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Application of the TRIZ Methodology in the Construction Industry

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Abstract The relevance of the research is due to the definition of the Theory of Inventive Problem Solving (TRIZ) concept as well as the effectiveness of the theory principles during various types of construction work. The purpose of this research is to formulate the concept of the Theory of Inventive Problem Solving, as well as to evaluate the laws of development of technical systems concerning typical construction operations, which generally determines the main prospects to apply the theory to the construction industry. The methodology of this paper is based on a combination of the method of system analysis of the essence of the TRIZ concept as a separate concept that finds its reflection in various fields of science and technology, with an analytical study of the prospects to apply the principles of the theory in construction work. The results of this research indicate significant prospects for the application of the TRIZ in the construction industry and serve as a reflection of these prospects since they demonstrate the broad possibilities to apply the theory in search of new typical construction operations and to improve the quality standards of construction work in general. The results and conclusions of this scientific study are of significant importance from the point of view of prospects to apply the principles of the theory during different construction work, are important for designers of construction projects, and direct performers of construction operations interested in effective and innovative technologies in the construction sector.

Keywords Innovative Technical Solutions, TRIZ, ARIZ, Quality of Construction, Construction of an Object, Management Solutions, Resources

1. Introduction

In the modern world, the practical application of the Theory of Inventive Problem Solving (TRIZ) is relevant in construction works. The modern construction industry develops rapidly, while this sphere of business activity affects numerous areas of public life, while the TRIZ acts as an innovative element in these areas. In general, the Theory of Inventive Problem Solving helps to overcome the inertia of thinking, refuse compromises, and get closer to the ideal [1]. The TRIZ expands the understanding of the world and makes it possible to solve problems that previously seemed unsolvable. The main idea of the Theory of Inventive Problem Solving is to determine the basic laws of the development of technical systems (TS), and these laws can be used for the practical solution of inventive tasks selected for practical application. At the same time, the TRIZ turns the production of new technical ideas into an exact science. Instead of blind searches inventive problem solving is based on a system of logical operations.

The development laws of technical systems should be considered the theoretical foundation of the TRIZ. First of all, this implies the provisions and principles of materialist dialectic [2]. It is also necessary to take into account some analogues of biological laws, some principles have been identified in the study of historical trends in the development of technology, the general principles of the development of systems are widely used. The laws have been verified, systematised, detailed, and sometimes tested in the analysis of large arrays of patented data on the main decisions made (tens and hundreds of thousands of selected patents and copyright certificates). The entire volume of TRIZ tools has been also gradually determined and developed based on the study of huge volumes of patent data taking into account the funds of physical, chemical, geometric effects, any improvement in the TRIZ is subject to detailed verification and correction on patent and historical and technical materials [3]. This makes it possible to perceive the TRIZ as a generalisation of the creative experience of many generations of inventors: data that bring results were selected and examined, and all conclusions formulated in this context were evaluated.

The main law of improving technical aspects should be considered the desire for maximum improvement: a perfect technical system is considered that one which is outwardly absent when its main functions are fully performed [4]. When trying to increase the ideality of the system in question by conventional (trivial) methods, one indicator improves (for example, the weight of the vehicle decreases) due to the deterioration of other parameters (for example, strength decreases). A designer finds a compromise solution that is universal in each episode under consideration. An inventor should overcome a compromise to improve one parameter without changing the others. Therefore, in the most common cases, the process of practical inventive problem solving can be perceived as the identification, analysis and resolution of emerging technical contradictions. The Algorithm of Inventive Problem Solving (ARIZ) and the system of inventive standards are typical working elements of improving TS and forming new ones in the TRIZ [5].

The solution of emerging problems according to ARIZ proceeds without a lot of unjustified trials, the initial formulation of the problem is systematically, consistently adjusted according to certain rules, the model of the task is built, the available material-field resources (MFR) are determined, the ideal ultimate result (IUR) is formed, physical contradictions are identified and analysed, operators of non-standard, creative transformations are applied to the problem being solved, psychological inertia is extinguished and imagination is forced [6]. The practical application of TRIZ principles in construction contributes to accelerating the pace of construction work and improving the quality of construction operations, which generally has a positive effect on the development of the construction industry, contributes to improving the skills of construction workers. In construction, the TRIZ is a qualitatively new method of development of the entire industry, which is essential from the point of view of improving the overall economic situation in society and searching for new, more effective methods of economic development of the entire state.

The purpose of the article is to formulate the concept of the TRIZ, as well as to evaluate the development laws of technical systems concerning typical construction operations, which generally determines the main prospects for applying the Theory of Inventive Problem Solving concerning the construction industry.

2. Materials and Methods

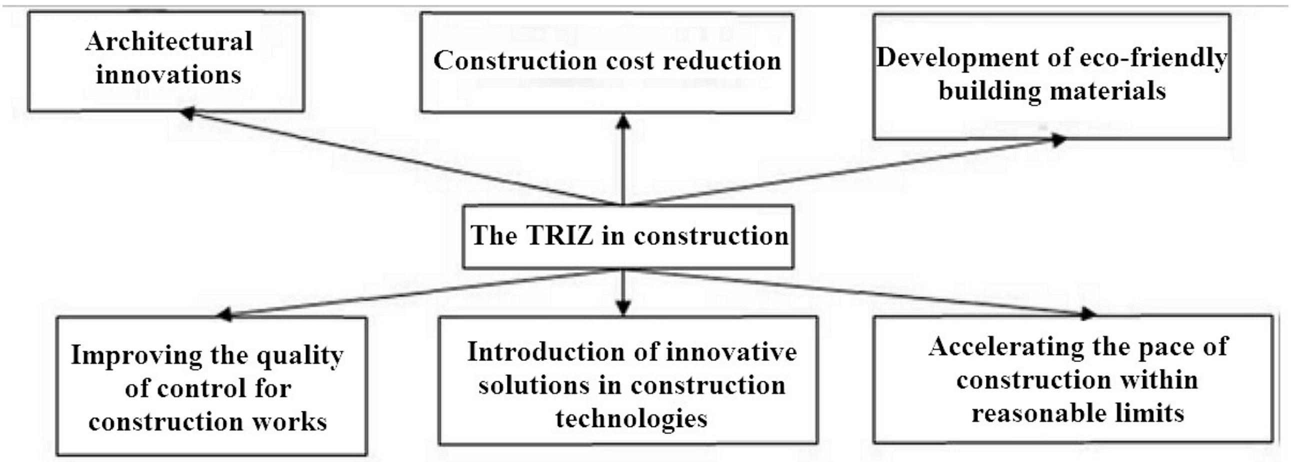
A system analysis of the Theory of Inventive Problem Solving as a separate concept was used as a methodological basis of this scientific study, which finds its reflection in various fields of science and technology, combined with an analytical study of the prospects for applying the TRIZ in construction. Theoretical studies of the issues submitted for consideration are carried out taking into account the latest developments of scientists in the field of studying the prospects of the Theory of Inventive Problem Solving in general and concerning the construction industry in particular, which makes the combination of methods used in practice in this scientific study optimal from the point of view of forming a qualitative assessment of the role and significance of TRIZ principles in construction. The methods used in this scientific research provide an effective combination of theoretical and practical developments within the framework of the stated subject of scientific research, which, in turn, is required to obtain objective results of scientific work and form logical and structured conclusions based on them. The theoretical basis of this research work is numerous available publications of scientists devoted to the study of the practical application of the principles of the Theory of Inventive Problem Solving in various fields of modern science and technology in general and the construction industry in particular.

To facilitate the readers' perception of the information provided in this scientific study and to form the most objective and qualitative picture of scientific research, all the achievements of authors from other countries, taken in the order of citation and presented in this scientific work, have been translated into Russian. All the materials that make up the theoretical basis of the base of this scientific research were selected in strict accordance with its stated subject matter, to fully and objectively disclose it. This scientific research was carried out in several stages. At the first stage of this research work, a theoretical study of the features of the Theory of Inventive Problem Solving in general and concerning the construction industry, in particular, was carried out, in combination with a systematic analysis of the essence of the concept of the Theory of Inventive Problem Solving as a separate concept that is reflected in various fields of science and technology.

At the second stage of this research work, an analytical study was carried out of the prospects to apply TRIZ principles in construction. In addition, at this stage of the scientific research, the results obtained during this research work were compared with the results of other researchers involved in the development of practical application of TRIZ principles in various fields, including in the construction industry. At the final stage of this research work, the conclusions were draw based on the results obtained, summarising the results of the entire complex of scientific works carried out during this scientific research. In general, the results and conclusions of this scientific study are an objective and qualitative reflection of the study of the essence of the practical application of the principles of the Theory of Inventive Problem-Solving during construction work and can serve as a reliable scientific basis for further scientific research in this direction.

3. Results

The practical application of the Theory of Inventive Problem-Solving during construction works contributes to improving the efficiency of construction operations, reducing the risks of construction work and accelerating the pace of construction. In addition, TRIZ promotes the development of creative abilities of builders and is an effective solution to a number of issues of key importance in the development of complex and responsible construction projects. A precisely formed and constantly replenished database is of great importance in the TRIZ: pointers for the practical use of physical, chemical and geometric effects, a bank of standard techniques for resolving technical and physical contradictions that may occur during construction work. This fund is the operational basis of all TRIZ instruments. The methodology for the development of creative imagination should be considered a special section of the TRIZ, which is essential for carrying out construction work. This makes it possible to expand the existing ideas about the methods of construction objects and create the latest, more efficient technologies for construction work [8]. Figure 1 shows the main prospects for the use of TRIZ in construction.



Source: compiled by the authors

Figure 1. Main prospects for the TRIZ in the construction industry

As can be seen from the diagram presented in Figure 1, the Theory of Inventive Problem Solving has significant prospects in the construction industry, which is confirmed by the variety of practical applications of TRIZ principles. At the same time, the TRIZ makes it possible to effectively solve not only existing problems in this industry but also to predict the emergence of new problems and options for their practical solution. The results of such forecasting are much more accurate than those obtained using subjective methods, in particular, through the use of expert assessments. The TRIZ strives for the systematic development of the technical systems used. Thus, the modern TRIZ in construction turns into the Theory of Technical Systems TTS [7]. The TRIZ originated from technology, based on a powerful patent fund. However, there are other systems: scientific, artistic, social in addition to technical systems. The development of all systems is subject to similar patterns, so many ideas and mechanisms of the TRIZ can be used in the construction of theories for solving non-technical creative tasks. In the construction sector, the TRIZ involves the possibility of training the personnel of construction organizations, which subsequently allows us to solve many new production tasks in practice. The application of the fundamental principles of the Theory of Inventive Problem Solving in the construction sector allows us to solve the following typical tasks effectively:

1. Development and practical application of non-standard solutions that effectively solve the problems of construction objects in remote geographical areas.
2. Innovative technical systems when constructing new projects.
3. Development and implementation of innovative building structures to improve the quality of construction work.
4. Implementation of an improved quality control service for construction operations.
5. Determination of prospects for the development of the construction industry as a whole, using innovative construction technologies.

Table 1 shows some technical solutions in the construction sector that were developed using the principles of the TRIZ [9].

Table 1. Technical solutions in the construction sector developed using the principles of the TRIZ

Ser. No.	Name	Intended purpose	Degree of development	Patent availability
1	Reinforced concrete pile structures	Extended application of pile foundations, to reduce the number of piles under an object being built	Project idea	Repeatedly patented
2	Switch of the direction of the flow of bulk substances in pipeline pneumatic transport	Improving the reliability of rotating components and drive mechanisms	Used	Patented
3	Vibrating type bulk material feeder	Ensuring stable and systematic delivery of bulk substances from storage bunkers	Used	Patented
4	Filling mechanism	Provision of automatic shut-off of the liquid supply when filling tanks. Does not require electricity, gas and other types of energy	Experimental research	Repeatedly patented
5	A precipitation measuring device of a building structure	An alarm signal is given when the maximum permissible value of precipitation is exceeded	Experimental research	Absent
6	Domestic electric current switch	Increasing the service life of domestic incandescent lamps, providing the possibility of choosing the lighting mode	Experimental research	Absent
7	A device for removing exhaust gases from an automobile engine	Protection of industrial and other premises from exhaust gas pollution	Experimental research	Absent
8	A water lift using solar power	Lifting water from wells, using solar energy, does not require additional energy sources	Experimental studies	Absent
9	Laying channels in the ground	Laying channels in the ground of any type without large energy costs	Technical idea	Repeatedly patented
10	Device for determining the depth of thawing of frozen soils	Collecting information about the depth of freezing and thawing of the soil without additional energy consumption	Technical idea	Patented

Source: compiled by the authors

As follows from the data presented in Table 1, to date, not all design solutions in the construction industry, developed using the principles of the Theory of Inventive Problem Solving, have been accepted for practical implementation. This list contains only some similar projects taken for consideration to get acquainted with the prospects of the practical application of the TRIZ principles in the construction field. It is stated that some solutions are at an experimental stage. For example, a precipitation measuring device of a building structure. The traditional scheme of controlling the settlement of a structure involves manual geodetic observations from fixed points of the altitude. However, an alternative way of controlling settlement is an automated monitoring system based on contact sensors of physical values of various designs. The most common variant is a surface tiltmeter, which is installed at several points along the perimeter of the foundation. The device registers the changes in the angle of inclination of the foundation structure due to the development of deformation processes. Then, by means of mathematical transformations, the obtained data are compared with the allowable values of roll and settlement. And in case the permissible level of settlement is exceeded, an alarm is given.

Another solution that is still under development is a device for removing exhaust gases from an automobile engine. Exhaust smoke, fumes tend to accumulate in every crevice and corner. It is difficult to vent with open doors alone. During a cold engine start in an enclosed area, the level of exhaust can reach such high levels of toxicity that it can cause serious and dangerous illness, as well as damage to sensitive electronic diagnostic instruments. Thus, through several processing steps in the exhaust system, the gases leave the room through movement through the muffler, giving the opportunity to protect human health and to keep equipment from possible damage.

Also, one of the experimental solutions is a water lift using solar power. The purpose of the invention is to simplify the design and increase the operational reliability by eliminating the controlled hydrodistributive assemblies of the water elevator and heat insulation between the chambers of its diaphragm pump.

One of the main ideas of the classical TRIZ concerning the construction sector involves a consistent narrowing of the field of search for solutions, which means a possible aggravation of existing contradictions. This led to the creation of an algorithm for solving inventive problems – the fundamental tool of classical TRIZ for working with atypical problematic issues. As this tool has evolved, different classes of contradictions have emerged and their role in working on the problem of TRIZ application in construction [10]. When the task of constructing a construction object is formulated in the form of a contradiction, thereby it is quite clearly stated and clearly outlines the main directions of searching for a possible solution to the problem to obtain the expected result. With the help of a contradiction, it is possible to identify particularly significant elements of the system that create the problems under consideration, and this sharply narrows the field of search for possible solutions, since there is no need to sort through a large number of options that are not related to the problem under study.

The system of contradictions embedded in the ARIZ serves as a compass to understand the underlying causes of the problem and why it cannot be solved in the existing conditions. After all, the task should be solved precisely in specific conditions using the resources that a specific problem situation provides. This is another factor that helps to reduce the search for options and purposefully solve the problem on those resources that are available in a specific problem situation. This is one of the main, basic ideas of the TRIZ: the task should be solved in the specific conditions of a specific problem situation [11]. The TRIZ in construction contributes to the search for new, more effective ways of conducting experimental and practical developments in the construction sector, which contributes to the optimal expansion of the real possibilities of construction work and the practical implementation of innovative methods in the construction field. The practical novelty of this scientific research lies in the visual expression of the main typical tasks in the construction field, which can be effectively solved using the principles of the TRIZ, which can serve as a qualitative basis for subsequent scientific research in this direction.

4. Discussion

First, the TRIZ should be considered as a method of solving technical problems. Nevertheless, with prolonged use of such a tool, its influence on the person who uses it significantly increases. The influence of the TRIZ in its systematic use is manifested in the gradual development of a new style of thinking. Currently, the TRIZ principles are actively used in the management of innovative projects where it provides an innovative component of developments. Medium-term projects should be considered the most productive area of the TRIZ application where cross-functional project teams are needed. The essence of any creative technology is that new information is consistently presented in the form of problematic and inventive tasks. In the process of knowledge exchange, listening to the answers and assumptions of other participants, everyone activates their mental activity, turns on, makes an individual contribution to solving the designated problem, picks up, and thinks up various declared ideas, which, of course, affects the receipt of an effective solution and the development of creative abilities [12].

The Theory of Inventive Problem Solving concerning the construction sector opens up broad prospects for improving the quality of construction operations and the introduction of innovative solutions in the construction industry, allowing us to solve the usual issues of the industry at a higher quality level. Using the TRIZ in the construction sector contributes to solving the problem of effective solutions to the problems of this industry without a long search for options, while maintaining effective solutions and without wasting time evaluating the ideas received. It should be taken into account that such a statement of the problem implies that the evaluation of the received ideas should be given already when searching for a solution. Ideas should be selected automatically without a preliminary study of options, their evaluation and rejection. This is not always quickly realized in real conditions, since the ideas being brought out may contradict with the established stereotypes of thinking, in which options are first proposed, and only then evaluated according to the degree of reality of their practical implementation. According to the fundamental principles of the TRIZ, a difficult problem should be considered a situation in which professionals in any field do not have the opportunity to find a simple solution to this situation, there are also situations in which the solution has been known for a long time, but it does not suit one or several specialists of the field in question or customers of works that apply to the construction field. At the same time, the problem can be both complex and simple, depending on the point of view on it [13].

It is also of significant importance whether specific specialists in a given field are familiar with common standard solutions to the problems under consideration. Individual problems of the construction sector can pose a significant complexity even for professionals in their field, not to mention customers of construction works who do not know all the subtleties of construction. In this situation, it is essential that the technological solutions used in solving the problems faced by representatives of the construction field are constantly being improved, opening up new opportunities for practical solutions to the problems of the construction industry. According to the principles set forth by G.S. Altshuller [14], each optimal solution can transfer the system in question to a new level of evolutionary development in his system of transformation of technical systems and the matrix of contradictions. The problem lies in the fact that even with the constant development and improvement of modern technical systems used in construction work, it is not always possible to find a timely solution to the complex technical situation that occurs during the construction of a construction object [15]. Compliance with the engineering decisions should be considered the fundamental principle of the TRIZ, concerning the construction sector, made not only with the basic laws of physics, mathematics and chemistry but also with the principles of the evolution of systems. With a qualitative understanding of these laws, it becomes possible to manage the evolution of technology and more purposefully come to an understanding of the basic principles of solving engineering problems.

According to the principles set forth by G.S. Altshuller [14], an effective problem-solving technology should lead to the strongest solution to the problem back in the second half of the twentieth century without going through the options, without the need to generate a set of solutions, and then form their evaluation. Often, the formulation of a problem creates the impression of its insolvability, and this is although the solution to the problem has been known for a long time and has been implemented more than once in the practical plane. Of considerable importance in this context is psychological inertia, which does not allow to adequately assess what is happening and properly perceive the opening prospects from the introduction of various inventions that can bring to a qualitatively new technical level issue of process management in any area. The TRIZ forms scientific technologies for working on the final problem, presenting it through operations, like other scientific methods. The execution of these operations can be understood at the learning stage. Just like teaching any other scientific knowledge using modern effective educational technologies created by specialists in the GTSF (general theory of strong thinking) - TRIZ. The selection and formation of a model is the initial stage of each scientific method to identify the problem. For this reason, it is necessary to translate the description of a given situation into a specific model, a certain canonical structure.

Unlike the original problem situation, it should be considered a problem. The transition of the initial problem situation into the main problem occurs just as in the process of solving a complex quadratic equation, it is reduced to a special form, after which formulas are used that give the parameters of the roots of the quadratic equation. The fundamental principles of the TRIZ concerning the construction industry indicate that it is necessary to complete its description in the necessary canonical form before taking on a specific task. The system of contradictions is such a form to describe problems in the TRIZ. After isolating a final task from the initial conditions, it is required to perform its description in the form of a complex system of contradictions, after which a model of the designated problem is built. In the following sections of the ARIZ, there is a consistent analysis of the main possible ways to solve this problem. The first part of the ARIZ ends with the construction of a problem model. So, the first part of the ARIZ of G.S. Altshuller [14] is designed to build a task model. If the situation complicates significantly, it also complicates the identification of a system of contradictions, as well as the use of methods developed within the framework of the TRIZ and having significant prospects for their subsequent use in the construction sector [16].

The task of the second part of the ARIZ is to analyse the constructed model and prepare for the identification of deeper contradictions that lie at the root of the problem. In the second part, the analysis of the problem model is reduced to the analysis of resources that can be used to solve the problem: the resources of space, time, substances and fields. All technical systems used in the construction sector are built based on substances and fields and occupy a certain space, working at specified time intervals [17]. These resources of the problem model and the initial problem situation are analysed in the second part according to certain rules developed within the framework of both the classical TRIZ and the GTSF-TRIZ approach. The TRIZ in construction helps to spend significantly less time making objectively correct decisions on the organisation of construction work, the selection of qualified personnel to perform standard operations and evaluating the effectiveness of construction work. At the same time, it should be noted that in the process of using the ARIZ, almost always, starting from the first step, problem solvers have all sorts of partial solutions that, although they do not solve the problem as a whole, bring some positive ideas. Partial solutions are the components that will be used to construct a conceptual solution to the problem of finding the optimal solution for organizing construction work on a specific site [18].

The activation of TRIZ resources available to perform construction operations in a given unit of time contributes to the most effective search for non-standard solutions that can bring the quality of construction work to a higher level and contribute to the speedy solution of the problems of the construction industry. Like any other skill, using the ARIZ requires extensive practice both on educational and, of course, on real tasks, of which there are many in the construction field, especially when constructing objects using the latest, innovative technologies. Often, innovative technologies are incomprehensible to specialists in the construction sector and require additional time for their comprehension and elaboration – in such cases, decisions can be made only after careful study and verification of the compliance of the level of perception of the tasks set by specialists with their general level of training [19]. In any case, the success of the introduction of innovative methods of solving problems in the construction sector is determined by the level of readiness of the technical staff of the facility and its ability to implement quickly and efficiently the technical solutions adopted.

The classical TRIZ involves a non-standard approach to solving typical issues of performing construction operations, using the full innovative potential of employees. At the same time, the practical application of GTSF-TRIZ models in the implementation of the laid principles of the ARIZ ensures the independence of the problem analysis mechanism from the identified problem area. After all, elements of systems from any field of activity of a construction organisation can be described using specified parameters and their numerical values. At the same time, the nature of the system no longer plays a special role. The objective connection of the key parameters of the system with each other is important. Such a relationship between parameters within the framework of the GTSF-TRIZ approach is commonly called law or effect [20]. Thus, the words "parameter association law" and "effect" are synonymous within the framework of the GTSF-TRIZ approach. During construction work, the choice of materials used is often of key importance, especially in cases where it is necessary to achieve high strength and efficiency of the work performed. In addition, the principles of TRIZ in construction work are irreplaceable in cases where it is urgently necessary to find a non-trivial solution to a typical situation with limited construction time and the need to maintain high-quality standards of operations performed.

All the steps dictated by the principles of the TRIZ and its main tool – the ARIZ are logically interconnected and follow one from the other. Moreover, the designation of new technical terms in simple words is one of the basic rules of the TRIZ, which are essential for the implementation of a full range of construction works within a single, specific object, to avoid confusion and misunderstanding of what is happening [21]. Within the framework of the key GTSF-TRIZ approaches, such principles can be further developed, which is expressed in the fact that a group of synonymous words can be used instead of one word. This allows you to see the analysed phenomenon from different points of view and understand more deeply what the analysed system should do. The TRIZ in construction opens up broad prospects for the development of the entire industry and the search for new, promising opportunities to improve the standards of construction operations. The theoretical concepts under consideration are not intended to replace a person's thinking, they only help him choose the right direction. To see and understand the hints that the ARIZ or any modern TRIZ-based software product carries, you need a sufficiently deep knowledge of the TRIZ itself and the mechanisms of operation of tools built on its basis.

5. Conclusions

The practical application of the TRIZ in construction makes it possible to increase the efficiency of solving a wide range of tasks related to improving the quality of construction operations, introducing innovative construction technologies into this industry and solving complex design tasks that require a non-trivial approach. In addition, technical problems of the construction sector can be effectively and timely solved through the ARIZ, which is the fundamental tool of the classical TRIZ for dealing with atypical problematic issues. the ARIZ allows finding effective solutions to complex problems in the construction sector through the consistent use of standard actions designed to resolve complex problematic issues of the area under consideration. The result is numerous innovative technical solutions developed and put into practical use at construction sites and during the construction of new structures, which allows us to conclude that there are significant prospects for applying the principles of the TRIZ and ARIZ in the construction industry.

The conducted research has shown that the basic ideas of the classical TRIZ, which help to solve the problem of reducing trial and error in solving complex problems of the construction sector, are applicable for the practical resolution of controversial issues that determine the choice of the main directions of construction work and the development of innovative technological solutions that contribute to the overall improvement of their quality. At the same time, not in all cases do innovative ideas immediately find their way to practical application in the construction sector since the situation is often complicated by the need for their practical refinement and bringing to the stage of the possibility of obtaining a patent for an invention. The TRIZ in construction has significant prospects for further application since it contributes to the development of the creative abilities of all participants in this process without exception and is the fundamental principle of introducing qualitatively new, previously unknown solutions that ensure the withdrawal of the entire complex of works to a new level of material and technical equipment.

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