that the management parameters (MP) and Problem-Solving Principles (PSP) are defined and derived. The model is to assist the construction engineers in solving various emergent problems they encounter daily.

Along with amelioration of conflict resolution methods for construction projects using TRIZ, a number of steps towards improvement of value engineering (VE) in construction were taken as well. One of such attempts was, for instance, performed by Mao X. et al. [37]. The paper presents a value engineering knowledge management system (VE-KMS), which applies TRIZ and integrates its tools into the creativity phase of the VE process and, hence, makes the creativity phase more systematic, organized and problem-focused. Procedures of the improved VE creativity phase consist of the following steps: (1) collect project explicit knowledge and VE team information, (2) break project into subsystems, (3) identify harmful functions in each subsystem Function (using TRIZ function analysis), (4) identify and solve technical contradictions (the TRIZ contradiction matrix), (5) identify and solve physical contradictions (four general separation principles to solve physical contradictions: (a) separation in time, (b) separation in space, (c) separation between the whole system and its parts, and (d) separation based on different conditions), (6) conduct substance-field analysis, (7) improve the project according to technological evolution trends (using TRIZ nine evolution patterns). The direction regarding value engineering in construction was developed by the same scientists in their following work [38] where they explored the possibility of incorporating TRIZ into the workshop session of the value engineering exercise by initiating three new procedures in this session: (1) an initial design procedure to examine the functions of a proposed project; (2) a function trimming procedure to fully utilize existing resources and ensure low life-cycle cost and sustainability of the proposed project; and (3) an interaction analysis procedure to assess the proposed project in a broad perspective with social, economic, and environmental awareness. The objective of the following paper [39] by Yang J. et al. is to investigate the characteristics of contradiction in idea creation, and use them to create better design alternatives in construction VE. An Idea Breakdown Structure (IBS) was applied as the principle of problem solving. Ding Z. et al. developed in [40] a “TRIZ and patent laboratory” (TP Lab) platform to promote innovations and manage the knowledge in the construction industry where TRIZ was applied in order to extract available patent knowledge.

7. Conclusion

Despite the fact that innovation is not the key feature of construction industry, it cannot be considered to be a technologically lagging behind. The key players on the market are cautious about innovation possibly because reliability, stability and meeting existing codes requirements are more demanded aspects. However, real breakthroughs and proven ideas could destroy that conservatism barrier.

The literature review on the subject of TRIZ application in building industry has shown that a number of researchers are working in this direction and making attempts to use TRIZ tools when it is required to find unique ideas and solve specific complex issues in such areas as development of construction techniques and technologies, design of new structures and construction materials, construction project management and value engineering, etc. However, successful application of these tools is not possible without creative adaptation. On the other hand, the number of publications in this field is relatively small which allows us to conclude that TRIZ use is still very limited in construction.

The classic Theory of Inventive Problem Solving was created to solve common technical issues and, therefore, does not provide specific tools for specific industries. Despite that TRIZ has proven to be a quite unique methodology, there are still many controversial situations requiring TRIZ tools to be adapted to a specific industrial field, and construction is not an exception. For practical use of TRIZ in technic it is necessary to have a number of specialized versions of TRIZ differing by nomenclature and content of information assets. The same target can be set regarding construction industry.

8. Suggestion for future work

The review result has shown that the most applied TRIZ tool in construction is the Contradiction Matrix that presents a database of known solutions and enables stakeholders to resolve contradictions using 40 inventive principles. Based on above, it is relevant to adapt such TRIZ tool as the contradiction matrix to problem solving in construction
engineering and management and provide a number of case studies. In this case such methodology could be brought into conservative industries like construction more easily. Supporting this idea, we can add that similar studies were already performed in papers [41]-[45] for such areas as Process Engineering, Redesign Service, Quality Improvement, Electric Energy Storage Systems and Service Related Context.

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