The Importance of Mathematics for Future Architects and Civil Engineers

E V Sergeeva

Department of Mathematics, Nosov Magnitogorsk State Technical University, 38, Lenin Avenue, Magnitogorsk 455000, Russia

E-mail: sew1108@yandex.ru

Abstract. Since ancient times, the main methods of design belonged to mathematics. Mathematics in Ancient Greece was one of the sections of architecture and was based on the classical geometry of Euclid. And now professional competence of graduates of construction specialties of the University is impossible without the developed mathematical competence. Developing mathematical competence of future architects and civil engineers, we solve applied problems with students, perform professionally-oriented tasks and projects. Any design solutions in architecture and construction should be mathematically justified. Therefore, any architect, civil engineer should know the theoretical foundations of mathematics, be able to build mathematical models, solve applied problems using the methods of mathematical statistics for processing experimental data.

1. Introduction
Since ancient times, the main methods of design belonged to mathematics. Mathematics in Ancient Greece was one of the sections of architecture and was based on the classical geometry of Euclid. Mathematics at that time was applied to the construction of complex objects of architecture.

This relationship of mathematics and architecture with urban planning from ancient times lasted until the 18th century. With the creation in 1747 of the first Engineering school in Paris, engineering science moved away from architecture, mathematics and architecture began to develop in parallel. With the development of computer technology mathematics and its methods again firmly penetrate into architecture and urban planning. Modern mathematical apparatus has to be used in solving a number of problems of design and analysis of structures, buildings and other building structures. These applied mathematical problems include, for example, the problem of determining the strength of structures, structural optimization, stability and control modes of their operation.

2. Urgency
The study of mathematics in construction specialties in a technical University is very important, because mathematics is the base for the study of professional disciplines. We got acquainted with the works of O. Boev and O. Imas [1], R. M. Zainiev [2], whose authors believe that the University should have a quality fundamental mathematical training. There are supporters of the bias towards professional, applied orientation of mathematical training at the University, this is devoted to the work of B. V. Gnedenko [3], M. V. Noskov and V. A. Shershneva [4], O. V. Petunin and L. I. Mamonova [5]. In their works, they focus on solving applied problems. From our point of view, the purpose of
mathematical education for students of construction specialties of the University is to obtain fundamental mathematical knowledge, the development of mathematical competence of the future architect or construction engineer, the development of skills to apply their mathematical knowledge in solving applied problems. It is impossible to teach students to solve all types of applied problems that they can meet in their future professional activities in the allotted time for mathematics, therefore, it is also important to develop a culture of logical thinking, the ability to creatively approach professional issues in a non-standard way. Another important point is the ability to search for the necessary information in books, reference books, the Internet. Therefore, in teaching mathematics on construction specialties in a technical University, we focus on three areas: 1) strengthening the applied orientation of mathematical tasks of laboratory work, 2) the development of logic and non-standard thinking, 3) the development of creativity in the implementation of projects.

Graduates of technical University within the limits of the construction specialty have to be able: to construct mathematical model on available data; to formulate a mathematical problem; to choose the suitable mathematical method and algorithm for the solution of a task; if necessary to use for the solution of a problem numerical methods with application of the computer; on the basis of mathematical methods of research to draw practical conclusions.

3. Theoretical part
A competent architect and civil engineer should know how to calculate the loads affecting the building during its operation, structural stability, how to make the best choice of building materials, how to design engineering systems, infrastructure, road junctions and so on. In order to make the projected object harmonious and expressive, you need to know the ratio of the rhythmic series, and therefore be familiar with the progressions. It is also necessary for the future architect and civil engineer to know linear algebra and analytical geometry, mathematical analysis, probability theory and mathematical statistics, mathematical modeling, numerical methods, etc.

Studying mathematics in high school, a student should not feel its separation from real life and future professional activities. Therefore, studying any branch of mathematics, we try to give students not only fundamental knowledge, but also to show the applied orientation of this particular topic. This is achieved primarily by solving applied problems.

We give examples of applied problems on the topic "Bodies of rotation".

1) On the construction site wet sand after acceptance laid in a pile of conical shape. The stack has the following dimensions: the circumference of the base 64 m, the slope length of 14 m. Calculate the volume of incoming sand, applying a discount on humidity 10 %.

2) The plaster figure has the form of a truncated cone, the radii of the bases of which are equal to 20 cm and 15 cm, and the generatrix is equal to 30 cm. How much paint will be needed to paint 10 such plaster figures on both sides, if 150 g of paint is required for 1 m²? (Thickness of walls of plaster not to take into account).

For example, when studying the topic "Integral calculus" you can consider the following tasks:
1) find the coordinates of the center of gravity of the figure, bounded by the arc of the ellipse \(x=3\cos t, y=4\sin t\), located in the I quarter, and the coordinate axes;

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1;
\]

2) find the volume of the three-axis ellipsoid

3) using a crane removed concrete hemisphere from the bottom of the river depth of 10 m. What work is done if the hemisphere has a size of 500 to 250 mm? Concrete density 2000 kg / m³, water density 1000 kg / m³.

Any student studying in the construction specialty must be able to build a mathematical model from the available data. After all, many tasks of the organization, planning and construction management are characterized by a plurality of its possible solutions, often great uncertainty and dynamic processes. In the process of working on a plan for the construction of any construction object,
it is necessary to compare different options and choose the most appropriate criteria. The criterion is a certain indicator, which is a standard, a measure of compliance with the requirements.

For preliminary analysis of the object, search for the best forms of organization, as well as planning and construction management modeling is used.

Modeling is the creation of a model that reproduces the essential properties of the original, the process of construction, study of the model, correlation of available information about the model with real information about the object, experimental verification of the information obtained. Modeling is the main tool for analysis, optimization and synthesis of building systems. Under the model we understand the generalized, idealized, visual-logical image of the object (process) under study, more accessible to study than the process itself [6].

Modeling allows us to identify the essential features of the real object for the researcher, helps to make experiments. The researcher analyzes the results of calculations and experiments obtained on the model, possibly using a computer. That is, the model is an instrument of research, therefore, it should reflect the properties of the real object as accurately as possible.

The process of mathematical modeling includes three stages: 1) formalization, 2) solving the problem within the model, 3) interpretation. Teaching students mathematical modeling, we pay special attention to the work on the stages of formalization and interpretation, because these two stages cause the greatest difficulties for students [6].

In mathematics classes, students compare real objects and their mathematical models. For example, when studying the topic "Analytical geometry", the analogy is drawn between the linear function \( y = kx + b \) and

- a) speed and time in uniformly accelerated motion \( v = v_0 + at \);
- b) between the volume of gas and its temperature at constant pressure \( V = (1 + \alpha t) \);
- c) the relationship between the length of the rod and the heating temperature \( l = (1 + \alpha t) \);
- d) pressure and temperature of gas at constant volume \( p = (1 + \beta t) \).

At home students are tasked with continuing this analogy and providing examples from architecture or construction.

An important means of teaching students mathematical modeling are subject problems. We use plot problems in the study of various branches of mathematics, translating them into mathematical language [7].

Consider one of the tasks.

In some areas there are 2 concrete plants. One of them produces daily 400 t of concrete and another 560 t Concrete from these plants is sent to 4 of the construction site. At first the site comes a day 220 tons of concrete, on the second 200 tons, the third – 180 t, the fourth – 360 t. The Cost of transportation of one ton of concrete from each plant to each site is known. It is required to organize the transportation of concrete from factories to construction sites, so that the total cost of all transportation is minimal.

From the substantive formulation of the problem, let's move on to the mathematical one. If to designate through \( C_{ij} \) - cost of transportation of one ton of concrete from I plant on j a building site (these are known sizes), and through \( x_{ij} \) - quantity of tons of concrete which needs to be transferred from I plant to j a building site (these are required sizes), the cost of all transportations will be expressed by function (1).

\[
\begin{align*}
\min f = & \sum_{i=1}^{4} \sum_{j=1}^{5} C_{ij}x_{ij} \\
\sum_{j=1}^{5} x_{ij} = & 400, \sum_{j=1}^{5} x_{i1} = 560, \sum_{j=1}^{5} x_{i2} = 220, \sum_{j=1}^{5} x_{i3} = 180, \sum_{j=1}^{5} x_{i4} = 360 \quad (1)
\end{align*}
\]

In mathematical language, the problem is formulated as follows: find the minimum function (1), provided that its arguments satisfy the system of equations (2).

Within the framework of the constructed mathematical model, it is necessary to find the extremum of a given function, the arguments of which are restricted. We got the problem of mathematical programming.
Consider an example of a group story problem in the study of the theme "A certain integral. It is necessary to calculate the length of the decorative fence enclosing a birch grove in a public square. Input data and clarifying requirements: on the territory of the Park is the building rental equipment. The base of this building is a square with a side of 9 meters. In front of the facade of the building, at a distance of 5 meters from it, there is a round gazebo with a radius of 1 meter. This gazebo is at the same distance from the nearest two corners of the building. Behind the fountain, at a distance of 5 meters from it, there is a straight treadmill parallel to the facade of the building. The fencing shall consist of three parts and settle down so that the arbour was in a grove. Two parts of the fence should naturally continue the side walls of the building. The third part runs in an arc, each point of which should be at the same distance from the gazebo and treadmill. For students also formulated an additional task: to come up with material for the construction of a decorative fence and calculate its cost.

A very important section of mathematics for future architects and civil engineers is the theory of probability and mathematical statistics. According to the theory of probability we can give a lot of problems of applied value. Let us consider some examples of tasks on mathematical statistics performed by students in the form of laboratory work. Students perform them in Microsoft Excel.

Target 1. At the plant of reinforced concrete products N to create a brand of high quality concrete, a study was conducted of 100 different test grades of concrete, for which the percentage of compressive strength (random value X) and the percentage of resistance of the same grade of concrete to rupture (random value Y) was calculated. The following result is obtained (a table containing 100 X and 100 Y)

Find the expression of the two-dimensional empirical distribution (X, Y), the empirical distribution of components X and Y, build a graphical display of the distributions.

Target 2. According to task 1, to determine whether there is a relationship between the signs of X (percentage of compressive strength of concrete) and Y (percentage of resistance of concrete to rupture).

To show the applied orientation of the mathematics course, students are given not only plot tasks, but also tasks to create tables.

For example, at one of the very first classes in mathematics, students are given the task to create a table at home "Contact of mathematics and architecture" (for future architects), "Contact of mathematics and construction" (for future civil engineers). In this table, students compare basic mathematical and architectural (construction) terms, their meaning, for example: symmetry, proportion, point, line, geometric figure, geometric body, space, curve, surface, volume, etc. The main criterion for the selection of terms for the table was the similarity of their meanings and significance for mathematics and architecture (construction).

On the contrary, at one of the last classes of mathematics at the University students receive homework to create a table "Classification of mathematical methods used in modern architecture (construction)." Students determine the need for mathematical methods in architectural design. When creating a table, the following principles are used:

1) selection of methods used in the creation of mathematical models;
2) formulation of design tasks for three-dimensional architecture and urban planning;
3) establishing links between tasks and methods.

In order to show the applied orientation of mathematics, for the development of students’ creativity, the ability to look for missing information in various sources, students in the process of studying mathematics, be sure to engage in project activities. They carry out projects on major sections of the course of higher mathematics and interdisciplinary projects. One of the first themes of the projects is the "Golden section in architecture and life". "Golden section" is a mathematical formula by which the architect calculates the proportions of buildings. The use of mathematics in architecture and construction is not only the use of the "Golden section".

When studying the topic "Curves of the second order", students prepared group projects on the topic "Parabola in mathematics and architectural structures". In their works they considered the
concept of parabola, its properties, revealed the features of its application in architecture. Most often parabolic form is found in the structures of arches and bridges, and the students gave many such examples.

In the process of studying mathematics, students performed other various projects, showing the relationship of mathematics with the future profession, with everyday life. For example, carried out projects of the future giving or future house, connected mathematics with the specialty and others. We have considered examples of such projects in our previous articles [7, 8].

4. Results of experimental work

Mathematical competence is an integral part of the professional competence of University graduates. Therefore, we are engaged in the development of mathematical competence of students. Experimental work was carried out. Three groups of students were chosen for the experiment: one group with the direction of training "Architecture" and two groups of training "Construction". Of the last two groups, one group is trained in the profile of "Industrial and civil construction", the other "Heat and gas supply and ventilation". Let us denote these groups I, II, III. At the beginning of the experimental work, criteria and indicators of the level of development of mathematical competence of students were developed [9]. At the first classes in mathematics the primary diagnostics of level of development of mathematical competence of students was carried out. It showed a fairly low level of interest among students in mathematics, creativity, project activities. Students do not see the connection of mathematics with future professional activities.

During the experiment, a standard fundamental course of mathematics was taught in group III. Groups I and II, in addition to studying the basics of fundamental mathematics, engaged in project activities and solve applied problems and tasks. At the end of the course of mathematics at the University was repeated diagnosis. The results of the experimental work showed that the number of students with an average and high level of development of mathematical competence increased, the majority of students realized the importance of mathematics for future professional activities. Students with great pleasure spoke about their project activities.

Table 1. Changes in the levels of development of mathematical competence of students as a result of the experiment

| Group | Number of persons | Stage | Levels | $\chi^2_{\text{obs.}}$ |
|-------|------------------|-------|--------|----------------|
| I     | 38               | Initial | 23 | 11 | 4 | 0.13 |
|       |                  | End    | 3  | 24 | 11 | 10.52 |
| II    | 32               | Initial | 19 | 11 | 2  | 0.17 |
|       |                  | End    | 3  | 22 | 7  | 7.66 |
| III   | 34               | Initial | 20 | 11 | 3  | -   |
|       |                  | End    | 13 | 17 | 4  | -   |

In the analysis of the results of experimental work to determine the causes of changes in the level of mathematical competence of students used statistical criterion "Chi-square" Pearson. According to the zero statistical hypothesis, the change in the levels of mathematical competence of students in all groups will be the same.

As a result of the experiment at the level of significance $\alpha=0.05$ in experimental groups I and II $\chi^2_{\text{obs.}} > \chi^2_{\text{crit.}} (\chi^2_{\text{crit.}} = 5.99)$, that is, the condition for the use of professionally oriented tasks and projects in the process of teaching mathematics is statistically significant for the development of mathematical competence of students. Therefore, an alternative hypothesis was adopted. Thus, the successful development of mathematical competence of students-builders and architects of the first and second considered groups is not accidental, but is a consequence of the use in mathematical training of students of applied and professionally oriented tasks, creative tasks and projects.
5. Summary
Any design solutions in architecture and construction should be mathematically proved. Therefore, any architect, civil engineer should know the theoretical foundations of mathematics, be able to build mathematical models, solve applied problems, using methods of mathematical statistics to process experimental data. That is, he must have a well-developed mathematical competence.

The results of the experiment showed that due to the application of applied tasks, implementation of applied tasks and projects, the development of mathematical competence of students-builders and architects is more qualitative.

Students of construction areas, engaged in project activities in mathematics lessons, able to translate professional tasks into mathematical language, easier to learn in their specialized disciplines, easier to adapt to modern economic conditions. They have a higher level of professional competence at the end of University.

References
[1] Boev O and Imas O 2005 Trends in mathematical training of engineers Higher education in Russia 4 pp 15–18
[2] Zainiev R M 2008 Professional orientation of mathematical training of engineers Higher education today 5 pp 88–90
[3] Gnedenko B V 1986 Mathematical training-applied orientation Bulletin of higher school 9 pp 49–52
[4] Noskov M and ShershnevaV 2005 Mathematical preparation as an integrated component of competence engineer High school Herald 7 pp 9–13
[5] Petunin O V and Mamonova L I 2007 Professional orientation of physical and mathematical training of engineers Higher education today 10 pp 21–22
[6] Sergeeva E V 2017 Development of mathematical competence of students in the process of professional training in technical profiles: dis. kand. pedagogical sciences p 179 http://ds.rsvpu.ru/sites/default/files/2017/ sergeeva_e.v_.dissertaciya.pdf
[7] Sergeeva E V 2018 Project activity of students of construction specialties in universities IOP Conference Series: Materials Science and Engineering (MSE) (ICCATS 2018) vol 451 https://iopscience.iop.org/article/10.1088/1757-899X/451/1/012119
[8] Sergeeva E V 2018 How to interest a student in mathematics? Problems of modern pedagogical education 59(4) pp 244–247 https://elibrary.ru/download/elibrary_35130349_57385079.pdf
[9] Sergeeva E V 2016 Criteria determining the level of development of mathematical competence of students World of science: online journal 4(1) http://mir-nauki.com/PDF/37PDMN116.pdf
[10] Dewey J 1997 The Psychology and pedagogy of thinking (Moscow: VLADOS) p 412
[11] Chechel I D 1998 Research projects in school practice Management of research activities of teachers and students in a modern school (Moscow: September) pp 83–128
[12] Kilpatrick W H 1989 Dewey's Influence on Education The Philosophy of John Dewey (Illinois)
[13] Polat E S 2007 Modern pedagogical and information technologies in the education system: educational manual (Moscow)
[14] Pereverzev L B 2002 Project approach and requirements to the teacher School and industry 1 pp 14-16
[15] Slobodchikov V I 1996 The basics of designing and development training (Petrozavodsk)
[16] Sidenko A S 2003 Project method: history and practice Head teacher 6 pp 96–111
[17] Shukina G I 1986 The role of activities in the educational process (Moscow: Education) p 144
[18] Nishitani Kendo 1962 The History and Present Status of the John Dewey Society (Tokyo: Sept. 12)
[19] Stoof A, Marrens R L and Merrienboer Jeroen J G 2004 What is competence? Constructivist approach as a way out of confusion (Open university of the Netherlands) www.ht.ru