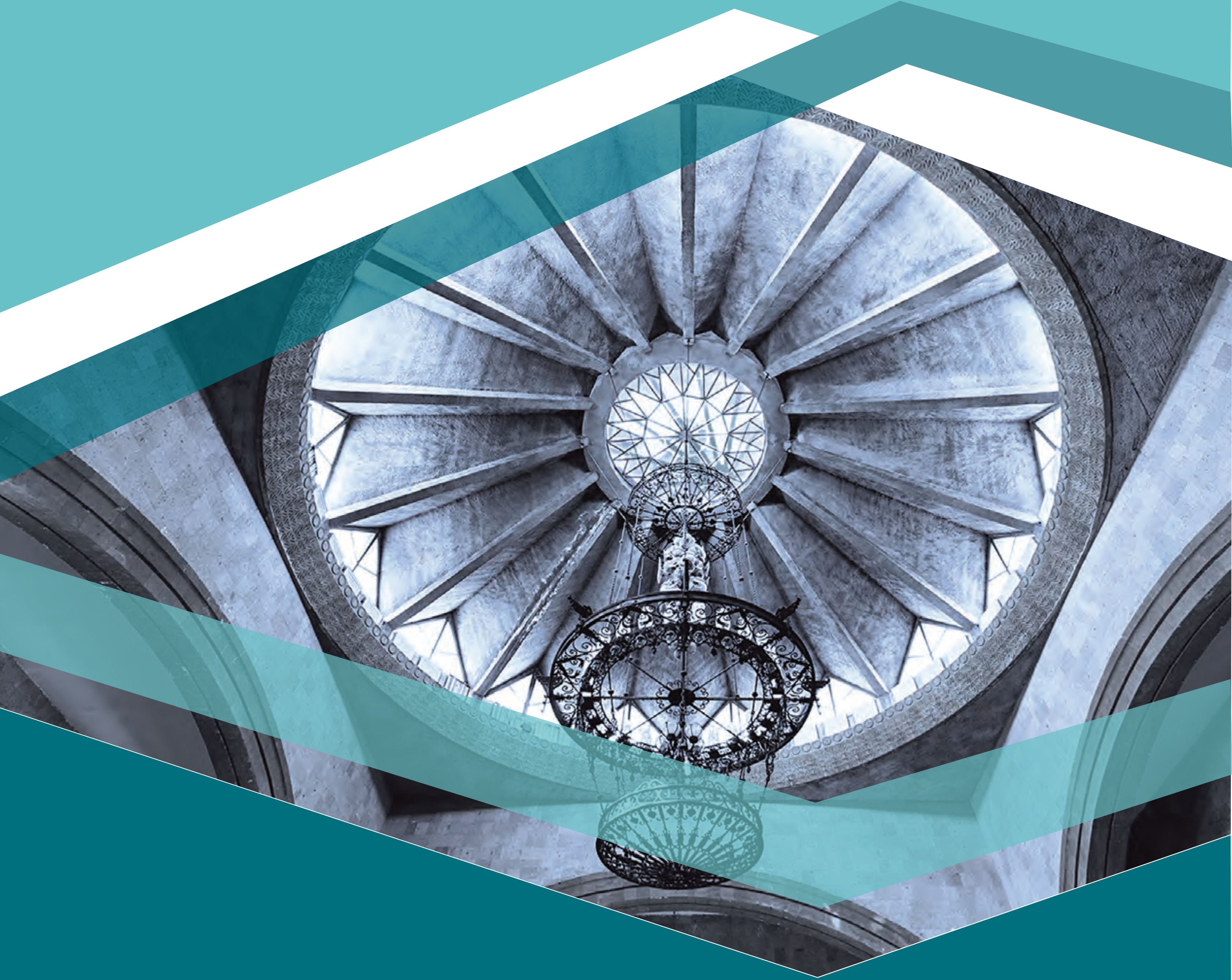
ISSN 2738-2656

2023-5



JOURNAL OF ARCHITECTURAL AND ENGINEERING RESEARCH

National University of Architecture and Constraction of Armenia approve the journal for publication
Scientific Council

JOURNAL OF ARCHITECTURAL AND ENGINEERING RESEARCH

2 0 2 3 - 5

YEREVAN 2023

CONTENT

MECHANICAL BEHAVIOR OF 2D FGP BEAM WITH UNEVEN POROSITY DISTRIBUTION

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Abstract: *This study gives the mechanical behavior of 2D functionally graded porous (FGP) beams using the finite element method. The Matlab code with simple Timoshenko beam elements is written to solve 2D FGP beam problems under distributed load. On the basis of a simple model and approximate results, we can then apply it to analyze this type of structure. The transverse deflections are plotted along the length to provide mechanical views about this structure in reality.*

Keywords*: 2D FGP beam, Uneven porosity, Bending, Transverse deflection.*

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Received: 26.06.2023

Revised: 18.08.2023

Accepted: 19.09.2023

Introduction

In recent years, functionally graded structures have been used in many modern engineering applications due to varying material properties over dimensions which allow them to improve the strength of material, high resistance to temperature shocks and high strength to weight ratio. Authors [1-12] devoted a considerable number of studies to predicting and to understanding the mechanics of functionally graded structures. In [1], the main idea of this paper's developed method was the control over the produced gradient and did not require burning binder phase. The nonlinear bending analysis of FGP beams was investigated using an efficient numerical algorithm associating a meshless collocation technique uses the multiquadric radial basis function approximation method and a higher-order Taylor series-based continuation procedure. Material properties of the FGP beams were described by adopting a modified power-law function taking into account the effect of porosities as in [2]. Besides, the [3] was aimed to develop an efficient and high-performance four-node iso-parametric beam element, which was composed of FGM. In addition, different patterns of material distribution were considered through the height of element. On the other hand, beam's imperfection such as porosity, was taken into account by using the rule of mixture. In order to alleviate the shear locking, MITC was utilized by using tying points. Strain interpolation at some tying points reduced the order of strain functions. The effects of porosity on bending static analysis of FG beams was first introductioned by using a refined mixed finite element beam model. Two different types of porosity namely even and uneven distributions were also considered in [4]. For better understanding of the behaviour of FGM in high temperature environment, a reliable and efficient numerical tool was required for predictions of heat transfer behaviour and thermally-induced stresses in them as [5]. The thermal performance of several engineering devices, such as heat exchangers, volumetric solar receivers and thermal energy storage systems, was improved by open-cell metal or ceramic foams. Among them functionally-graded foams, through which morphological characteristics are variable, look promising. Heat transfer and pressure drop in a functionally-graded foam, with a uniform heat flux entering one of its sides, were investigated numerically in paper [6]. Porosity and cell size variable in the direction of the entering heat flux according to different power-law functions were considered in [6]. A microscale FG Timoshenko beam model was developed for the static bending analysis based on the modified couple stress theory as in [7]. The material properties of the FG microbeams were assumed to vary in the thickness direction and were estimated through the Mori–Tanaka homogenization technique and the classical rule of mixture. The equilibrium equations and the related boundary conditions were derived by using the principal of the minimum total potential energy. In [8], a higher-order element based on the unified and integrated approach of Timoshenko beam theory was developed. A two-node beam element with Hermitian functions of a 5th-degree polynomial (4 dofs per node) was proposed to solve the problems of static and free vibration in this reference and so on. Among many different beam theories, the simple Timoshenko beam model helps us to reduce the computational cost with the resulting error within the allowable range. This article gives the bending behavior of the 2D FGP beam by using a finite element (FE) procedure with simple Timoshenko beam elements respectively.

It is given in four sections. Section 1 shows the introduction as above. Section 2 presents the formulations as well as section 3 shows some essential results. Finally, a few comments are also given in the last section.

Methods

2D FGP beam with uneven porosity distribution

A 2D FGP beam of length *L*, width *b*, thickness *h* and uneven porosity distribution as shown in Fig. 1 is studied in this article. It is made by changing from *c* (ceramic) to *m* (metal) phases through x and z directions.

The volume fraction of the ceramic can be presented in Eq. (1) by following the power law form:

$$V_c(x,z)=\left(1-\frac{x}{2L}\right)^{n_x}\left(\frac{1}{2}+\frac{z}{h}\right)^{n_z}. \quad (1)$$

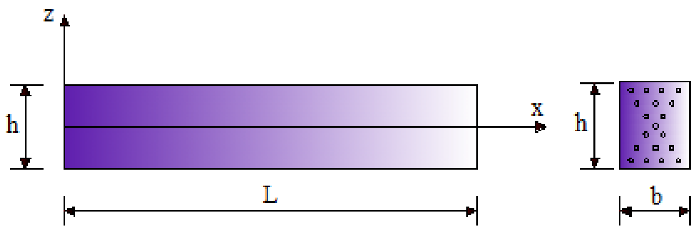

Fig. 1. *A 2D FGP beam with uneven porosity distribution*

The material properties can be calculated as below for an uneven porosity distribution with coefficient α and then Fig. 2 also shows the modification of E, respectively:

$$E(x,z)=(E_c-E_m)\left(1-\frac{x}{2L}\right)^{n_x}\left(\frac{1}{2}+\frac{z}{h}\right)^{n_z}+E_m-\frac{\alpha}{2}(E_c+E_m)\sin\left(\frac{|z|}{h}\pi\right), \quad (2)$$

$$G(x,z)=(G_c-G_m)\left(1-\frac{x}{2L}\right)^{n_x}\left(\frac{1}{2}+\frac{z}{h}\right)^{n_z}+G_m-\frac{\alpha}{2}(G_c+G_m)\sin\left(\frac{|z|}{h}\pi\right), \quad (3)$$

$$\nu(x,z)=(\nu_c-\nu_m)\left(1-\frac{x}{2L}\right)^{n_x}\left(\frac{1}{2}+\frac{z}{h}\right)^{n_z}+\nu_m-\frac{\alpha}{2}(\nu_c+\nu_m)\sin\left(\frac{|z|}{h}\pi\right). \quad (4)$$

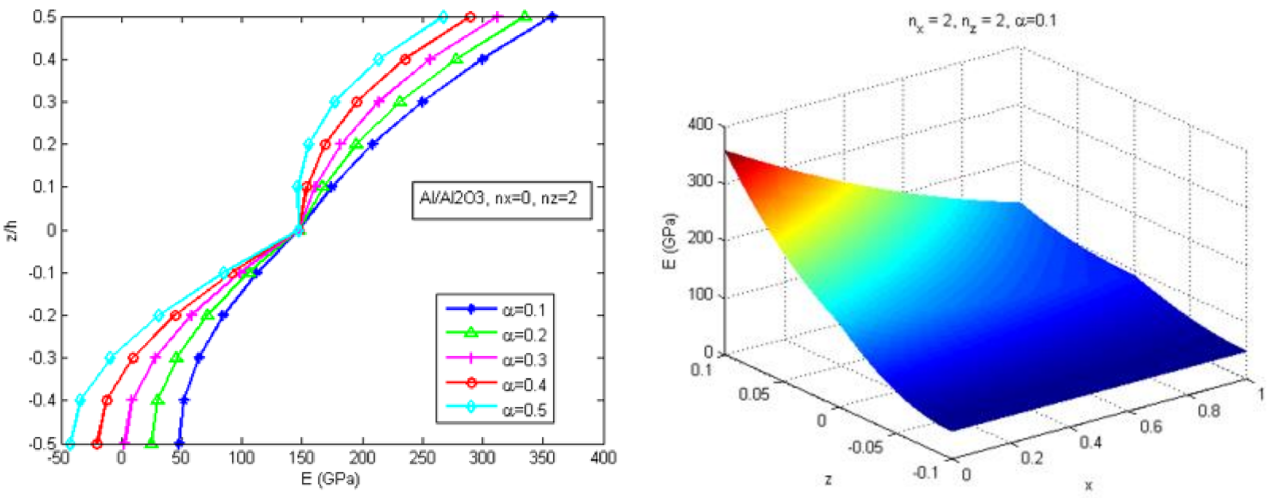

Fig. 2. *The modification of E*

Two dofs associated with a node of a simple Timoshenko beam element are a transverse displacement and a rotation. The beam element stiffness matrix will be derived

$$\mathbf{K}_{el} = \frac{E_{el} I_{el}}{L_{el}^3 (1+\Xi)} \begin{bmatrix} 12 & 6L_{el} & -12 & 6L_{el} \\ 6L_{el} & (4+\Xi)L_{el}^2 & -6L_{el} & (2-\Xi)L_{el}^2 \\ -12 & -6L_e & 12 & -6L_{el} \\ 6L_{el} & (2-\Xi)L_{el}^2 & -6L_{el} & (4+\Xi)L_{el}^2 \end{bmatrix}, \quad (5)$$

with

$$\Xi = \frac{12 E_e I_e}{G_e k A_e L_e^2}, \quad (6)$$

and k =5/6 is called the shear correct factor. According to the principle of minimum total potential energy and after assembly, the transverse deflections can be obtained by solving the following equation:

$$\mathbf{Kd} = \mathbf{F}\ . \quad (7)$$

Results

Some numerical tests are presented to verify the applicability of proposed method. A 2D FGP beam with length L = 1m, b = 0.1m, length to thickness ratio L/h = 20 and distributed load $q = 10^4$ N/m is considered and the material properties can be seen in Table 1 for two-phase.

Table 1. The material properties

Al_2O_3	E_c = 380Gpa	ν_c = 0.3
Al	E_m = 70Gpa	ν_m = 0.3

Table 2. The comparison of normalized maximum tranverse deflection of (CC) 2D FGP beam with α=0

L/h = 20	n_x			
n_z	0.5		2	
	[9]	present	[9]	present
0.5	0.9238	0.9323	1.2279	1.2399
2	1.2414	1.2548	1.5664	1.5838

Firstly, the normalized maximum transverse deflection is formulated by $\bar{v} = 100 E_m b h^3 v_{max} / q / L^4$ as well as all results related to this proposed method for boundary condition (CC_clamped-clamped) are compared with other solutions from [9] by author Karamanli based on Smoothed Particle Hydrodynamics (SSPH) method as shown in Table 2 under coefficient of porosity α = 0. It can be seen that the results obtained from this study are approximate with the solutions of SSPH method. The relative error among these results can be explained by using different approaches.

Finally, to review the influence of material coefficients (n_x, n_z, α) as well as boundary conditions (CC_clamped-clamped, CS_clamped-simply supported, CF_clamped-free) on the deflection of a 2D FGP beam with uneven porosity distribution, Fig. 3 presents curves showing transverse deflections along the length of the beam. It is clear that the deflection value increases when these material parameters increase in all cases.

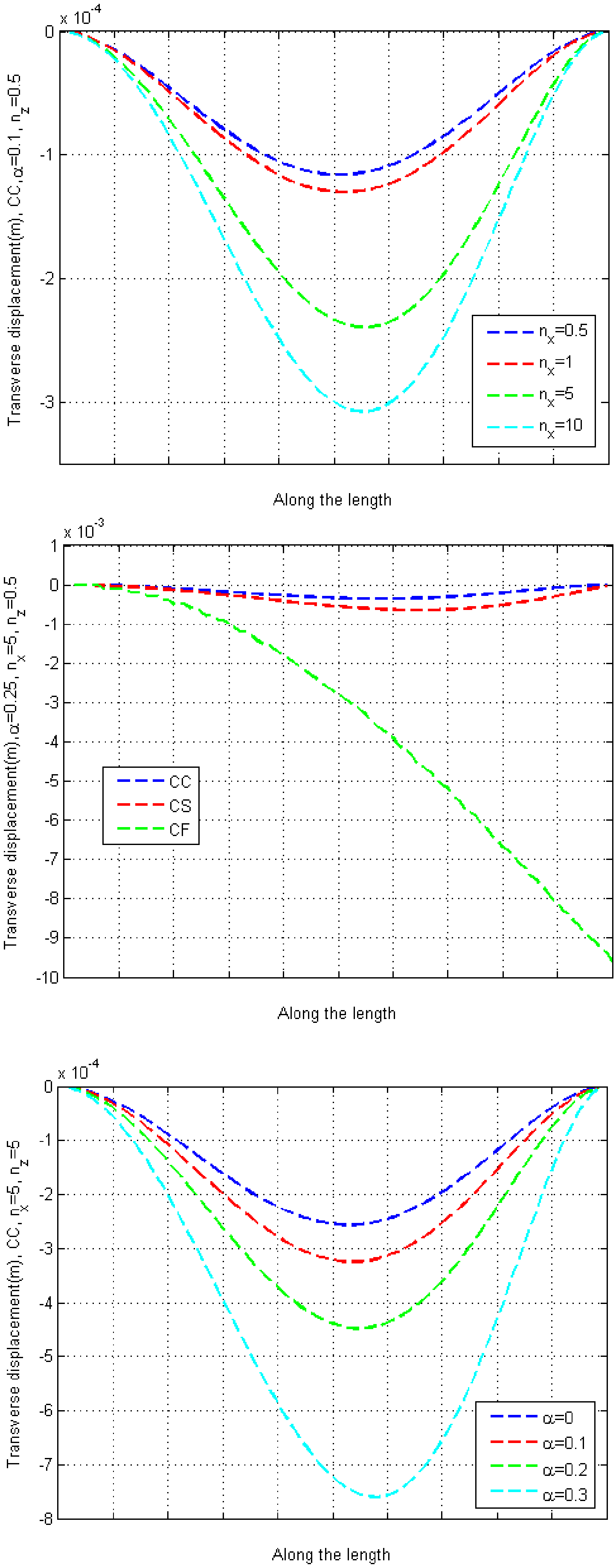

Fig. 3. *The curves of transverse deflection*

Conclusion

In this study, the mechanical behavior of 2D FGP beam with uneven porosity distribution is shown. The simple Timoshenko beam elements based on the FE procedure are applied to analyze the bending behavior of this structure. The results of this article are approximate with other solutions in reference. On the basis of a simple model and approximate results, we can then apply it to analyze this type of structure.

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STUDENT PERCEPTION OF BAMBOO ARCHITECTURE (PROCESS OF ARCHITECTURAL EDUCATION IN INDONESIA)

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Abstract: *In Indonesia, bamboo is an easy-to-find building material. In addition to being valued as a plant, bamboo is also used as an alternate material in building. One example of how bamboo is evaluated from both a strength and an aesthetics perspective is the development of bamboo as a substitute material in architecture. In order for the educational system, one of which is UIA, to produce professional architects in the future, architectural education is one of the systems that will do so. The International Union of Architects has three examinations, including knowledge, design, and skills, through the APTARI Association of Indonesian Architectural Higher Education, an association for all architectural higher education in Indonesia. The bamboo architecture learning system is tested using these three factors as parameters. The research methodology combines quantitative analysis with qualitative design using the JMP 17 software to produce an overview of the UIA-related education system.*

Keywords: *Knowledge, perception, bamboo architecture, design, abilities.*

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Received: 14.08.2023
Revised: 14.09.2023
Accepted: 02.10.2023

Introduction

Many different types of bamboo can be found in Indonesia. Out of the 1620 species of bamboo that come from 80 different nations worldwide, 176 kinds are found in Indonesia. As a result, Indonesia is home to 10% of all bamboo species worldwide. In actuality, Indonesia is home to 105 endemic species of bamboo. 50% of the bamboo that grows in Indonesia is endemic, and the community has consumed half of this quantity [1]. According to scientific studies, indigenous Indonesian populations, particularly the Javanese, Dayak, Balinese, and Papuan communities, have close social, economic, and cultural ties to diverse types of bamboo [2].

Currently, there are changes and shifts in the characteristics of bamboo use in architecture, particularly in the context of vernacular architecture that has evolved traditionally in society. This is an interesting topic to bring up because it involves not only technological advancements, design innovations, and the physical level of architectural forms, but also the vernacular architecture that has developed traditionally in society. When compared to wood, bamboo has a number of advantages, including a quick growth cycle. Because of its elasticity and excellent ornamental value, bamboo may be curled and used as a building construction material in five years [3]. The many varieties of bamboo must also be taken into account when designing because some varieties of bamboo can only flourish in particular environments. Ordinary people still typically believe that bamboo is a weak, outdated, and unpractical material. Bamboo is typically associated with home furnishings, temporary structures, and construction supports [4]. In some places, some individuals even believe that homes made of bricks and concrete signify a middle-to-upper class of socioeconomic standing, whilst homes made of bamboo are said to signify a middle-to-lower class. Currently, bamboo is regarded as one of the sustainable building materials that is pertinent to the problem of global warming. As a result, bamboo is viewed as a material that offers a sustainable solution to issues with strength, durability, and beauty. The general public still has very little awareness of bamboo, and some still believe that it is a cheap material that only makes boring shapes. Even the community's bamboo has a tendency to allow bamboo plants age, weather, or turn into useless piles of trash that float out to sea [5].

Architectural education, which creates future architects, is crucial in ensuring that students have knowledge and understanding of bamboo in light of the changing qualities of bamboo use in architecture [6] beginning with the preservation, processing, and design development processes. To ensure that students are conversant with the subject of bamboo, it is necessary to review the educational process in Indonesia's architecture education system. The learning process will be more successful if students are already familiar with the subject of bamboo. The quality of architectural education recommended by APTARI, the association of Indonesian architecture institutions, which refers to UIA including design, knowledge, and skills, is related with an efficient learning process. Based on these standards, instruction in bamboo architecture is provided through a trial process (workshop), followed by design. In order for students to be able to come up with answers to issues in the future, the learning process must be balanced with creative values.

Perception theory is used in the analysis process because it is seen to be the best way to find out information about the bamboo learning process that has been carried out and because perception is connected to student opinions on bamboo. Fundamentally, perception is a process that takes place as a person watches another person or an object. Understanding of information shared by others who are conversing, connected, or working together, so involving everyone in the perceptual process [7]. Perception is not something that merely happens to someone; there are undoubtedly outside influences [8]. There are a number of factors that influence perception, including structural factors (which are physical stimuli) such as those related to touch, smell, sight, taste, and hearing, functional factors (which are factors that are personal), situational factors (that the word that is mentioned first will direct the next judgment, or how adjectives affect the judgment of a person), and personal factors (personal factors that influence people's perceptions of us or vice versa are experiential factors) [9]. It is intended that by adopting a perceptual method, we will be able to map the process of ideal learning for students. We also work to meet the demands of students in order to support the learning process in accordance with UIA standards.

Methods

A qualitative study approach is used to understand how bamboo building is perceived. The qualitative approach is a research technique that generates descriptive data from persons or activities that can, either in the form of written or spoken language. Data collecting is a strategy or approach that researchers can use to gather information, and data collection instruments are tools that researchers choose and employ during data gathering tasks to make these tasks more organized and simple [10].

The gathering of qualitative data through observation, questionnaires, and documentation during data collecting. Primary data come from sources like questionnaires designed specifically for architecture students, which give data to data collectors directly. In addition to using surveys, interviews and literature reviews were also used to obtain data. In the process of obtaining information for architectural design, data collection was done to learn more about student preferences for bamboo architecture. Students in the Architecture S1 education program at UPN "Veteran" Jawa Timur served as the study's sample group. The total student population in the third, fourth, and fifth years, with an average of about 99 people, was used to calculate the number of samples. According to statistics, a bigger sample size is predicted to produce better findings. The obtained mean and standard deviation have a high likelihood of resembling the population mean and standard deviation when the sample size is large. This is due to the fact that statistical hypothesis testing has anything to do with the quantity of samples. A large sample is preferable, but a small sample that was chosen at random can still accurately represent the population [11]. According to this justification, 80 to 100 students are chosen as samples because the sampling rate for a population under 1000 is approximately 30%. This study uses a number of (UIA) criteria. The International Union of Architects is an international group made up of national architectural associations that collaborate to bring together architects from all over the world. Criteria for graduating architects that are customized for the use of bamboo materials, are the subject of this study. The questionnaire was constructed based on 3 selected criteria which were judged most relevant to the topic of bamboo materials, with a combination of open-ended questions and closed-ended questions. These requirements are divided into 3 categories, namely:

a. Design
    - ability to engage imagination, think creatively, innovate and provide design leadership,

- ability to gather information, define problems, apply analyses and critical judgement and formulate strategies for action,
- ability to think three-dimensionally in the exploration of design,
- ability to reconcile divergent factors, integrate knowledge and apply skills in the creation of a design solution.

b. Knowledge
- Cultural and Artistic Studies,
- Social Studies,
- Environmental Studies,
- Technical Studies,
- Design Studies,
- Professional Studies.

c. Skill

The three data points obtained from questionnaires will be quantitatively analyzed with JMP 17 software and then rendered in a descriptive manner. Data gathered from the outcomes of respondents' answers are tested using data analysis techniques before being evaluated. As a result, descriptive quantitative analysis was utilized in this study, which means that no general conclusions were intended as a result of the analysis of the data that had already been collected [12].

Results and Discussion

The samples taken were UPN "Veteran" Jawa Timur architecture students who were still enrolled and enrolled full-time, specifically from the classes of 2022, 2021, 2020, and 2019 (Fig.1). Using the 99 students that responded as responders.

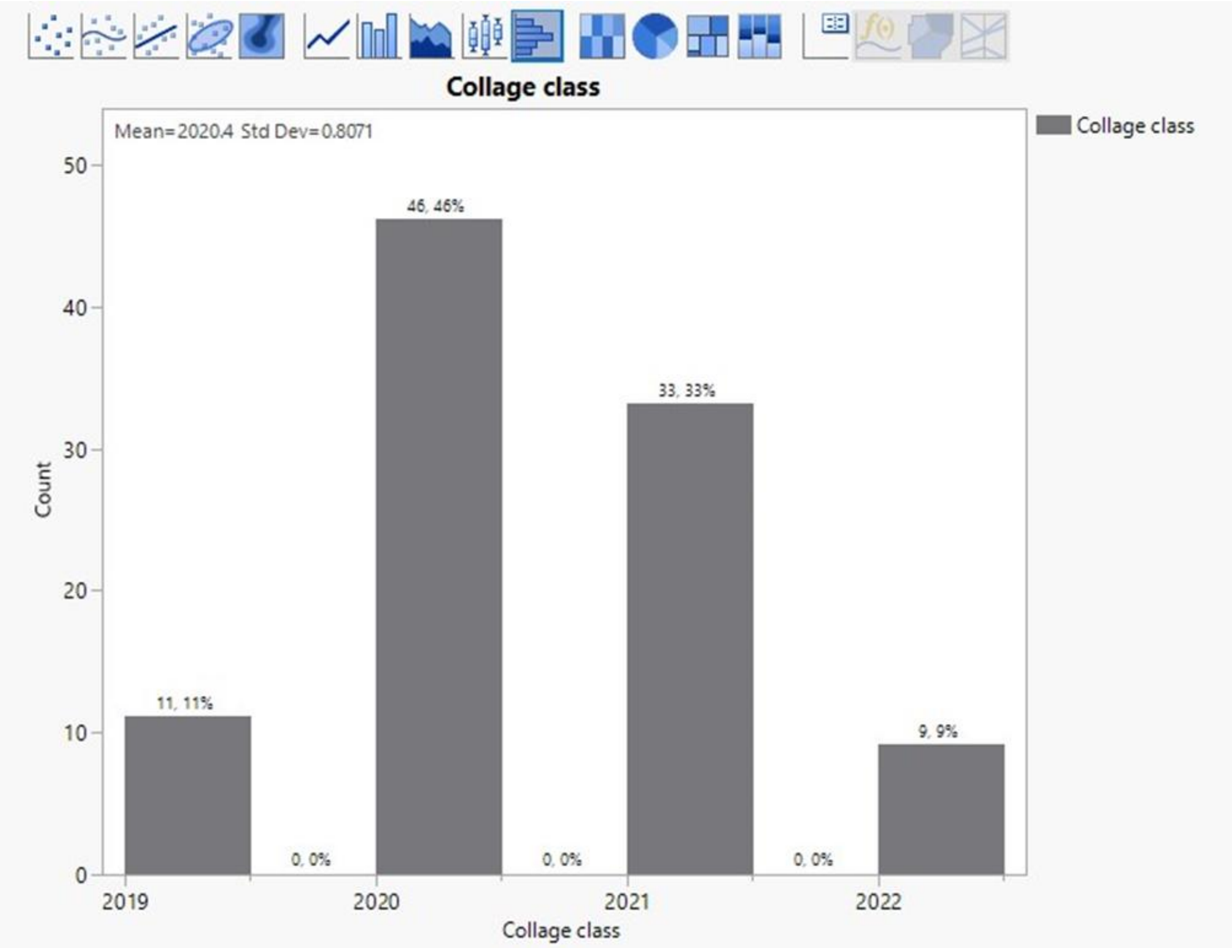

Fig. 1. *The distribution of respondents*

Based on distribution analysis, which was used to get the results, the majority of respondents were 46 students from the class of 2020. The 2020 class has completed three design and structural courses that allow students to use bamboo as a material as part of the architecture study program. In addition to serving as the primary material, bamboo may also be used in conjunction with other materials like wood, concrete, and others. Analysis of students' impressions of bamboo architecture includes design, knowledge, and skills, the three UIA components[1].

Design

Design criteria according to UIA include:

- ability to engage imagination, think creatively, innovate and provide design leadership,
- ability to gather information, define problems, apply analyses and critical judgement and formulate strategies for action,
- ability to think three-dimensionally in the exploration of design,
- ability to reconcile divergent factors, integrate knowledge and apply skills in the creation of a design solution.

The four criteria in the questionnaire were converted into two questions about students' capacities for designing and carrying out research or engaging in research based on these design criteria.

Student exposure to bamboo material

Through design and research projects, students gain experience with bamboo architecture. Students must create architectural drawings as part of their coursework in the design studio class, commencing with a site analysis, consideration of culture and sociocultural factors, and the development of design concepts that are related to structure and construction. The design is then shown at the conclusion in both two- and three-dimensional architectural drawings. While conducting research, students carried out an analysis process and chose approaches relevant to the topic at hand. The thorough and organized analysis approach helps students fully comprehend bamboo architecture. According to UIA guidelines, a student has met the Skill criterion if they have ever developed and explored bamboo architecture based on these two experiences.

Experience has shown that 6.8% of the 2022 and 2019 classes, 36.47% of the 2020 class, and 29.38% of the 2021 class have students who have created employing bamboo architecture. The 2020 class has made greater use of bamboo construction. The 2022 and 2019 batches, however, hardly ever use bamboo construction. The studio and structural tasks for the class of 2020 required students to incorporate bamboo architecture, so they did (Fig.2).

Designing bamboo can be learned through research or design

According to the findings of the quantitative investigation, students learn the most through design rather than research. 38.4% of the class of 2020 students selected design, compared to 2.4% of those who selected based on the findings of their research experience. In the class of 2021, research is the subject chosen by 3.1% of students, while design is selected by 30.3%. According to the findings of the quantitative analysis, the design process - rather than research - is where most students' experience with bamboo architecture comes from. Students get research experience through engaging in research projects led by lecturers or by conducting their own independent studies. Currently, research students are expected to complete their Final Assignments in full as well as serve as an output product for several courses. This encourages students to become more aware of current architectural issues and to use critical thinking to identify the best solutions (Fig.3).

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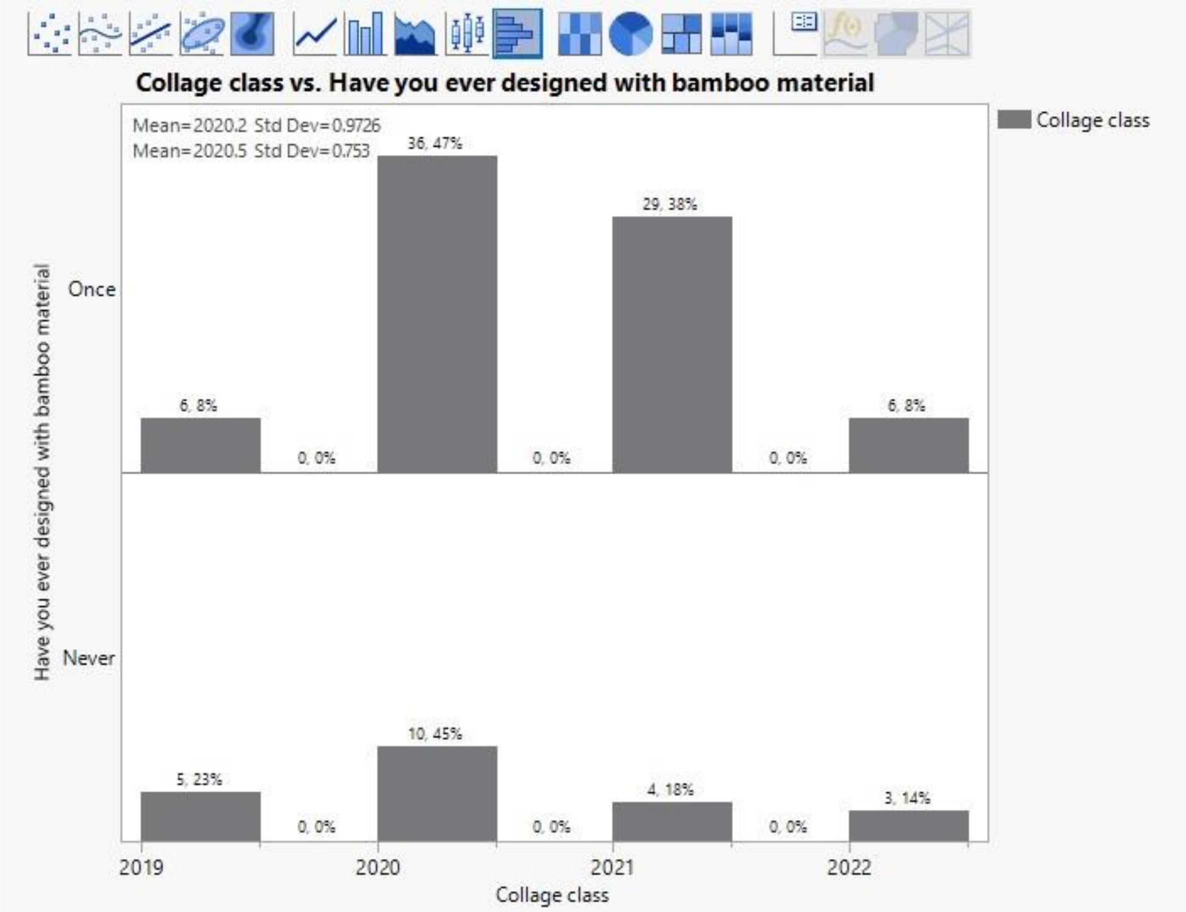

Fig. 2. *Student exposure to bamboo material*

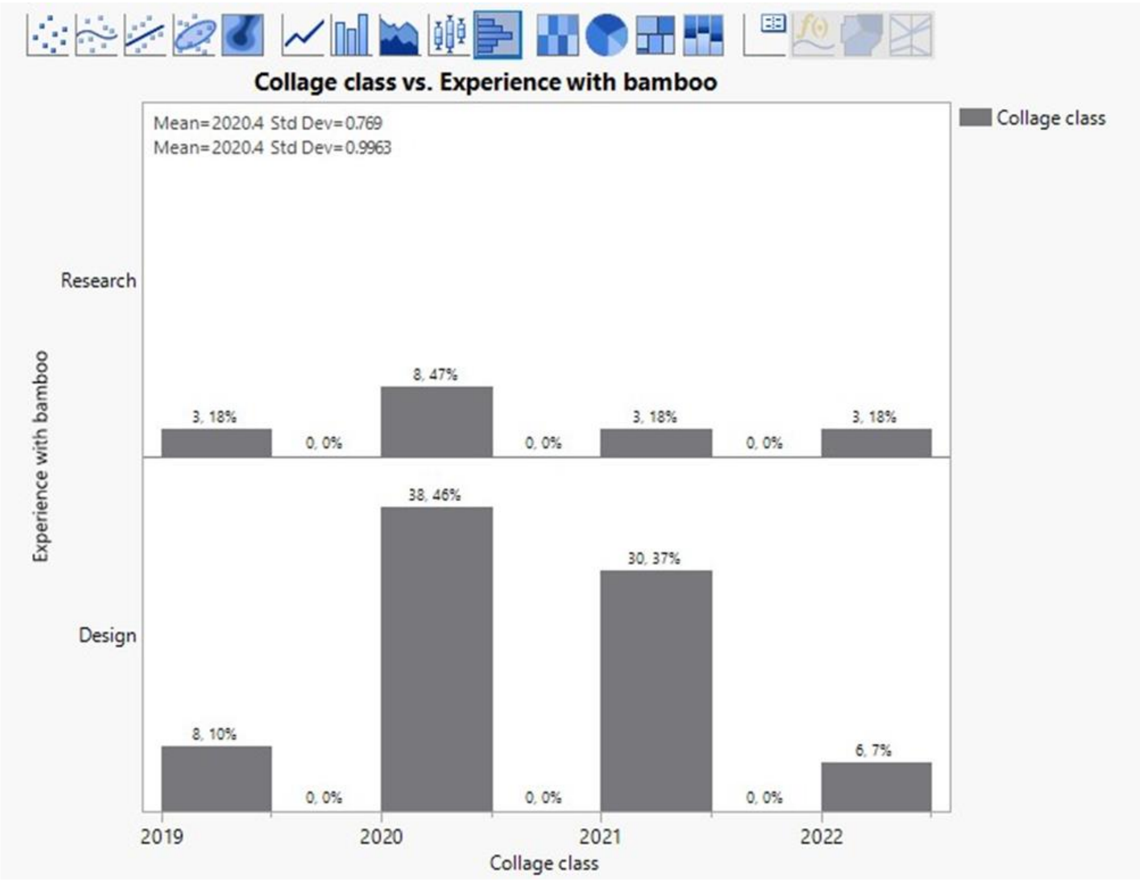

Fig. 3. *Designing bamboo can be learned through research or design*

Knowledge

Knowledge criteria according to UIA include:

- Cultural and Artistic Studies,
- Social Studies,
- Environmental Studies,
- Technical Studies,
- Design Studies.

Based on these knowledge requirements, students' understanding of bamboo architecture is evaluated in numerous areas, including cultural (bamboo culture), structural, and environmental factors, design, and technical (workshops, lectures, and comparative studies) elements. The four questions that are attached to the questionnaire demonstrate the student knowledge that was attained based on the five UIA criteria.

Information about bamboo

As one of the many trees that flourish in Indonesia, bamboo is no longer restricted to use as a building material. As a sustainable and local material, bamboo is associated with architecture in the minds of students. 61.6% of students, according to the results of the questionnaire analysis, saw bamboo as having a connection to architecture, while 28% saw it as having a connection to tradition and the remaining percentage as having a connection to art.Students' erceptions of bamboo architecture are relevant to the field of architecture since bamboo is no longer regarded as a low-cost material but rather as one of the materials capable of producing stunning and unusual forms. This is connected to the many bamboo architectural items that are popular among students (Fig.4).

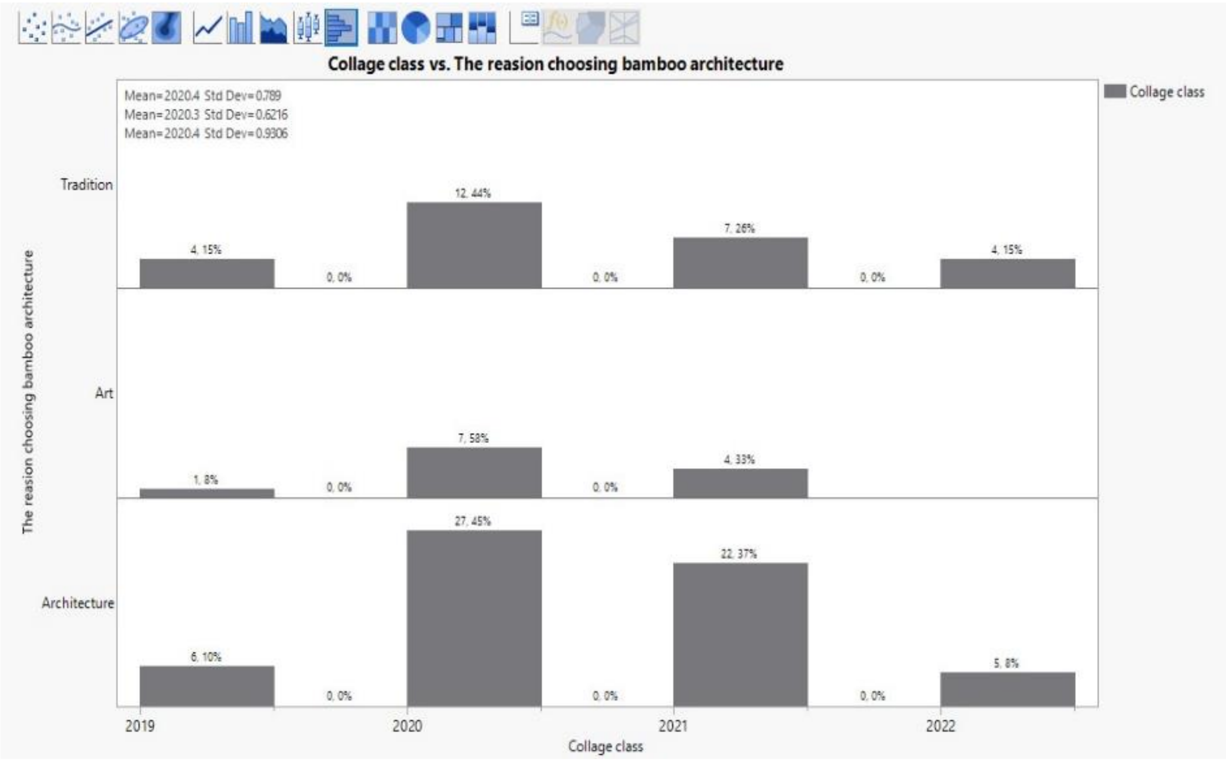

Fig. 4. *Information about bamboo*

The role of bamboo in architectural structures

Bamboo is one of the structural building materials available today that combines outstanding strength and aesthetic appeal [13]. Making bamboo is currently quite popular as a material for building. This is evident from the varied purposes for which bamboo is used in Indonesian architecture. One of the various applications of bamboo architecture is the commercial one. Yellow bamboo, tamarind Mediterranean, and Kapal Bambu restaurant are a few examples of commercial structures that utilise effstudio bamboo architecture. The quantitative analysis's findings indicate that students' perceptions of bamboo architecture are identical to those of commercial structures by 52.4%, while residential functions account for 29.4%, educational functions for 16.6%, and residents account for the remaining functions. Commercial buildings have a role that depends on the aesthetic appeal of the facade, which is something that bamboo materials may explore. Another factor in choosing bamboo materials is the appearance of nature (Fig.5).

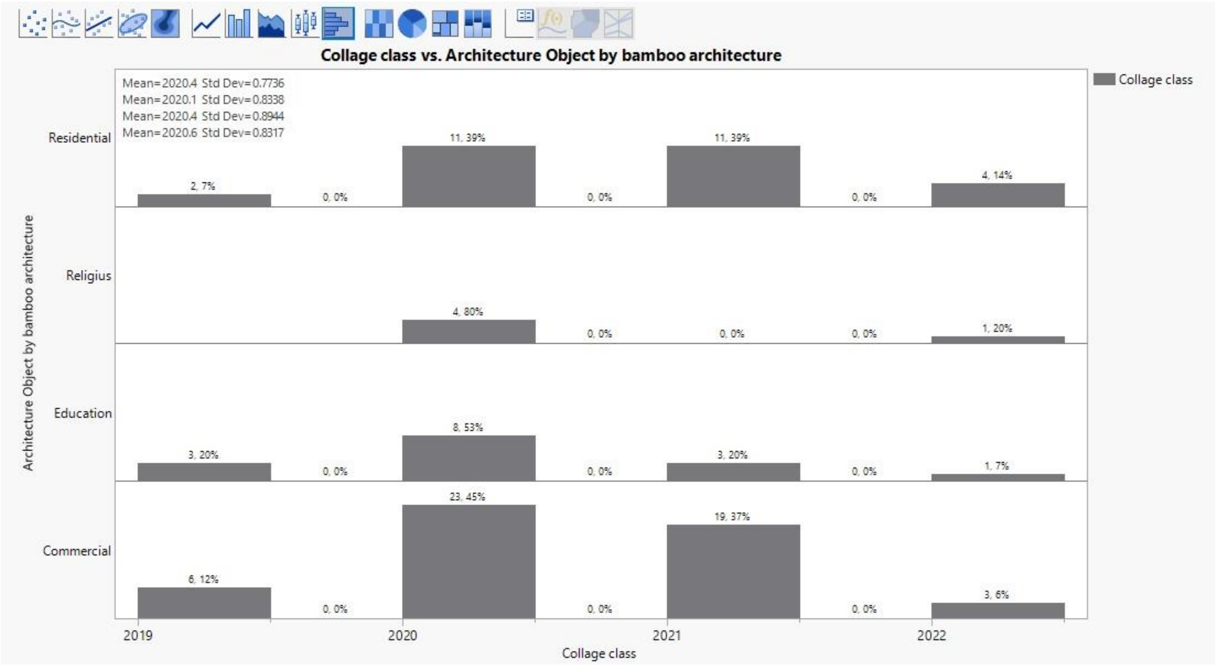

Fig. 5. *The role of bamboo in architectural structures*

An efficient method for learning bamboo architecture

The bamboo architectural learning process that was taught in class needs to be evaluated, and student preferences for the learning method that is thought to be appropriate and beneficial for students are required.

According to students, the most effective learning approach involves workshops, which account for 24.5% of learning, followed by class study (12.5%), research, and comparative studies. The fact that students actively participate in the planning process makes workshops an effective teaching strategy. Students are actively taught how to practice bamboo joints on a real scale during the course. Because students are intimately involved in the creative process on a real scale, this workshop is typically longer than 1 day and as long as 3 days. Students believe that providing material in class is the second approach to be effective. To be able to give students a deeper grasp of bamboo architecture, the course material is not only theoretical but also continues with discussion sessions (Fig.6).

Research is also one of the methods chosen by students which is considered effective in providing an understanding of bamboo architecture. Through research students can carry out analysis related to bamboo architecture both assessed from cultural, construction, aesthetic and social aspects. So by doing research on bamboo architecture, it will provide a lot of in-depth understanding regarding bamboo architecture for students.

Knowledge of bamboo among students in environmental studies

Bamboo is regarded as one of the unique materials because it is not only used as a material but also has a strong connection to culture and the arts. According to the findings of the quantitative research, 61.6% of students believe that bamboo is a component of architecture. In the design process, students enjoy experimenting with bamboo. Regarding its connection to culture, students believe bamboo to be a material that is closely tied to Indonesian culture by 27.8%. The Gila bamboo dance and bamboo puppetry are two cultures that are strongly tied to bamboo [14]. Other cultures in Indonesia also use bamboo for instruments like the angklung and the flute (Fig.7).

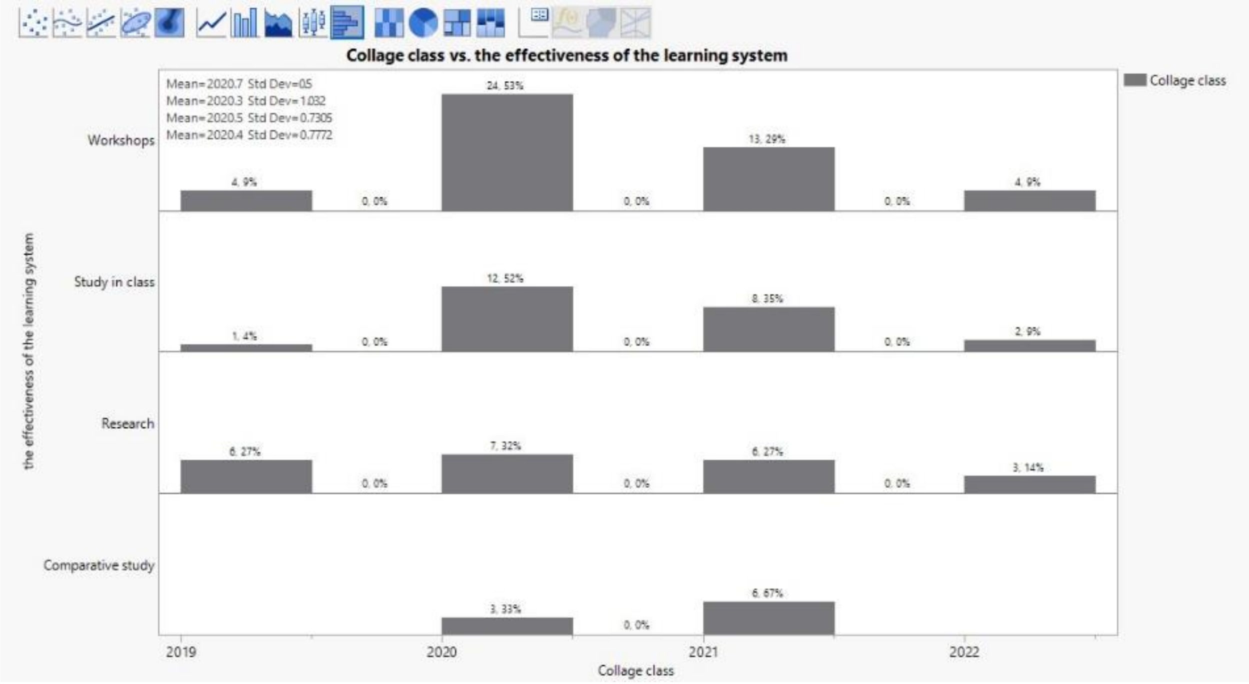

Fig. 6. *An efficient method for learning bamboo architecture*

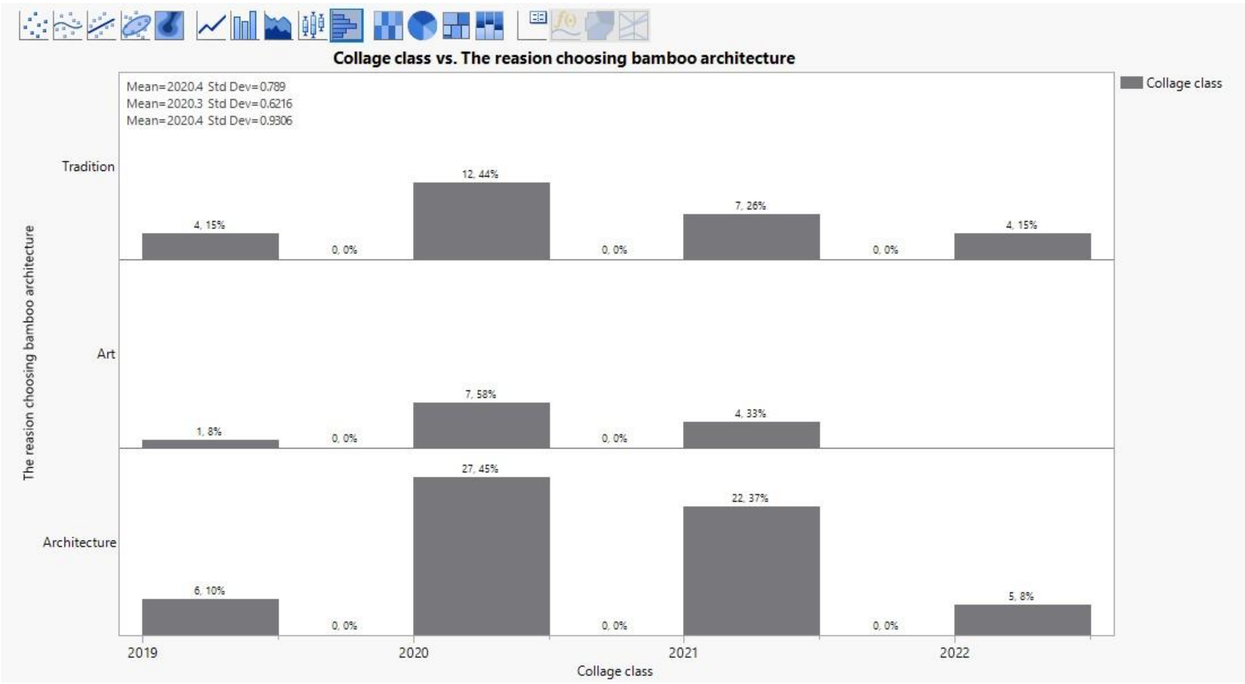

Fig. 7. *Table knowledge of bamboo among students in environmental studies*

The fact that bamboo is a 41% sustainable material also contributed to the students' decision to use bamboo for their projects. Students believe that bamboo may be used as a building material to address climate change issues and the idea of the SDGs. In addition, bamboo is a locally produced, abundant, and available resource in Indonesia. If employed as a building material, this variety will provide aesthetic value (Fig.8).

Skill

How to convey the design of bamboo building is stressed in the UIA competency criterion. According to the findings of the quantitative data research, animation is a successful method for communicating design outcomes by 48.7%, while mockups are no longer a student choice for showcasing bamboo architectural works by 35.2%. While scholarly publications continue to be the best option for showcasing bamboo building (Fig.9).

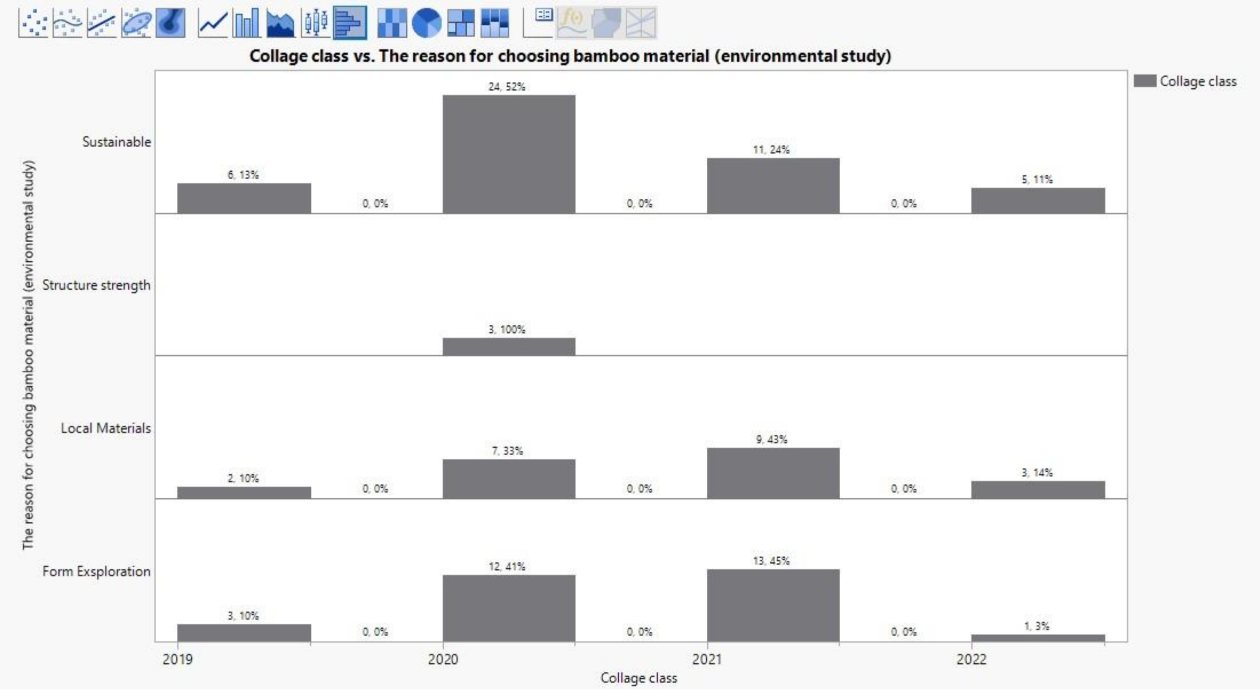

Fig. 8. *The students' decision to use bamboo*

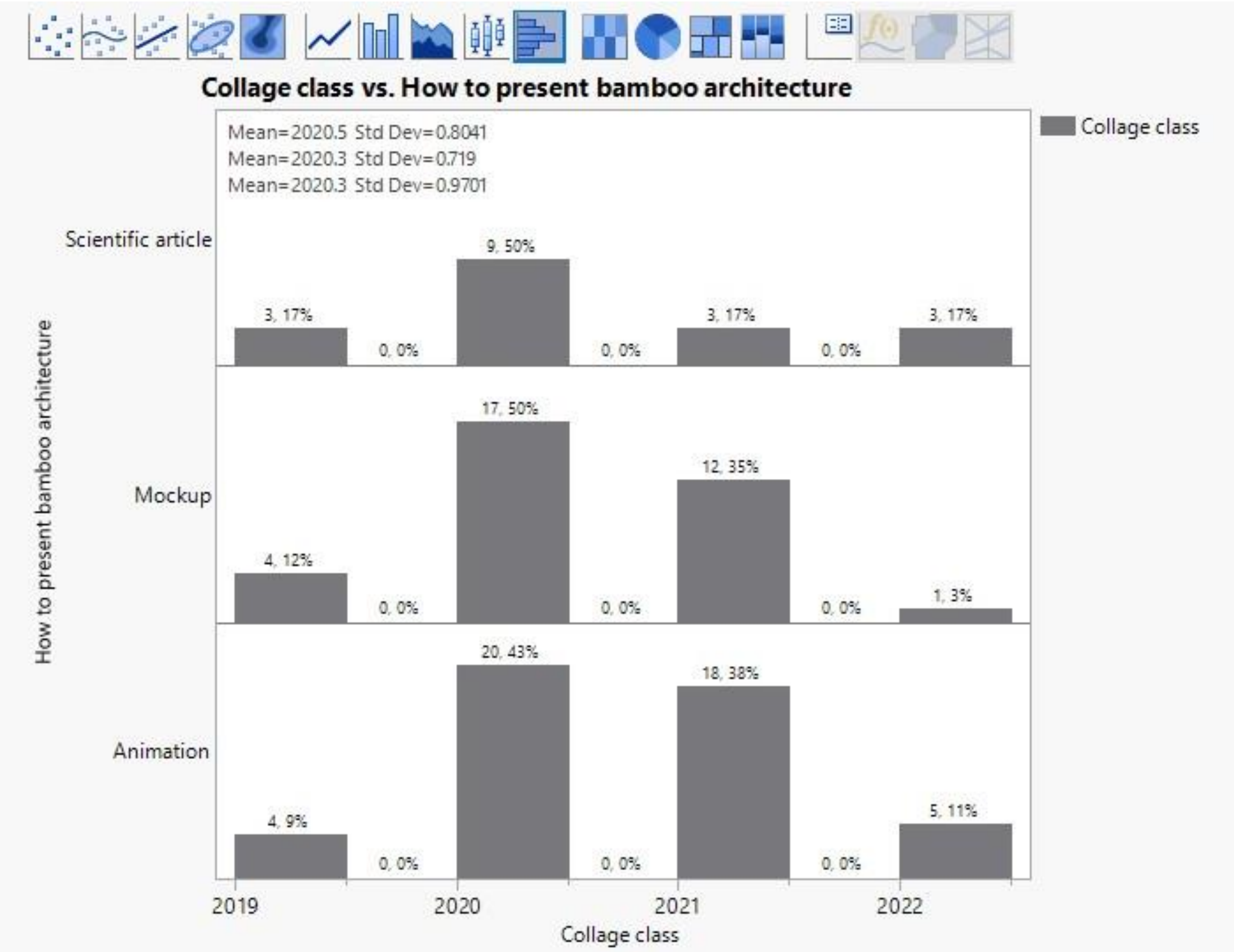

Fig. 9. *Method for communicating design bamboo architecture*

Conclusion

Based on the analysis's findings, it is possible to draw the following conclusions: (1) There are a number of teaching strategies that are appropriate for students, but there are also some lessons that could be improved; and (2) The UIA criteria, which include aspects namely knowledge, design, and skills, are associated with architectural education in Indonesia using a perceptual approach. Due to requests from the Indonesian Architecture Education, which also needed to meet international standards, repairs were made. More precisely, bamboo architecture has a stronger bond with students since it is an original Indonesian material with regional qualities in terms of culture, art, and architecture.

Based on the knowledge component, a workshop-based learning system is an efficient learning method. One of the active learning methods is hands-on practice with instructors who are specialists in the field of bamboo architecture; this method is typically used on a real size in the field. The psychomotor and cognitive capacities of the students can be stimulated by this learning approach. Students can more easily learn about bamboo through study, comparative analysis, and the internet.

In the meantime, students decide to use animation to be able to present the results of their design work from a skill perspective. Students believe that animation is a tool that is simple to use and use. Given that modern digital technology is more in accordance with what people require. When measured from the perspective of design, nearly 50% of students used bamboo materials in their designs. As a result, bamboo is now one of the materials that students prefer for building because of its strength, flexibility, sustainability, and aesthetic appeal. Students evaluate bamboo architecture in terms of its ability to offer both aesthetic value and strength, so that the experience of designing serves as the foundation for the desire to design.

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RESTORATION PECULIARITIES OF GROUND WATER BASINS IN THE MOUNTAINOUS RELIEF REGIONS

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Abstract: *The goal of the present research is to figure out how to increase the efficiency with which water resources are used in mountainous relief regions on the example of the Ararat Artesian Basin of the Republic of Armenia. The accumulation of significant water runoffs in reservoirs under difficult hydrogeological conditions requires not only large investments in construction, but also in the transportation of water to the consumer, which is fraught with significant water infiltration losses. The paper shows that by the example of artificial recharge of the Ararat Artesian Basin, instead of building a new reservoir to collect 40 million m^3 of water per year, which requires huge capital investments (5.75-6.25 USD/m^3), the financial costs can be significantly reduced (0.05-0.075 USD/m^3) by pumping the same volume of water into the groundwater basin. The obtained results can be used both in different regions of Armenia and in countries with mountainous relief.*

Keywords: *river flow regulation, groundwater basin, artificial recharge, well, environmental and economic justification.*

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Received: 22.09.2023

Revised: 25.10.2023

Accepted: 07.11.2023

Introduction

Surface water and groundwater resources are considered to be one of the most important material resources necessary for human survival and development. In addition, these resources are key to the sustainability of the natural environment and the evolution of ecosystems [1,2]. The conservation and efficient use of water resources currently face variable and unpredictable global challenges that manifest themselves in various ways [3-5].

The conservation and efficient use of surface and groundwater resources are particularly important in the mountainous regions [6,7]. At present, the issues of regulation and conservation of water resources in mountainous areas are very poorly studied due to their peculiarities [8], and there is an objective need for additional studies, including:

- seasonal fluctuation of river water flows due to spring and autumn floods, as a result of which the efficiency of their use during the growing season is sharply reduced,
- accumulation of water runoff in reservoirs under difficult hydrogeological conditions requires not only large investments in their construction, but also in the transportation of water to the consumer, which, in turn, is fraught with significant water losses due to infiltration and evaporation.

In the present research, taking into account all the aforementioned features, the example of Armenia is considered as a country with a mountainous relief that has similar problems. Such studies are conducted for the first time in the Republic of Armenia.

It is noteworthy that in Armenia the average annual indicator of water resources is 19.70 billion m^3 of water, a significant share of which is occupied by evaporation: 11.48 billion m^3, and the outflow of the river streams, generated from precipitation, groundwater and boundary waters, is approximately 7.12 billion m^3 of water per year. In this regard, there are difficulties in the management and conservation of water resources, which are mainly caused by seasonality and uneven distribution of water sources. In the rivers of Armenia, maximum river water flow is observed in April-May and September-October during active snow melting and heavy rains [9]. As a result, due to the reduced water requirements of plants during the winter season and the scarcity of water in rivers due to light summer rainfall, utilizing these water resources for agricultural crop irrigation becomes challenging. It is worth nothing that approximately 70% of the required total amount of water is not stored in reservoirs and is used inefficiently [10]. In recent years, various ameliorants, as well as, new innovative technologies, have been widely used to improve the efficiency of water use in agriculture [11].

To address the problems of seasonal fluctuations in river flows, 79 reservoirs with a total capacity of 1.40 billion m^3 have been built in Armenia, which are used mainly for agricultural soil irrigation to ensure food security within the country and play a significant role in water resource conservation [12]. It should be noted, that many reservoirs in mountainous regions of Armenia constructed in the second half of the 20th century were mostly replenished with outdated pumping equipment and, as a result of long-term operation, may soon cease to function [13].

Notably, significant financial resources are necessary for the reservoir construction (approximately 3-7 USD per $1m^3$ of water, depending on its volume). In mountainous regions with challenging hydrogeological conditions, a substantial portion of the reservoir construction cost pertains to anti-filtering measures for the reservoir's base and walls, along with irrigation canals. This significantly augments the required investment amount. Massive expenditures are also required for measures to ensure the safety of hydraulic structures, most notably dams [14,15].

To address water basin management issues and ensure equitable distribution of water resources in one of RA regions, the construction of the Yeghvard Reservoir was planned. According to the design, the proportion of expenses allocated to anti-filtering measures in the overall construction estimate amounts to 66.8%. Despite the use of expensive anti-filtering materials, calculations reveal notable infiltration losses within the project, amounting to 0.05% per day. Over the course of a year, these losses can accumulate to as much as 18.25% of the collected reservoir water volume. According to calculations, similar losses during water transportation through irrigation canals under the Yeghvard Reservoir project, reach 46%.

Thus, we can conclude that in mountainous areas, the construction of a reservoir for water storage and transportation through canals across plain terrain is inefficient and leads to considerable water losses. International studies in this direction also confirm the difficulty of building in mountainous regions [16,17].

Groundwater, stored in underground basins in mountainous regions, plays a vital role in the formation of water resources [18-20]. For example, in Armenia, 2.40 billion m^3 of groundwater runoff is formed per year, out of which 1.19 billion m^3 is accumulated in Ararat Artesian Basin (hereinafter referred to as “AAB”), from which artesian wells can provide a stable water flow rate of 5-100 l/s, according to design data. In contrast to surface reservoirs, the groundwater basins are less polluted [21,22], do not require significant operating costs for collection and storage (the cost of pumping them out is relatively low) [23] and are safe from man-made disasters [24]. Therefore, accumulating and pumping water resources from groundwater basins is frequently more effective than building open reservoirs and using water from them for national economic needs. Nevertheless, the intensive and poorly planned exploitation of groundwater basin resources not only results in groundwater depletion, but also leads to deterioration of water qualitative indicators and environmental problems [25-27].

A similar problem arose in AAB between 2007 and 2013, when the growth of numerous spontaneously emerging fish farms was recorded, for the water supply of which a large number of artesian wells were built [28]. As a result, the groundwater basin's water balance has shifted dramatically (Fig.1).

In 1983, the total volume of water used in AAB was 34.6 m^3/s with well fountains accounting for 12.9 m^3/s and deep pumps accounting for 21.7 m^3/s, while water from the groundwater basin was not used in fish farming. Despite the increase of total water use which was only 1.8 m^3/s in 2007, the water withdrawal from well fountains increased dramatically, reaching 30 m^3/s. In comparison with 1983, the increase was 17.1 m^3/s while deep-well pump water withdrawal dropped dramatically to 6.4 m^3/s. Tariffs for electric powerincreased as a result of these measures.12.7 m^3/s of the total water withdrawal was used for fish farming. The reduction of water reserves in AAB reached a peak in 2013, the total withdrawal amounted to 55.5 m^3/s (1.6 times higher than the allowable water withdrawal of 34.6 m^3/s), 35.5 m^3/s of which was used for fish farming, which is 22.8 m^3/s higher than the water withdrawal for the same purposes in 2007.

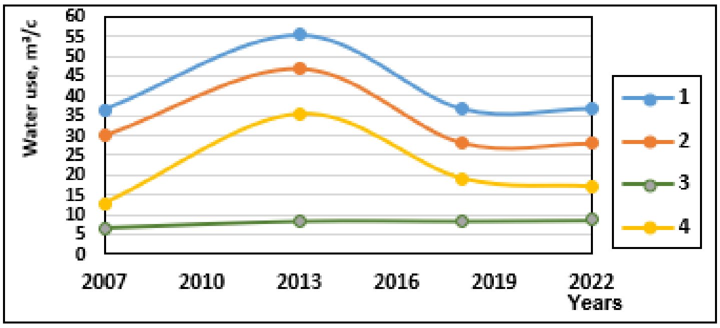

Fig. 1. *Dynamics of water use by years in AAB: 1-general water use, 2-from well fountains,3-by deep-water pumps, 4-for the needs of fish farming*

It should be noted that the well fountains contributed to the increase in total water consumption by providing water not only for irrigation but also for drinking and household needs.

It is also noteworthy that as a result of the 2013-2018 measures, total water withdrawal has decreased and has reached 36.6 m^3/s (from 2018 to 2021, there were no significant changes in water use), which stabilized the water balance in AAB, but the negative effects remained. The territory in AAB, which has a positive pressure of groundwater, has decreased threefold (from 32.760 ha in 1983 to 10.706 ha in 2013). Simultaneously, 31 communities were partially or completely cut off from water for irrigation, domestic use and drinking, which they had obtained from well fountains (Sahakyan and Yedoyan, 2020). It should be noted that 122 wells used previously are no longer operational (for this purpose). The flow rate of the Sevjur River water has decreased significantly from 26.1 m^3/s in 1983 to 3.0 m^3/s in 2013. As a result of lowering the groundwater level on 7.0 thousand hectares of irrigated lands, water consumption for crop cultivation increased by 25% (by 14.0 million m^3).

The problem emerged in Armenia about the lack of drinking, irrigation and household water in the region requires an immediate solution, including by increasing the water inflow into the groundwater basin.

International experience shows that the best way to solve this problem is artificial groundwater recharge [29-32]. Artificial groundwater recharge (hereinafter referred to as AGR) is not a new concept. Similar hydrogeological activities have been carried out since the mid- 19th century [33]. The United States has wide experience in the use and development of AGR schemes, in particular, systems of infiltration structures and water-absorbing wells have been built in many states [34]. In the Netherlands, since the 1990s, due to the AGR, the annual volume of water resources has exceeded 180 million m^3 [35]. In Germany, about 15% of the total drinking water is generated by AGR [36]. Since 1960, artificial recharge of aquifers by preliminarily purified river waters has been carried out in England [37]. In the field of AGR, Israel is one of the world's leading countries, employing the method of water injection (pumping) [38]. AGR is also used in other countries, including Russia, Kazakhstan, India, New Zealand, Argentina, Egypt, etc [39-41].

There are two types of infiltration structures used for AGR: open and closed ones. The first one includes basins, canals, etc, and the second one includes wells, pipelines and water tanks. The open infiltration structures are commonly used to recharge the first groundwater aquifer [42]. These are systems of basins with a sand-covered bottom. The closed infiltration structures are recommended when the ground surface is covered with low- penetrating soils or when the aeration zone has a multilayer structure. The vertical closed infiltration wells are used here, with pumping stations that require significant operational costs [43].

Thus, in mountainous regions river flows are characterized by significant seasonal fluctuations due to spring and autumn floods, as a result of which the efficiency of their use during the growing season is sharply reduced.

The accumulation of river runoffs in reservoirs under difficult hydrogeological conditions requires not only large investments in their construction (3-5 USD/m^3), but also in the transportation of water to the consumer, which is fraught with significant infiltration losses from the built structures. Therefore, in many countries it is preferable to use water from groundwater basins, into which, in addition to precipitation, river flows are forcibly directed.

It should also be noted that in mountainous regions, the use of the difference of natural elevations makes it possible to pump water into groundwater basins without the use of expensive high-performance pumping stations. In addition, artificially recharged water must undergo preliminary treatment: settling, filtration, oxygenation, etc. [44], and in some cases chemical treatment methods must be applied that increase the prime cost and reduce the effectiveness of water collection in groundwater basins. At the same time, in contrast to plain areas, in mountainous regions during spring and autumn, rivers are formed due to melting snow, rainfall, underground sources and do not need treatment.

The goal of the present research is to improve the efficiency of water resource use in mountainous regions, for which the following objectives should be set:

- to study the peculiarities of water resource management in mountainous regions,
- to substantiate the strategy of regulation and preservation of water resources,
- to study the possibility of AGR in AAB without the use of pumps,
- to study the hydrogeological conditions and determine the hydrogeological parameters of the Karbian Gorge,
- to perform hydraulic calculations of water flow rate in individual wells, as well as the total water flow rate pumped into the groundwater basin,
- to provide economic and environmental justification for the activities carried out.

The novelty of the presented work is to develop a strategy for the implementation of water regulation, taking into account the characteristics of mountainous regions, which will make it possible to provide significant economic efficiency, without disturbing the ecological balance of the environment.

Materials and Methods

The object of research and its formal description

The object of the given research is AGR in mountainous regions. The subject of the research is the Karbian Gorge of the Kasakh River in Aragatsotn Marz of Armenia (Fig.2.), where 12 wells with diameters of 50 cm and depths of 300 m were dug and hydrogeological studies were conducted in 1984-1985.

The average width of the gorge is 0.8 km, its length is 2.0 km, and its depth is 0.1 km. Groundwater depths range from 33 to 38 m. Effluent seepage into the gorge amounts to 165 l/s. In the upper part of the gorge, at an elevation of 1310 m above sea level, the Arzni-Shamiram Canal runs, which takes water at a rate of 13 m^3/s from the Hrazdan River and during the growing season (1.05-30.10) provides approximately 40 thousand hectares of irrigated land with irrigation water.

Fig. 2. *Drainage basin of the Ararat valley*

Fig. 3 shows the geological section of the canal and a number of wells laid from north to south through the Arzni-Shamiram Canal and 5, 3, 6, 1, 12, 8 wells [1].

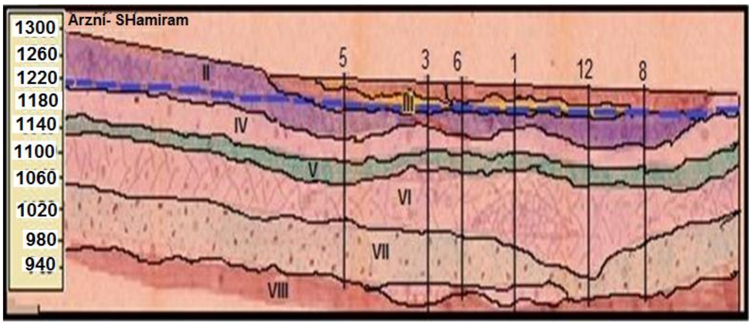

Fig. 3. *Hydrogeological section passing through the Arzni-Shamiram Canal and 5, 3, 6, 1, 12, 8 wells: I-hard clay with pebbles and gravel, II-boulder-pebble deposits with gravel and uneven-grained sand, III-tuff, IV-andesites and basalts, fractured, slightly water-bearing, V-pebble-gravel deposits with boulders, water-bearing, VI-andesite-basalts, strongly fractured, porous, VII-boulder-pebble deposits with sandy filler, strongly water-bearing, VIII-andesite-basalts monolithic and massive*

Fig. 4 shows the geological and lithological structure of well № 3, as well as the names of the geological layers, which are identical to the names in Fig. 3.

The section shows that it has three water-permeable layers: the first at a depth of 14-29 m with a thickness of 15 m, the second at a depth of 90-105 m with a thickness of 15 m, and the third at a depth of 200-280 m with a thickness of 80 m,[2] and it is in this layer that water is planned to be pumped to fill the water resources of the Ararat Artesian Basin.

It is envisaged to let water runoffs through the canal and pump it into existing wells, using the natural relief differences in relative height.

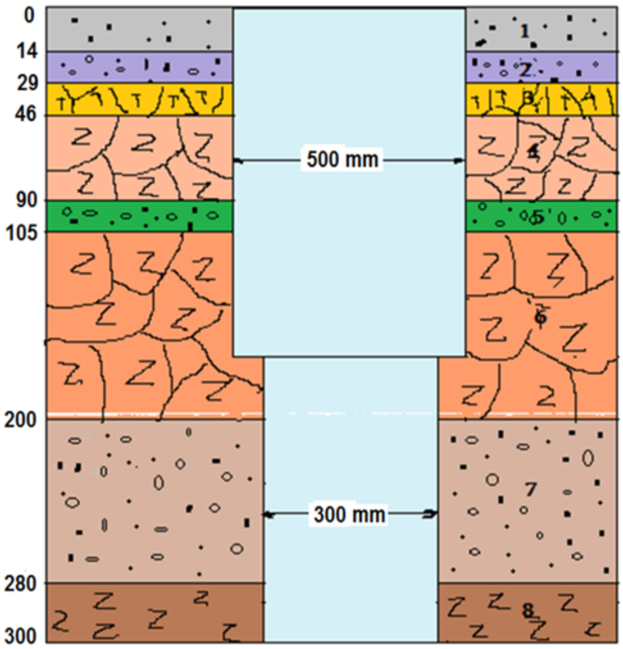

Fig. 4. *Geological-Lithological structure of well 3*

Research methodology

According to the proposed idea, it is planned to transfer water to the Karbian Gorge within three spring months by building a pipeline and pumping water into the third aquifer at a pressure of about 100 m through the Arzni-Shamiram Canal of the Hrazdan River. Hydraulic calculations were performed using the hydrogeological parameters of the third aquifer.

The dynamics of the decrease in groundwater level when pumping water from wells, as well as the dynamics of restoring the water level in wells after pumping stopped were used to calculate the soil filtration coefficient. The pumps were placed at a depth of 70-80 m to pump out water. The water flow rate in the wells ranged from 14 to 52 l/s. With group pumping, the total flow rate was 300 l/s. Pumping is carried out from 10 wells, and two wells (10 and 11) are used as observation wells. The pumping process must be carried out until a stationary regime is established (when a further decrease in the groundwater level stops).

Fig. 5 shows data on the maximum decrease in groundwater level after the establishment of a stationary regime. In the main wells, from which groundwater was pumped out, the level of the decrease varied from

[1] Gidrogeologicheskiye usloviya i podschet ekspluatatsionnykh zapasov presnykh podzemnykh vod Karbinskogo mestorozhdeniya paleodaliny reke Kasakh v Ashtarakskom rayone Armyanskoy SSR po sostoyaniyu na 1.01.86 g., Otchet «ARMGIROZEM», Yerevan, 1986, 246 s. (fondovyye materialy, in Russian).

[2] Ibid.

5.81 to 10.65 m. In the observation wells (10 and 11), the decrease in the groundwater level was 1.56 and 1.79 m, respectively.

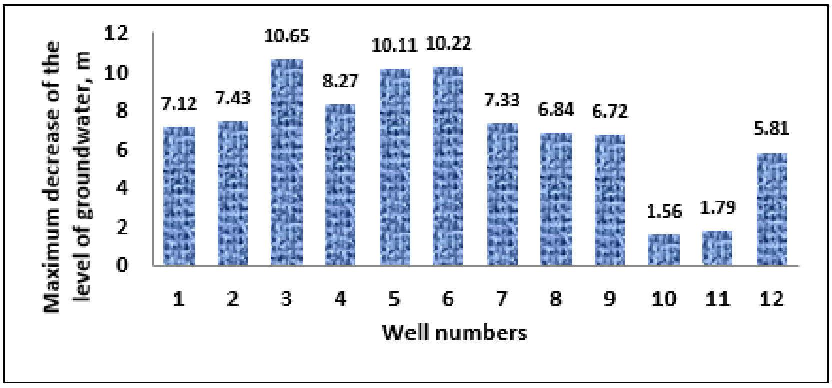

Fig. 5. *The maximum decrease of the level of groundwater in wells after the establishment of a stationary regime after 33 days of pumping*

The soil filtration coefficient is determined in accordance with the restoration of the maximum level of groundwater when the pumping of water stops.

To calculate the filtration coefficient, we used the following formula [3]:

$$S = \frac{0.183Q}{kH\,lg\ ((t_0 + t)/t)}, \tag{1}$$

where S is the lowering of the level of groundwater in the well, m; Q is the water flow rate during pumping out of the well, m^3/day; k is the filtration coefficient of the aquifer, m/day; H is the thickness of the aquifer, m; t_0 is the duration of pumping until the establishment of a stationary regime, days, t is the current time for the restoration of the groundwater level within days.

The filtration coefficient is determined by the following formula:

$$k = \frac{0.183Q}{HB}, \tag{2}$$

where B is the angular coefficient of a straight line on a graph plotted in the coordinates S and lg((to + t)/t) is determined by:

$$B = \frac{S}{lg\frac{(t_0 + t)}{t}}, \tag{3}$$

In addition, soil filtration coefficients were also calculated using the method of lowering groundwater levels in wells during water pumping, using formulas 4 and 5 [4].

$$k_{n-1} = 0.366Q\frac{(lg\,x_1 - lg\,r)}{H(S_n - S_1)}, \tag{4}$$

$$k_{n-2} = 0.366Q\frac{(lg\,x_2 - lg\,r)}{H(S_n - S_2)}, \tag{5}$$

where k_{n-1} and k_{n-2} are the soil filtration coefficients in the n-th well in relation to the observation wells 1 and 2, m/day, Q is the water flow rate from the n-th well during pumping, m^3/day; x_1 and x_2 are distance between the n-th well from observation wells 1 and 2, m/day; S_n, S_1 and S_2 are the maximum groundwater level drops after steady state conditions in wells n and observation wells 1 and 2, m; r is the radius of the well, m; H is the thickness of the aquifer in m.

Results and Discussion

Calculation of the filtration coefficient

Table 1 shows the initial data for calculating the angular coefficient B and the soil filtration coefficient k. Fig. 6 shows the graph for calculating the angular coefficient B.

[3] Rekomendatsii po opredeleniyu gidrogeologicheskikh parametrov gruntov metodom otkachki vody iz skvazhin. Stroyizdat, Moscow, 1986 (in Russian).
[4] Ibid.

Table 1. Initial data for calculating the angular coefficient B and filtration coefficient k

Wells	S, m	t_o, day	Q, m^3/day	H, m	0.183 · Q/H
1	7.12	33	2592	94	5.05
2	7.43	33	4493	69	11.92
3	10.65	33	2765	110	4.60
4	8.27	33	3586	116	5.66
5	10.10	33	2635	108	4.47
6	10.22	33	3672	112	6.00
7	7.33	33	3568	97	6.73
8	6.84	33	3404	87	7.16
9	6.72	33	3508	95	6.76
12	5.80	33	1210	113	1.96

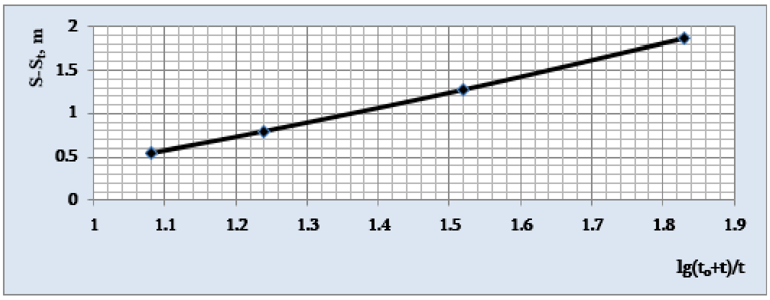

Fig. 6. *Dependence of the level of groundwater restoration from relative time*

Table 2 shows the soil filtration coefficient calculated using the methods described above. Summarizing the indicators of soil filtration coefficients (Table 2), it can be stated that for aquifers of the Karbian Gorge, they vary from 2.45 to 12.43 m/day according to the method of restoring the groundwater level after the cessation of pumping water, and from 1.70 to 12.90 m/day according to the method of reducing the maximum level of groundwater in wells when pumping water.

Despite some differences in the obtained values of the filtration coefficients determined by various methods, they can be considered identical when the complex lithological structure of soils is taken into account.

According to experimental data, boulder-pebble grounds filled with fine-grained sand have a filtration coefficient of 2-10 m/day, which is typical of the aquifers of the Karbian Gorge, confirming the accuracy of the calculations.

Table 2. Calculation of the soil filtration coefficient, various well performance methods

Wells	1	2	3	4	5	6	7	8	9	12
According to the dynamics of the restoration of the groundwater level, after the cessation of pumping water										
0.183 · Q/H	5.05	11.92	4.60	5.66	4.47	6.00	6.73	7.16	6.76	1.96
B	1.76	1.81	1.88	1.59	1.17	0.28	0.71	0.63	1.13	0.67
k, m/day	2.87	6.57	2.45	3.57	3.81	12.43	9.53	11.43	5.96	2.94
According to the decrease in the maximum level of groundwater in wells during water pumping										
k_{n-1}	4.20	7.00	1.90	3.30	1.90	12.90	5.80	10.80	6.10	2.20
k_{n-2}	4.10	7.80	1.70	3.60	1.80	12.70	5.40	11.70	5.90	2.30

Hydraulic calculation of AGR in the AAB

Fig. 7 shows a plan of the Karbian Gorge, which gives the location of 12 wells in the area, the level of groundwater, the horizontal relief and pipelines feeding wells.

The volume of water pumped into groundwater aquifers is determined by the pipeline water pressure, the filtration properties of the aquifers, the number of wells, the distance between them, etc. The formula (6) [45] determines the water flow rate (Q) under simultaneous group pumping.

$$Q = \frac{2\pi k f h(H_n - H_w)}{\phi \, ln \frac{\sigma_n}{\pi r_w}}, \quad (6)$$

where k_f is the filtration coefficient of the aquifer, in m/day, h is the thickness of the aquifer in m, H_p is the pressure created in the well (the difference between the absolute heights of the Arzni-Shamiram Canal and the groundwater level in the well), m, H_w is the loss pressure in the pipeline, m; φ is the coefficient that takes into account the effect of floating particles in water on the filtration properties of aquifers (φ = 1 when pumping clean water, r_w = 0.25 m - well radius; σ_n = 100 m - half the distance between wells). The data obtained by formula (6) were compared with the data obtained by the well-known formula of V.M. Nasberg [5].

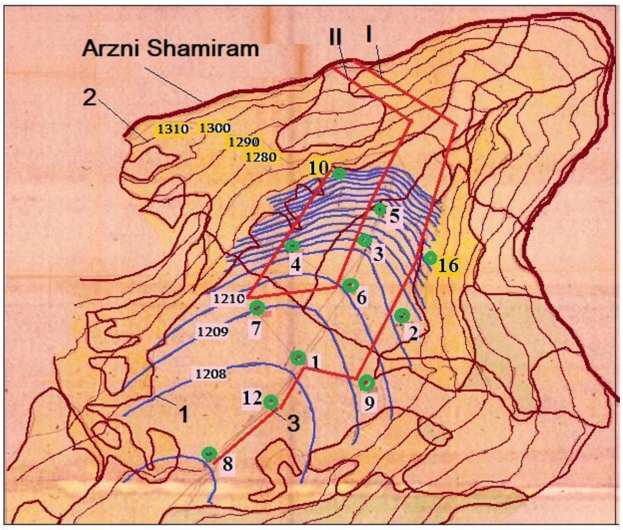

Fig. 7. *Scheme of the location of wells and feeding pipelines in the plan of the territory of Karbian Gorge:*
1 - groundwater level, 2 - relief horizontals, 3 - wells,
I and II - pipelines of water supply

$$Q = \frac{k_{\Phi} H^2}{0.423\, lg \dfrac{2H}{r_{\text{ск}}}}, \tag{7}$$

where:

$$H = H_p - H_w\,. \tag{8}$$

Formula (7) does not take into account the influence of the thickness of the aquifer h, because h depends on the water flow rate (Q) in a straight-line law, in formula (7) it is proposed to introduce a dimensionless correction factor α in the form of formula (10).

$$Q = \frac{\alpha k_f {H_T}^2}{0.423\, lg \dfrac{2H_T}{r_w}}, \tag{9}$$

$$\alpha = \frac{h}{h_{av}}, \tag{10}$$

where h_{av} = 50 m is the average thickness of the aquifer.

To calculate the flow rate of the pumped water, road and local pipeline losses must be determined. The volume of water and flow rates in 12 wells calculated according to formula (6) is 5.287 m^3/s, assuming no pressure loss in pipelines. Two pipelines are proposed to supply this amount of water from the Arzni-Shamiram Canal and distribute it to wells. According to terrain calculations, the length of the first line is 1866 m, with 1222 m of the initial part having a diameter of 1220 mm and the last part having a diameter of 820 mm due to a decrease in flow rate along the way. The second line II has a length of 1669 m in the first part 892 m and a diameter of 1220 mm, and the second part: 820 mm. Water from these pipelines is distributed through wells via pipes 500 mm in diameter and 200 m in length. Each line, in accordance with the calculation, the water flow rate will amount to 3.0 m^3/s. Based on the initial data, road and local losses were also calculated along the pipeline and in the well pipes.

The initial data, as shown in Table 3, were used to calculate the flow rates of water pumping into the wells.

[5] State Committee of Water Economy Ministry of Energy Infrastructures and Natural Resources The Republic of Armenia, Preparatory survey for Yeghvard irrigation system improvement project, Final report, 2016 (in Armenian).

Table 3. Initial design indicators and water flow pumping into wells

Wells	H_p, m	H_w, m	H_p-$H_п$, m	k_f, m/day	h, m	Q_1, m^3/s	Q_2, m^3/day	α = h/50	$Q_3 = αQ_2$, m^3/s
1	102	5.67	96.33	4.2	50	0.316	0.366	1.00	0.366
2	99	3.34	95,66	8.4	20	0.251	0.725	0.40	0.290
3	99	2.72	96.28	2.0	80	0.244	0.175	1.60	0.280
4	99	5.36	93.64	3.5	55	0.282	0.290	1.10	0.319
5	95	2.61	92.39	3.8	53	0.290	0.308	1.06	0.327
6	100	8.82	91.18	12.4	50	0.882	0.973	1.00	0.973
7	101	7.72	93.28	9.5	48	0.664	0.777	0.96	0.746
8	103	11.41	91.59	11.4	52	0.847	0.896	1.04	0.932
9	101	4.53	96.47	6.0	45	0.406	0.525	0.90	0.473
10	88	5.15	82.85	2.5	39	0.124	0.165	0.78	0.129
11	94	3.64	90.36	6.2	47	0.437	0.481	0.94	0.452
12	103	6.97	96.03	6.2	47	0.411	0.536	0.94	0.504
∑						5.153	6.217		5.789

Thus, by pumping 5.153 m^3/s of water through 12 wells into the groundwater basin, the volume of pumped water per day can be 445219 m^3, and for three months of operation of the wells, 445219x30x3 40069710 m^3 or approximately 40 million m^3 of water can be transported to AAB.

Discussion

Thus, the obtained data on water flow rate calculated using (7) and (9) formulas produce similar results. This provides reason to believe that these water flow rates calculations can be trusted. It is possible to increase groundwater reserves and solve problems associated with their decrease by artificially recharging the AAB in the amount of 40 million m^3/year. The outcomes of methodological approaches can be applied in a variety of mountainous countries.

Environmental justification of artificial recharge of AAB reserves

Physical and chemical indicators of water are important for artificial recharge of water reserves in the groundwater basin. We distinguish the temperature and the number of floating particles from the physical indicators of water (Table 4).

Table 4. Qualitative indicators for the Hrazdan River water at the Arzni-Shamiram Canal water intake site

Months	Qualitative indicators					
	t, C°	Floating particles, mg/l	pH	Water hardness, meq/l	EC, mS/cm	HCO_3, meq/l
III	7.3	1.0	8.06	3.7	0.598	2.55
IV	8.3	10.1	7.95	3.3	0.677	2.35
V	9.5	73.8	7.45	1.9	0.181	2.35

Water temperature during the water supply period ranges between 7.3 and 9.5^{0}C, which corresponds to the groundwater temperature and cannot cause environmental problems. The content of floating particles, particularly in May, amounts to 73.8 mg/l, which can lead to a decrease in the soil filtration coefficient. However, these particles settle as the water moves along the Arzni-Shamiram Canal.

From March to May, the waters in the Hrazdan River are formed mainly from precipitation, snow melting and underground sources, therefore, have good chemical indicators. The Republic of Armenia standards were used to assess the chemical composition of the water. It can be concluded that the critical indicators (pH, hardness, electrical conductivity and hydrocarbonates) of water do not exceed the maximum permissible concentrations (MPC).

The content of contaminated elements in canal water is shown in Table 5. Sulfates and chlorides, which can seep into domestic water, as well as nitrates, ammonium and phosphates (which get in by washing agricultural fields), do not exceed the MPC. Soils above the Arzni-Shamiram Canal are not cultivated.

The concentrations of a number of microelements in the Hrazdan River at the water intake area of the Arzni-Shamiram Canal are shown in Table 6. The MPC is not exceeded in the concentrations of extremely toxic elements such as cobalt, lead, arsenic, nickel and copper.

Table 5. Content of pollutants in the Hrazdan River at the water intake section of the Arzni-Shamiram Canal

Months	Content of Materials, mg/l				
	Sulphates MPC = 100	Chlorides MPC = 300	Nitrates MPC = 40	Ammonium MPC = 0.5	Phosphates MPC = 3.5
III	72.66	55.24	13.72	0.19	0.16
IV	53.97	38.66	36.33	0	0.15
V	32.47	13.81	14.74	0	0.20

Table 6. Concentrations of a number of microelements in the Hrazdan River at the water intake section

Months	Concentration, mg/l						
	As 0.05	Mo 0.5	Pb 0.1	Mn 0.01	Co 0.01	Ni 0.01	Cu 0.001
I	0.008	0.002	0.0001	0.006	0.0001	0.001	0.001
II	0.008	0.002	0.0001	0.0032	0.0001	0.001	0.001
III	0.003	0.001	0.005	0.0035	0.0001	0.001	0.001

Pesticide traces were also not found in water analyses. AAB water is primarily used for irrigation and fish farming, and when used for drinking and domestic purposes, it is usually subjected to biological treatment in each community. Consequently, there is no need to construct a special biological water treatment station when water is pumped from the Karbian Gorge.

However, the process of water pumping in the Arzni-Shamiram Canal should be the focus of environmental monitoring services, which should conduct regular monitoring of water quality to exclude the groundwater pollution (Sahakyan and Yedoyan 2020; Sahakyan et al. 2021), and it is also necessary to continue the studies on the effect of artificial recharge of AAB on quantitative (groundwater reserves, groundwater level and pressure) and qualitative (chemical composition) indicators of water quality after operation of the pumping system in the Karbian Gorge.

It should be noted that in the mountainous regions, water, especially in the spring months, is formed from atmospheric precipitation, has fairly good quality indicators and does not require additional purification.

Economic justification of artificial recharge of AAB reserves

In order to implement AGR technology for AAB of Karbian Gorge it will be necessary to implement construction works on Arzni-Shamiram Canal for the intake of 5-6 m^3/s, where 2 water intakes and 2 lines of pipelines with diameter of 1220 mm, water valves, grids for preventing penetration of floating bodies, automatic systems for water flow regulation and closing automatic water entry in case of accidents should be installed (Table 7). Two pipelines with a diameter of 1200 mm and a length of 2114 m, the diameter of which will be reduced to 820 mm and the total length will be 1421 m after the reduction of water flow along the way. Then a pipe with a diameter of 500 mm and a total length of 2400 m will be descended into each well. It is necessary to install 16 water valves of different diameters, which will regulate the flow and distribution of water to the wells.

The economic calculation of the activities of the artificial recharge system of the AAB shows that in order to pump 40 million m^3 water, it is necessary to invest about 2 million 26 thousand USD (0.05 million USD for one cubic meter of water) on construction-installation operations, including water intake, pipeline and well treatment. In comparison with the construction, the annual maintenance, and the transportation of the same volume of water to the point of consumption through canals, according to Yeghvard Reservoir project will cost at least 230 million USD (5.5 USD/m^3) [6]. It should be noted that the Government of Armenia did not approve of the construction of the Yeghvard Reservoir due to the need for large investments.

Table 7. Estimate of measures for artificial recharge of water resources in the AAB

Wells	Name	Diameter, mm	Length, m	UnitCost, $ US	Quantity, pcs	Total Sum, $ US
1	Metal Pipe	500	2400	150	-	360000
2	Metal Pipe	820	1421	200	-	284200
3	Metal Pipe	1220	2114	330	-	697620
4	Water Valve	500		2000	12	24000
5	Water Valve	820		2500	2	5000
6	Water Valve	1220		3800	2	7600
7	Well Treatment			5000	12	60000
8	Construction Work			150000	1	150000
9	Water Intake			100000	1	100000
10	Total					1688420
11	VAT, 20 %					337684
12	Total Sum					2026104

Thus, in mountainous areas, using the difference in relief heights as well as high quality indicators of pumped up water, artificial recharge of groundwater basins can be provided with high economic efficiency.

Conclusion

- River flows are extremely seasonal in mountainous regions, with spring and autumn floods reducing the efficiency of their use significantly in the crop growing period. The accumulation of runoff in reservoirs under difficult hydrogeological conditions requires not only a significant initial investment in construction (3-5 USD/m^3), but is also accompanied by significant infiltration and evaporation.
- It is mostly efficient to direct river flows into the groundwater basins. In lowland countries, these activities require significant financial outlays for water purification and its pumping into groundwater basins with the help of powerful pumping stations, which significantly increase the prime cost of waterobtained in this way. In mountainous regions, the water is characterized by high quality indicators, and relief differences in relative heights make it possible to pump water without using powerful pumping stations.
- Based on the example of AGR of AAB of Armenia, it is demonstrated that financial costs can be significantly reduced to spending less than 2-3 million USD (0.05-0.075 USD/m^3) for construction of a facility to pump 40 million m^3 of water per year into the groundwater basin, which includes a water intake, pipeline and well treatment, rather than capital investments for construction of a new reservoir to collect 40 million m^3, its annual maintenance and transportation to the point of consumption by canals costs 230-250 million USD or 5.75-6.25 dollars/m^3. The artificial recharge of AAB of Armenia in the amount of 40 million m^3/year makes it possible to increase the groundwater reserves and to solve the emerged problems due to their decrease as a result of their active use for national economic purposes.

[6] State Committee of Water Economy Ministry of Energy Infrastructures and Natural Resources The Republic of Armenia, Preparatory survey for Yeghvard irrigation system improvement project, Final report, 2016 (in Armenian).

- The findings of the present research, as well as the methodological approaches proposed in it, can be applied not only in the regions of Armenia, but also in a variety of countries with mountainous relief.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

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UNCONFIRMED FLUID MOVEMENT IN THE PYRAMID-SHAPED WELL OF THE CENTRIFUGAL PUMP

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Abstract: *The article touches upon the unconfirmed fluid movement in the prism-shaped receiving basin of a multi-unit pumping station, which is fed from a large-volume basin through a fluid pressure overflow pipe. During the joint operation of the units, a constant fluid level is established in the receiving basin when the total output driven by the pumps equals the output of the overflow pipe. When one (or several) units are shut down or initiated, an unconfirmed movement occurs in the overflow pipe and the receiving basin. The pattern of change of the fluid level in the receiving basin over time and the timeframe for the formation of a new level have been determined. This study is of practical significance from the perspective of excluding the discontinuity of fluid flow in the pump suction pipe as well as in terms of avoiding cavitation.*
Keywords: *unconfirmed movement, cavitation, discontinuity, stationarization period, unit.*

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Received: 03.07.2023
Revised: 18.09.2023
Accepted: 15.11.2023

Introduction

The discontinuity of fluid flow in the suction duct of a centrifugal pump is accompanied by cavitation. Cavitation refers to the formation of local bubbles when the absolute pressure drops to the level of the liquid's saturated vapor pressure. The tendency for cavitation to occur increases when the pump operates with a positive suction lift, approaching its calculated limit [1,2], particularly on the inlet part of the pump, such as the sealing ring, front disc, and impulse wheel. With a negative suction lift (self-suction), cavitation can also occur. Therefore, when operating three pumps in parallel, each with a capacity of 1850 l/s, if two pumps are shut down, the operational pump's performance, according to the main characteristic of the pump, should increase to 2500 l/s. However, this hydraulic mode of operation for the pumping unit is not achievable due to the absence of excess pressure between the water level in the discharge tank and the pump axis.

This mode leads, on the one hand, to an overtolerance load on the electric motor and, on the other hand, to pulsating ruptures of the water column in the suction pipe of the pump because the hydraulic resistance of the latter prevents the passage of such a flow rate with a given excess pressure. Secondly, it causes pulsating ruptures of the water column in the pump's suction pipe. The excess pressure can not pass through the pipeline because of resistance. At the Mkhchyan pumping station in Armenia, which consists of nine units, each with a capacity of 1600 kW, the leading edges of the impeller blades experienced an average reduction in length of 20 to 23 mm due to cavitation wear. This wear occurred during the irrigation season. When centrifugal machines enter the cavitation mode of operation, it not only has mechanical consequences but also affects hydraulic parameters and energy indicators. Specifically, pumps experience a decrease in productivity and pressure, while turbines - a significant decrease in efficiency [3].

Therefore, it is crucial to identify and prevent the initiation and development of cavitation in centrifugal machines. There are several methods available for preventing cavitation, and in our opinion, the most simple and reliable methods are acoustic [4,5] and vibrational [6,7]. It has been observed that high-frequency implosions of vapor bubbles interact with the low-frequency passing of the rotating blades. Detection of semiopen impellers cavitation at initial and intermediate stages of cavitation development, it is found that the high frequency implosions of vapor bubbles interact with the low frequency passing of the rotating blades and compose part of the vibration signal under initial cavitation conditions [8].

Materials and Methods

The calculations related to the studies were performed by the following well-known hydraulic principles and laws. The experimental studies were conducted directly on the water supply network under production conditions.

The effect of transient phenomena on the pump suction process in the pump suction pipe

Let us consider the non-stationary fluid movement in a prism-shaped well of limited volume (receiving basin) of a small pumping station, which is fed from a large-volume basin by the q and from which a Q constant output is pumped out.

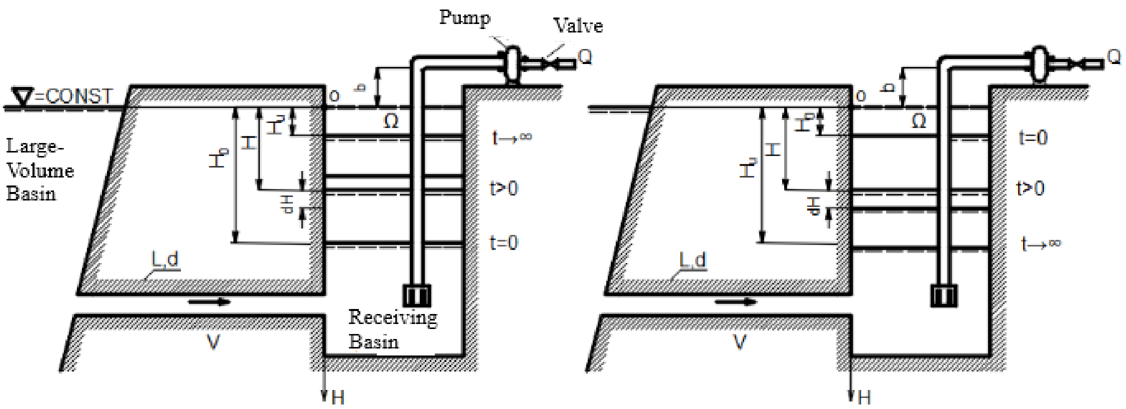

Fig. 1. *Side view diagram of the hydraulic system*

Fig. 1 shows a side view diagram of the hydraulic system. The well is connected by a pipe to a large-volume basin in which a constant fluid level is maintained. The basin feeds the well at the q output variable depending on the varying fluid level in the well over time.

Let us assume that at the initial $t = 0$ moment of time the fluid level in the well is lower than the fluid level in the basin in H_0 amount and $Q = const$ output is pumped out of the well. Since there is a H_0 difference in fluid levels between the basin and the well, the basin feeds the well through a pipe. The output feeding the well is determined using Bernoulli's equation written for the cross-sections of the basin and fluid levels of the well [9,10]:

$$H_0 = \sum h_W, \tag{1}$$

where $\sum h_W$ is the total energy loss in the feeding pipe [11].

$$\sum h_W = h_1 + h_L + h_2 = \frac{V^2}{2g}\left(\varsigma_1 + \lambda\frac{L}{d} + \varsigma_2\right), \tag{2}$$

V is the average velocity of fluid movement, ς_1 and ς_2 are the local resistance coefficients of the pipe input and output, λ is the coefficient of frictional resistance of the pipe, while L and d are the length and diameter of the pipe.

Let us insert (2) into (1) and determine the average V_0 velocity of the fluid flow in the pipe at the $t = 0$ moment of time:

$$V_0 = \sqrt{\frac{2gH_0}{\varsigma_1 + \lambda\frac{L}{d} + \varsigma_2}}.$$

Therefore, the initial q_0 output feeding the well will be [12]

$$q_0 = \frac{\pi}{4} d^2 \sqrt{\frac{2gH_0}{\varsigma_1 + \lambda \frac{L}{d} + \varsigma_2}} \quad \text{or} \quad q_0 = \mu A \sqrt{2gH_0}, \quad \left(\mu = \frac{1}{\sqrt{\varsigma_1 + \lambda \frac{L}{d} + \varsigma_2}} \right). \qquad (3)$$

It is obvious that in the established hydraulic regime, the q_0 output feeding the well will equal to the Q output pumped out of the well: $q_0 = Q$.

In case one of the pumps is decommissioned at the $t = 0$ moment of time, the output feeding the well exceeds the output from the well, which leads to an increase in the fluid level in the well.

Let there be the z increase in the level at the $t > 0$ moment of time, and the pressure difference between the ends of the pipe feeding the well becomes $H_0 - z$, as a result of which the output issued through the pipe becomes

$$q = \frac{\pi}{4} d^2 \mu \sqrt{2g(H_0 - z)} = k\sqrt{(H_0 - z)}, \; k = \frac{\pi}{4} d^2 \mu \sqrt{2g}. \qquad (4)$$

At dt timeframe the level will increase in dz. The fluid level in the well continues to increase until the feeding output has not equaled the $Q - \Delta Q$ output from the well, when the hydraulic established regime is reestablished, where the ΔQ is the output of the decommissioned pump.

At dt timeframe the volumes of liquid filling the well and withdrawing from the well will correspondingly be as follows:

$$qdt \quad \text{and} \quad (Q - \Delta Q)dt.$$

Since the output feeding the well exceeds the output withdrawing from the well: $q > Q - \Delta Q$, an increase emerges in the Ωdz fluid volume in the well, where the Ω is the cross-sectional area of the prism-shaped well.

Therefore:

$$qdt - (Q - \Delta Q)dt = \Omega dz \Rightarrow dt = \frac{\Omega dz}{q - (Q - \Delta Q)}.$$

A differential equation with separable variables (z, t) has been obtained. Inserting q from (4) into the above equation, we obtain

$$dt = \frac{\Omega dz}{k\sqrt{H_0 - z} - (Q - \Delta Q)} = \frac{\Omega}{k} \frac{dz}{\sqrt{H_0 - z} - \frac{Q - \Delta Q}{k}}.$$

Let us denote:

$$\frac{Q - \Delta Q}{k} = \sqrt{H_U} \Rightarrow k\sqrt{H_U} = Q - \Delta Q. \qquad (5)$$

The left side of equation (5) represents the q feeding the well and the right side represents the output withdrawn from the well. Therefore the H_U is the boundary depth of the fluid level in the well below the fluid level in the basin at which these outputs equalize.

After the given notation, the differential equation takes the following form:

$$dt = \frac{\Omega}{k} \frac{dz}{\sqrt{H_0 - z} - \sqrt{H_U}}.$$

Let us integrate the differential equation under the following initial condition:

$$t = 0, \qquad z = z_0.$$

$$\int_0^t dt = \frac{\Omega}{k} \int_{z_0}^{z} \frac{dz}{\sqrt{H_0 - z} - \sqrt{H_U}}.$$

Let us denote $\sqrt{H_0 - z} = x \Rightarrow x^2 = H_0 - z \Rightarrow dz = -2xdx$.

Let us calculate the integral with the new variable:

$$\int_{Z_o}^{z}\frac{dz}{\sqrt{H_0-z}-\sqrt{H_U}}=2\int_{\sqrt{H}}^{\sqrt{H_U}}\frac{xdx}{x-\sqrt{H_U}}=2\int_{\sqrt{H}}^{\sqrt{H_U}}\frac{x-\sqrt{H_U}+\sqrt{H_U}}{x-\sqrt{H_U}}dx=$$

$$=2\int_{\sqrt{H}}^{\sqrt{H_U}}dx+2\sqrt{H_U}\int_{\sqrt{H}}^{\sqrt{H_U}}\frac{dx}{x-\sqrt{H_U}}=2\left(\sqrt{H_0}-\sqrt{H}+\sqrt{H_U}\,ln\frac{\sqrt{H_U}-\sqrt{H_0}}{\sqrt{H_U}-\sqrt{H}}\right).$$

Inserting the expression of k from (4), we finally obtain

$$t=\frac{2\Omega}{\mu A\sqrt{2g}}\left(\sqrt{H_0}-\sqrt{H}+\sqrt{H_U}\,ln\frac{\sqrt{H_U}-\sqrt{H_0}}{\sqrt{H_U}-\sqrt{H}}\right). \qquad (6)$$

This solution result coincides with the case of discharge from a prism-shaped basin under variable pressure, when the basin is fed from above by a constant output.

The difference between the problem under discussion lies in the fact that a constant output is withdrawn from the well, while the well is fed from a large-volume basin with a variable output.

It follows from solution (6), that

a) in order for the logarithm to exist, it is necessary for the initial H_0 and variable H depths of the fluid to be simultaneously greater or less than the H_U boundary level,

b) when the variable level tends to reach the boundary level $H \rightarrow H_U$, then $t \rightarrow \infty$, i.e. transition to an established regime is a seamless process.

c) if the H_0 initial level in the well is lower than the H_U boundary level, the H variable level increases asymptotically towards the H_U boundary level, and if it is high, it tends to the same boundary level by decreasing.

Fig. 2 shows the curves of the change in the fluid level in the well.

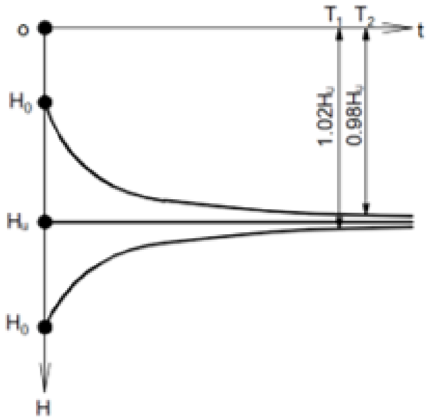

Fig. 2. *Change in fluid level over time*

Results and Discussion

The determination of the period for the generation (stationarization) of the established hydraulic regime has an applied significance. In practice, it can be determined with any accuracy. For example, to determine the T timeframe of stationarization with a 2% accuracy, we accept that $H = 1.02H_U$ in case of increasing the level in the well and $H = 0.98H_U$ in case of decreasing the level in it.

If all the pumps are decommissioned, i.e. $Q = 0$, according to (5), $H_U = 0$ and the solution (6) will take the following form:

$$t=\frac{2\Omega}{\mu A\sqrt{2g}}\left(\sqrt{H_0}-\sqrt{H}\right),$$

which will determine the T_0 timeframe, during which the fluid levels in the well and the basin are equalized $H = 0$ over time, in case of variable (decreasing) pressure feeding the well from the basin, i.e.:

$$T_0=\frac{2\Omega\sqrt{H_0}}{\mu A\sqrt{2g}}.$$

Example: Two identical centrifugal pumps with parallel connection pump out an output of $Q = 0.17$ m^3/s from the prism-shaped well. Determine the timeframe for the stationarization of the hydraulic regime, if one of the pumps is decommissioned. The values of the geometric dimensions and hydraulic quantities of the system given in Fig. 1 are:

$H_0 = 3$ m, $d = 300$ mm, $L = 100$ m, $\Omega = 10$ m^2, $\varsigma_1 = 0.5$, $\lambda = 0.025$, $\varsigma_2 = 1$.

Solution: In case of established movement during the operation of both pumps, the H_0 initial fluid depth in the well from the level of the basin, according to (4), will be

$$H_0 = \frac{Q^2}{2g\mu^2A^2} = \frac{0.17^2}{19.62 \cdot 0.32^2 \cdot 0.071^2} = 2.88 \text{ m},$$

where

$$\mu = \frac{1}{\sqrt{0.5 + 0.0247\frac{100}{0.3} + 1}} = 0.32\,, \quad A = \frac{3.14}{4}0.3^2 \approx 0.071\text{m}^2.$$

The productivity of the pump in operation increases from its productivity in case of joint operation to 0.085 m^3/s. Let us consider it $Q_1 = 0.1$ m^3/s and determine the depth of the H_U boundary level from the fluid level of the basin:

$$H_U = \frac{Q_1^2}{2g\mu^2A^2} = \frac{0.1^2}{19.62 \cdot 0.32^2 \cdot 0.07065^2} = 1.0\text{m}.$$

Inserting $H = 1.02H_U$ in (6), we obtain the T timeframe of the stationarization of the fluid flow movement in the well with a 2% accuracy:

$$T = \frac{2 \cdot 10}{0.32 \cdot 0.07065 \cdot \sqrt{2 \cdot 9.81}}\left(\sqrt{2.88} - \sqrt{1.02 \cdot 1} + \sqrt{1}\, ln\frac{\sqrt{1} - \sqrt{2.88}}{\sqrt{1} - \sqrt{1.02 \cdot 1}}\right) = 988\text{s} \approx 17\text{min}.$$

It is obvious that the increase of the fluid level in the limited-volume receiving basin by 2.88-1 = 1.88 m within the T timeframe leads to the improvement of the suction process of the operating pump, because the suction height of the pump gradually decreases.

Now let us assume that two pumps are in operation and another is being started. In this case, the fluid level will decrease in the receiving basin, and after some time, a lower fluid level will be established, i.e., a greater suction height will be established, as a result of which the suction process of the pumps will deteriorate.

The number of pumps with parallel connections is reasonable to implement with three identical pumps, which have a relatively large permissible vacuum gauge height due to the significant variation in pump suction height.

Conclusion

1. The variation in liquid level within the well, in response to changes in the number of units in operation, remains independent of the well's cross-sectional area.
2. The time needed for the well to achieve stationary motion is directly proportional to its cross-sectional area.
3. Selecting a pipe with higher roughness can decrease the time required for the fluid flow in the well's feeding pipe to establish a consistent movement.

Therefore, to mitigate the effect of the transient phenomenon on the pump suction process in the suction pipe of operating pumps, it is necessary to take the following measures:

1. Before shutting down one of the operating pumps, first the output of the operating pump needs to be reduced by throttling its discharge valve to closing, then the pump should be shut down, and the discharge valve of the operating pump should be opened.
2. Before operating a new pump, it is necessary to reduce the initial output first by throttling its discharge valve to the closed position, then start the pump operation, and after a short time open the valve.

It should be noted that the degree of throttling of the valve is determined experimentally. The present experiment has been performed by us on the discharge conduit of the Khor Virap pumping station. The noise (like a shot) that can be heard from the body of the pump, as well as soft vibrations of the suction pipe, can be considered a signal. During the transition from one established hydraulic regime to another, the inertial pressure, which is equal to zero when the established regime of fluid flow occurs, conditions the mentioned actions (valve throttling).

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MULTILAYER READING OF THE URBAN ENVIRONMENT AS A METHOD OF STUDYING SPACE TRANSFORMATION

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Abstract: *The article discusses the transformations of the urban environment under the influence of various factors, as well as the methodological problems of forecasting these changes in the context of sustainable development. The questions urban science addresses, from which point of view and with what tools it examines the urban space, and which phenomena are ignored and/or incompletely studied in that process was studied. Based on the level of complexity of the constituent elements of the city system and the interrelationship of these elements, the non-comprehensive and fragmentary character of studies of modern urban science has formulated the need to "read" the city and form the "language" of the city through it, applying the concept of "textuality" as an interdisciplinary method of study of space, as well as the principles and methods of reading space.*

Keywords: *urban planning, urban environment, the transformation of space, textuality, the identity of space.*

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Received: 22.11.2023

Revised: 04.12.2023

Accepted: 09.12.2023

Introduction

Studying the causes, forms and consequences of environmental transformations is one of the keys to spatial planning, which allows to form multi-layered foundations of the theory of sustainable development, while contributing to increasing its level of resilience. Referring to the historical experiments of urban environment research, it is worth noting that they led to mostly partial results, because in many cases complete chains of cause-and-effect connections were bypassed. Many comprehensive urban studies address various topics such as the history of the forms and functions of the city [1], the formation and decay of cities [2], the relationship between city and people [3], as well as some studies of specific cities, their landscape, architecture, image, identity and semiology [4,5]. Nevertheless, economic-technical research of urban structures prevails, and modern urban science is gradually directed toward the tools of mathematical modeling and data science.

Such a vector of development, in turn, leads to the neglect of key anthropological and cultural questions, pushing them out of the scope of research. Moreover, for architects and urban planners engaged in spatial planning, from the perspective of design methodology, it is important not only to know the legal acts related to the environment, technical norms, infrastructure placement, requirements related to the protection of the environment and cultural heritage, but also the ability to see through the eyes of residents - "users" of the city.

This article refers to previous research on spatial structures and their transformations, principles and methods of object observation, from mathematical modeling experiments to studies carried out in the contexts of sociology and philosophy.

Considering all the above, the interdisciplinary approach to the research of spatial structures has been emphasized, which implies researching the city in different spatiotemporal contexts as an anthropological, cultural, architectural, engineering, economic, political and civilizational text.

And textuality, as an effective method of research, implies reading the research object at different levels of subjectivity and through various reading tools.

Materials and Methods

Cities, as the largest anthropogenic structures, are constantly undergoing changes that are sometimes unpredictable and chaotic. The complex of interacting factors of the city-system is constantly growing.

Combinations and effects of factors are gradually increasing, and their management is becoming more complicated. Even the dominant role of social and technical factors does not make the development of the city completely manageable, and the study of the urban environment allows only to a certain extent to predict the consequences of anthropogenic impact on the environment [6].

A comprehensive study of socio-economic, ecological, political, and cultural realities is key in the urban planning process. Their integrity has become a prerequisite and context into which the city needs to be integrated in order to ensure its vitality [7]. The totality of these factors is also a set of problems and questions to which the city must respond. The urban landscape at all stages of its design and formation should be considered in dynamic development, which is the result of the interaction of the natural and man-made structures of the city [8].

Economic relations, social, political, ideological and ecological factors directly influence the urban environment, and the guarantee of sustainable development lies only in the range of predictability and controllability of these factors. Meanwhile, modern realities prove once again that this range is too small, because these structures can collapse due to epidemics, wars and other major upheavals.

Along with its social nature, the city also becomes the space where traces of various historical developments are fixed, it is simultaneously an arena of ideological disputes and a record of past "victories". These realities not only transform the spatial structure of the city, but also the daily life of the city, as a result of which the society and the city form an eternal cycle of interaction: the city becomes both the effect and the cause at the same time. Each layer of historical geography eliminates the physical existence of the previous one or exists by articulating it [9].

Apart from the primary, short-term impact, socio-economic, political and cultural realities also leave their secondary, long-term impact. The response of the urban organism to these breakthrough events forms new spaces, they gradually harden in the urban fabric and become a material record of historical realities. Historical layers become one of the most important factors of architectural creation [10]. Considering the tendency of people to perceive themselves as a social group based on some spatial category (neighborhood, city, etc.) [11], it follows that the new space forms and consolidates new social strata, reformulating and interfering with the processes of public life in the city [12].

The mentioned realities have allowed individual researchers to conclude that cities live with their own unique logic, which can equally be considered both in the framework of cognition and hypotheses. In that case, the objective history of cities is considered not as a living environment (Habitat), but as a result of the activities of those who realize it (Habitus) [13].

There are many technical and economic studies of urban space, which, based on data science and using mathematical modeling tools, address a number of issues, such as urban microclimates [14], the ratio of land use [15], the intensity of human and transport flows, and even the predominance of preferred routes for cyclists in urban space [16].

Of course, the ever-changing nature of the city-organism is the guarantee of its development and long-term stability, but it also raises problems of the formulation of the identity of the environment and its preservation. This cycle of interaction makes the city a mosaic of historical realities, the shades of which bear the imprint of the intensity of breakthroughs and changes. Sustainable urban development implies a smooth spatio-temporal transformation, where it is possible to see the sliding of the layers of space. Unfortunately, when the city faces sharp breaks, the sliding of the layers of space gradually turns into an unreadable noise (Fig. 1).

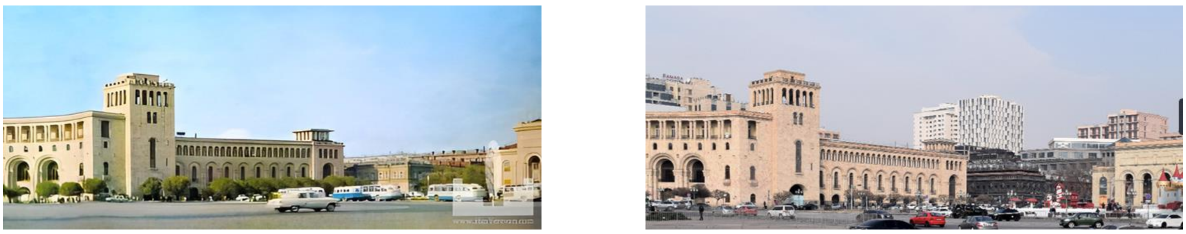

Fig. 1. *Republic square of Armenia at 1973 and 2022*

In order to make the situation manageable, urban planning, as a theory, defines a certain design methodology, formulates a vision of the city's development, tries to predict the vector of further development, through design restrictions and legal regulations to ensure the stable and balanced development of the city, to make the city more resistant in crisis situations [17].

However, there are many cases where these levers do not work at breakthrough stages and the city faces dynamic changes. The multi-layered nature, structural complexity and variety of component factors of the concept of "city" make it almost impossible to define a universal formula for predicting city transformations in the theory of urban development, because to assess the state of the urban environment, it is important not so much to have an idea of the quantitative significance of a certain factor, but rather to have an idea of the environment under the influence of that factor, determining and evaluating the level of qualitative changes, taking into account its intensity. In this sense, it is first of all necessary to understand the constituent elements of the living environment and their relationships with the processes taking place in it, which can be done through a comprehensive analysis of the urban space, the task of which is to take into account the totality of factors, regardless of the prevalence of their characteristic features, a single methodological apparatus and a comprehensive assessment with the help of a standard.

Such studies of urban space are extremely important and informative in their nature. However, for comprehensive research, technical and economic analyzes are necessary, but not sufficient, because they are only one of the many perspectives of reading the space. Unfortunately, and perhaps still, this methodology cannot answer a number of anthropological and cultural questions related to space.

The complexity of modeling the state of the urban environment lies in the obvious structural heterogeneity of the characteristics of the studied object, which is caused not only by the qualitative differences of the generating features, but also by the difference in the degrees of complexity of the considered factors and components[1]. In the case of such differences in structural complexity, even in the case of mathematical modeling, any prediction of the development of urban space becomes impossible, and such a deterministic approach is nothing more than an attempt to create a Laplace monster ("Laplace's monster" is a mental experiment proposed by a French mathematician in 1814. Pierre-Simon Laplace. The protagonist of that experiment is a fictional, intelligent being who, knowing the position and speed of each element in the universe at every moment in time, is able to predict the universe's past and future).

In the indeterministic reality, we have to accept the impossibility of universal space research/planning tools and move to a specific research approach, a multiple and diverse *reading* of each city, through which it is only possible to form or perceive the language of space.

"A city is a space of endless discovery and exploration, where at every moment there is more than the eye can see and more than the ear can hear, an environment or scene waiting to be discovered. Nothing lives by itself, but constantly relates to the environment, previous realities and the memory of past experience" [18]. It becomes necessary only to take the willingness to read the space and form the language of the city.

The primary function of environmental legibility and recognizability is to identify a place for a person, a way to orient oneself and not get lost. More profoundly, the landscape, spatial, climatic, cultural and ethnic characteristics of the city shape identity and image [19], and the reading of space is central to the formulation of the identity of the environment and subsequent interaction with it.

The use of the word "reading" implies the consideration of space as a text, in other words, the textualization of space, the consideration of space as a social, economic, cultural, political, and civilizational multi-layered text.

This approach was first used by theorists and philosophers of the 20th century, who made textuality an interdisciplinary concept and applied it to various fields of science and culture, particularly urban studies. As

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[1] Preobrazovaniye sredy krupnykh gorodov. Research and Design Institute of Urban Planning, Kiyev, 1977 (in Russian).

noted by theorist and philosopher Roland Barthes: "Most of us will be required to try to decipher the city we are in, starting, if necessary, with a personal report. By collecting all the readings from different categories of decoders (as we have a full range of readers from local to foreign), we will be able to develop the language of the city. That is why I say that the most important thing is not so much to multiply the functional/technical studies of the city as to make readings of the city, of which, unfortunately, so far only writers have given us some examples" [20].

The multi-layered nature of the urban environment, which needs to be studied through reading, creates the very problem of the application of the method: legibility. Michel de Certeau defines the city as fragmentary and "paged" histories, hidden pasts, accumulated times that can be "opened", narratives that are kept in reserve and remain a mystery, and finally, symbols [21]. Due to this level of complexity, the city seems to avoid being read, therefore, this barrier can be overcome only in case of defining and formulating the fundamentals of multidimensional study of space.

Depending on the status and characteristics of the subject reading the space, the observation, study and relationship with the space are carried out in two main approaches (Fig. 2):

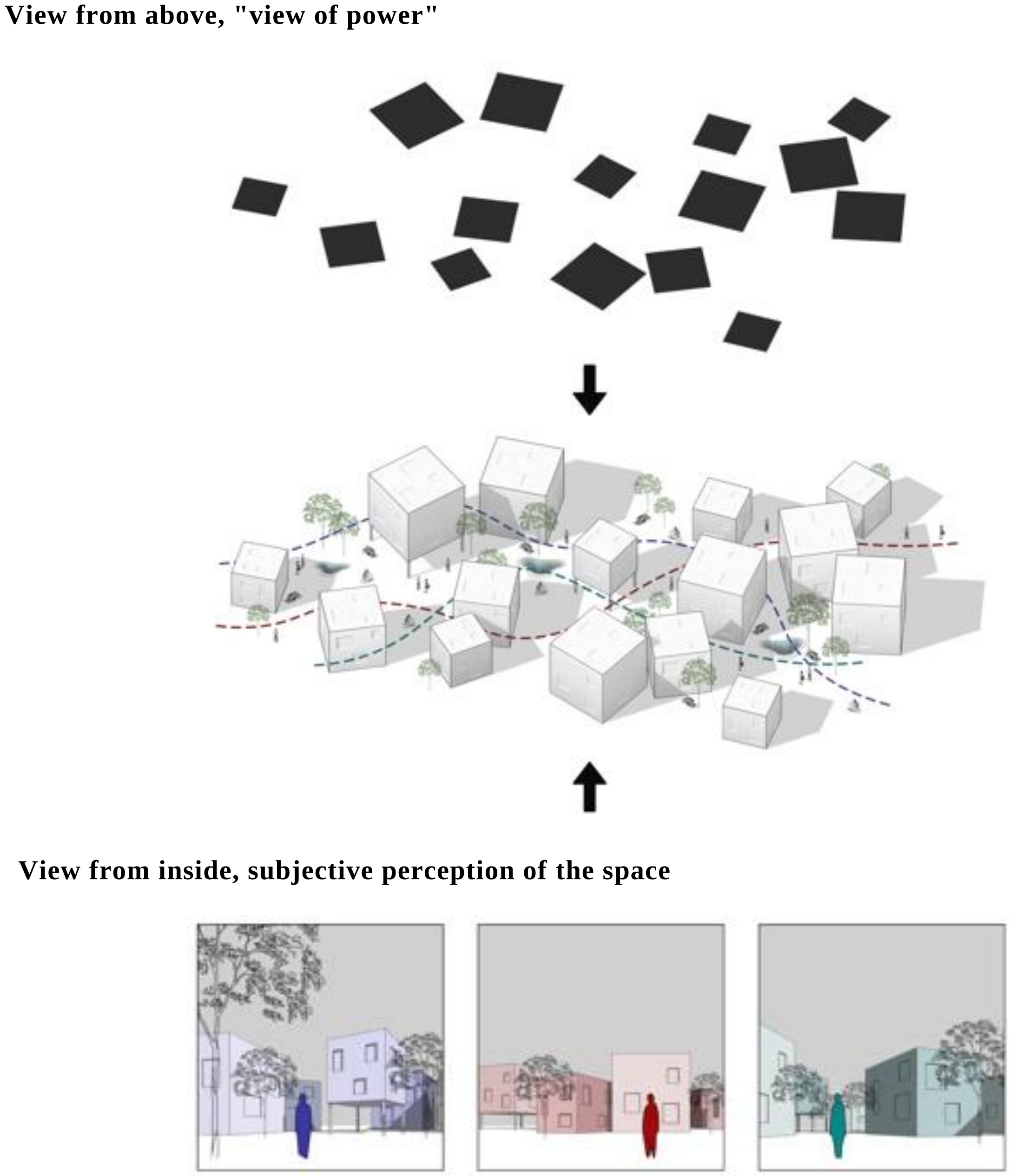


Fig. 2. *Basic approaches of space observation*

1. View from above: "all-seeing view of power" [22]. A perspective, a distanced view, characteristic of an architect, urban planner or cartographer, which lacks the sensuality that Roland Barthes considered necessary. A point of view that blocks and alienates the observer from the environment. Note that this approach dominates professional publications.

2. A view from below/inside, which is mainly possessed by the "ordinary" implementers of space, the ordinary "users" of the city, who live "below", where the object of observation as a whole is absent. They walk, which is the basic form of spatial experience, they are pedestrians (Wandersmänner) whose bodies are subject to all the inflections of the urban "text", they write without being able to read that script. They realize the areas that cannot be seen. In their knowledge of those territories, they are as blind as lovers in each other's arms. Paths that make up these textures, unrecognizable poetry where each body becomes a constituent element of multiple readings that avoid being read [21].

Thus, in the case of considering the urban environment as an object of reading, it is necessary to examine the features of the perception of the environment at different levels of subjectivity, as well as the content layers of the environment as an object of reading.

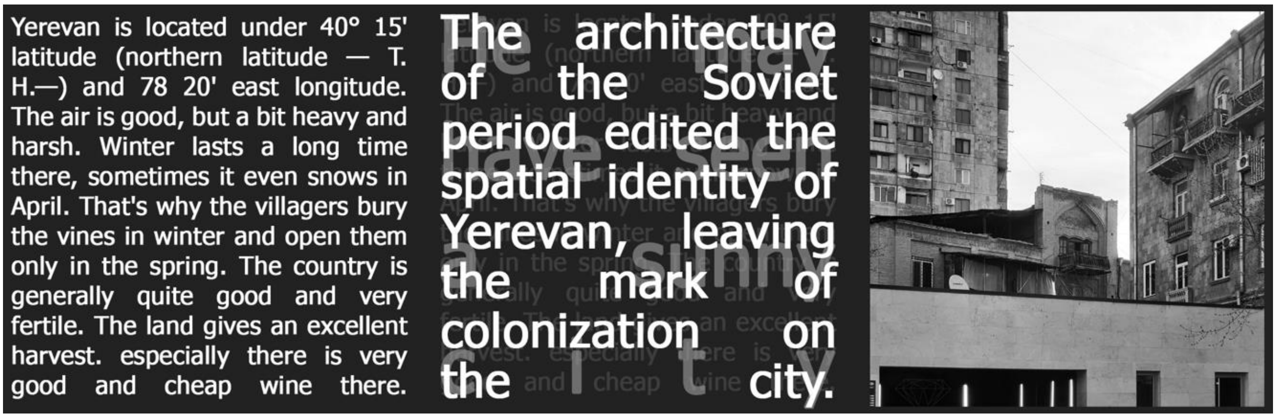
Results and Discussion

Firstly, we should present the peculiarities of the perception of various objects built on textuality and the key difference between the reading of the environmental text and the perception of other texts (Fig. 3 a, b, c).

a. Ordinary printed, handwritten or audible text is read directly in its entirety (regardless of the nature of perception and degree of understanding).

b. The reading of a multi-layered text or palimpsest is possible only in the case of separation of different layers, that is, each layer as an object of perception can be accessed provided that it is observed separately from other layers, in other words, simultaneous reading of different layers of the palimpsest is impossible.

c. The reading of the urban environment has a completely different character, where different layers of the palimpsest are combined, however, unlike the usual textual palimpsest, in the environmental palimpsest all texts are directly and simultaneously visible and legible. Therefore, from the point of view of a purely scientific methodology, it is important to evaluate both the content components of the reading object, the urban environment, and the features of the perception of the environment by different groups of readers.



a *b* *c*

Fig. 3. *a. ordinary text, b. palimpsest, c. environmental text*

Object

Secondly, let's present what kind of layers of content the urban environment, as a historically formed material reality and as an object of perceptions, can offer to the readers.

We believe that identity, structure and functions should be considered key components of the urban environment (Fig. 4).

A. Identity: the character, image and semiotics of the environment, which a person perceives and directly relates to.

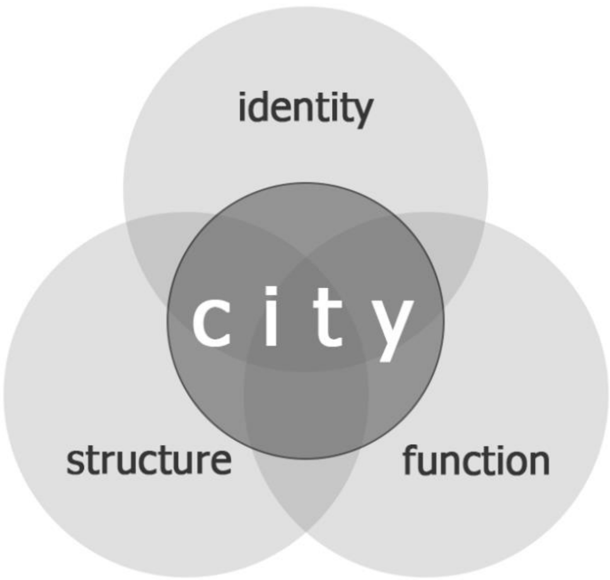


Fig. 4. *The content layers of the environment*

Man seeks to understand the identity of the space to which he belongs or which he realizes. Is the structure of the city, the symbolic objects that carry and define that identity (separate structure, street, district), the integrity of diverse identities perceptible, or does it not create any sense of identity at all? During a few minutes of walking, you can find yourself in different identity spaces, they combine, coincide, intersect, and in their absence, it is easy to get lost and lose the sense of place and belonging.

B. Structure: what is the shape, scale and position of the elements forming the environment in space, proportions and both mutual and human relations, opening or closing perspectives, even the texture and color palette - in other words, the factors determining the level of comfort of the environment?

C. Function: what key goals are the environment and various functional objects or their combinations (housing, work, rest, movement, trade, culture, sports, etc.) designed to achieve, to what extent do they correspond to people's ideas, does the qualitative level of functions satisfy one or another circle of users (readers)?

Subject

The perception of the environment by different subjects may differ depending on the social role of the reader, features of psyche, memories related to the place, motivation to appear in the space and other factors.

From the point of view of subjectivity, the circle of "readers" of the environment can be divided into two main groups: **creators** of the environment and **users**.

Of course, the boundaries of this separation are very vague and inclusive, and each of the groups has its own actors. In particular, in the framework of environment creators should be included not only urban planners, architects, and other subjects participating in the design and construction processes, but also, as key actors, government bodies and clients. An equally important role here is played by maecenases, developers, investors and even vulnerable stratum of the population, carrying out spontaneous or voluntary construction.

Hence, even among the creators of the environment, the sameness of perceptions or reading is excluded due to the differences in the motivation of the readers, as well as the inevitable contradictions.

Even the motivation of the **government** can be radically different depending on the political system and the nature of the government. The monarch (pharaoh, emperor, king, etc.), as the orderer of the environment, reads it in a completely different field of perception than the city government elected by the population, although in both cases we are dealing with a "view from above".

In the case of those who create the space, deep reading is necessary if there is an ambition to intervene in spatial planning. The professional community and, in particular, the **planner** who is actively involved in urban development processes, must master the tools and methods of multidimensional reading of the space, be able to identify and formulate the identity of the space, realize the importance and necessity of preserving that identity in order to be able to carry out transitional interventions in the urban environment.

At the same time, if the view of the professionals directly involved in the design and construction processes can be described as "from above" or even "from the inside", then the **professional community** outside the processes is more characterized by a view from the "side" with the motives of the observer, critic or evaluator of the environment and its changes.

From the **inhabitant's** point of view, the holistic perception of the environment is a means of defining the collective identity of the place and its inhabitants, which is an integral part of the individual identity of the person. Perceptions of this layer can be much more sensitive, conditioned by memories related to a particular object, street, neighborhood and even a city, to observe changes in the environment in the range of personal life experience, with a conscious or emotional approach.

The **temporary visitors** are a unique layer of urban environment readers, whose perceptions or reading characteristics may be determined by the purpose of the visit, motivation and timing, cultural experience, justification or non-justification of the expectations of the visit, etc.

Of course, a complete picture of the textual features of each individual urban environment, as well as the nature and components of the perception of different groups of readers, can be revealed by conducting surveys among these groups and summarizing the results of the survey.

Conclusion

Taking into account the heterogeneity of the constituent elements of the spatial structures of urban systems, the high level of complexity of their relationship and the impossibility of accurate predictions using accepted methods of environmental research, it can be argued that there is no single universal research formula and each study should be carried out based on the environment and influencing factors of economic, social and cultural originality.

In other words, the individual, multidimensional and comprehensive reading of space becomes the method of research, the totality of readings of urban space, which includes studies of semiotic, operational and volume-spatial formation of the environment, observations of the urban landscape.

Thus, referring to the previously carried out studies regarding the urban environment and its transformations, the principles and methods of observation of the object in them, the mutual effects of the environment and people, it is suggested to consider them as a special text when conducting research on spatial structures.

The following components of environment reading were the subject of research:

- urban environment as an object of perceptions and historically formed material reality and its content layers: identity, structure, and functions,
- features of perception of the environment by different entities: those who create the environment (authorities, clients, designers) and those who realize the environment (residents, temporary visitors, etc.).

The results of the research can be a methodological basis for studies aimed at evaluating individual environments, which must necessarily include social surveys in different circles of readers.

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INFLUENCE OF CARBON NANOTUBES CONCENTRATION ON THE MECHANICAL PROPERTIES OF CEMENT MORTARS

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Abstract: *In recent decades, mechanical properties of composite materials containing carbon nanoparticles, in particular single-walled or multi-walled carbon nanotubes (SWCNTs or MWCNTs), have been researched, taking into account their excellent physical and mechanical characteristics. In this work, the influence of the concentration of MWCNTs (0.1, 0.2, 0.3, 0.35 wt.%) on compressive and flexural strengths of the cement mortar was investigated. The results of the research show that the compressive and flexural strength of the 7 and 28 days curing period samples reach their maximum value at 0.3% of nanotube concentration. In comparison to the control sample the compressive strength increased by 10.93% within 7 and by 32.0% within 28 days. And in the case of flexure, the strength of the test samples increased by 33.67% within 7 and by 36.50% within 28 days. It can be concluded that in the case of the selected carbon nanotubes and the material composition at 0.3% of MWCNTs, the compressive and flexural strength reaches its maximum value.*
Keywords: *carbon nanotubes, cement mortar, compressive and flexural strengths.*

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Received: 22.11.2023
Revised: 11.12.2023
Accepted: 18.12.2023

Introduction

In recent decades, the mechanical properties of composite materials containing carbon nanoparticles, in particular single-walled or multi-walled carbon nanotubes (SWCNTs or MWCNTs), have been researched, taking into account their excellent physical and mechanical characteristics [1,2,3].

Carbon nanotubes (CNTs) are cylindrical fibrous nanomaterials with a diameter from 0.4-3 nm to 1.4-100 nm (depending on the wall layers quantity) and a very high aspect ratio (100-1000). Depending on the number of wall layers, nanotubes can be SWCNTs and MWCNTs. They have high tensile strength (50-200 GPa) and high Young's modulus (1 TPa), which significantly increases the strength, rigidity and crack resistance of the composite material [1]. They have excellent electrical conductivity, due to which the composite gets self-sensing property [4].

CNTs are able to improve cement materials properties because of their excellent mechanical characteristics [3,7]. Many researches have indicated that CNTs are able to increase the mechanical properties [8,9] and durability [10-13] of cement materials. CNTs effectively improve both stiffness [14] and crack resistance of cement-based materials [3,15]. Usually, the quantity of CNTs used by researchers in the cement materials is 0.01 – 0.5 wt.% [16,17], suggesting an increase in strength of 15% - 50% [3,7,8].

At the same time, depending on the CNTs' properties and type of material composition (physical, chemical properties of sand and cement, ratios of w/c and s/c) the optimal amount of CNTs for the cement composite changes. In this work, the influence of the concentration of MWCNTs (0.1, 0.2, 0.3, 0.35 wt.%) on the cement mortar's compressive and flexural strengths were investigated.

The aim of this work is to determine the optimal amount of MWCNTs for the compressive and flexural strength of the cement mortar, depending on the selected material composition and type of MWCNTs used in this study, as well as to increase and develop the physical and mechanical properties of cement mortar of the same composition.

Materials and Methods

Materials

In this work, Portland cement 52.5 (GOST 31108-2020, available in Hrazdancement Factory) was used as a binder in the composite. Tables 1 and 2 show the physical and mechanical characteristics of selected Portland cement and sand, respectively.

In Fig. 1 MWCNTs were obtained from Zhengzhou University of China, which were synthesized using a chemical vapor deposition method (CVD)[1]. The necessary physical and mechanical properties of nanotubes are shown in Table 3.

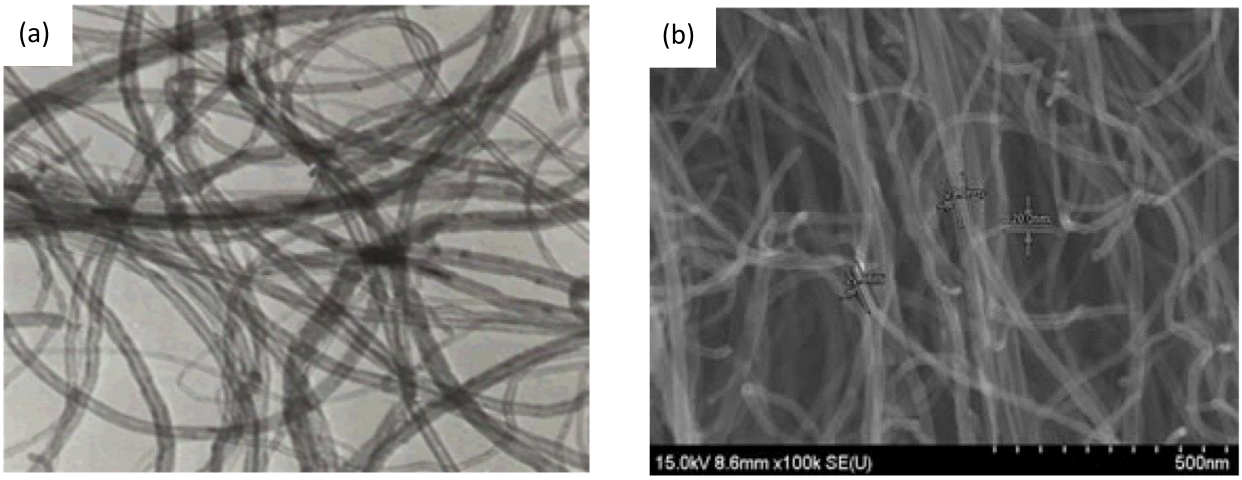

Fig. 1. *(a) Transmission Electron Microscopy (TEM),*
(b) Scanning Electron Microscopy (SEM), × 50.000 of MWCNTs

Table 1. Physical properties and chemical composition of the cement

<table>
<tr><td colspan="9">Physical properties of cement</td></tr>
<tr><td colspan="4">Properties</td><td colspan="5">Results</td></tr>
<tr><td colspan="4">Norm consistency (%)</td><td colspan="5">27</td></tr>
<tr><td colspan="4">Specific gravity (g/sm^3)</td><td colspan="5">3.1</td></tr>
<tr><td colspan="4">Blain’s fineness (m^2/kg)</td><td colspan="5">328.3</td></tr>
<tr><td colspan="3" rowspan="3">Compressive strength (MPa)</td><td>3 days</td><td colspan="5">20</td></tr>
<tr><td>7 days</td><td colspan="5">36</td></tr>
<tr><td>28 days</td><td colspan="5">52</td></tr>
<tr><td colspan="3" rowspan="2">Setting time (min)</td><td>Initial</td><td colspan="5">45</td></tr>
<tr><td>Final</td><td colspan="5">315</td></tr>
<tr><td colspan="9">Chemical composition of cement (wt.%)</td></tr>
<tr><td>SiO_2</td><td>Al_2O_3</td><td>Fe_2O_3</td><td>MgO</td><td>CaO</td><td>SO_3</td><td>Loss of ignition</td><td>Insol. Resid.</td><td>Free CaO</td></tr>
<tr><td>21.6</td><td>4.5</td><td>2.2</td><td>1.1</td><td>61.9</td><td>2.1</td><td>3.2</td><td>1.9</td><td>1.5</td></tr>
</table>

Table 2. Physical characteristics and chemical composition of the sand

Fineness modulus	Specific gravity	Bulk density in Loose state (kg/m^3)	Bulk density in Compact state (kg/m^3)
3.4	2.45	1700	1925

[1] Technical data, TNM5. Chengdu Zhongke Times Nano Energy Tech Co., Ltd., 1-5.

Table 3. Physical properties of MWCNT

Outer Diameter	Length	Purity
20 – 30 nm	20 – 30 µm	> 98 wt.%

Dispersion of MWCNTs

According to the literature reviewed, there are many methods for dispersing multi-walled carbon nanotubes. In this paper, MWCNTs and water in the needed concentration and amount were continuously mixed with each other to ensure proper mixing by ultrasonic dispersion. The sonication process was carried out using an ultrasonic device UP400S at room temperature. The sonication time was considered 30 minutes. The dispersion method was carried out at all concentrations (0.1, 0.2, 0.3, 0.35 wt.%) selected in this study.

Mixing and Sample Preparation

The w/c ratio and c/s ratio used in this work were 0.47 and 0.25, respectively. Portland cement and sand were mixed by E095 Mortar mixer for 2 min, then the nanotubes/water mixture was added and blended for 5 min. The sample molds were chosen with dimensions of 4 cm × 4 cm × 16 cm. The composite was vibrated using a vibrating table C278 for 30 s. The process of mortar mixing and preparing without nanotubes occurred in the same way. After 24 h, the specimens were de-molded and were submerged in water at 20.0 ± 0.2°C temperature (Fig.2).

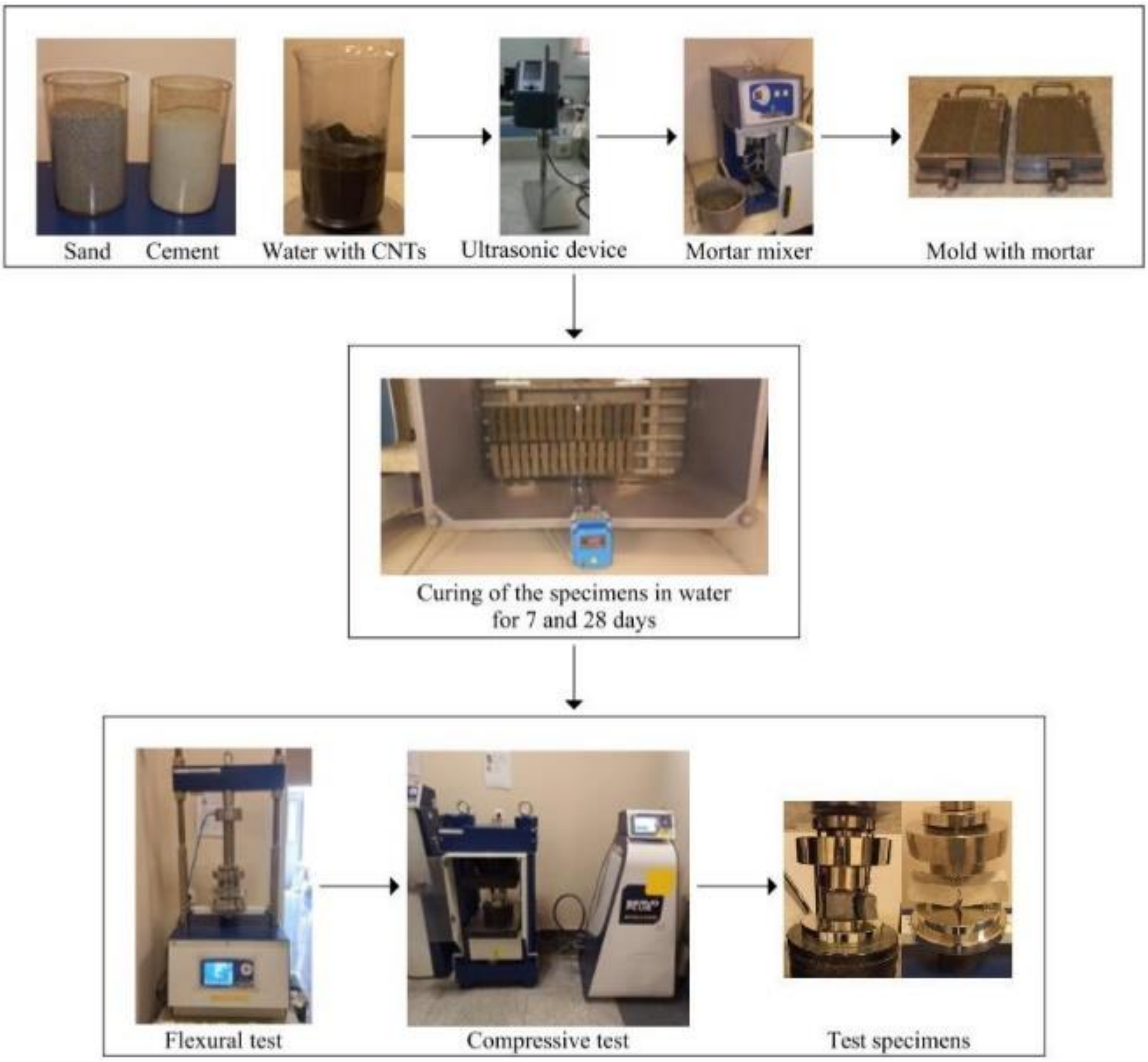

Fig. 2. *Diagram of experimental procedure*

Experiment

Compressive and flexural strength testing

Three specimens were randomly selected from each batch to test their average compressive and flexural strength.

Compressive tests were carried out on an automatic pressure machine (C089) (Matest, Treviolo, Italy) with a loading rate of 0.5 kN/s at the age of 7 days and 28 days, according to the standard EN 196-1, and specimen sizes were 4 cm × 4 cm.

The flexural strength of 4 cm × 4 cm × 16 cm samples were tested by Unitronic Compression/Tensile 50 kN testing machine within its maximum by standard test method. The experiment was based on a three-point bending test of the poured prism. Specimens aged 7 and 28 days were subjected to three-point bending at a loading rate of 0.05 kN/s.

Results and Discussion

Figs. 3,4 show the compressive and flexural strength of the composite samples with different wt.% of nanotubes for 7 and 28 days, respectively. C0 - C4 correspond to 0%, 0.1%, 0.2%, 0.3% and 0.35% of MWCNTs by weight of cement, respectively.

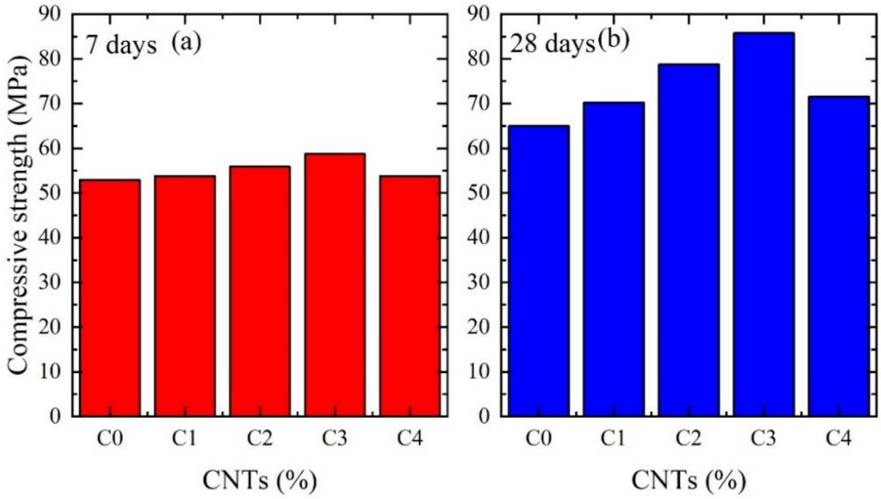

Fig. 3. *Compressive strength of cement specimens with different wt.% of MWCNTs. (a) for 7 days, (b) for 28 days*

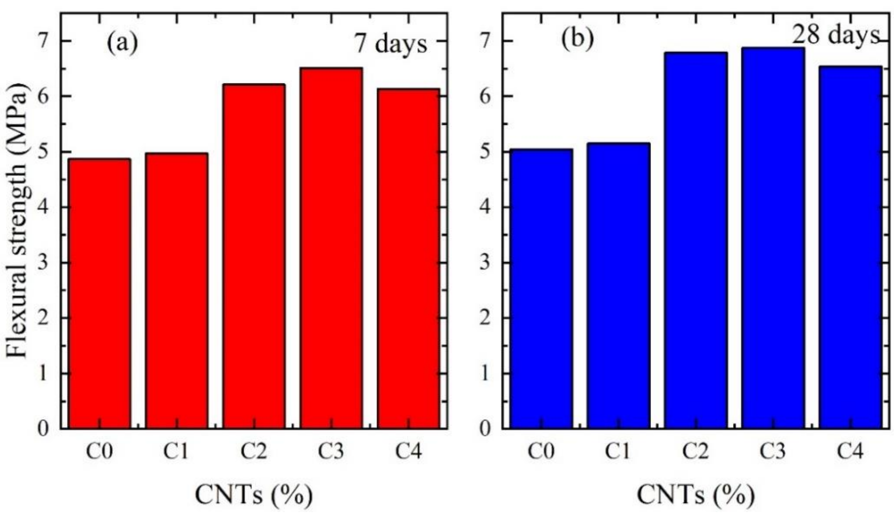

Fig. 4. *Flexural strength of cement specimens with different wt.% of MWCNTs. (a) for 7 days, (b) for 28 days*

The results indicate that the compressive strength of the cement specimens aged 7 and 28 days obtains its maximum value at 0.3% of nanotubes. It is clear from the figures that the strength of the test samples increased by 10.93% within 7 days and by 32.0% within 28 days.

In the flexural case, maximum strength of the 7 and 28 days curing period specimens was reached at 0.3% of MWCNTs. In particular, the strength of the test samples increased by 33.67% within 7 days and by 36.50% within 28 days.

From the Figs. 3,4 it can be concluded that in the case of the selected carbon nanotubes and material composition at 0.3% of MWCNTs, the compressive and flexural strength reaches its maximum value.

On the other hand, in the case of 0.35 wt.% both compressive and flexural strength decreases. The reason is the low-efficiency dispersion of the nanotubes in the water, which will decrease the hydration degree. From the results it can be visible that the compressive strength grows with growing curing period, which can be explained by increasing hydration with time [2].

The increase of flexural strength is explained by increasing of crack resistance, due to the fact, that the CNTs bridge the cracks at the mid-span of specimens by moving the tensile stresses across the cracks and preventing the cracks from growing [1,18].

Conclusion

In this work, the influence of the concentration (0.1, 0.2, 0.3 and 0.35 wt.%) of multi-waled carbon nanotubes (MWCNTs) on the compressive and flexural strength of the mortar was researched. The results of the research indicate that the compressive and flexural strength of composite samples at 7 and 28 days reaches its maximum value at 0.3% concentration of nanotubes. Compressive strength increased by 10.93% within 7 and by 32.0% within 28 days. And in the case of flexion, the strength of the specimens increased by 33.67% within 7 and by 36.50% within 28 days.

It can be concluded that in the case of the selected carbon nanotubes and material composition at 0.3% of MWCNTs, the compressive and flexural strength reaches its maximum value.

Acknowledgments

The work was supported by the Science Committee of RA, in the frames of the research project № 23-2DP-2F012.

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WAYS OF DEVELOPMENT OF MODERN URBAN ENVIRONMENT IN THE CONTEXT OF APPROPRIATION OF UNDERGROUND SPACES

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Abstract: *Today, in many countries of the world, the appropriation of underground areas is directly related to urban planning and development. If, until now, the subsoil was considered a technical area through which the engineering and technical infrastructures passed, a new task is presented: to develop the principles of functional zoning of the given areas by the master plan of the city, which is considered in the article. The purpose of this article is to develop a method of systematic appropriation of underground areas, which will contribute to the solution of socio-economic problems in the context of urban development. During the research, a study of local and international experience was carried out, on the basis of which an analysis of the situation of underground and above-ground areas was developed in the context of the urban environment, on the example of Yerevan. A methodology was formed based on the principle of effectiveness of the interconnection of the discussed underground and above-ground areas and the application of new volume-spatial approaches.*

Keywords: *Underground spaces, environment, above-ground space, principles of cooperation.*

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Received: 30.11.2023

Revised: 18.12.2023

Accepted: 28.12.2023

Introduction

The congestion of the modern urban environment, especially the center, has led to the fact that in many cities of the world, underground areas have been used. It provides the opportunity to have spaces where infrastructure that serves the population can be located without disrupting the appearance of the above-ground part of the city. By developing the city vertically in several levels underground, these spaces can include transportation networks, tunnels, industrial structures, and various other infrastructures. The use of underground spaces can lead to a series of positive processes, one of which is the reduction of the load on above-ground spaces, as well as the improvement of the local environment and the preservation of green areas. One of the purposes was also to create a method for establishing a connection between public utilities and the transportation system. The experience of underground construction has left behind a controversial legacy of irregular intervention, creating a demand for mastering the interconnectedness of underground and aboveground spaces [1]. It is also necessary to mention the relocation of structures of public significance from aboveground urban spaces to underground areas, which will lead to the replacement of freed spaces with green areas, thereby improving the urban environment.

The specialization of underground spaces has become not just a goal but a necessity and a problem in modern major cities. This is explained by both the growth of urbanization and also by the negative effects of the intense expansion of cities, which leads to inadequate maintenance of infrastructure. Underground spaces require various means for construction, but for the urban environment, they represent the most rational solutions.

Studies show that if the service life of above-ground structures is 100 years, then the service life of underground structures is longer, for example, for tunnels it is 500 years. As it is known, the first underground power plants were built in Germany in 1907, and then in 1910 they were built in Sweden. Moreover, an underground factory was built in Germany in 1917, serving as both an environment and structure for underground structures [2]. During the Second World War, in order to ensure safety, factories, power plants, food, equipment and fuel warehouses, as well as vaults for the preservation of cultural values, etc., were located in the underground areas. Already in the 50s, underground industrial organizations were operating in 50 countries of the world. In the 70s, there were almost 450 underground facilities in NATO countries alone. In the 80s, their number increased 3 times [3]. Studies related to the field were carried out by J.Carmody, R.Sterling, which were based on the systematic observation of urban surface and underground areas, taking into account their interconnections, the transport system, possible risks and environmental impact limits [4]. These areas serve as environments for underground structures and, at the same time, essential parts of urban territory. According to some studies, in the case of certain underground structures, depending on the depth of the structure, the construction materials and energy can be saved [5]. Special attention is being paid to energy efficiency worldwide. The experience of developing underground spaces shows successful economic utilization of energy and heat. Studies show that this activity is highlighted as a main prerequisite for using underground space.

Urbanists and architects in their still theoretical research are inclined towards underground cities. For example, researchers M.E. Bazilevich and N.E. Kozyrenko at the twelfth international scientific conference of the Faculty of Architecture and Design of the Pacific State University in Khabarovsk said literally the following: "The image of the underground in the minds of people gradually transformed, following the changes that took place in science and culture in different historical eras. Previously, the underworld, perceived as the kingdom of death and the underworld, today has practically lost its sacred meaning and acts as a field for the development of new computer and construction technologies. The most current and promising direction in this area is the construction of underground cities. The image of the underground city has clearly formed in the public consciousness and reflects the socio-cultural, scientific and technical levels of development of modern society. The conducted comparative analysis shows the similarity of most of the components and properties of the images of the above-ground and underground cities. The identified inconsistencies are due only to differences in planning schemes and the specifics of underground construction" [6]. Thus, research by specialists confirms that in the minds of people (consumers, users) the readiness to perceive the benefits of underground space has matured.

The experience of utilizing underground construction shows that there are three fields in the use of underground spaces: technical, legal, and psychological [7]. According to conducted analyses, the technical issue includes solutions related to underground water drainage, ventilation, water supply, and air exchange systems. The legal issue is particularly relevant to the United States and those countries where, historically, land ownership also includes the rights to the underground space. The psychological issue refers to people's subjective opinion that the conditions in underground spaces cannot match the specific environmental conditions of above-ground spaces.

Materials and Methods

It is known that the exploration and utilization of underground spaces are conditioned by the following factors:

- Preservation and restoration of historically formed urban structures,
- Supplementing urban vacant spaces with underground spaces,
- Relief and division of urban transport flows,
- Future development of cultural, residential, and communal service systems,
- Improvement of transport routes of different social significance,
- Development of the city's engineering, communal, and warehouse economy [8].

The research methodology includes a complex approach to the discussed problem, a study of professional literature, as well as a comparative and situational analysis of underground and surface areas. As is known, the functional zoning of a space is determined by the main development strategy of the city. Indeed, the functional zones of above-ground spaces can include various categories such as social, commercial, residential, recreational, industrial, and communal, as well as engineering, transportation infrastructure, agricultural, and other types of functional zones. These diverse zones are integral to the overall development and functioning of the city. The functional zoning of underground spaces is based on the typologies of underground zoning. For this reason, to implement the functional zoning of underground spaces, it is necessary to develop a typology that will correspond to the city's above-ground zones in the future. The decision to place this or that underground structure is made depending on the conditions and type of the service network's development, the functional zoning of the living area, and the structure of the transportation network, taking into account the types of streets and roads, also including geological and ecological conditions [9].

It is also proposed to place shelters for self-defense in underground areas, vehicle and rear tunnels, metro stations, and train stations. The mentioned objects can be significant by their purpose:

- monofunctional, multifunctional,
- placed separately or attached,
- shallow and deeply embedded (-15m) or below (-15m) [10].

The proposed method can become an essential factor in the formation of main outlines during the phase of urban planning document development. Aboveground spaces, relieved of transportation means, can become green zones, expanding into circular parks and connecting the green segments of the city with each other. The proposed methodology has a unique significance for the city of Yerevan, as until today, this issue has not received the appropriate attention. From the experience studied in many countries, it can be concluded that when constructing underground spaces, it is necessary to maintain the sequence of functional zones, ensuring the connection between aboveground and underground spaces.

Results and Discussion

As a result of the analysis, a method for the integrated ownership of the city's underground and aboveground areas has been formulated, which includes the following types: engineering and transportation structures, commercial and public food places, administrative, entertainment, and sports facilities, engineering equipment objects and networks. There are the following concepts: "functional zoning" and "territorial zoning", which are the main elements in the urban planning process [11]. As is known, functional zoning is defined by the master plan, providing the future development plan of the city, and territorial zoning is defined by development and land use legislation. In practice, to this day, functional and territorial zoning in RA has not been specified, because the appropriate toolkits for exploitation and complex appropriation of underground areas have not been developed.

The main processes, which are used in developed countries, are regional zoning according to functional significance, presented in the following classification:

- Special purpose (defense objects),
- Engineering – communications,
- Infrastructures, transport,
- Multifunctional public facilities,
- Recreational [12].

The principle of interconnectivity formed based on the typology methodology of underground and aboveground areas allows the implementing of urban environment improvement programs in a multifaceted and integrated manner, which are based on the application of the main functions of urban management. The developed methodology will allow for the efficient implementation of functional management processes of underground and aboveground structures, ensuring convenient integration with the transportation system and effective resolution of existing socio-economic issues in the city, thereby improving the surrounding environment.

The schematic below (Fig.) presents the method of typology of underground zones of the city, based on the results of comparative analysis and generalization of the theoretical foundations of underground construction. Their connection with the existing functional zoning of the above-ground part will also be ensured.

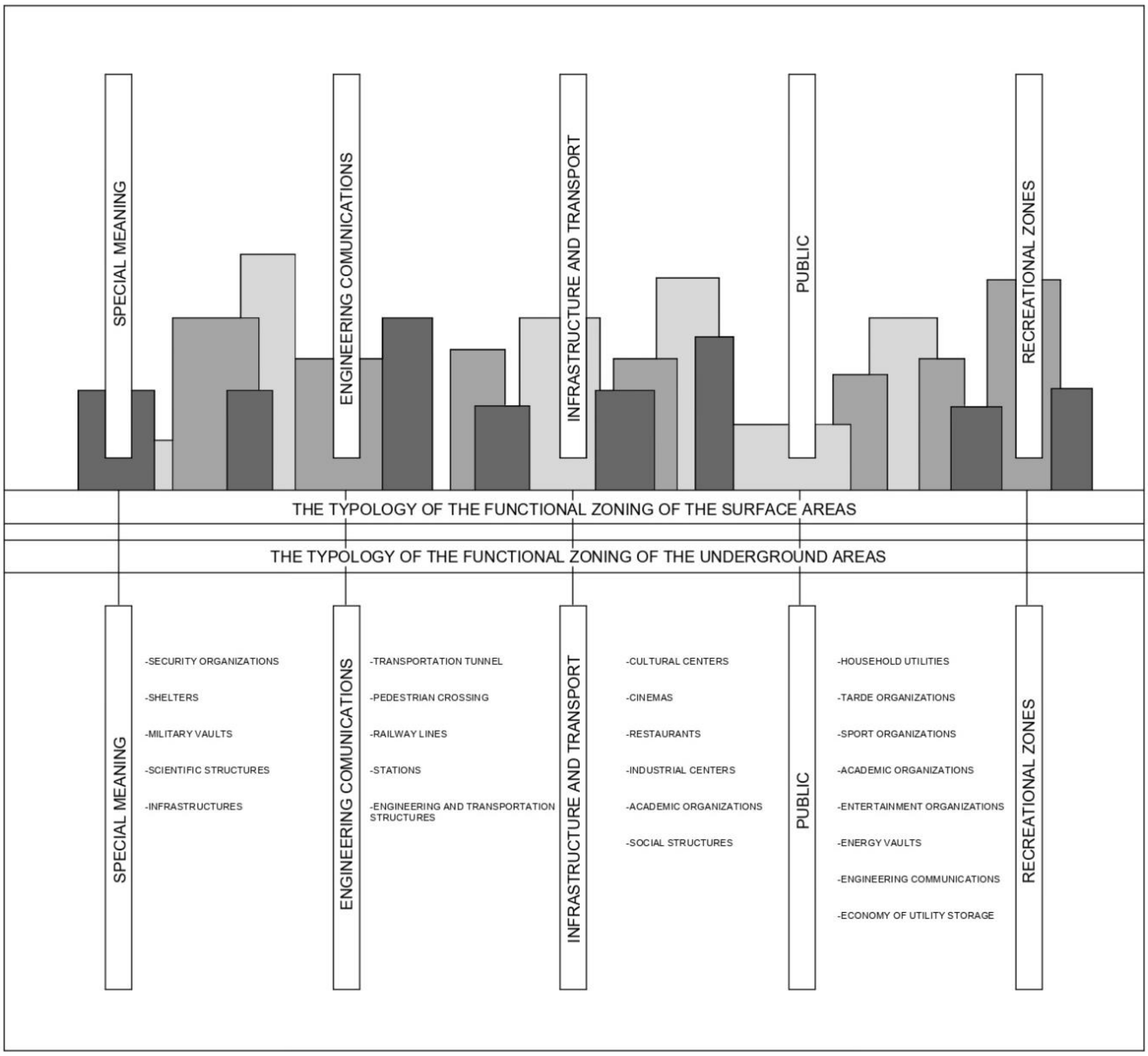

Fig. *Schematic of the integrated ownership method for underground and aboveground spaces*

The typology has been formulated following the functional purpose of the underground space. It should be applied in the development of urban planning documents in the phase of forming the main outlines for the development of cities. The above-described methodology of spatial planning is proposed for application in the development of multifunctional public underground areas of Yerevan city as part of the functional zoning of underground spaces. The suggested problem for the city of Yerevan has a significant meaning, however, until today, there was very little consideration of that issue.

From the experience of various countries, it can be inferred that every city, with its unique characteristics, can undertake the construction of underground spaces and implement the construction of functional zones in a necessary sequence [13]. The primary issue for Yerevan city is the creation of transportation and rear paths in underground spaces, connecting them with the aboveground transportation network. The next phase may involve the development of structures around them, such as commercial, administrative, communal, industrial, and engineering-technical function buildings.

Conclusion

For the construction, erection, and organization of underground spaces, certain principles are distinguished, including that all structures must present themselves as part of a unified spatial-temporal system, which will have a more complex zoning in conjunction with aboveground buildings. Their interrelations within the space must be carried out by identifying existing obstacles, taking into account geographical and geological conditions.

Including underground spaces in urban spatial planning creates a new system of complex utilization and usage opportunities, allowing the city's development in a vertical direction, limiting extensive expansion horizontally.

Placing transportation means in underground spaces will relieve the population from transportation noise and many other inconveniences.

An analysis of methodological developments in the theory of underground urban planning shows the absence of a unified systematic approach; existing studies are of a private nature. To achieve the greatest total (social, urban planning and economic) effect from the development of urban underground space, it is necessary to summarize theoretical developments, agree on the typology of underground and above-ground space objects, and also implement further work on the development of the proposed methodology with the identification of functional zones of the urban environment. The effectiveness of solutions for the development of underground space contained in urban planning documentation directly depends on the development of the theory of underground urbanism. Consequently, at present in Armenia there is an acute issue of the formation of scientific methods for planning the underground territory of cities.

Based on the methodology, the functional zoning of the underground areas was carried out, based on the proposed typology, which will be interconnected with the above-ground zones of the city of Yerevan. The presented study can serve as a basis for the present and future of the city of Yerevan, providing a reliable and safe environment for the population, making the city more comfortable and profitable.

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