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DEVELOPMENT OF TECHNOLOGY AND A CONVERTER FOR NEUTRALIZING GREENHOUSE GASES EMITTED FROM AUTOMOBILES



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Abstract: The article touches upon the issues of global warming associated with carbon dioxide (CO_2) emissions into the atmosphere from vehicle internal combustion engines (ICE). To neutralize existing greenhouse gases emitted by ICE, in particular CO_2 , the interaction of the latter with various chemicals has been studied. The dynamics of exhaust gas emissions from ICE cylinders were observed. The experimental research was conducted to develop a greenhouse gas neutralization technology. Carbon dioxide neutralization converter with three neutralization batteries and a homogenization device is presented. This converter can guarantee CO_2 neutralization of up to 92%. The formation of CO_2 in the cylinders of modern petrol engines is due to the final combustion of the air-petrol fuel mixture. The combustion of the latter in the cylinder can be heterogeneous and diffusive. In addition, CO₂ is generated in large quantities during diffusion combustion. The most effective method of diffusive combustion was chosen by the constructors of modern ICE, which is the formation of an artificial turbulent gas-dynamic condition for the fuel mixture due to the increase in the temperature of the air adsorbed in the cylinder, which ensures the engine's thermal energy efficiency coefficient of up to 35%. The CO₂ volume in the exhaust gases of such engines reaches up to 16%. Thus, considering the perfection of modern ICE design for providing a high-efficiency reaction for the hydrocarbon oxidation in the fuel mixture in the combustion chamber, it becomes apparent that the presence of about 16% CO₂ in the fractional composition of emitted dissolved gases is a serious problem in terms of increasing the volume of greenhouse gases in the atmosphere. Therefore, the goal of this article is to develop a reduction technology.

Keywords: greenhouse gases, absorption, converter, molecular network effect, activator, zeolite, ion exchange, mass exchange, ecology, diffusion combustion.

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Introduction

The problem of global warming is in the limelight of the member states of the United Nations. In December 2015, the leaders of around 190 countries of the Paris Framework Convention on Climate Change, organized by the United Nations, adopted an agreement aimed at reducing greenhouse gases (mainly CO₂) of anthropogenic origin, which are the primary reason for global warming. The same issue was discussed within the framework of the G-20 in Buenos Aires in December 2018 and in Glasgow in November 2021 [1,2,10,11,13]. Global warming is causing climate change, resulting in more frequent natural and climate disasters. The annual emissions of greenhouse gases into the atmosphere are about 15.0 billion tons. The total CO₂ volume emitted into the atmosphere is approximately 25%, or 6.7, of which 75% are greenhouse gases emitted by vehicles [3,4,7,8]. The volume of CO₂ in the exhaust gases emitted from automobile internal combustion engines (ICE) is 14 ψ 16% [4].

Worldwide, over 1.1 billion automobiles are in operation, and this number grows annually, thus contributing to the growth in the volume of greenhouse gases released.

This means that CO_2 neutralization in the gases emitted from the ICE is an important environmental issue. For the mentioned problem solution, scientific research with the development of relevant technologies and

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devices is required, the use of which in automobile structures, more precisely in the exhaust gas emission system, will enable the neutralization of greenhouse gases, particularly carbon dioxide.

Therefore, research aimed at reducing CO_2 levels in the atmosphere and the development of new technologies are of vital ecological significance.

Literature review and problem statement

It is known that CO_2 emissions during different fuel combustions are particularly: 1.85 tons/thousand cubic meter of natural gas (methane), 3.15 ton/ton of diesel fuel, and 3.0 ton/ton of petrol. The neutralization of carbon dioxide is possible in several ways, mainly through absorption processes, where the CO_2 is absorbed by an absorbent, which then converts into other substances. There is another way for CO_2 to be neutralized, namely through platinum-palladium and aluminum-copper chloride catalysts. The high cost, the pair blocking phenomenon that occurs when several organic chemicals are absorbed, the poisoning of the catalyst with lead compounds, and the lack of heat resistance are the disadvantages of this method.

Another method for neutralizing greenhouse gases involves the exhaust gas passage emitted from ICE through anode sludge, which is formed through the electrolytic treatment of zinc-reducing solutions. The essence of this method is that the gases emitted from the ICE pass through the vortical device, acquire rotational motion, and contacting with the catalyst, where the greenhouse gases are released into the atmosphere. The following compounds represent the fractional composition of the catalyst: MnO_2 - more than 50%, PbO₂ - up to 15%, AgO₂ - up to 0.15%, and other mixtures.

Various neutralization reactions are possible, as with potassium hydroxide, calcium oxide, magnesium, etc. [4]. According to the fundamentals of classical chemistry [8], the main reaction for neutralizing CO_2 gas is the reaction with calcium hydroxide, which results in formation of calcium carbonate and water. But, the rate of this reaction is slow and does not provide the needed CO_2 neutralization productivity in the exhaust gases released from the ICE.

The choice of high-speed and high-performance CO_2 neutralization technology and the development of devices, the converter structural design, manufacturing, testing, correction, and installation in the removal system of exhaust gases emitted from ICE will make it possible to reduce the emissions from the automobiles into the atmosphere, particularly CO_2 , which is the main requirement of the decision of the 2015 Paris Framework Convention.

The aim and objectives of the study

The aim of the study is to develop a technology that will enable to reduce the amount of CO_2 in the fractional composition of the exhaust gases emitted from the ICE, accepting the condition that the more improved the ICE structure, it's supply and fuel system, the design of the combustion chamber (volume and surface area ratio coefficient), and other factors, the greater is the volume of CO_2 formation. The opposite solution to the problem is to reduce the amount of CO_2 in the exhaust gases emitted from the ICE, which leads first to the engine's efficiency coefficient decreasing and an increase in fuel consumption, and secondly to an increase in carbon monoxide (CO), which is a toxic gas, and for its neutralization, petrol-engine automobiles are equipped with platinum-palladium catalysts. Therefore, the primary method of reducing the greenhouse gases included in the fractional composition of the exhaust gases emitted from the ICE before they are released into the atmosphere is the installation of a device (a unit) using neutralization technology in the pipeline for the removal of dissolved gases.

To achieve this aim, the following objectives are accomplished:

- to ensure high efficiency and productivity of CO₂ absorption and neutralization reactions by choosing the optimal fractional composition of the materials used and structural improvements to the converter.
- to ensure high productivity of neutralization reactions, availability of used materials, a simple preparation method.

Materials and Methods

Numerous tests of the neutralization absorbent's fractional composition in the converter have shown that CO_2 mass and ion exchange significantly change the temperature of the emitted gases, the number of crankshaft revolutions, and the absorbent.

In particular:

1. Absorbent based on the following chemical reaction:

$$Na_2CO_3 + H_2O + CO_2 \rightarrow 2NaHCO_3,$$

when the temperature of the absorbent is $\psi 80^{\circ} \psi 95^{\circ}$ C, the engine revolutions are:

$$Nmin = 1800 \frac{rpm}{min}, \quad Nmax = 4000 \frac{rpm}{min}$$

 CO_2 absorption ranges from 62% to 37% depending on min and max rpm.

2. CO₂ absorption in the medium of Mg, CaO, Ca(OH)₂, KOH is formed through the following reactions:

a.
$$2Mg + CO_2 \rightarrow 2MgO + C$$
,
b. $CaO + CO_2 \rightarrow CaCO_3$,
c. $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 \downarrow + H_2O$,
d. $KOH + CO_2 \rightarrow KHCO_3$.
(1)

The temperature of the exhaust gases was 80° \phi95°C during testing, and the engine rpm:

$$Nmin = 1800 \frac{rpm}{min}, Nmax = 4000 \frac{rpm}{min}$$

A homogenization device with three neutralizing batteries is installed in one container, composed of the gas neutralization converter (Fig.1). A homogenizing device is located at the converter input. Next is the first stage of the three-stage battery. The fractional composition of the first-stage battery is calcium hydroxide Ca(OH)₂ (93.5%) and sodium hydroxide NaOH (6.5%), which acts as an activator, i.e., accelerates ion exchange [4,8,14]. The exhaust gases pass from the first-stage battery to the second, where the fractional composition is primarily composed of natural clay powder (88%, SiO₂-47%, Al₂O₃-33%, H₂O-14%), Na₂O (8%), and KOH (4%). Finally, the third battery has the following fractional composition: SiO₂-25%, Al₂O3-1%, Fe₂O₃-4%, CaO-30% (powdered), volcanic slag grains with an average diameter of 5 mm, 40% [5,12,13,15].

The chemical reactions and material exchange in the first battery are based on the well-known reaction between calcium hydroxide and carbon dioxide, as given in (1). According to the developed method, the experiment resulted in a mass exchange in the first battery from 72 % to 80%, at a 4000 rpm to 1800 rpm interval.

In the second and third batteries of the converter, the process of CO_2 absorption of the exhaust gases continues. According to the experimental results, the neutralization process proceeds in the second battery according to the following interaction reactions:

$$Na_2O + CO_2 \rightarrow Na_2CO_3, \tag{2}$$

$$2KOH + CO_2 \rightarrow K_2 CO_3 + H_2O. \tag{3}$$

Powdered mineral clay containing (AlSi₂) O₄ is used as an absorbent for neutralization.

The final process of CO_2 gas neutralization occurs in the third battery of the converter, which is a mineral with high catalytic activity - zeolite.

Zeolite is characterized by the following main features [3,6]:

- catalytic property of accelerating chemical reactions,
- ion exchange ability for cation exchange,

- absorption - ability to absorb, and form other substances.

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The mentioned features lead to the carbon dioxide neutralization in the exhaust gases emitted from the ICE. In addition, it has been proven [6,14] that (AlSi2) O4 present in the zeolite open cavity has a negative charge, which counteracts and compensates the counter-ions (ion exchange mechanism) [14].

The CO₂ absorption process is based on the molecular-network principle of interacting substances [14]. Granulated mineral zeolite separates CO₂ from other gases, making the absorption process more effective. The Republic of Armenia is rich in natural zeolite reserves (Noyemberyan region). It has the following fractional composition: SiO₂, TiO₂, Al₂O₃, Fe, O₃, M₂O, CaO, K₂O.

It should be noted that $(AlSi_2) O_4$ was also used in the third battery of the converter.

The fractional compositions of the absorbents in the converter three batteries were determined experimentally (around 150 experiments). The data were stored on the PC in the form of a graph.



Fig. 1. General structure of the converter



Fig. 2. General image of the converter



Fig. 3. Infrakar 1-M 1 gas analyzer



Fig. 4. Lifan-170B single-cylinder, four-stroke gasoline engine

The diagram of the converter structure for the neutralization of greenhouse gases, especially CO_2 , present in the exhaust gases from ICE is shown in Fig.1, and the general image is presented in Fig.2.

Having CO₂ neutralization technique and a converter for exhaust gases from the ICE, scientific and experimental studies were conducted.

The research was carried out with a special *Infrakar 1-M 1 gas analyzer* (Fig.3), which transmits the measured data in digital form and with a special program to the PC, which records the indicators to be measured every 2 seconds and draws the diagrams of the changes.

The tests were carried out with a four-stroke petrol single - cylinder air - cooled engine, Lifan-170 B, with a working volume of 245 cm³ and 7 horsepower (Fig.4).

These diagrams are presented in the next section, in the discussion of results.

Results

The chemical compounds and minerals used in the converter are non-toxic

A method has been developed for conducting scientific research, which regulates the technicaltechnological data of scientific experiments, the duration of the experiments, the method for recording the results, the types according to the change of engine's rotation numbers n, the fractional composition of absorbent materials in the three batteries of the converter, the temperature, humidity, and atmospheric pressure (altitude above sea level) in the environment, as well as the octane number of petrol used for engine operation (determined by the SX-100 k octameter).

The results of the scientific research were measured and recorded in diagrams. In the PC, they are given in Figs. 5, 6. The numerical data are shown in Table 1.



Fig. 5. CO₂ emissions from ICE exhaust gases at different rotation numbers



Fig. 6. Carbon dioxide emissions after passing through the neutralization converter at different engine rotation numbers

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	ICE rotation numbers, rpm						
CO ₂ emissions %	n	1596	2159	2587	3037	3498	3977
	CO ₂	1.82	1.97	2.36	2.65	2.97	3.08
CO ₂ emission % after neutralization	n	1537	1987	2499	3007	3499	3969
	CO ₂	0.3	0.4	0.53	0.69	0.8	0.99
Difference (times)		6.01	4.9	4.45	3.84	3.71	3.11

Table 1. Experimental study on carbon dioxide emissions

The amount of CO_2 emitted from the ICE at the same engine rotation numbers was measured in the exhaust gases (Table 2). The exhaust gases were then directed and passed through a neutralizing converter. Based on the received digital data, diagrams were constructed, which are shown in Fig.7. The numerical data are given in Table 2.



Fig. 7. Carbon dioxide emissions at the same rotation numbers after passing through the neutralizing converter

e						
	ICE rotation numbers, rpm					
Measurement mode	1558	2087	2537	3028	3549	3956
CO ₂ % without neutralization	2.01	2.14	2.45	2.69	2.87	3.12
CO ₂ % through neutralization	0.96	1.12	1.37	1.56	1.78	1.86
Reduction (times)	2.09	1.91	1.79	1.72	1.161	1.67

Table 2. Emissions of CO₂ and quantitative values of their neutralization during the same ICE rotation numbers

The comparison of carbon dioxide numerical data shows that CO_2 neutralization is stable under increased engine rotary numbers, i.e., the process is technically proficient and effective, and has stable characteristics. It seems from the experimental data analysis, that the rate of CO_2 neutralization decreases with the increase in the ICE rotation numbers. The reason is the relatively small active surface of the neutralizing converter, i.e., the productivity of the neutralizer is insufficient for the gas volumes released from the ICE.

It means that, for the complete neutralization of the CO_2 emitted from the ICE, it is necessary to create an analytical relationship between the ICE working volume and the active surface of the converter.

Used materials

According to the findings, the main CO_2 absorption process is provided by the converter's first battery, which has a fractional composition of $Ca(OH)_2$ at 94.5% and NaOH at 6.5%. The second battery fractional composition is Na₂O (8%), KOH activators, and a filter in the form of natural clay powder. The third battery contains zeolite SiO₂ (24%) with Al₂O₃ (1%), Fe₂O₃ (4%), and CaO (30%) with a 40% mass of volcanic slag for absorbing dry materials from exhaust gases.

The absorption process mainly occurs in the first battery of the converter based on the molecular network effect, according to the following chemical reaction:

$$Ca(OH)_2 + CO_2 = CaCO_3 \downarrow + H_2O_2$$

The absorption process proceeds through the medium of activators in the converter's second and third batteries in accordance with the following chemical reactions:

$$CaO + CO_2 = CaCO_3$$
, $KOH + CO_2 = KHCO_3$.

Zeolite, dry clay powder, and volcanic slag were used as absorbent mineral materials. The total cost of the used materials is 3-5\$.

Discussion of CO₂ gas neutralization test results

Neutralization of CO_2 is because of the chemical reactions occurring in the converter, in which activators, volcanic slag and dry powdered clay are present.

The peculiarity of CO_2 neutralization among the existing methods is the absorption process, which occurs in the medium of mineral dry materials and is the only acceptable method for automobiles.

The study's limitation is the need to change periodically the converter's absorbent batteries.

The disadvantage of the study is the need for three different batteries in the converter, which can be eliminated by combining them into one common mass.

The further development of the study is to develop high-efficiency and productivity absorbents, which requires long-term experimental studies.

Conclusion

- With the proper structural modifications (adjustments), the developed technology and converter for the neutralization of greenhouse gases and CO2 emitted from the automobile exhaust system can be installed in the automobile pipeline for exhaust gas removal and provide CO2 reduction of up to 92%, according to the analysis of the conducted scientific results.
- 2. For calculating the CO2 neutralization converter capacity and productivity, it is necessary to solve a simple analytical problem regarding the dependence of the ratio of the engine's working volume and the active surface of the converter.

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.

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Abstract: The aim of this action research project is to (re)define and (re)get to know the material trachyandesite. A magmatic rock that has contributed to the identity of the Massif Central region, through the construction of towns since the 15th century, its exploitation has accelerated with industrial growth. Its presence grew and its uses spread throughout France. If this stone confers a specific and visual identity, it is today one of the components of the built heritage of a French region, at one with the landscape because it is at its heart. Understanding the materiality of this stone and its many characteristics is a key factor in the restoration of old buildings. Could knowledge of the qualities of trachyandesite (refractory stone, high pyroscopic resistance) as a local, low-carbon-emission material enhance the value of constructions and/or restorations that could be described as geosourced?

Keywords: trachyandesite, resource, future, natural material.

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Introduction

If the notions of "architectural heritage" and "contemporary architecture" seem at first sight to be opposed, defining them proves to be a complex exercise. Their semantic contours fluctuate according to each person's outlook, background and training, but also according to cultural identities and the temporality of their definition. The notion of architectural heritage seems intrinsically linked to the notion of identity and culture of a region and/or a country [1-3]. As a result, the article presented here will find its limits in the historical and heritage culture of French training and outlook.

At a time of energy crises and global warming, building on what already exists requires us to confront the polysemy of the term "heritage". It also requires us to question the substrate - the existing - with/on which the architect intervenes within the framework of the project: whether it's a construction *a novo*, a restoration or a rehabilitation.

The Anthropocene era is prompting us to rethink environmental issues and think about energy transitions on an international scale. In this context, we believe it's essential to work with materials already in use, identifying them as a "resource". Preserving what has been identified and described as "architectural heritage" should be in keeping with the global challenges of preserving the planet. Can reuse be a first solution to our questions? Can the choice of an old, local material provide some answers?

Our questioning stems from a general observation, based on discussions with consulting architects: many homeowners wish to thermally insulate their building or house. However, not all buildings are eligible for external insulation: this is particularly true of many French historic centers. French legislation, which protects the historic and artistic values of its old town centers [4], does not allow for the alteration of facades and buildings whose age is an integral part of their heritage [5].

Energy-efficient renovation of old town centers cannot therefore always involve thermal insulation from the outside, and alternative solutions must be found. In addition, the small size of older homes means that they cannot always be insulated from the inside. Entire neighborhoods are in a state of disrepair due to the lack of thermal insulation. Many architects and town planners point to this alarming situation, which makes it hard to

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reconcile "heritage" and "energy renovation", precisely at a time when the impact of global warming no longer needs to be demonstrated. What are the solutions for sustainable environmental design can we propose to this kind of heritage?

Materials and Methods

France's national schools of architecture: training for existing buildings

On October 20th, 2015, the French Minister of Culture, Fleur Pellerin, announced a list of 30 measures to be implemented - organized around six axes - as part of the National Strategy for Architecture¹.

Starting from the observation that "architecture is of general interest and concerns all citizens. In addition to emblematic and representative places, [it] must take charge of ordinary, everyday places"². This architecture must therefore take into account the daily lives of citizens, as well as their concerns for the future, such as the many needs they express in terms of thermal comfort.

In the case of town centers, the challenge of architecture in line with sustainable development is a major concern. Dealing with what already exists, the " $dnj\Omega l\Omega$ " cannot be reduced to buildings described as "heritage". All architects now have to deal with the context in which they work, which is often marked by the legacy of more recent buildings (post-war, or more broadly 20th century).

The second theme of the National Strategy for Architecture, entitled "Taking into account the architectural heritage of the 20th and 21st centuries and developing architectural intervention to enhance and transform the existing built environment", proposes, in its seventh point to *Strengthening the initial and ongoing training of architects in intervention on the existing environment*. Since the publication of this report, France's national schools of architecture have been working to develop training courses in working with what's already there.

The territorial roots of architecture schools, and the expertise that their teacher-researchers can bring on this same territory, seem to be an indispensable resource in the training of young architects: how can an architectural project be conceived without understanding the historical depth of a site, without knowing the local materials and how they are (and were) used?

This National Strategy for Architecture is the subject of reflections for improvement within the Architecture Department of the French Ministry of Culture. The aim is to take better account of the challenges of ecological transition, the diversification of architectural professions and the rehabilitation of existing buildings, while restoring contemporary architectural creation to its rightful place.

The points of this National Strategy for Architecture, entitled *Strengthening the scientific and economic* anchoring of schools at territorial level ³; Fostering architectural quality, creation and innovation or *Experimenting with the "permis de faire"* ⁴ encourage ENSAs in their role of territorial training and research. With research through experimentation, through action research, or through other schemes, they have clear objectives to achieve here. We would now like to turn our attention to a concrete example.

Local materials: the example of trachyandesite

Trachyandesite is a magmatic rock found in large quantities in the Massif Central (France). Its petrochemical composition must be distinguished from other, more common volcanic rocks (such as basalt, trachyte or andesite).

¹ <u>https://www.culture.gouv.fr/Espace-documentation/Rapports/Strategie-nationale-pour-l-architecture</u> consulted on September 25, 2023.

² <u>https://www.amc-archi.com/article/les-30-mesures-de-la-strategie-nationale-pour-l-architecture,6375</u> <u>consulted on September 2, 2023.</u>

 $^{^{3}}$ 12th point, included in the 3rd axis: , Articulate training-research-trades and bring together the professional worlds of architecture, construction and the living environmentt.

⁴ Respectively points 29 and 30 of the 6th and last axis of the national strategy for architecture: "Supporting the experimental approach and its cultural value".

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There are several Auvergne trachyandesite flows, originating from different magmatic chambers, but the three main ones that are and have been particularly exploited are located in the Puy-de-Dlm e⁵ (Auvergne department, France): a quarry at Mazayes, where the "Chambois lava" is found [6]; another flow located in the Monts Dore massif; and the wellknown quarries in the town of Volvic [7]. Although other trachyandesite flows are mined, the name "Volvic stone" has become generic [8]. On the one hand, this testifies to the expansion and diffusion of the material from the Volvic quarries [9], but it also reflects the extent of ignorance about the material.

It has to be said that, scientifically speaking, little is known about this material at present: neither university research nor restorers specializing in this type of rock exist in France. Only a few geologists, quarrymen and craftsmen working exclusively with this material seem to know much about it. The challenge here is to bring together craftsmanship and technique, on the one hand, with scientific, academic, historical and museum knowledge, on the other⁶.

To develop our knowledge of the material, we are currently working on joint research projects with public institutions such as the Institut National du Patrimoine (INP), the Laboratoire de Recherche des Monuments Historiques (LRMH), the Musre Lecoq (a museum located in Auvergne), university research laboratories and architectural history students.

Following our initial research^{7,8}, some characteristics of this magmatic rock have enabled us to understand its advantages for both ancient and modern construction. Trachyandesite is a compact, vacuolated rock with a hardness ranging from marble to granite (depending on the sample). Among other things, its bubbly composition makes it resistant to gelifraction, which gives it great constructive qualities in its area of use in the Massif Central: a mid-mountain region. Described as an "inalterable rock" in the 19th century, it is highly weather-resistant, watertight from 12cm upwards, has a low coefficient of expansion⁹, a rare pyroscopic resistance¹⁰ (enabling it to be glazed) and good resistance to traction, flexion, compression and crushing, whether cold or hot. Finally, it is resistant to most acids, which is why it is still used in the chemical industry. Trachyandesite can therefore be used for a wide range of applications, whether in industry, construction or restoration.

With its many advantages, not least its ability to adapt to thermal changes, trachyandesite has played a key role in the identity of the Massif Central region, in the construction of towns and cities since the 15th century. Its use accelerated with industrial growth, and its presence expanded throughout France as its uses declined and its qualities became appreciated.

But in the 21st century, what do we retain of this material? Why not make the most of its thermal properties, particularly its insulating qualities, for a refractory stone?

In the age of the Anthropocene and global questions about environmental issues and energy transitions, it is time to take a serious look at this material - trachyandesite - as a resource. Is trachyandesite exhaustible? What about its accessibility and possible conflicts of use?

Although quarries are currently shrinking (due to a lack of men and women wishing to work in the stone industry, and the difficulty, harshness and demanding nature of such a profession), the fact remains that the puys chain is a sleeping chain, not an extinct one. So, is the material renewable on a human scale?

⁵ Puy-de-DI me departmental archives, fonds Brosson-Baudusson, ratings 2 S 64 to 2 S 83.

⁶ J.-B Roger, Momoire sur l'emploi des produits volcaniques dans les arts, read in acadomie des sciences, belles- lettres et arts de Clermont-Ferrand, july 1827

⁷ Exhibition "Enamelled lava techniques", June-September 2022, Musne Sahut, Volvic; J.-P. Naud, Chabrol de Volvic (1773-1843) – Bicentenaire de l'nœle d'Architecture, Volvic, 2021; Various information gathered from the Institut des Motiers d'Art de la Pierre et de la Construction (IMAPEC, Volvic) and from Mr. Simon Laroche, student restorer at the Institut National du Patrimoine, Paris.

⁸ Museum Sahut, "Bicentenary of the Volvic School of Architecture", curated by G. Gayet-Kerguiduff, Volvic, 2021.

⁹ Less than 7 per 1000, at 1000°C.

 $^{^{10}}$ Heat-resistant, the rock melts and becomes lava between 1.200 and 1.800 $\!\mathrm{C}$.

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The *Magmas et Volcans* university laboratory has no doubt that the next eruption will take place (insofar as a chamber of magma is still active beneath the puys chain), without being able to say where, when or in what form. So, what about trachyandesite? Geosourced material, source and resource for decades to come?

A number of obstacles remain to be overcome: the stone trades are less attractive and there are fewer applicants for training¹¹. The result is the loss of traditional, often local, human know-how. Regional, national and even European policies are likely to investigate the possibility of creating funding for this type of local employment, thus preserving the memory of traditional techniques, or promoting a short supply chain for carbon footprint reasons. Of course, quarries are finite and it can take a long time to obtain materials. But aren't there alternative solutions that take into account and combine the technical qualities of stone with current and, above all, future environmental needs? There is still a lot of thinking to be done on this rock, such as the possibility of composing an "insulating concrete from trachyandesite" from its cutting waste.

Food for thought: an insulating concrete from trachyandesite?

Insulating concrete, which is generally made from clay, shale or pumice aggregates, could be augmented or enhanced in its composition by pozzolan, or trachyandesite aggregates. Various types of concrete are dedicated to thermal insulation, and the possibility of composing a new type of concrete using trachyandesite is not a completely new idea. In fact, several attempts to combine looted trachyandesite with clay and a flux were already made in the 19th century¹². These experiments enabled the creation of stone casts for fireplaces and mantelpieces, for example.

Aggregates (combined with sand and cement) are the main components of today's insulating concrete, and determine its thermal conductivity. However, the vacuolar composition of pozzolan - or of certain samples of trachyandesite - would enable concrete to intervene in the thermal regulation of the building. What's more, the aforementioned qualities of magmatic material (resistance to acids, weathering, thermal amplitudes, good compressive strength, low coefficient of expansion, etc.) would make it possible both to develop a building's thermal qualities and to control its aesthetics through molding. The mechanical performance combined with the recyclable and geosourced qualities of such a material could facilitate its use in heritage areas.

The advantages of insulating concrete made from trachyandesite could be studied in greater depth. As an eco-responsible material that can be reused and recycled, it could offer very interesting constructive and thermal characteristics for the future of both heritage and contemporary architecture. Despite its higher cost compared with traditional concretes, this choice would combine new technologies for architecture (whether intervention on existing structures or construction from scratch), with a deliberate posture of using local, geosourced, recyclable materials, to design the future in a responsible and sustainable way.

Conclusion

In this National Strategy for Architecture, we would like to emphasize the desire for a territorial scientific anchoring, as well as the encouragement for a "right to make". Encouraging experimentation to combine current construction techniques with local materials is likely to yield satisfactory results.

However, over and above ministerial encouragement and guidance, and over and above the lack of knowledge about many materials, we must stress the lack of financial support or experimental programs for this type of research. Let's hope that they will develop in the years to come.

Insulating concrete made from reused or waste trachyandesite aggregates could provide a range of solutions, depending on the proportions used. The rehabilitation of existing buildings, the restoration of

¹¹ La pierre dans l'architecture: conservation, restauration, crnation, Revue Monumental, Ed. du patrimoine, CMN, 1 | 2019.

¹² For his final dissertation, Simon Laroche, a student in the Master of Restoration program (specializing in the art of fire and ceramics) at the Institut National du Patrimoine in Paris, chose as his subject a masterpiece conserved at the Musne d'Orsay made from Volvic enamelled lava. According to his initial bibliographical and archival research, the material is probably crushed trachyandesite mixed with clay and flux.

heritage buildings in Auvergne's town centers, or a simple local implementation resulting from a constructive posture, could make it possible to think cohesively and concomitantly about existing (heritage or not), contemporary and future architecture.

Conflict of interest

The author declares that there is 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.

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PREVENTIVE CONSERVATION OF CULTURAL HERITAGE IN ARMENIA: A PRELIMINARY STUDY OF THE INTERNAL SURFACES IN THE GEGHARD MONASTERY



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Abstract: In the Armenian context, most of the architectural heritages are monasteries often subjected to geological hazards and degradation of materials due to the environmental conditions. The aim of this study, in collaboration between the Ca' Foscari University of Venice and the National University of Architecture and Construction of Armenia, was a preliminary analysis of the state of conservation of the UNESCO heritage site of Geghard Monastery. Specifically, this research reports the results of the multi-disciplinary investigation on the internal stone surfaces of the caved "Proshian family room" belonging to the XIII century. In situ analyses that consisted of a careful visual survey of the stone surface, environmental monitoring, water absorption and ultrasonic measurements were conducted.The collected data constitute a starting point for monitoring the degradation phenomena, which is helpful for future preventive conservative interventions.

Keywords: Armenia, Geghard Monastery, preventive conservation, non-invasive analyses.

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Introduction

Historic buildings such as Armenian monasteries are valuable architectural heritages that can often be found in secluded places. The immovable nature of these structures, their not-so-easy access, and the great variability of materials along with the geological hazards, and weathering processes to which they are subjected, could result in a challenge for their conservation and maintenance [1,2]. For this, a multidisciplinary approach should be engaged to suggest the most accurate approach according to the degradation phenomena present, the history of the monument as well as its previous restoration interventions, the building materials used, the architectural structure, etc. [3]. In particular, preliminary analyses are essential for thoroughly comprehending the heritage situation, aiding in understanding its development over time and its protection and prevention of future damages. These analyses, which should always be carried out, establish the fundamental groundwork upon which conservation and restoration works should be constructed, thereby guaranteeing the preservation of the cultural heritage.

The Geghard Monastery

Due to the high seismic activity to which Armenia is subjected, Geghard monastery was restored a lot of times, with also the total reconstruction of some parts, indeed, to this day, little remains of the original monastic complex [4].

In accordance with Mery Danielyan, one of the restorers that worked in Geghard [5], in the last fifty years, large-scale restoration works were carried out, comprehending the closing of cracks present in the carved rock structure.

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Fig. 1. First floor planimetry of Geghard Monastery, highlighted the Proshian familiy room (Žamatoun)(by Ara Stepanian, Telman Gevorgian, Edik Hovhannisian, Hratchia Gasparian li Edward Frangoulian, 1971)

Materials and Methods

The main subject of this research is the conservation assessment of the Proshian family room (Žamatoun) in the Geghard Monastery, where most of the investigations were conducted (Fig.1). This choice is linked to the analyses that were already carried out in 2019 during the summer school organized by the National University of Architecture and Construction of Armenia (NUACA) and the willingness to compare the past situation with the current one. In 2019, indeed, a damage assessment of the western wall of the *Żamatoun* was carried out, resulting in a degradation map. The main stones present in Geghard were also identified during a summer school as tuff and basalt, both divisible into two different typologies according to their porosity values [6,7].

Measurements were done in situ using portable instruments, allowing us to know the Proshian family room's conservation state. Considering specially built heritage, micro-analyses on some specific point may not be representative. In this sense, portable instruments play an important role in a better understanding of the object as a whole [8]. Moreover, these surveys are of great importance in the selection of micro-samples for further laboratory analyses [9].

Environmental monitoring

Knowledge of the environmental condition is essential to assess the influence of possible fluctuations in humidity and temperature on the stability of materials [10]. The environmental conditions were monitored with a data logger EasyLog EL-USB-2-LCD, which allows the measurement of air humidity and temperature from 25/04/2023 until 02/06/2023. Generally, the T and RH% monitoring requires at least one year of measurements. Due to organisational needs, we decided to collect these parameters during the season transition from spring to summer. The instrument was located at a height of ° 3 m on the architrave of the entrance of the analysed room. Temperature and humidity were measured every 30 minutes.

Visual survey: degradation maps

Once a research and conservation campaign on cultural heritage monuments has been planned, a visual survey is the first step to pursue. These surveys are essential to have a clearer understanding of the state of conservation of the monument and the main degradation phenomena with their extension and possible causes.

These evaluations should always be paired with photographic documentation, which was done also in the Geghard complex in 2018, paying more attention to the Proshian family room, where also degradation maps of the different sections of the space were constructed following the ICOMOS glossary guidelines l.

The degradation maps were made using the AutoCAD drawings shared by architect Nanar Kalantarian and subsequently modified according to the needs and the GIMP-Image manipulation program to highlight the different degradation patterns. These maps are fundamental to having an immediate view of the situation, and they must be understandable by everyone to be a base for future interventions and analyses. To complete this survey, microscopic pictures were also taken in visible and UV light with a Dino-Lite portable microscope (magnification: 51,3x; unit: mm).

¹ ICOMOS-ISCS: Illustrated glossary on stone deterioration patterns, 2008.

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Water absorption measurement: sponge-test method

The sponge method2 is a valid, non-invasive way to measure the initial rate of water absorption of the materials. The amount of water absorbed is in relation to the physical characteristics of the materials and their state of conservation. In addition, it gives crucial information on future conservative interventions with protectives and consolidants [11].

In the case under analysis, around 240 points were analysed, always using the same kind of sponge (contact area = 110 cm2) with the same initial quantity of water; the contact time between sponge and stone surface was 30 seconds, following the normative UNI Normal 11432-20113. The distance from one measurement to another was $^{\circ}$ 40/50 cm, and they reached a maximum height of 180 cm. To better visualise the results, we reported the water absorption at the different points as g/m2 directly on the images also used for the degradation maps.

Ultrasonic analyses

The ultrasonic investigation is a non-destructive method to study the internal structure of a material without affecting it. This method relies on analysing the wave velocity that crosses the selected object, enabling the assessment of intrinsic material properties, including homogeneity, and the presence of fractures or cavities. The results are based on the "travel time" or "time of flight" of the generated acoustic waves that cross the sample. Altered and weakened zones of the structures, along with the occurrence of microfractures and material flaking, can be spotted by lower acoustic velocity values than in unaltered materials [12].

Knowing the distances between the source (usually a piezoelectric transmitter that emits a frequency higher than 20 kHz) and receiver it is possible to calculate the wave velocity inside the material (1). Usually, the time of flight of the analysed material is compared with its healthy counterpart or a reference standard [13].

Wave velocity formula:

$$V = \frac{L}{t - t_0},\tag{1}$$

V = ultrasonic wave velocity, L = measuring length, t = measured time, t0 = time correction value.

Based on data collected at different points, it is feasible to compute tomographic maps. These representations offer a visual depiction of the internal condition of the structure or object under analysis, with distinct colours corresponding to varying travel times.

In the case under analysis, it was used the All-in One SYSTEM (SolGeo Instrument) in 4 different areas of the Proshian family room walls and on the big basaltic octagonal column. To overcome possible problems with the stone's high level of sensitivity, it has been decided to use the ultrasonic method with a piezoelectric transmitter with a frequency of 55 kHz. To reach more precise results, especially for the walls where it was not possible to measure significant distances, that can induce a signal's lack, the analyses were carried out in different coherent areas and then merged together. Figures 2a and b report the analysed wall areas and the corresponding paths. Except from area (1) all the analysed walls were measured more than once with the same matrix of points as it is possible to understand from the images. Figure 2c shows the multi-path in the octagonal column.

Results and Discussion

Environmental monitoring

From the environmental monitoring results (Fig.3), it is possible to observe how, from 25/04/2023 until 02/06/2023, the temperature swings between a minimum of 9 ' C and a maximum of 17.5 ' C and the relative humidity values go from a minimum of 55% to 83%. These values are coherent with what was expected since

² UNI Normal 11432-2011, Beni culturali, Materiali lapidei naturali ed artificiali - Misura della capacit∩ di assorbimento di acqua mediante spugna di contatto.

³ Ibid.

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the analysed room is carved into the rock, and inside the monastery, there is no heating system [10]. For these reasons, the oscillations in the Proshian family room could be associated with the number of tourists inside the room and the external weather conditions.



Fig. 2. Ultrasonic paths used for the analyses. a lu b) Points where the ultrasonic analyses were carried out on area (1), (2), (3) and (4) with the correspondent analysed paths; c) Resulting column paths



Fig. 3. Environmental monitoring results from 25/04/2023 to 02/06/2023

Even the dew point behaviour could correspond to the possible number of visitors as it increases at the busiest visiting hours. Crowded rooms are known to have more moisture content due to people's breathing [14]. Despite that, the water vapour condensation is never reached. Moreover, the temperature is slightly increasing over the months, which would be consistent with the external weather conditions of that period. We can also notice that higher temperatures usually mean higher RH values.

Visual survey: degradation maps



Fig. 4. 2018 and 2023 picture comparison: on the left-side, pictures corresponding to 2018, on the right-side pictures corresponding to 2023; a lı b - Detail of the Proshian family room, c lı d - Detail of the outside

Thanks to the comparison of 2018 pictures, it is generally possible to notice that in the monastic complex we cannot observe important differences over 5 years, as shown in Figures 4a and b. However, some exceptions are present, such as in the case represented in Figures 4c and d, where a piece of rock above the stairs fell during the considered time span.

The degradation maps depicting the vertical surfaces of the analysed room are presented in Figure 6. A comprehensive legend is provided in Figure 5 illustrating various patterns along with brief descriptions⁴, their corresponding definition and representative images, all arranged alphabetically.

To promptly understand the situation, a less detailed legend is reported on each map where it was decided to emphasize the most evident degradation processes.

In general, scaling is evident on all walls alongside a white encrustation, probably due to salt crystallization and wax deposits. Additionally, it is possible to observe, especially on the sculpted sections, that the lower zones exhibit a considerably more critical condition than the higher zones.

Water absorption measurement: sponge-test method

Figure 7 shows the graphical representations of the water absorption measured in the different areas of the Proshian family room. Each of these visual representations is subsequently linked to quantitative values expressed in g/m^2 sec, following the UNI Normal 11432-2011⁵. The scales used in the colour maps report their maximum and minimum value according to each zone and the values are reported in grams.

The colour maps in Figure 7a depict the western wall of the analysed room, showcasing a distinct alignment of the results with the wall's morphological features and degradation patterns. This is particularly evident on the right side of the drawing, specifically at the single arch. A comparison of these values with the degradation map of the corresponding area reveals a possible correlation between the two datasets. Water absorption, for instance, is 19.64 $g/m^2 sec$ in the eroded area and 6.06 $g/m^2 sec$ in the closest better-preserved area. The relationship between degradation patterns and water intake is observable in all the analysed areas.

Throughout these findings, a recurring pattern emerges, particularly in areas exhibiting greater deterioration, where water absorption appears to increase, as seen in the scaling regions. An opposite behaviour is observable in those areas characterized by a thick layer of wax deposit, as expected.

⁴ ICOMOS-ISCS: Illustrated glossary on stone deterioration patterns, 2008.

⁵ UNI Normal 11432-2011, Beni culturali, Materiali lapidei naturali ed artificiali - Misura della capacit∩ di assorbimento di acqua mediante spugna di contatto.

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Macr	o-picture	Micro- VIS	picture UV	Degradation pattern's name	ICOMOS definition	Annotations
	1			Blistering	Separated, air-filled, raised hemispherical elevations on the face of stone resulting from the detachment of an outer stone layer. This detachment is not related to the stone structure.	
	M	*	1¥	<u>Chalk</u> Graffiti	Engraving, scratching, cutting or application of paint, ink or similar matter on the stone surface.	Here it was deliberately specified «chalk» to distinguish these graffitis from those made with wax.
	E	199	S. ()	Colouration	Change in hue, value and/or a gain in chroma.	
大	Ŕ	C.	10	<u>Crack</u>	Individual fissure, clearly visible by the naked eye, resulting from separation of one part from another.	
				Cut	Loss of material due to the action of an edge tool. It can have the appearance of an excavated cavity, an incision, a missing edge, etc	
		193		Erosion	Loss of original surface, leading to smoothed shapes.	This term was used to distinguish whenever there were other and more intensive mechanical damages related to mechanical loss.
	*			Improper intervention	Intervention with the aim of restoring the concerned object, which, however, is not appropriate. It may be due to the application of inappropriate materials (colour and texture clearly different from the original material)	TERM NOT PRESENT IN THE ICOMOS GLOSSARY
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		St.	陸	<u>Loss of</u> <u>Matrix</u>	Partial or selective elimination of the stone matrix, resulting in protruding compact stone components.	
4	X			Missing part	Empty space, obviously located in the place of some formerly existing stone part.	
		+		<u>Moisture</u> <u>area</u>	Corresponds to the darkening (lower hue) of a surface due to dampness.	This term was used as a general term for those surfaces where the water presence is evident. Thus also for areas that were actually wet.
	T			Salt encrustation	Compact, hard, mineral outer layer adhering to the stone. Surface morphology and colour are usually different from those of the stone.	«Salb» was deliberately specified to highlight the presence of an adherent natural white material
				Scaling	Detachment of stone as a scale or a stack of scales, not following any stone structure and detaching like fish scales or parallel to the stone surface. The thickness of a scale is generally of millimetric to centimetric scale.	
	-			Staining	Kind of discolouration of limited extent and generally of unattractive appearance.	
	23 Y			Rounding	Preferential erosion of originally angular stone edges leading to a distinctly rounded profile. Rounding can especially be observed on stones which preferably deteriorate through granular disintegration	
				Wax deposit	Accumulation of exogenic material of variable thickness.	The term «wax» is used to specifically indicate that this kind of deposit is often a thick adherent layer and nothing like a dust deposit for instance.
	i i		P.P.	<u>Wax</u> graffiti	Engraving, scratching, cutting or application of paint, ink or similar matter on the stone surface.	Here it was deliberately specified «wax» to distinguish these graffitis from those made with a chalky material.

Fig. 5. General legend used for the identification of the degradation patterns highlighted in the degradation maps



Fig. 6. Resulting degradation maps of the Proshian family room: *a* - Western wall, *b* - Octagonal column (view from the centre of the chamber), *c* - Northern wall, *d* - Eastern wall, *e* - Southern wall

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Fig. 7. Sponge-test results: a - Western wall, b - Columns and base (view from the centre of the chambre), c - Northern wall, d - Eastern wall, e - Southern wall, f - Octagonal column

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Ultrasonic analysis

The tomographic maps are accompanied by a reference scale of the time of flight, which on the wall surfaces ranges from 1000 to 3000 m/s, while on the column it spans from 1500 to 5000 m/s (Fig. 8). The survey results of the wall surfaces were also associated with the corresponding image (representative of the area) to better comprehend their localization.

Figure 8a showcases the areas we analysed on the western wall of the Proshian family room. Notably, we observe lower values (represented in black) concentrated primarily along the border of the central arch (area (2)). Conversely, higher values are evident in area 1. These findings align with the surface conditions: differential erosion on the left side of the large arch and the presence of engraved crosses on the right side. The stone between these two points exhibits lower velocity values, indicating a healthier and more compact condition.

Area (4) predominantly reflects a compact and relatively healthy condition (Fig. 8b). However, there is a spot in the middle with slightly higher values, corresponding to an area with scaling. In contrast, area (3) displays higher values, which, confronted with the degradation map of the northern wall, match the degradation patterns such as scaling as well as blistering on the left side.

The column results are reported in Figure 8c where, as previously mentioned, the scale is much higher than for the other analysed areas. This feature highlights the compactness of this architectural element reflecting what is observable to the naked eye. Anyway, Figure 8c displays different sections of the measurements where some lower values can be noticed on one edge on the upper side of the column.





Fig. 8. Tomographic results: a - Western wall area (1) and (2), b - Northern wall area (3) and (4), c - Octagonal column

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Conclusion

In conclusion, this work thesis aimed to give guidelines for future interventions in the Geghard Monastery that could also be applied in other Armenian realities and other secluded heritages with similar situations. Specifically, the in situ investigations are user-friendly thanks to their easy application. However, a digital transposition of the results associated with colour maps is truly important since it can give an immediate and straightforward understanding of the studied circumstances.

The non-invasive in situ analyses also gave essential indications of the state of conservation of the monastery, primarily of the room analyzed. The first step was the visual survey with the development of degradation maps, which allowed us to quickly realize the localization and main ongoing degradation phenomena. It was also helpful for the comparison of the other non-invasive analyses. The comparison of the conservative situation related to the examined area status over five years, thanks to the use of 2018 pictures, reports a relative structure stability that requires, in any case, urgent conservative interventions.

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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.

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CHANGE OF AXIAL FORCES IN LAYERED RUBBER–STEEL BASE ISOLATORS OF HIGH-RISE BUILDINGS AT EARTHQUAKE IMPACT



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Abstract: Seismic isolation technology makes buildings more capable of withstanding earthquakes, protecting them from major damages or collapse. The same methods of analyses are not suitable for all types of buildings. The isolation system used Armenia, unlike foreign countries ones, cannot take any tension forces since the system doesn't have structural connections to superstructure and substructure of a building. The consequence of this fact can be the occurrence of additional stresses after the redistribution of axial forces in rubber base isolations in high-rise buildings during a seismic action. The stress-strain state analyses of rubber base seismic isolation systems in reinforced concrete dual frame-wall buildings with application of a finite element method carried out in the manuscript. An increase of the stresses during seismic action is discussed and investigated using both Fast-nonlinear time history analysis (FNTHA) and Direct-integration nonlinear time-history analysis (DINTHA). Analysis of the results of the study shows that the axial forces after their redistribution during horizontal earthquake loads in most seismic isolators of high-rise building do not exceed 8%, but for some isolators this difference varies within the range of 12-18%. Taking into account the vertical component, the difference does not exceed 20%, with the exception of three isolators, where it can reach up to 23%. An average increase of the compressive axial forces in the seismic isolation bearing systems of the tall building as a result of redistribution can be taken about 10%. In this case, the displacements and the axial forces of the seismic isolators during analysis of their bearing capacity must be considered simultaneously, but not separately from each other.

Keywords: base isolation, high-rise building, earthquake, nonlinear analyses.

Introduction

Safety issues are always primary in terms of priority in building science. Therefore, various technologies for reducing the risk of emergency situations are in the focus of researchers. Armenia is located in one of the highest seismic risk zones in the region and has experienced many strong earthquakes over the centuries. The latest huge one was Spitak earthquake in 1988 (M7.0), many buildings were destroyed. The territory of Armenia is divided into three seismic zones, in which ground acceleration can be achieved up to 0.3g, 0.4g and 0.5g respectively [1]. The use of various type of seismic isolation systems is one of the main directions for reduction of seismic risk. Therefore, after the Spitak earthquake, seismic isolation systems began to be used in Armenia.

Development of seismic isolation all over the world began in 1909 with the patent of Johannes Avetician Calantarients, a medical doctor from the northern English city of Scarborough. It was an early example of earthquake resistant design strategy known as base isolation or seismic isolation [2]. This marked the beginning for the implementation of seismic isolation systems throughout the world. A lot of mechanisms have been invented since 1909. Nowadays, different types of active and passive seismic isolation devices are used all over the world, such as: Laminated Natural Rubber Bearings (NRB), Laminated Lead Rubber Bearings (LRB), Laminated High Damping Rubber Bearings (HDRB), Rotating Ball Bearings (RRB), Slide Bearings (SB) with High and Low Friction. Together with the seismic isolation systems, dampers are also used, such as: Hysteresis

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(Steel, Lead or other types) Dampers (HD) and Fluid (Viscous or Oil) Dampers (FD). Seismically isolated layered rubber-steel bearing devices are the main type of isolation system used in Armenia. (Fig.1), while synthetic (hot-vulcanized) rubber is used instead of natural rubber. Elastomeric isolators are made up of alternating layers of steel laminates and hot-vulcanized rubber, due to the type of rubber compound.





Fig. 2. The main types of seismic base isolation system location

In the Republic of Armenia, there are more than fifty (new and reconstructed) buildings with seismic base isolation. In terms of the number of buildings with seismic isolation, Armenia is ranked sixth globally, it lags behind Japan, China, Russia, Italy, the USA, and is ahead of France, Taiwan and New Zealand [3].

Due to the fact that only one type of seismic isolation support has been adopted as a standard in Armenia, seismic isolators in the buildings are located close to each other, in contrast to analogues in foreign countries, where the isolators are mainly located singly. The preliminary number of seismic supports is selected depending on the maximum allowable vertical load acting on a support. Seismic Isolation Laminated Rubber Steel Bearings (SILRSBs) are placed between the substructure (foundation or the several lower stories of the building) and the superstructure (part of the structure above the seismic isolation system) (Fig.2).

Materials and Methods

In accordance with the Armenian earthquake resistant construction design codes the oscillation period of buildings with seismic isolation is determined depending on the total stiffness of the seismic isolation supports as a Single Degree of Freedom System (SDFS). The fundamental period of a natural oscillation of the building by the 2D or 3D Finite Element Method (FEM) shows that the value is greater than the same one obtained from the SDFS calculation.

This is associated with the influence of the fundamental period of natural oscillation of the superstructure, i.e. the first fundamental period of natural oscillation will be equal to the sum of (*T*) the fundamental period of natural oscillation of SILRSBs calculating as for SDFS and (T_{sup1}). The first fundamental period of natural oscillation of the superstructure is defined as for a free-standing and at the bottom fixed building:

$$T_{build1} = T + T_{sup1}, \tag{1}$$

The value of the free oscillation period T for buildings and structures with seismic isolation systems with horizontal stiffness corresponding to the effective stiffness of the seismic isolators is determined by (2):

$$T = 2\pi \sqrt{\frac{Q}{K_{eff}g}},$$
(2)

where Q is the sum of the nominal gravity static loads (weight of the superstructure) taking into account shortterm live load's reduction factor, K_{eff} is the stiffness of the seismic isolation system, which is equal to the sum of effective stiffnesses of the seismic isolators that comprise the system, g is the gravitational acceleration.

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The design horizontal displacement of SILRSBs is determined by (3):

$$D = Agk_o \frac{\beta[T]}{\beta[\theta]} \left(\frac{T}{2\pi}\right)^2,$$
(3)

where the values of k_{θ} and A are determined from [1], the coefficient β [T] depends on the soil category of the foundation base, and the values of the coefficient β [θ] depending on the critical damping coefficient θ are given in Table 1, where intermediate values of θ and the value of β [θ] are determined by linear interpolation. The value of β [θ] in various building codes and standards are varies, while the highest values are taken in Japanese building codes¹.

According to the Earthquake resistance building codes of Armenia [1], seismic isolation is used for buildings and structures with a natural period of oscillation no more than 3.0 sec. At the same time, the natural period of the same system without seismic isolation (with regular foundation) has to be within 0.1 - 1.0 sec. Elastomeric isolators are very stiff in the vertical direction and can support the dead load with negligible creep effects during the whole life of the structure. Seismic isolators are flexible in the horizontal direction and have high vertical stiffness, and at the same time the damping is about 10 - 15%. The shear modulus G ranges from 0.4 to 1.4 MPa.

By the structural concepts, according to [1], two types of seismic isolation systems are used. The first type is the system located below the level of the pavement around the building, and second type is the system located above the level of the pavement but not higher that second-story level of building. The choice of the seismic isolation type is determined by subsoil conditions and the functional purpose of the building.

The analyses of buildings and structures with seismic isolation systems are carried out by two methods: according to design response spectra [1] or by earthquake response spectra compiled on the basis of recorded or synthetic accelerograms generated for the specific construction site. The design forces should be taken as the least favorable of the two analyses mentioned. The preliminary number of SILRSBs was calculated based on response spectral analysis, providing all the conditions specified in the building codes of Armenia. At the second stage, a time history nonlinear analysis is considered, and the change in axial forces in SILRSBs is estimated, taking into account the vertical component of the earthquake load as well as the lack of seismic isolators' work under axial tension forces.

According to the main geometrical and physical-mechanical parameters of SILRSB are presented below:

- number of rubber layers (n = 14),
- number of internal steel plates (13),
- external diameter (D = $2R = 380^{\circ} 2.0 \text{ mm}$),
- internal diameter central hole (19° 1.0 mm),
- height (202.5° 2.5 mm),
- thickness of the rubber layers ($t_r = 9.0^{\circ} 0.1 \text{ mm}$),
- diameter of the steel shim plates (360° 0.5 mm),
- thickness of the steel shim plates (2.5° 1.0 mm),
- external diameter of flanges (376° 0.5 mm),
- thickness of flanges (20.0° 0.2 mm),
- thickness of flanges' cover layer (2.0° 0.1 mm),
- mass of the SILRSB (W=77.5° 2.5 kg),
- shear modulus (G = 0.97 ° 0.15 N/mm²),
- vertical stiffness ($K_{eff,v} = 300 \text{ kN/mm}$),
- effective stiffness (K_{eff} = 0.95 kN/mm),

¹ The Building Standard Law of Japan, 2016. https://www.bcj.or.jp/en/services/publication/

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- horizontal stiffness ($K_d = 0.81$ ° 0.1 kN/mm),
- elastic stiffness ($K_e = 2.95 \text{ kN/mm}$),
- maximal displacement ($D_{max} = 280 \text{ mm}$),
- maximal allowable vertical force ($P_{max} = 1500 \text{ kN}$),
- yield force ($F_y = 56$ kN),
- equivalent viscous dumping ($\beta_{eff} = 10$ %).

There are two main parameters that characterize seismic isolators. The first one is S_1 - Primary Shape Factor (PSF), which mainly characterizes the vertical stiffness of the seismic isolator and the bending stiffness, and the second one is S_2 - Secondary Shape Factor (SSF), which characterizes the horizontal stiffness of the seismic isolator and the bending stiffness². Most of the seismic isolators (SILRSB) have a cylindrical shape. In Armenia just only cylindrical seismic isolators are used in the buildings.



Fig. 3. Force-displacement relationship of the SILRSB

https://www.armstandard.am/en/standart/1673.

SILRSB, used in Armenia, has the following characteristics: R = 190 mm, $n t_r = 14 \text{ x } 9 = 126 \text{ mm}$, $t_r = 9.0 \text{ mm}$. As a result, we have the following main parameters:

$$S_1 = \frac{0.5R}{t_r} = 10.6, \ S_2 = \frac{2R}{nt_r} = 3.0.$$
 (4)

PSF increases as the rubber layer is thin, SSF indicates the degree of flatness of the laminated rubber bearing. For the design of buildings and structures with seismic isolation, it is necessary to know the force-displacement relationship (Fig.3) and various physical-mechanical parameters of seismic isolators (SILRSB).

The buckling analysis of a seismic isolator is based on a linear theory [5] that is similar to the longitudinal bending analysis of a column and, as in conventional theory, provides a longitudinal bending load or stress when it is buckling in an undeformed position. This is of crucial importance in the structure of the seismic isolator, since the maximum compressive load on it will occur simultaneously with the maximum horizontal displacement, and in combination, this will be one of the limit states for which it will need to be calculated.

Complex nonlinear analysis is needed to study the behavior of a seismic isolator under the combination of a vertical axial load and maximum horizontal displacement. There are two hypotheses [6] for approaching the limit state of an isolator when it is simultaneously subjected to a vertical load and a horizontal force.

The first hypothesis is that the critical displacement, defined as the displacement at which the isolator exhibits zero increasing horizontal stiffness, is the lateral displacement at which the compressive stresses of the reduced zone are determined from the ratio of the vertical force to the area A_r (Fig.4). A_r is the overlapping sectional area of the top and the bottom of the seismic isolator, and θ is a half of the angle located between the extreme points of the area A_r .

The second hypothesis is that the area A_r is replaced by $0.5AxA_r$. This option is more reliable because the concentration of vertical stress caused by displacement will not affect the bending stiffness, but may reduce the shear stiffness [6].

In all cases, the maximum compressive stresses in this section can increase up to P_{cr} (Fig.5). Both hypotheses for the supports are considered in the work. Calculations were carried out on the basis of both hypotheses [6] for seismic isolators used in Armenia³.

² How to Plan and Implement Seismic Isolation for Buildings, The Japan Society of Seismic Isolation, 2005.

³ AST 261-2007, Seismic Isolation Laminated Rubber Steel Bearing. Specification, Yerevan, 2007.

The ratio of the values P and P_{cr} for an isolator having a circular cross section, according to the first hypothesis [6], is equal to

$$\frac{P}{P_{cr}} = \frac{2}{\pi} \left(\frac{\pi}{180} \arccos \frac{D}{2R} - \frac{D}{2R} \sin \left(\arccos \frac{D}{2R} \right) \right).$$
(5)

The ratio of P and P_{cr} for the same isolator, according to the second hypothesis [6], is equal to

$$\frac{P}{P_{cr}} = \sqrt{\frac{2}{\pi}} \cdot \sqrt{\frac{\pi}{180} \arccos \frac{D}{2R} - \frac{D}{2R} \sin \left(\arccos \frac{D}{2R}\right)}.$$
(6)

Assuming a linear relationship, the ratio of P and P_{cr} will be equal to

$$\frac{P}{P_{cr}} = 1 - \frac{D}{D_{cr}},\tag{7}$$

where:

$$P_{cr} = \frac{\pi^2 R^3}{2nt_r} \sqrt{\frac{GE_c}{3}} = \frac{3.14^2 \times 0.19^3}{2 \times 9 \times 0.014} \sqrt{\frac{970 \times 4 \times 10^5}{3}} = 3055 \text{ kN},$$
(8)

in this case, the following condition is satisfied:

$$S = \sqrt{\frac{E_c}{6G}} = \sqrt{\frac{4 \cdot 10^5}{6 \times 970}} = 8.3 > 5.$$
(9)

The results of the calculations, depending on the angle θ in the range from 0 to 900 and the displacement *D*, are shown in Figure 5.



Fig. 4. Overlapping sectional area of the top and bottom sections of the SILRSB at displacement D

Analyzing the obtained data, it should be noted that seismic isolators have various permissible values of horizontal displacements at different vertical axial loads, that is, limiting horizontal displacement, the corresponding allowable value for the vertical axial load must be specified. The seismic isolator used in the Republic of Armenia based on second hypothesis, with a maximum allowable vertical load of 1500 kN4, has a 244 mm horizontal displacement when the isolator remains stable (Fig.5). However, with a displacement of 280 mm, the vertical load should not exceed 1200 kN, thus, according to calculations, the loss of stability of the isolator according to both hypotheses occurs at different displacements. For base isolators with axial forces less than $0.2 P_{cr}$, the use of isolators is assessed as ineffective, and for axial forces more than $0.8 P_{cr}$, problems arise related to the reliability of the isolators. These conditional limits are ensuring both the reliability and efficiency for usage of base isolation [7].

⁴ AST 261-2007, Seismic Isolation Laminated Rubber Steel Bearing. Specification, Yerevan, 2007. https://www.armstandard.am/en/standart/1673

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in the Republic of Armenia on the vertical force

16-storey reinforced-concrete frame-shear wall building (Figs.6,7,8) with SILRSB seismic isolation systems calculated under seismic action is considered in the work. The distribution of columns and shear walls is symmetrical according to the main axes (longitudinal X and transverse Y). A quantity of seismic isolators (206 isolators) (Fig.8) was determined from the two main conditions that the maximal horizontal displacement at the top of the isolator will be less than 280 mm and the maximal vertical design load will be less than 1500 kN. Different options of seismic isolators are considered in the manuscript: the first problem with base isolators supporting in the vertical direction (Z), both compressive and tensile forces are assumed, and the second problem, carried out by isolators in the vertical direction (Z), takes only compressive forces.

The story height for the building was unchangeable and equal to 3.0 m, the thickness of the slabs and the cross section of square columns were equal to 16 cm and 50650 cm, respectively. The thickness of shear walls of superstructure is equal to 16 cm. Sections of the girders are different: 550x550 and 500x560 mm. All loads are assumed by the building codes. Concrete type B25⁵ was used for analysis: the cube strength of concrete is 25 MPa, and the modulus of elasticity is equal to 30000 MPa. All calculations have been carried out with the implementation of both fast nonlinear time history analyses and nonlinear time history analyses with direct integration. At the same time, the Spitak earthquake accelerograms recorded in Gukasyan were used.

Maximum values of acceleration were increased to 0.4g in the horizontal direction (for the accelerogram in direction Y, Fig.9) and to 0.28g in the vertical direction (for the accelerogram in direction Z) (Fig.10). Structural FEM analysis of a three-dimensional model of the building with frame and shell elements are used in the manuscript (Figs.6,7).

The first fundamental natural period of vibration of the building in Y direction is equal 2.09 sec. The height and number of stores of the building were taken from the condition that the first fundamental natural oscillation period of the superstructure without seismic isolation would not exceed 1.0 sec. For assessing the change of forces in the base isolators during seismic action, SILRSBs located along axes 3 (Fig.11) and 4 (Fig.12) are considered.

⁵ RABC 52-01-2021 Concrete and Reinforced Concrete. Building Codes of Armenia, 2021.

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Fig. 6. 3D view of a building (three-dimensional model)



Fig. 9. Horizontal record (Gukas Y)







Fig. 7. 3D view of a bearing system: columns and shear walls



Fig. 8. location of SILRSBs (206 base isolators)

The main peculiarity of the work is an investigation of "tensile forces" in the base isolators of high-rise buildings at seismic impact. A comparative analysis of two different models was carried out since seismic isolators used in Armenia do not work on tension. The seismic isolators in the first model are considered ordinary finite elements of seismic isolation (Link) that are accepted in SAP2000.

The seismic isolation system in the second model was described by nonlinear elements operating only on compression. A comparison analysis of seismic isolators from 1 to 21 is considered in the work (Figs.11,12).

Calculations were performed by SAP2000 software, where the effect of increasing stresses during seismic action was investigated with the best known time history nonlinear analysis methods: FNTHA (Fast nonlinear time history analysis) and DINTHA (Direct-integration nonlinear time history analysis) [8,9]. At the same time, two possible combinations were considered in the manuscript. One of them is static (dead load, short - term and

long-term live loads) and earthquake load in the horizontal direction (Y axis), and second combination is the same as the first one in addition with earthquake load in the vertical direction (Z axis).

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Fig. 12. Location of SILRSBs along axis 4

The main peculiarity of the work is an investigation of "tensile forces" in the base isolators of high-rise buildings at seismic impact. A comparative analysis of two different models was carried out since seismic isolators used in Armenia do not work on tension. The seismic isolators in the first model are considered ordinary finite elements of seismic isolation (Link) that are accepted in SAP2000. The seismic isolation system in the second model was described by nonlinear elements operating only on compression. A comparison analysis of seismic isolators from 1 to 21 is considered in the work (Figs.11,12).

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Results and Discussion

The results of the calculation using the FNTHA and DINTHA methods are presented in Tables 2 and 3. Time history analysis for some SILRSBs is presented (Figs.13,14,15).

The change in forces and displacements in seismic isolators during seismic action shows that the horizontal displacements of seismic isolators, taking into account the vertical component of the seismic load, are insignificant. At the same time, the vertical seismic load has a significant effect on the change in the vertical force in the seismic isolator (Table 2). Comparative analysis of the axial forces in seismic isolators shows that the vertical component of the seismic load (Component Z) increases the axial force from 5 to 35%, while this value depends on the location of the isolator in the plan of the building and on the other seismic isolators located in the central part of the building (see SILRSB number 10 or 20) (Figs.13,14,15), while for isolators located at the edge and corner of the buildings, the effect is not huge enough (see SILRSB number 2) (Figs.13,14,15).

The analysis of the results of a high-rise building showed that the value of axial forces in SILRSBs according to FNA, in comparison with the direct-integration method, turned out to be greater. For example, the maximal vertical force in the seismic isolator, which can take only compression, with the DINTHA method was 1476 kN, while with the FNTHA method it was 1861 kN. Some results of fast-nonlinear analysis do not provide the bearing capacity of the seismic isolator (according to the Armenian standard on SILRSB⁶, the values of axial force must not exceed the ultimate value, which is equal to 1500 kN, it is the standard value from the manufacturer). In the case of DINTHA, the maximal compressive axial forces in all isolators do not exceed 1500 kN. It should be mentioned that even if some results of FNTHA don't satisfy the ultimate value of axial force, the seismic isolator can be acceptable (Fig.5), provided that the displacements of the seismic isolators are not very large and located below the line (7) – the maximum permissible values.

⁶ AST 261-2007, Seismic Isolation Laminated Rubber Steel Bearing. Specification, Yerevan, 2007. https://www.armstandard.am/en/standart/1673
Reference	Critical damping, %				
RABC 20-04-2020 [1]	5	7	10	15	20
ASCE 7-22 ⁷	1.00	1.10	1.30	1.60	1.70
Eurocode 8 ⁸	1.00	1.08	1.20	1.35	1.50
The Building Standard Law of Japan 2016 ⁹	1.00	1.09	1.22	1.41	1.58
Earthquake Spectra and Design ¹⁰ [10]	1.00	1.13	1.33	1.66	2.00

Table 1. The values of the coefficient β [θ] depending on the critical damping coefficient

Table 2. The values of Maximum Axial Compression Forces in the SILRSBs by Gukas Y and Gukas Z records depending on types of nonlinear analyses, finite elements of seismic isolation and directions of earthquake loads

Seismic isolator	mic Seismic isolators (finite elements) ca tor both tension and compression				Seismic isolators (finite elements) can take only compression			
by Figure 8	Fast non history a rec	linear time nalysis by cords	Direct-ir nonlinear t analysis l	ntegration time history by records	Fast nonlinear time history analysis by records		Direct-integration nonlinear time history analysis by records	
	Gukas Y	Gukas Y and Gukas Z	Gukas Y	Gukas Y and Gukas Z	Gukas Y	Gukas Y and Gukas Z	Gukas Y	Gukas Y and Gukas Z
	kN	kN	kN	kN	kN	kN	kN	kN
1	950.1	1028.0	920.5	970.9	1005.0	1114.0	933.4	987.2
2	1098.0	1197.0	1067.0	1130.0	1149.0	1297.0	1081.0	1147.0
3	1030.0	1134.0	1004.0	1068.0	1077.0	1228.0	1016.0	1083.0
4	937.6	1057.0	917.6	982.5	985.1	1131.0	931.8	993.6
5	880.6	1004.0	861.2	916.4	913.8	1056.0	872.5	924.0
6	775.6	950.9	756.1	870.1	776.4	1013.0	758.1	870.4
7	866.2	1059.0	851.5	960.6	871.4	1214.0	861.2	962.5
8	964.4	1173.0	953.9	1025.0	970.2	1343.0	963.2	1028.0
9	1098.0	1320.0	1086.0	1162.0	1107.0	1512.0	1097.0	1165.8
10	1237.0	1478.0	1222.0	1305.0	1252.0	1691.0	1234.7	1311.0
11	1118.0	1225.0	1094.0	1167.0	1138.0	1341.0	1109.0	1184.0
12	769.4	983.5	757.0	860.2	784.4	1002.0	758.0	859.4
13	1297.0	1510.0	1254.0	1345.0	1327.0	1538.0	1262.0	1353.0
14	896.0	947.7	854.6	846.0	958.0	995.4	871.1	860.2
15	1050.0	1130.0	1004.0	1038.0	1103.0	1193.0	1024.0	1051.0
16	998.0	1090.0	953.7	1019.0	1029.0	1173.0	972.1	1031.0
17	1103.0	1626.0	1096.0	1357.0	1120.0	1704.0	1100.0	1358.0
18	1183.0	1790.0	1179.0	1476.0	1198.0	1861.0	1180.6	1476.0
19	1080.0	1649.0	1076.0	1350.0	1089.0	1699.0	1077.0	1350.0
20	1166.0	1644.0	1161.0	1397.0	1166.0	1745.0	1164.0	1397.0
21	1189.0	1404.0	1152.0	1241.0	1214.0	1422.0	1160.0	1249.0

https://wiki.csiamerica.com/display/kb/Damping+in+response-spectrum+analysis.

⁷ ASCE/SEI 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, ASCE, 2022.

⁸ EN 1998-1:2004, Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings, BSI, 2004.

⁹ The Building Standard Law of Japan, 2016. https://www.bcj.or.jp/en/services/publication/

¹⁰ Damping in response-spectrum analysis.

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Table 3. The values of Maximal Displacement of the SILRSBs by Gukas Y and Gukas Z records depending
on the type of nonlinear analyses, the finite elements of seismic isolation
and the directions of earthquake load

Seismic isolators (finit	e elements) can take	Seismic isolators (finite elements) can take		
both tension and	l compression	only compression		
Fast nonlinear time history analysis by records	Direct-integration nonlinear time history analysis by records	Fast nonlinear time history analysis by records	Direct-integration Nonlinear time history analysis by records	
mm	mm	mm	mm	
93.0	77.9	86.3	73.8	

The differences between the results of the two nonlinear methods are no more than 20%, at the same time, for models with SILRSB that can take tension axial forces, the difference for the majority of elements is not more than 5%.

The top displacement of all seismic isolators is the same due to the presence of rigid diaphragms at both the top and bottom of the seismic isolators (Table 3).

Time history comparative analysis of seismic isolators shows that in the models with isolators, which can take both tension and compression at certain moments, have tensile stresses (see SILRSB number 1, A and B) (Fig.13). At the same time in the models where seismic isolators can take only compression forces in the same isolators mentioned before, the values of axial compressive forces decrease to zero (see SILRSB number 1, A and B) (Fig.14,15). There is a sharp increase in axial forces of isolators (see SILRSB numbers 10 and 20, B) (Fig.14), which is associated with stress redistribution at a time when some other isolators (see SILRSB numbers 10 and 20, B) (Fig.14) no longer take the vertical load. The period of time when not all seismic isolators will work under axial compressive load is not large, it can be from a fraction of a second to several seconds, while due to the sign change of the seismic load, the continuous parts will be insignificant.

This study shows that for low-rise buildings with seismic isolation, redistribution of forces in SILRSBs is not observed, since there are always only compressive forces in all elements of the seismic isolation system. The results obtained by FEM analysis show that the redistribution of forces in seismic isolation depends on different factors, the main of which is the height of the building [7]. At the same time, the forces increase depending on the ratio of the height to the length (width) of the building. In our case, a redistribution of the forces in the base isolators occurs only when an earthquake force acts in the Y direction, but all seismic isolators are compressed when the force acts in the X direction, i.e. the height to length (width) ratio has a significant influence on the redistribution of the axial forces. It is also necessary to pay attention to ensuring the bearing capacity of reinforced concrete structures located under and above the seismic isolation supports, these members should be sufficiently rigid, especially linear elements without shear walls. An increase in axial force leads to an increase in bending moments and transverse forces [11], which must be taken into account in the calculation of reinforced concrete structures.

Conclusion

It should be noted that the increase of axial forces after their redistribution during horizontal earthquake loads in most SILRSB does not exceed 8%, but for some isolators, this difference varies within the range of 12-18%. Taking into account the vertical component, the difference does not exceed 20%, with the exception of three isolators, where it can reach up to 23%. An average increase in the compressive axial forces in the seismic isolation bearing systems of this building as a result of redistribution can be taken about 10%.

There may be cases when the displacement of the seismic isolator and its axial force are outside the recommended area for design (Fig.6), even when the conditions $D \le D_{max}$ and $P \le P_{max}$ are provided. For this reason, the displacement and axial force of the seismic isolator during the analysis of its bearing capacity must be considered simultaneously but not separately from each other.

For the seismic isolators used in the Republic of Armenia, the dependence of the maximum allowable

horizontal displacements on the action of the vertical axial forces under seismic effects has been obtained. The necessity of taking into account the maximum horizontal displacement and the vertical force acting on the SILRSB in order to assess its bearing capacity under seismic action is shown.

The obtained numerical data for SILRSB will make it possible to more accurately estimate the possible maximum allowable horizontal displacements of the seismic isolator from vertically acting total static and seismic loads.

Often the vertical component of the seismic loads has a strong influence on the stress-strain state of building structures, and for load-bearing structures of high-rise buildings with seismic isolation can be decisive. Therefore, the application of the calculation methodology and results of the analysis specified in this manuscript will allow to study the influence of vertical seismic impact on the bearing capacity of structures in high-rise buildings with seismic isolation.

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.

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Abstract: Due to the military operations conducted by the opponent during and after the 2020 Artsakh war, as well as potential future risks and threats, the Republic of Armenia faces the challenge of ensuring the secure livelihoods of border settlements and implementing programs aimed at territorial development. Therefore, raising the issues regarding the resistance of these settlements to possible military operations is of strategic importance and demands immediate attention.

The research examines normative and technical documents adopted from both international and local experiences to mitigate the impact of military attacks. It delves into the potential for reducing casualties and material damage by organizing the spatial environment of settlements. Furthermore, it emphasizes the necessity of defining new terminology and formulating key assessment criteria. The proposed solutions can be the basis for proposing a new scientific theory in architecture and contributing to the development of new resistance solutions in architecture along with military technologies. **Keywords:** Armenia, architecture, military resistance, passive defense, warfare, spatial planning.

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Introduction

The deployment of advanced combat weaponry in contemporary military conflicts has led to extensive destruction in settlements, damaging buildings, structures, historical monuments, and resulting in significant civilian casualties¹. Technological advancements, such as the incorporation of unmanned aerial vehicles in aviation and the evolution of networked control systems in military science, offer the opportunity to create highly precise armaments capable of targeting without regard to distance or positioning.

A retrospective analysis of military experts' perspectives, coupled with an examination of the current state of potential theaters of military operations, reveals a notable gap in military science concerning the study of military geographical aspects of urbanism [1]. This gap is particularly concerning given the prevailing trend of armed confrontations in urban areas, as evidenced by recent wars and conflicts (such as those in Syria, Artsakh, Ukraine, Israel, and Palestine). The relevance of addressing this issue is paramount, especially considering that even after the conclusion of the Artsakh war, existential challenges persist for the Republic of Armenia.

Therefore, in the border settlements, it is important to note that the defense of the state is structured not solely within the military but across all spheres of activities. This defense is an ongoing process, operational not just during wartime but persistently in times of peace as well [2]. Therefore, within these settlements, apart from devising military strategies such as anti-aircraft defenses, there is a crucial need to implement a comprehensive system ensuring resistance through spatial planning. This necessitates the establishment of scientific and methodological principles that align with the substance and strategy of contemporary military operations. In this sense, this research delves into historical precedents and contemporary approaches to settlement defense, concentrating on their relevance within the context of the Republic of Armenia. Notably,

¹ PAX / Article 36, Areas of Harm, ISBN 978-94-92487-05-6/NUR 689, 2016, 6-12.

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the accumulated experiences of nations like the State of Israel, the Swiss Confederation, the United States of America, and the Islamic Republic of Iran serve as valuable study materials. These countries have developed normative-technical frameworks encompassing technical directives and requisites for territorial and civil protection. However, none of these states has released an all-encompassing solution adaptable to the specific needs of the region under consideration.

In cases where a settlement becomes a local theater of military operations, prioritizing the safety of the civilians demands the creation of an environment that not only ensures the safety of human lives but also doubles as a defense infrastructure. Simultaneously, it should offer conducive living conditions during periods of relative peace. Moreover, settlements play a pivotal role in a country's economy, serving as the lifeblood and supplying vital resources, particularly in border regions, crucial for the armed forces. Consequently, the resistance of these settlements significantly influences the combat readiness of the armed forces [1].

The methodology employed in this article integrates scientific principles with empirical data. It utilizes research methodological approaches, factual materials, analysis results, comprehension of terminology, and essential scientific-methodological principles to formulate and implement a novel concept concerning special architectural measures for organizing the spatial environment in border settlements of the Republic of Armenia (RA). In the context of this article, the term "border settlements" of the Republic of Armenia refers to the Decision of the Government of the Republic of Armenia on approving the list of communities of border settlements of the Republic of Armenia, N713².

The research aims to analyze existing international and local norms and technical solutions, highlighting the imperative of incorporating the theory of spatial environment resistance to military operations into architectural and urban planning activities for the border settlements of the Republic of Armenia.

Materials and Methods

The analysis encompasses a range of methodologies to conduct a comprehensive study on the subject. This includes reviewing existing terms in scientific literature, studying normative-technical, archival documents, employing photo-fixation for visual documentation, examining legal frameworks, and analyzing analogies in their formation.

The assessment of military resistance for buildings and structures in this research is based on specific criteria, enabling conclusive findings within its framework. The following criteria are recommended as the foundation for developing the methodology for assessing military resistance:

- 1. Location of livelihood facilities,
- 2. Assessment of the minimum and maximum damage inflicted by the employed weapon,
- 3. Planning and Designing Solutions for Buildings and Structures Positioned within the Immediate Danger Zone,
- 4. Assessing the Maximum Distances between Buildings and Structures in the Spatial Environment,
- 5. Choosing Construction Materials for Building or Structure Construction and Reconstruction.

Results and Discussion

Significance of defining the term "Military resistance"

The mitigation of human casualties and material devastation during military assaults on settlements can be attributed to various factors. These encompass distinctive architectural designs of buildings and structures, their potential for future restoration, as well as the nuances of spatial planning and architectural arrangements.

² Decision of the Government of the Republic of Armenia on approving the list of communities of border settlements of the Republic of Armenia, N713 of November 17, 1998, Yerevan (in Armenian).

The layout and interconnectedness of buildings and infrastructures within the spatial environment play a pivotal role in enhancing territorial defense capabilities and minimizing vulnerability [3].

The organization of territorial defense stands as a pivotal aspect of a nation's defense strategy. It holds particular significance for smaller states lacking extensive military fronts and strategic rear areas [4]. Notably, from the adversary's perspective, a "successful" military offensive often involves disrupting the normal livelihood in settlements along the frontline. Hence, settlements can serve as integral components of territorial defense, underscoring the critical importance of implementing measures to bolster the defense capabilities within these areas [2].

The Construction Standards for Civil Defense Structures in the Republic of Armenia are applicable within the country. According to these norms, underground buildings situated within the building's basement or separately constructed within settlement territories are classified as Civil Defense Structures (CDF)³. Their primary function is to provide shelter and ensure the safe evacuation of civilians, serving as integral components of passive defense measures.

Passive defense strategies aim to mitigate potential human and material losses during significant natural disasters or hostile actions by adversaries in times of war. Unlike active defense, which involves military tools and actions to counter threats, passive defense relies on non-combative, unarmed strategies [5].

Within the scope of civil defense, blast resistance, and defensive architecture play pivotal roles. Explosionproof measures aim to safeguard environments from explosive weapons. In the United States, this term encompasses governmental actions dedicated to shielding society from terrorism, lawlessness, and insurgency. In contemporary parlance, defensive architecture, extending beyond traditional notions of fortifications and military structures⁴, embodies a suite of control mechanisms governing public spaces. These mechanisms contribute to defining the "disciplinary" nature within urban settings [6].

As a parallel example, the existing normative document system in construction includes earthquakeresistant building construction norms⁵. The profound impact of the devastating 1988 earthquake in Armenia reverberated through the region's architectural landscape. This seismic event prompted a comprehensive reassessment of building construction and seismic mapping. Despite the perennial occurrence of earthquakes in Armenia, legislative action and systematic solutions addressing this issue were only initiated after a significant earthquake event, prompting a revision of the Richter magnitude scale from 8 to 9.

These principles encompass fundamental guidelines including volume-planning solutions, allocation of stiffnesses and masses, and specifications for constructing load-bearing elements. They are imperative to adhere to during the design and construction of buildings and structures in regions prone to earthquakes⁶. When comparing the seismic impacts with those induced by projectile use, distinct similarities and differences become apparent.

Unlike seismic effects, the forces resulting from the use of projectiles can manifest in all spatial dimensions, including aerial ones. In addition to propagating pressure waves through the air, some of the weapon's energy is transmitted through the ground. This phenomenon resembles a high-intensity, short-duration earthquake, inducing shock pressure at the interfaces between structures and soil [7]. In both cases, structural damage, destruction, and human casualties can result if the building is not designed to withstand such forces. The logic behind earthquake resistance involves extensive scientific studies aimed at comprehending the forces and repercussions of earthquakes on buildings and structures. Similarly, when addressing the challenge of

³ Construction Standards for Civil Defense Structures in the Republic of Armenia, 31-03.02-2022 Order No. 06-H, dated April 4, 2022, issued by the Chairman of the Urban Development Committee of the Republic of Armenia, https://www.arlis.am/DocumentView.aspx?DocID=161785 (in Armenian).

⁴ Cambridge Dictionary, https://dictionary.cambridge.org/dictionary/english/defensive-architecture.

⁵ Earthquake-resistant construction standards, CNRA 20.04-2020, Normative documents in construction, construction norms of the Republic of Armenia, Committee of the Republic of Armenia, Yerevan, 2020, https://www.arlis.am/DocumentView.aspx?DocID=172012 (in Armenian).

⁶ Ibid.

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confrontations utilizing military means within settlements, conducting scientific studies to grasp the effects of military operations on buildings and infrastructure becomes equally crucial.

In examining the Defense Law of the Republic of Armenia, it is essential to note the observation regarding the organization of Armenia's defense. It is crucial to note that the defense organization of the Republic of Armenia is the "resistance" to armed attacks, immediate threats, and military operations within its borders⁷.

Examining the aforementioned concepts within the scope of territorial defense, especially concerning spatial development in border settlements, highlights the necessity for a systematic scientific exploration within local science. This exploration should focus on researching the resistance of buildings and structures.

Exploring the factors defining the resistance of buildings and structures amidst military operations underscores the necessity for an integrated scientific framework. This comprehensive system should interconnect these concepts and incorporate them within a unified strategic framework. The currently existing civil defense system in the Republic of Armenia does not meet the current military-scientific challenges, because they are based only on the features of building basement shelters and does not meet the requirements of the urban warfare that have become characteristic of the 21st century and increasing the resistance of the spatial environment of the settlement.

Drawing from the Defense Law's directives regarding military threats, the rationale for establishing a normative document system, and the specific application of the aforementioned concepts, the following conclusion is derived:

The term "military resistance" is proposed to encompass the array of methods and tools employed to counter military threats, facilitating the achievement of the goal outlined in this research.

Military resistance pertains to the ability of facilities within areas of immediate military peril or ongoing operations to resist the effects of weaponry and tools in use, as well as their aftermath, ensuring the continuity of the livelihood facilities.

Currently, the concept of military resistance lacks a comprehensive scientific foundation. Establishing the military resistance of settlement or vital facilities necessitates a multifaceted approach, commencing with situational analysis and spatial planning, and extending to technical solutions.

The planning of spatial environments and the design solutions for vital structures directly align with the field of architectural and urban planning science. Consequently, within the realm of ensuring military resistance, architecture plays a distinctive and vital role. Given the nature of the discussed subject matter, it necessitates a specific scientific-methodological theory. Hence, the primary objective of the theory of military-resistant architecture lies in fortifying the resistance of spatially organized structures and facilitating the continuation of daily life activities by implementing architectural strategies resistant to measures employed during military operations. Similar to any scientific theory, it should encompass fundamental concepts, principles, and foundations based on empirical experiences and their interconnecting patterns. The theory of military-resistant architecture will entail a coherent model for comprehending observable phenomena, coupled with an internal structure and a sequence of action mechanisms. The scientific value of a theory hinges on its effectiveness in fulfilling these fundamental functions.

Criteria for Assessing Military Resistance

The primary determinant in assessing military resistance involves the specific characteristics of a building, structure, or any object. As the distance from the attacker increases, the necessity for more long-range methods to strike the target grows. Consequently, these methods may entail a restricted payload or warhead. Within the scope of the discussed issue, it is pertinent to examine spatial planning features through the lens of military resistance across three dimensions [8]:

⁷ Law of the Republic of Armenia on Defense, Chapter 1, Article 5: Basic Concepts of the Law. https://www.arlis.am/documentview.aspx?docid=117631

- a) When livelihood facilities are located close to the direct contact line of the border or within the combat zone, it's crucial to consider not only the possible utilization of vertical air assets but also the risks associated with skirmishes, military offensives, and the deployment of other military resources in the horizontal plane. This consideration is especially pertinent in the border settlements such as Aygepar and Shurnukh.
- b) When livelihood facilities are situated within the rear zone of the border but remain within the potential range of enemy weapons, it becomes imperative to consider the risk of airstrikes. This concern is particularly pertinent settlements such as Ijevan and Vayk.
- c) When livelihood facilities are situated far from the military contact line, within a relatively safe zone, spatial planning measures become crucial for rapidly organizing and furnishing the spatial environment in response to a military threat. This is particularly pertinent in a city like Yerevan.

Taking the Syunik Region as an example, it is noteworthy that the main settlements within the region are border settlements located within Zones a) (Fig.1).



Fig. 1. Map of Border Settlements in the Syunik Region of Armenia

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The military resistance of buildings and structures is significantly influenced by the physical terrain, tectonics and spatial planning characteristics. Natural landscape features, especially in mountainous areas, serve as natural barriers, both between buildings and for underground infrastructure placement. Blast waves refracted by the ground are subject to reflection by terrain type and elevation irregularities. Depending on the slope of the ground, these waves can bounce backward or forward. In this context, the selection of materials to cover the environment and their fragility become crucial factors aimed at minimizing the generation of destructive fragments during an explosion [7]. In this regard, Armenia, known for its mountainous terrain and a historical legacy of leveraging landscape features for strategic defense since ancient times, holds significant potential to utilize its physical terrain for enhancing modern national security measures. So, the integration of landscape characteristics with construction forms and density is a complex system that profoundly affects the military resistance of a settlement⁸.

For instance, ground characteristics in residential areas play a crucial role as they determine the varying effects of weapons based on the surrounding ground attributes (Fig.2).

The analysis of military-geographic characteristics of settlements and the implementation of military resistance measures will serve as a basis for the development of various military theories, and the creation of spatial environments adapted for the use of special military equipment and weapons for combat operations [1].



Fig. 2. The impact crater in a residential neighborhood in Stepanakert, Sasountsi David Street after aircraft attack, 2020, photo source: Human Rights Watch



Fig. 3. Effects of a Smerch Artillery Rocket Strike on the Maternity Ward of the Republican Hospital in Stepakanakert, 2020, photo source: Human Rights Watch

The nature of weaponry employed by the adversary stands as a crucial factor. Understanding the arsenal of military resources at the opponent's disposal allows for predictions regarding the potential minimum and maximum impact of their means. Each weapon category possesses distinct characteristics, causing specific forms of damage and impact [9].

Assessment of damage to buildings and infrastructures typically involves evaluating the effects of these phenomena on diverse structures. This assessment considers the construction materials, design principles, and the resulting post-damage condition.

For example, during the 44-day Artsakh War of 2020, long-range rocket launchers were widely used. There were both high explosive and cluster projectiles in them. According to the analyses carried out by the research centers in 2021, it was recorded that the mentioned weapons are still present in the arsenal of the Republic of Azerbaijan [10]. This observation suggests the potential future deployment of these weapons by Azerbaijan, not only against the armed forces of the Republic of Armenia but also towards civilian settlements, should further conflicts occur (Fig.3).

⁸ Headquarters, Department of the Army Washington United States. Intelligence Support to Urban Operations. 2015. – C. 0110, pp 1(2)-1(3).

Considering that essential livelihood facilities might exist within the immediate danger zone; a primary requirement is to plan these facilities strategically [11]. This planning aims to ensure the population's shelter in a relatively secure manner and the resistance of the buildings. Architectural typologies can make military-resistant architectural solutions and can significantly mitigate damage caused by bombings [12]. Consequently, the ergonomic attributes of the architectural environment stand as pivotal factors in enhancing military resistance [13] (Fig.4).

In this context, planning and designing buildings and structures should facilitate:

- Mitigation of explosion aftermath,
- Establishment of systematic and streamlined crisis management strategies,
- Creation of conditions enabling the continuity of daily life activities during military operations [9],
- Adapt the settlement for territorial defense.

While organizing the territory, it is crucial to plan construction solutions facilitating safe and swift population evacuation and minimizing the impact of unit projectiles in the spatial environment.

Construction density. When developing projects for planning and constructing settlements in the border zones of the Republic of Armenia, it is essential to consider factors that directly impact increasing military resistance. The first aspect to address in enhancing military resistance is the density of construction in the area [3]. Unlike urban environments, which typically feature dense construction, rural areas tend to have more dispersed development. The extent of damage caused by a military weapon employed by the enemy is directly proportional to the density of the built-up area. Higher building density results in greater damage from a single shelling or bombing incident.

As illustrated in Figure 5, shelling often leads to damage to several attached residential houses at once, rendering them unusable and causing extensive injuries across a large area. Thus, it can be inferred that maintaining a certain distance between buildings and structures of different significance is a critical factor in increasing military resistance. Depending on the characteristics of the explosion - such as distance, caliber, and type of weapon, as well as the height of the explosion - the extent of injuries can also vary.

To address these concerns effectively, urban planners and architects should prioritize designs that incorporate appropriate spacing between structures. This strategic approach minimizes the impact of attacks, reduces collateral damage, and enhances the resistance of settlements in border zones. Additionally, implementing defensive measures and fortifications where feasible further strengthens military resistance and ensures the safety and security of residents.

During spatial planning, it's crucial to consider the positioning of residential buildings, structures, and infrastructures concerning strategic targets. This is because during military operations, hitting a target may cause damage to adjacent buildings of varying importance simultaneously. Special attention should be given to the military resistance of residential and public buildings located near potential military targets, ensuring a safe distance between them.



Fig. 4. A residential building destroyed by shelling in Borodyanka, 2022, photo source: Reuters Photo



Fig. 5. Residential houses after shelling, Artsakh 2020, photo source: Armenian Unified Infocenter

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For instance, in 2020, an attack on the electric substation of Stepanakert resulted in at least 10 impact sites within a 300-meter radius. Some of these strikes directly targeted the main control building for transformers and sub-transmission lines, leading to damage to the substation and several nearby residential and commercial buildings. Additionally, strikes targeted the courtyard of School No. 10 (Fig.6)⁹. From this, it's evident that maintaining a specific safe distance and establishing a neutral zone is imperative.



Fig. 6. Attacks on Electrical Substation Area, Stepanakert, October 4, 2020, photo source: Human Rights Watch

Military resistance demands theoretical analysis coupled with derived technical solutions. The nature and accumulation of debris hinge not just on the weapon type but also on building and structure types, construction materials, and density. Hence, considering the selection of construction materials and the potential risk of debris collapse is vital when situating emergency transit exits.

Conclusion

The specific cases outlined in this research offer a foundation for drawing overarching conclusions concerning the resistance of buildings and structures against the destructive impact caused by combat munitions.

The Republic of Armenia, despite its small territory, hosts a relatively large number of border settlements, leading to significant security challenges. Addressing these challenges necessitates a comprehensive approach that incorporates insights from military science, spatial planning, and architectural considerations.

The analysis of various scientific and research studies pertaining to contemporary armament, alongside an examination of international territorial defense concepts and existing normative and technical documents, underscores the significance of employing terms like "military resistance" and "military-resistant architecture" to characterize the spatial environment of border settlements in the Republic of Armenia in the context of

⁹ Azerbaijan: Unlawful Strikes in Nagorno-Karabakh, Investigate Alleged Indiscriminate Attacks, Use of Explosive Weapons, December 11, 2020 3:00AM EST

military operations. This is particularly emphasized through the delineation of specific scientific and methodological principles required for the development of the theory of military-resistant architecture.

- They define minimum mandatory requirements for ensuring the military protection of buildings and structures, considering the problem in the spatial planning system. These fundamental requirements are suggested for incorporation into normative and technical documents.
- The considerations concerning the military resistance of border regions warrant a distinct level of analysis compared to general assessments. Spatial planning for each border area should meticulously integrate criteria for military resistance, considering whether the area is integrated into the territorial defense system or not.
- When evaluating military resistance, the assessments must be based on analyses of existing highprecision weaponry and their impact, historical prototypes, and technical and methodological attributes.
- Maintaining a certain distance between buildings and structures of different significance is a factor of increasing military resistance.

Conflict of interest

The author declares that there is 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.

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Abstract: This paper focuses on studying structural changes in the viscous fluid during turbulent unsteady plane-parallel pressure flow. This investigation analyzes how hydrodynamic parameters change in viscous fluid unsteady motion, particularly by calculating the turbulent viscosity coefficient. The study addresses the boundary problem that arises when there are axisymmetric changes in the flow. The selection of boundary conditions aligns with the patterns associated with the arbitrary distribution of pressure gradients and velocities within the section. Based on the initial and boundary conditions, the boundary value problem is formulated. The method for solving this boundary value problem was developed, and the regularities of the instantaneous speed change along the cross-section were obtained. The solution to the boundary value problem is derived by integrating partial differential equations, ensuring the satisfaction of all boundary conditions. Analytical solutions have been derived, enabling the determination of velocity patterns at any given moment. On the basis of the general solutions to the problem, solutions were obtained for the accelerating motion under the influence of a constant pressure gradient on a fluid at rest. The computer analysis generated composite graphs displaying average velocities across various time intervals. The provided solutions enable the visualization of average velocity changes within conditions of plane-parallel turbulent flow. These findings allow for the conclusion of the design of individual units within hydro-mechanical equipment.

Keywords: plane-parallel motion, turbulent motion, viscous fluid, velocity distribution.

Introduction

A characteristic feature of pressure systems is that ongoing hydro-mechanical phenomena are frequently accompanied by an unsteady flow of the working medium over time, resulting in changes in velocity and pressure at any point along the system.

When discussing practical problems, the one-dimensional unsteady motion model is employed as a computational framework to analyze these changes. In this model, current parameters are determined based on averaged values taken across the cross-section.

Kinetic energy coefficients and momentum take into account deviations of the averaged quantities from the hydro-mechanical parameters of the current shear points. Therefore, one of the issues of unsteady motion is the study of the change patterns of the mentioned coefficients, for which it is necessary to perform structural studies of unsteady motion.

Frequently, the necessity arises to employ complex mathematical models for conducting these studies. However, the results obtained from such models may not be suitable for practical applications. Therefore, to make certain simplifications in these calculations, we proceed from the quasi-stationary movement model. In this case, the unsteady flow is considered as a sequence of stationary motions.

At each moment in time, the average speed of the current is equated to the average speed of what appears to be stationary motion. Therefore, unsteady motion is conceptualized as a series of successive stationary motions. This assumption can yield realistic results, provided that the plot of the instantaneous velocity distribution closely adheres to the quadratic parabolic law.

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However, theoretical and experimental research suggests that the graphs representing the instantaneous velocity distribution can actually diverge considerably from the quadratic parabolic law. This deviation suggests that the frictional stress near the stationary wall cannot be the only factor influencing energy losses, as assumed in the quasi-stationary motion framework.

The frictional stress near the wall varies depending on the law governing the change in instantaneous velocity within the section, causing it to differ from the corresponding frictional stress in the quasi-stationary motion. In unsteady motion, to determine the variation in frictional stress occurring near the stationary wall, it is essential to examine the pattern of velocity change within the effective cross-section.

Literature review and problem statement

Thus, the main goal of the study is to determine the structural changes in the pressure unsteady flow of viscous fluid depending on time and coordinates of the points of the effective cross-section [5,6].

The plane-parallel laminar flow is among the least common motions of this nature [7,8]. Laminar flow mainly occurs in machine tools in narrow rectangular shear paths, which are characteristic of lubricated bearings [6].

Plane-parallel flows are mainly in the turbulent regime, and the hydrodynamic quantities often change depending on time, i.e., they are unsteady. In this sense, the study of turbulent unsteady motion has important practical significance and theoretical interest.

During turbulent motion, frictional stresses arising between current layers depend on the distance from the stationary wall [1,9]. In a turbulent current, the solutions obtained by the function introduced for the calculation of the turbulent stresses depending on the distance from the stationary wall provide the findings of the structural changes of the current [10]. Similar research was conducted in [14].

In reference [15], an attempt was made to account for the velocity component normal to the wall in addition to the longitudinal velocity component. The novelty of this research lies in the inclusion of the second velocity component, which was made possible through thoroughly conducted experiments. According to the study results, not all values of turbulent stress approach the self-similar asymptotic state at the same rate as the Reynolds number increases, with the Reynolds shear stress approaching this state more rapidly than the longitudinal normal stress.

Reference [16] presents the primary accomplishments in the study of the transition period and turbulence over the past thirty years. Despite all efforts, some inevitable omissions will continue to be explored as turbulence research continues to deepen. The impact of the pressure gradient on the universal logarithmic law governing the average velocity profile was investigated in reference [17].

The Aim and objectives of the study

The research aims to uncover the patterns governing changes in the hydrodynamic parameters of a viscous fluid during unsteady turbulent plane-parallel flow.

To achieve this objective, the following tasks are addressed:

- formulating the boundary value problem and specifying the initial and boundary conditions,
- developing a method to solve the boundary value problem and unveiling the patterns of change in hydrodynamic parameters in unsteady turbulent plane-parallel flow,
- constructing graphs illustrating the variations in axial velocities over time and with changes in pressure gradient,
- determining the stabilization time of the unsteady process.

Materials and Methods

Choosing a Calculation Scheme

As is well known, frictional stresses develop between layers of fluid in turbulent flow, with their magnitude dependent on the position of the current point.

According to Boussinesq, frictional stresses occurring between fluid layers in the case of smooth lateral movement are determined by the y-coordinate measured from the stationary wall, as described by the following equations [1,2 and 9].

$$\tau = -\rho \varepsilon \frac{d\overline{u}}{dy},\tag{1}$$

where ε is the kinematic coefficient of turbulent viscosity.

Kinematic viscous factor in case of turbulent unsteady flow has not been studied deeply, thoroughly. Therefore, to investigate turbulent unsteady flow, we will initially employ the assumptions made for stationary turbulent flows as a first approximation [4]. The kinematic coefficient of turbulent viscosity, depending on the distance of the point from the stationary wall, changes according to the linear law:

$$\varepsilon = n \cdot y. \tag{2}$$

A perfect match between theoretical and experimental investigations is provided by the link between the kinematic coefficients of turbulent viscosity (2) for stationary turbulent motions [2]. When stationary turbulent motion occurs under the flow section, this linear relationship results in a logarithmic power distribution. This power distribution closely matches the findings of experimental research [7].

Matching the linear relationship of the kinematic coefficient of viscosity in stationary turbulent flows with considerable accuracy can also provide some accuracy in unsteady turbulent motions.

Statement of the problem and formulation of the system of differential equations for the study

To formulate the equation of unsteady turbulent motion, let's isolate the mass of the elemental fluid from the moving current and establish the differential equation of its motion, so we have (Fig.1)

$$\mathcal{O}\frac{\partial u}{\partial t} = -\frac{\partial p}{\partial z} + \frac{\partial \tau}{\partial y}.$$
(3)

Inserting the value of the kinematic coefficient of turbulent viscosity in (3) we get

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$$\frac{\partial \overline{u}}{\partial t} = -\frac{1}{\rho} \frac{\partial p}{\partial z} + n \left(\frac{\partial \overline{u}}{\partial y} + y \frac{\partial^2 \overline{u}}{\partial y^2} \right). \tag{4}$$

Assuming plane-parallel flow to be axisymmetric and isothermal, it follows that the pressures within each fixed cross-sectional area are the same across all its points, meaning that:

$$\frac{1}{\rho} \cdot \frac{\partial p}{\partial z} = f(t).$$
 (5)

Therefore, the study of the unsteady turbulent motion in the case of a plane-parallel flow is presented by



Fig. 1. Schematic diagram of the plane-parallel turbulent flow

$$\frac{\partial \overline{u}}{\partial t} = -f(t) + n \left(\frac{\partial \overline{u}}{\partial y} + y \frac{\partial^2 \overline{u}}{\partial y^2} \right)$$
(6)

The above equation can be solved under the following boundary conditions:

$$\bar{u}(y,t) = 0$$
, when $y = 0$, $t > 0$,
 $\bar{u}(y,t) = \phi(y)$, when $t = 0$, $(0 < y < 2h)$. (7)

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Let's import dimensionless variables:

$$U(x,t) = \frac{\bar{u}}{U_0}, \quad \frac{y}{h} = x, \quad \frac{P}{P_0} = p ,$$
 (8)

where U_0 is the characteristic velocity of the cross-section, which is equal to the average velocity of the flow cross-section:

$$U_o = \frac{1}{h} \int_0^{+h} \varphi(y) dy.$$
⁽⁹⁾

Eq. (6) and the boundary conditions (8), when expressed in terms of dimensionless variables, take the following form:

$$\frac{\partial U}{\partial t} = -F(t) + \frac{n}{h} \left(\frac{\partial U}{\partial x} + x \frac{\partial^2 U}{\partial x^2} \right), \tag{10}$$

$$U(x,t) = 0$$
, at $x = 0, t > 0$, (11)

$$U(x,t) = \phi(x), \text{ at } t = 0, \quad (0 < x \le 1),$$
 (12)

$$\frac{\partial U(x,t)}{\partial x}|x=1=0,$$
(13)

where

$$F(t) = \frac{P_0}{\rho U_0} \frac{\partial P}{\partial x}.$$

Let's look for the general solution of (10) in the following form [3]:

$$U(x,t) = \sum_{k=1}^{\infty} C_k(t) \cdot J_1(\lambda_k \sqrt{x}).$$
(14)

It follows from the boundary condition (13) that

$$\frac{\partial U(\mathbf{l},t)}{\partial x} = \sum_{k=1}^{\infty} C_k(t) \cdot J_1'(\lambda_k) = 0, \text{ where } J_1'(\lambda_k) = 0.$$
(15)

Hence, (15) represents the characteristic equation of the problem, and its roots will serve as the eigenvalues. Inserting the general solution (14) into (10), we get

$$\sum_{k=1}^{\infty} C'_k(t) \cdot J_1(\lambda_k \sqrt{x}) = \frac{n}{h} \sum_{k=1}^{\infty} C_k(t) \cdot \left[\lambda_k^2 x J''_1(\lambda_k \sqrt{x}) + J'_1(\lambda_k \sqrt{x})\right] - F(t).$$
(16)

It is known that the solution of the below equation

$$\lambda_k^2 x J_1'' \left(\lambda_k \sqrt{x}\right) + J_1' \left(\lambda_k \sqrt{x}\right) + \frac{1}{4} \left(1 - \frac{1}{\lambda_k^2 x}\right) J_1 \left(\lambda_k \sqrt{x}\right) = 0$$
(17)

is the function $J_1(\lambda_k \sqrt{x})$ [3], therefore (16) will be transformed into the following form:

$$\sum_{k=1}^{\infty} C_k'(t) \cdot J_1(\lambda_k \sqrt{x}) = \frac{n}{h} \sum_{k=1}^{\infty} C_k(t) \cdot \left[\frac{1}{4} \left(1 - \frac{1}{\lambda_k^2 x} \right) J_1(\lambda_k \sqrt{x}) \right] - F(t).$$
(18)

To solve the problem, let us expand the F(t) function of the Fourier-Bessel series according to the eigenfunctions of the problem [3], we have

$$F(t) = \sum_{k=1}^{\infty} a_k \cdot J_1(\lambda_k \sqrt{x}), \tag{19}$$

where a_k are coefficients of the series.

In order to determine the above coefficients, multiply the two parts of (19) by the expression $J_1(\lambda_m \sqrt{x}) dx$ and integrate in the (0.1) range, we have

$$\int_{0}^{1} F(t) \cdot J_1(\lambda_m \sqrt{x}) dx = \sum_{k=1}^{\infty} a_k \int_{0}^{1} J_1(\lambda_k \sqrt{x}) \cdot J_1(\lambda_m \sqrt{x}) dx .$$
⁽²⁰⁾

In the case of arbitrary λ_m and λ_k values, we have the following relations:

$$\int_{0}^{1} J_{1}(\lambda_{k}\sqrt{x}) \cdot J_{1}(\lambda_{m}\sqrt{x}) dx = \begin{cases} 0 & \text{when } k \neq m \\ \int_{0}^{1} J_{1}^{2}(\lambda_{k}\sqrt{x}) dx = \frac{\lambda_{k}^{2} - 1}{\lambda_{k}^{2}}, \text{ when } k = m \end{cases}$$
(21)

From (19), (20) and (21) we get

$$a_k(t) = \frac{F(t)L_0(\lambda_k)}{L_1(\lambda_k)} , \qquad (22)$$

where

$$L_0(\lambda_k) = \int_0^1 J_1(\lambda_k \sqrt{x}) dx \quad , \tag{23}$$

$$L_1(\lambda_k) = \int_0^1 J_1^2(\lambda_k \sqrt{x}) dx .$$
⁽²⁴⁾

Inserting the value of the function F(t) from the (19) into the (18), we get

$$\sum_{k=1}^{\infty} C_k'(t) \cdot J_1(\lambda_k \sqrt{x}) = \frac{n}{4h} \sum_{k=1}^{\infty} C_k(t) \cdot \left[\left(1 - \frac{1}{\lambda_k^2 x} \right) J_1(\lambda_k \sqrt{x}) \right] - \sum_{k=1}^{\infty} a_k(t) \cdot J_1(\lambda_k \sqrt{x}).$$
(25)

To determine the $C_k(t)$ coefficients, let's multiply both parts of (25) by $J_1(\lambda_k \sqrt{x}) dx$ and integrate in the interval [0.1]. Taking into account the function orthogonality condition (21), we have

$$C_{k}'(t) + \frac{n}{4h} \frac{L_{2}(\lambda_{k})}{L_{1}(\lambda_{k})} C_{k}(t) = a_{k}(t), \qquad (26)$$

where

$$L_2(\lambda_k) = \int_0^1 \left(1 - \frac{1}{\lambda_k^2 x}\right) J_1^2(\lambda_k \sqrt{x}) dx.$$
⁽²⁷⁾

Let's present (26) in the following form:

$$C'_{k}(t) + \alpha \beta C_{k}(t) = -a_{k}(t), \qquad (28)$$

where

$$\alpha = \frac{n}{4h}, \quad \beta_k = \frac{L_2(\lambda_k)}{L_1(\lambda_k)}.$$

The solution of (28) will be

$$C_k(t) = \exp(-\alpha\beta_k t) \int_0^t a_k(\tau) \exp(\alpha\beta_k \tau) d\tau + C_k \exp(-\alpha\beta_k t).$$

Inserting the value $a_k(t)$ into the last equation, we have

$$C_{k}(t) = \frac{L_{0}(\lambda_{k})}{L_{1}(\lambda_{k})} \exp(-\alpha\beta_{k}t) \int_{0}^{t} F(\tau) \exp(\alpha\beta_{k}\tau) d\tau + C_{k} \exp(-\alpha\beta_{k}t).$$
(29)

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Let's consider a special case of the problem, when $F(\tau) = B_0 = Const$, we have

$$C_{k}(t) = \frac{L_{0}(\lambda_{k})B_{0}}{\alpha\beta_{k}L_{1}(\lambda_{k})} (1 - \exp(-\alpha\beta_{k}t)) + C_{k} \exp(-\alpha\beta_{k}t).$$
(30)

Inserting the value $C_k(t)$ into (14) we have

$$U(x,t) = \sum_{k=1}^{\infty} \left\{ C_k \exp(-\alpha\beta_k t) + \frac{L_0(\lambda_k)B_0}{\alpha\beta_k L_1(\lambda_k)} (1 - \exp(-\alpha\beta_k t)) \right\} \cdot J_1(\lambda_k \sqrt{x})$$
(31)

In accordance to the initial $U(x, 0) = \varphi(x)$ condition of the problem (12), we get

$$\phi(x) = \sum_{k=1}^{\infty} C_k \cdot J_1(\lambda_k \sqrt{x}), \tag{32}$$

from where

$$C_{k} = \frac{\lambda_{k}^{2}L_{k}(\lambda_{k})}{(\lambda_{k}^{2}-1)J_{1}^{2}(\lambda_{k})},$$
(33)

$$L_{k} = \int_{0}^{1} \phi(x) J_{1}\left(\lambda_{k} \sqrt{x}\right) dx.$$
(34)

Inserting the value of C_k from (33) into (31), we get the solution to the problem:

$$U(x,t) = \sum_{k=1}^{\infty} \left\{ \frac{\lambda_k^2 L_k \exp(-\alpha\beta_k t)}{(\lambda_k^2 - 1)J_1^2(\lambda_k)} + \frac{L_0(\lambda_k)B_0}{\alpha\beta_k L_1(\lambda_k)} \left(1 - \exp(-\alpha\beta_k t)\right) \right\} \cdot J_1(\lambda_k \sqrt{x}) .$$
(35)

It is obvious that the obtained solution satisfies the boundary condition of problem (11). Given that

Eq. (35) will take the following form:

$$U(x,t) = \sum_{k=1}^{\infty} \left\{ \frac{\lambda_k^2 L_k \exp(-\alpha\beta_k t)}{(\lambda_k^2 - 1)J_1^2(\lambda_k)} + \frac{B_0 \lambda_k^3 F \left\lfloor \left\{ \frac{3}{2} \right\}, \left\{ 2, \frac{5}{2} \right\}, -\frac{\lambda_k^2}{4} \right\rfloor}{3\alpha\beta_k (\lambda_k^2 - 1)J_1^2(\lambda_k)} (1 - \exp(-\alpha\beta_k t)) \right\} \cdot J_1 \left(\lambda_k \sqrt{x} \right)$$
(36)

Using the general solution to the problem, let's derive solutions for private cases. In particular, accepting $U(x, 0) = \varphi(x) = A_0$, we have

$$L_{k} = \int_{0}^{1} \phi(x) J_{1}(\lambda_{k} \sqrt{x}) dx = A_{0}L_{0} = \frac{1}{3}A_{0}\lambda_{k}F\left[\left\{\frac{3}{2}\right\}, \left\{2, \frac{5}{2}\right\}, -\frac{\lambda_{k}^{2}}{4}\right].$$

Therefore,

 β_k

$$U(x,t) = \sum_{k=1}^{\infty} \left\{ \frac{A_0 \exp(-\alpha\beta_k t)}{3} + \frac{B_0 \lambda_k^3}{3\alpha\beta_k} (1 - \exp(-\alpha\beta_k t)) \right\} \cdot \frac{\lambda_k^3 F\left[\left\{ \frac{3}{2} \right\}, \left\{ 2, \frac{5}{2} \right\}, -\frac{\lambda_k^2}{4} \right]}{(\lambda_k^2 - 1) J_1^2(\lambda_k)} J_1(\lambda_k \sqrt{x})$$
(37)

These solutions allow us to determine the axial velocities at any point within the cross-section at any given moment in time.

Discussion of experimental results

Eq. (37) determines the velocity change at the current shear point during an unsteady turbulent flow. Let us examine two specific cases.

1. The fluid in the pipe is stationary and is affected by a constant pressure gradient. Acceleration of the fluid occurs, the speed increases from A=0 and becomes equal to the speed of stationary motion. The change in strength at any point in the effective cross-section, depending on time (t), was determined by (37). After computer analysis, flat (Fig.2) and spatial (Fig.3) velocity change graphs were created.



Fig. 2. *Viscous fluid velocity change in case of unsteady plane-parallel flow when* $A_0=0$, $B=10 \alpha = 1$



Fig. 3. Spatial graph of viscous fluid velocity change in case of unsteady plane-parallel flow when $A_0 = 0$, $B = 10 \alpha = 1$

2. The incoming fluid possesses an initial velocity of $A_0=1$, and a constant pressure gradient influences the fluid. Velocity variations within the cross-section were derived from (37), and the corresponding graphs, for different time (t), are shown in Figure 4. The spatial image corresponding to these graphs is presented in Figure 5.

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Fig. 4. *Viscous fluid velocity change in case of non-stationary plane-parallel flow when* $A_0 = 1$, B = 5, $\alpha = 1$



Fig. 5. Spatial graph of viscous fluid velocity change in case of unsteady plane-parallel flow when $A_0 = 1$, B = 5, $\alpha = 1$

The velocity change graphs show that the fluid in a state of rest begins to move in the layers near the wall forming a boundary layer, in which friction forces arise, and the fluid moves like a solid body outside of it in the core of the flow. Here, there is no sliding between the layers of fluid, hence the presence of frictional forces. Gradually the boundary layer expands and cover the entire cross-section. The dependence of the viscous forces on the distance from the wall extends throughout the entire cross-section of the flow.

Conclusion

- 1. To study the alterations in hydrodynamic parameters during turbulent unsteady plane-parallel viscous fluid motion, a boundary problem was developed. This problem is constructed on the basis of variations in the dynamic viscosity coefficient of the fluid, considering its dependence on the distance from the stationary wall.
- 2. An analytical method was developed to solve the boundary value problem, resulting in analytical solutions for velocity variations under unsteady motion conditions. For instance, the hydrodynamic parameters of the flow during plane-parallel motion were observed under conditions of equal velocity distribution and constant pressure gradient in the stationary and inlet sections. The derived patterns of hydrodynamic parameter changes enable conclusions and generalizations to be made.

3. The graphs obtained enable to track down the evolution of hydrodynamic parameters and to assess the quantitative and qualitative impact of the geometric parameters of the problem on these parameters.

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.

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BETWEEN REASONING AND RESONANCE PROPOSAL OF INTELLIGIBILITY FOR INHABITING THE CROSSROADS OF THE FIVE CHINESE ELEMENTS AND THE FIVE PLATONIC SOLIDS

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Abstract: This thesis explores the heuristic virtues of a correspondence hypothesis between two cosmogenesis, the Greek 5 Platonic solids and the Chinese 5 agents - wuxing. This research deploys its coherence by weaving transdisciplinary links, from works in Chinese medicine, polyhedral geometry, philosophy, mechanics of structures, and systemic - and by using different methodologies: translation, metaphor, mathematic isomorphism... Hypotheses follow one another: 1- clarify the classification 5 or 6 of the wuxing (Granet, Lavier); 2- develop the geometric organon (Serres); 3- identify the sphere as a matrix (Fuller): 4 deepen the structural dualism (Wester): 5-recognize each of the cosmogonies as a general system (Bertalanffy, Rosen). By clearing a path between the epistemological regimes of the different disciplines, this work - if it sheds light on this mysterious Timaeus and explains the different systems of TCM proposes more broadly, a new intelligibility of living in resonance with the world (Rosa).

Keywords: Cosmogeneses, platonic solids, Chinese agents, resonance, geometric organon, general systemology, architecture, structural dualism.

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Introduction

Issues and objectives of the thesis

This article is a summary of the presentation of the architecture thesis that I defended on 8 December 2023 at the Ecole Nationale d'Architecture de Lyon - with Isabelle Lefort as research supervisor. The jury was composed of: - Jean-Pierre Chupin, Professor, PhD, CRC-ACME Chair, University of Montreal, rapporteur and president of the jury; - Jean Dhombres, Professor Emeritus at EHESS, Rapporteur; - Romain Anger, Professor STA at Ensa de Lyon, examiner; - Françoise Ged, Professor at UMR - EHESS China, examiner; - Antonella Mastrorilli, STA Professor at ENSAP, Lille, examiner; - and Isabelle Lefort, Professor Emeritus at Lyon 2, thesis supervisor.

This thesis - started at the Faculty of Philosophy of Lyon 3, with J.-C. Beaune, in the 90s - is the culmination of a long professional path - as a teacher of geometry and structural morphology - and an intellectual path - as a researcher and practitioner of Chinese culture, through *taiji quan* and its medicine.

Ultimately, I aim to try to establish a correspondence [1] between Greek thought and Chinese thought:

Greek thought produced geometric abstraction. It enabled what is known as Western modelling, the basis of the sciences, which are founded on primarily *causal reasoning*,

Chinese thought - on the other hand - developed a non-dichotomous approach, more closely linked to movement and energy transformations - it is closer to the living - and is based on more *correlative knowledge* [2].

To explore this correspondence, I have chosen to work on the foundations of these two cultures: firstly, the Platonic cosmogenesis that appears in the 5th century BC in the *Timaeus* [3] - with the 5 regular polyhedra, also known as *Platonic solids* - and the Chinese cosmogenesis, the *5 elements (wuxing* in Chinese; Ξ $\bar{\tau}$ which link man to his environment [4] and which appear in the work *Shu King*, from the same period [5]. The question then is: are we talking about the same cosmogenesis - or even of the same *general system*? (Fig. 1).

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Fig. 1. On the left: polyhedral variations based on the five Platonic solids. Etching from "Ein aigentliche und grundtliche anweysung in die Geometria" - Hirschvoge, 1543 (Public domain)
On the right: diagram of the interactions between the wuxing. The "generative" cycle is illustrated by blak arrows running clockwise on the outside of the circle, while the "destructive" or "conquering" cycle is represented by white arrows inside the circle.(Wikipedia - GNU Free Documentation License)

Why work on the 5 Platonic solids and the 5 Chinese elements?

First of all - on the Western side - because Plato describes the creation of the universe with these 5 polyhedra: this cosmogenesis is based on geometric forms "*in their nascent state*". However, the text of the *Timaeus* remains obscure! It offers few clues. The 5 polyhedra are associated with the 4 Greek elements. They are presented as *bodies in constant motion* (53c-54c). As a whole, therefore, they can be seen as a complete cycle of transformations (57d-58d). Architects are obviously concerned by this morphogenesis: geometry, proportions and harmonic lines are the basis of all architecture in the West - numerous treatises on the subject have been written from antiquity to the present day [6] (Fig.2).

On the other hand, on the Eastern side, the 5 *Chinese elements* are based on experience and observations dating back thousands of years concerning man's interaction with his environment: they are therefore a possible model for *inhabitation* in the sense of M. Heidegger [7]. These Chinese observations and experiences are brought together in the following table of correspondences (Table). In this Table, the 5 elements - wood, fire, earth, metal, and water - are associated with orients, seasons, the components of man's body, and everything that influences and interacts with his environment... For example, the element *fire* is associated with the South, summer, the color red, the organ of the heart, the tongue, joy, bitter taste, and so on.



Fig. 2. Portrait of Luca Pacioli, traditionally attributed to Jacopo de' Barbari, 1495 (Wikipndia- Public Domain)

 Table. In order to explain the integrity and complexity of the human body, Chinese medical scientists and physicians use the Five Elements theory to classify the human body's endogenous influences on organs, physiological activities, pathological reactions, and environmental or exogenous influences (https://en.wikipedia.org/wiki/Wuxing_(Chinese_philosophy))

Movement	Wood	Fire	Earth	Metal	Water
Planet	Jupiter	Mars	Saturn	Venus	Mercury
Mental Quality	idealism, spontaneity, curiosity	passion, intensity	agreeableness, honesty	intuition, rationality, mind	erudition, resourcefulness wit
Emotion	anger, kindness	hate, resolve	anxiety, joy	grief, bravery	fear, passion
Virtue	Benevolence	Propriety	Fidelity	Righteousness	Wisdom
Zang (yin organs)	liver	heart/pericardium	spleen/pancreas	lung	kidney
Fu (yang organs)	gall bladder	small intestine/San Jiao	stomach	large intestine	urinary bladder
Sensory Organ	eyes	tongue	mouth	nose	ears
Body Part	tendons	pulse	muscles	skin	bones
Body Fluid	tears	sweat	saliva	mucus	urine
Finger	index finger	middle finger	thumb	ring finger	pinky finger
Sense	sight	taste	touch	smell	hearing
Taste ^[23]	sour	bitter	sweet	pungent, umami	salty
Smell	rancid	scorched	fragrant	rotten	putrid
Life	early childhood	pre-puberty	adolescence/intermediate	adulthood	old age, conception
Covering	scaly	feathered	naked human	furred	shelled
Hour	3-9	9–15	change	15-21	21–3
Year	Spring Equinox	Summer Solstice	Summer Final	Fall Equinox	Winter Solstice
360°	45–135°	135–225°	Change	225–315°	315–45°

One of the ambitions of this architecture thesis is ultimately to be able to activate these correspondences and link the different qualities of built forms with *inhabiting*. In concrete terms:

The first objective is to complete this table with the 5 regular polyhedra, in both their *structural* and *structural* aspects [8] - and thereby propose an explanation of Platonic cosmogenesis,

In the 2nd stage, we will use - reciprocally - Plato's geometrical system to provide a cartography of Traditional Chinese Medicine: this in turn will make it possible to explain the *wuxing* and, once again, to relate forms and human existence in a new light,

Finally, the last ambition of this thesis - less developed in this article - is to consider how Plato's system and the *wuxing* can correspond to a *general system*, in the sense of L. von Bertalanffy.

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Methods, Context and Difficulties

In carrying out this work, I came up against epistemological and methodological obstacles.

On the Greek side, since Plato, cosmogenesis has remained an enigma as to its origin and meaning. This mystery has never been solved, despite attempts such as that of Kepler (Fig.3).

On the Chinese side, *wuxing* accounts for living processes, and is present in traditional thought and medicine throughout Asia. But as M. Porkert [9] points out, *wuxing* remains the doctrine of an empirical tradition - and therefore not credible to Western scientists. In addition to these difficulties, a rapprochement between these two cultures is rarely envisaged. M. Foucault considered such a rapprochement improbable [10] - so alien are these two modes of thought and expression considered to be [11] - and many sinologists (J. A. Lavier, F. Jullien) are similarly unencouraging [12]!

This epistemological context is compounded by other methodological difficulties. I'm not a specialist in the history of science, nor in Greek and Plato, nor Chinese: so I don't have direct access to historical sources. Despite this context - like the old Yugong of Lie Zi - I took up the challenge, and to get around these difficulties, I envisaged three main strategies - *ruses*, in reference to the *metis* of the Greeks [13].



Fig. 3. Inner part of the Universe model with the 5 polyhedra according to J. Kepler (Mysterium Cosmographicum. Translated by A. P. Segonds, Le secret du monde, Gallimard, 1993)

First strategy - the investigator uses clues to reformulate hypotheses

The first strategy is based on J. Dewey's *theory of inquiry*. There is no research without an investigator [14] - and at every stage of research, experience is transformative: of the subject, the objectives and the methods. As it is impossible to be a specialist in several disciplines, the investigator's posture enables him or her to orchestrate much expertise to move the research forward [15]. Thus, the researcher does not proceed by conventional argumentation, but by *abduction*, cross-checking clues and spotting anomalies [16]. And, as with an architectural project, he designs a unified proposal - a totality [17]. For my research, one of the anomalies is the 4 elements for 5 polyhedra in the *Timaeus* [18]; but also in China, the Five Elements themselves are sometimes counted as six! [19].

To sum up, this research is mainly part of a *minor* approach to science [20], as opposed to the *major* approach that has defined the rules of so-called scientific research. It accepts *paths with zig-zag itineraries* [21], reference to *minor* sources as much as first-hand ones, and questioning by successive hypotheses [22] - to end up with new propositions.

Second strategy - a detour outside to flush out the unthoughts

The second strategy consists of identifying the *unthoughts* of our own Western culture. In my opinion, we can only flush them out by a detour outside. I developed this approach – out of step – through China to understand Greece [23]. To highlight the desired correspondence, I carried out a *translation*, starting from *wuxing* towards polyhedra and not the reverse (except for the 5th Season). I therefore opted for a *correlative* approach [24] - which takes a step aside from the *causal* approach, dominant in the West.

Thus, to avoid the trap of the *unthoughts* of my own culture, I have avoided all sources and methodologies from the Western world concerning Plato's system. With this epistemological posture of a researcher in a *minor science*, my research method is therefore not a work of *comparativism* between China and Greece, because the

humility of the researcher makes any overhanging position impossible [25]. Rather than compare, F. Jullien proposes a translation as close as possible to the words, to reveal our *unthoughts*. For my work - which concerns not words, but *systems* - I propose to transpose as closely as possible to the processes of transformation of the Chinese and Greek systems, which, incidentally, enabled me to carry out this investigation without any prior linguistic knowledge. Finally, the aim of this detour via China is to shed light on my original discipline; mainly architectural design processes and structural morphology, but also to propose a response to General Systems Theory.

Third strategy - holistic, systemic approach and notion of organon

The practice of architectural projects has indeed led me to seek a holistic approach, an approach reinforced by my training in systems philosophy – with an emblematic work *Le Macroscope* by J. de Rosnay [26]. But, it is the reference to M. Serres that is central in this study - because he launched the idea of a *purely geometric, qualitative, and rigorous organon* - which would be the *summary of the sciences* [27]. He then clarified that for the description of a system - *topology and energetics are sufficient* [28]. In another seminal work of his philosophy, he puts it another way: "*Yes, knowledge has two centres*" [29]. I have thus been able to hypothesize that the 5 elements (wuxing) are this *energetic* description that is missing to understand Plato's *topological* system, forming together the two centres of knowledge. For my research, this is a real key to revealing the organon!

M. Serres' notion of the geometric organon: the guiding concept of this thesis

Indeed, this intuition of an *organon* - a kind of formal matrix evoking *geometric forms in their nascent state* - undoubtedly refers to Plato's system. This allusion to Aristotle's organon - the definition of which is linked to the notion of *tool* or *instrument* - is clarified in this central extract from M. Serres:

If we were to consider this in its purity, i.e. outside the historical example proposed here [...] we could easily obtain the general organon of sciences that are still only at the descriptive stage [...]. Assuming the success of this undertaking, which is required by all contemporary thought, a new family of real sciences would undoubtedly emerge, which could be called morphological sciences. [...] the language of this geometry, taken in its nascent state, is capable of providing this set of structures, sought after, consciously or unconsciously, by many of the thinkers of our time [27].

To ensure correspondence between Timaeus' cosmology and Chinese cosmology, the *organon* sought in this study is therefore a spatial arrangement of the 5 regular polyhedra, which expresses - by synthesizing them - the inter-relationships of this geometric system in 3D space. This arrangement is also intended to *translate/transpose* the logic of the *wuxing* transformations. The search for this *organon* became central to this thesis - conceived in 5 Seasons following the *wuxing* model (Fig.4). All the more so I have found no researcher who has successfully linked the 5 elements with polyhedra and even less who has transposed the *wuxing* into a *geometric organon*.

The argumentation will take place in 3 stages.

The 1st stage is the hypothesis of correspondence between the 2 cosmologies, Greek and Chinese, from system to system: matching these two worlds, East and West, through their cosmologies, is already a real challenge.

The 2nd stage consists in updating this *organon* - and checking that the geometric transformations at play in the chosen spatial arrangement do indeed translate the properties of the *wuxing*.

The 3rd step is to explore the properties of this *organon* in greater depth: - firstly, as a general system, to shed light on, or even propose, an organization and classification of Traditional Chinese Medicine systems; - secondly, to highlight the role of the sphere as a site for transforming geometric duality.



Fig. 4. Structuring the thesis into 5 seasons in correspondence with the wuxing

First step of the argument: polyhedral-wuxing correspondence - from system to system

The 1st stage of this thesis consists of establishing the *correspondence* between these two *systems* [29] (starting with *wuxing* and transposing to polyhedral geometry), which can finally be interpreted as the *correspondence* of two *models* of the same *system* (Fig.5). Indeed, the *structures* of these two *models* are analogous [30], which means that they can be brought together:

the elements, like polyhedra, are organised with 5 poles and follow a cyclic time [31],

the poles are divided into 2 series, dual for polyhedra [32] and yin/yang for the wuxing,

with a common *central* pole - the *earth* element and the tetrahedron which each belong to both the *yin/yang* and *dual* series - and which in both cases serve as the *origin function* [33] (cf. *compound polyhedra*),

the 2 main operators which define them have analogous transformation modes: *generation* and *control* [34]; and 2 to 2 nesting with portions of common faces or vertices and *duality* for polyhedra [35].



Fig. 5. Left: wuxing diagram, with the central element earth at the top - it is the "support" for both the yang series on the left and the yin series on the right (Wikipedia - GNU Free Documentation License).
In the middle: the 5 regular polyhedra arranged in two series: the series of polyhedra with triangular faces on the left and the series with triangular solid angles on the right - the tetrahedron belongs to both series. Right: correspondence between the two systems based on the wuxing time diagram oriented with the fire element at the top (personal illustration)

Thus the series of polyhedra with triangular faces will be considered yang - on the left in Figure 5 -, while the series with trihedral solid angles will be yin - on the right.

Second stage of the argument: to highlight the organon

John Conway polyhedra nesting principle

The *wuxing generation operator* being, by analogy, the 2 by 2 nesting for polyhedra, to form the *organon*, a first hypothesis consists of bringing together these successive nesting in a centred assembly. All that remains is to choose a particular nesting *sequence* to express as many of the relations in the cycle of transformations as possible - this in as minimal a configuration as possible. The English mathematician J. Conway recently developed a nesting configuration that starts with the icosahedron and ends with the dodecahedron [36] (Figs. 6,7).



Fig. 6. Sequence of nesting polyhedra 2 by 2, starting with the icosahedron (based on A. Pugh's sketches [32]). On the right, is a timing diagram of the wuxing, which also shows the correspondence with the polyhedra

In this hypothesis, the transformations between polyhedra are simply 2 by 2 nesting, without expressing the passages by geometric duality. This sequence of nesting polyhedra follows the cycle of the seasons from spring to winter. It begins with the icosahedron fitting into the octahedron, which in turn fits into the tetrahedron, then (on the 2nd line of Figure 7) the tetrahedron fits into the cube, which fits into the dodecahedron. Conway's model was made using a *Zometool* construction set sold under the name *Keplers Kosmos*. Figure 7 (on the right) shows the scale model.



Fig. 7. The different stages of nesting 2 by 2, starting with the yang series at the top left, then the yin series underneath. The colours of the polyhedra correspond to the colours traditionally associated with the Chinese elements (personal illustrations). Above right, Conway's Zometool model with other colours

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Is *Conway's model* an organon according to the criteria defined above? This model is interesting because: it does have 5 polyhedra,

it corresponds to Plato's account - with the dodecahedron on the outside ending the series,

and it places the tetrahedron at the centre - central polyhedron according to our correspondence.

However, there is no intrinsic geometric property of this nesting that allows the next cycle to be restarted, unless additional smaller and larger models are added indefinitely: we can therefore conclude that it does not reflect the continuity of the cyclical operation of *wuxing*. So we have to look for another way!

A 1st interpretation gap between Greek and Chinese spatiotemporal representations

To look at things differently, we need to pay attention to an initial discrepancy between the two cultures, Greek and Chinese. The structure of wuxing is based on a specific representation of space-time [37] - this representation is out of step with the Greek spatiotemporal representation, as J. A. Lavier has clearly identified in his various works [38] (Figs. 8,9).

For the Greeks, man was subject to two cycles of energy input:

that of the sun, which peaks at midday and at the summer solstice (if the day and year cycles correspond),

and that of the earth - a passive system - shifted by 6 hours for the day or 3 months for the year,

which defines 4 seasons: a hot summer season (white), a cold winter season (dark grey) and two shoulder seasons.



Fig. 8. On the left, the two influences of the sky and the ground on man's ternary energy structure, according to the ideogram attributed to Mencius [39]. On the right, the superposition of the two fundamental energetic influences, that of the sky on the left with a maximum during the day and that of the earth with a maximum in the afternoon (Personal illustrations based on J. A. Lavier's sketches [38])



Fig. 9. The 5 Chinese seasons (personal illustrations based on sketches by J. A. Lavier)

So the Western world sticks to this representation of the Attic calendar with 4 seasons, and this choice fits logically with the 4 *Greek elements*.

But for the Chinese, the red point below - which corresponds to the hottest point in the cycle - marks a boundary, a tipping point. This red point can be seen as an inflection point for the *yin-yang* function - i.e. a change in functioning between:

a 1st yang period - in energetic growth (anabolic),

and a 2nd yin period - decreasing (catabolic),

This means that the 4 Chinese seasons are shifted and centred on the solstices and equinoxes.

What's more, the Chinese calendar has 5 seasons, because the Chinese believe that between the *yang* period and the *yin* period, there is a middle period - a 5th *central season* that allows them to be linked. If the *yang* period is associated with the sky and the *yin* period with the earth, the middle period is associated with man [40], so there are 5 seasons in the year and, more generally, *5 Chinese elements*.

The double manifestation of the centre: a fundamental characteristic of Chinese thought

It should be noted that this *central season* - which corresponds to the *earth element* between *yin* and *yang* - is itself dualise. It is therefore double, belonging to either the *yang* or *yin* series. The consequence for Chinese thought is that there are always two ways in which the *central element* functions, even if this central modality only admits of a single geometric representation. In fact, the tetrahedron is double as soon as we consider the different size and orientation of its dual. This explains, in particular, the ambiguity linked to the number of *wuxing agents*, counted as 5 or sometimes 6.

Identifying a real flip-flop in the functioning between the two series *yin* and *yang* (i.e. an empty zone within the central season itself) means that all the elements that correspond to the *centre* (to the *earth* element in the correspondence tables) belong either to the *yang* series or to the *yin* series: they cannot be on this frontier, which has no *being* in China [41]. These choices of representations have given Chinese culture a particular conception of its relationship with the world - due to the attention it pays to the movement and functioning of the things it observes; whereas Greek culture took a different path, one more concerned with morphology and the state of things.

The aim here is to understand the implications of this shift for the geometry and design of the *geometric* organon. As J. A. Lavier identified, this double functioning of the centre - with a borderline at 45' on the temporal diagram of wuxing - corresponds, for example, to the two yellow colours of sodium [42]. This observation can also be linked to a remark made by F. Jullien in *Ce point obscur d'op tout a basculn*- where he clarifies his criticism of Greek geometry. He compares two motorway signs, one marking the 45th parallel and the other the boundary of a watershed [43]. In the first case, the line is a single, abstract geometric line; in the other, the line is dualized by two functions: the raindrop will reach either "*the olive trees of the Mediterranean or the mists of the Atlantic*". Finally, in the rest of this work, we will find the same distinction in the way the tetrahedron works, with the work of T. Wester. But first, we need to design the organon in a way that is consistent with this double consideration of the central element.

New organon hypothesis, tetrahedron to tetrahedron nesting

To incorporate the dual function of the tetrahedron into the design of the *organon* from the outset, this new hypothesis is based on a centred nesting (like that of J. Conway), but which starts with the first tetrahedron (which is on the inside of the *organon*) and ends with the last tetrahedron (on the outside). This new configuration of the organon is therefore made up of the 5 nested polyhedra - plus the last tetrahedron which completes the cycle: making a total of 6 polyhedra (Fig.10). We might also speculate that it was the same initial intention - to express the whole manifestation of forms - that led Lai Zhide to design his *taijitu* with two inner/outer circles thus expressing this dualization of the centre (Fig.11, on the right).



Fig. 10. Nesting of yin polyhedra on the left, then yang polyhedra on the right (own drawings)

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In this particular sequence, on the spatiotemporal diagram of the *wuxing* that serves as a reference (South above - in Figure 11, on the left), we can identify a transformation by duality, between dodecahedron and icosahedron. Initially, the one that operates between the two tetrahedrons is not represented.



Fig. 11. On the left, representation of polyhedra and 2 by 2 nesting in correspondence with the wuxing time diagram; in the centre, the centred organon; on the right, Lai Zhide's taijitu

The same question then arises as for Conway's model: does this nesting with the 6 polyhedra "translate" the functioning of the *wuxing* completely, and is it in fact the *organon* we are looking for?

Operation of the wuxing and geometric transformations of the organon

Now that the correspondence between polyhedra and elements has been established, we need to check that the logic of the *wuxing operators* has been correctly transposed into the geometric system. The main problem is still the transition between 2 cycles - with the tetrahedron ending the previous cycle and its dual tetrahedron starting the next. There are two possibilities:

or the next dual tetrahedron is larger than the previous one (which is normal in a growth cycle) and the model grows indefinitely, changing orientation with each cycle,

Or the dual tetrahedron that starts the next cycle is merged with the small initial tetrahedron - (in blue): in this case, the model reproduces itself identically and its orientation remains unchanged.

It is obviously this 2nd option that I have chosen to design the *organon*, because we can imagine that the large tetrahedron, through its *dual transformation*, reproduces itself - in the sense of biology - into a smaller one, which is coherent since this *passage* takes place at the beginning of autumn with the temporal correspondence. The *geometric organon* I propose is thus complete, autonomous and minimal: it can reproduce itself geometrically, indefinitely, without changing shape, orientation or size. Note that the *control operator* corresponds to the *dual transformation* capacity of each pair of polyhedra within the *organon*. This *dual* relationship operates through the 4 points of contact that link the tetrahedral pair and the 6 polyhedra together, and we can hypothesise that these 4 points of exchange belong to a central sphere that would be the very locus of the *dual transformation* [44] (Fig.12) - a hypothesis not developed here.



Fig. 12. How wuxing works and the geometric transformations of the organon

We should again highlight this difference with Conway's model, which has only one tetrahedron and could therefore be considered from a strictly geometric point of view as a Greek interpretation of the *organon*. Moreover, the question of the orientation in traditional Chinese space required to model the *organon* is addressed later.

The Organon and T. Wester's structural dualism

To give substance to this discovery (and to clarify the problems of classifying architectural structures), I then delved into the work of Ture Wester, since he is the only researcher to have identified the dual functionality of the tetrahedron, extending the notion of *geometric dualism* to structural morphology [45] (Fig. 13).

Although T. Wester made some errors of interpretation [46], this dual structural existence of the tetrahedron is essential for understanding the organon. Indeed, we have seen that the series of polyhedra with triangular faces is *yang* - and the series with trihedral solid angles is *yin*. When we look at the digital model of the *organon*, we can see that in order to make a stable scale model, it is necessary to materialise what connects the *yang* polyhedra - i.e. their common face portions - and what connects the vin polyhedra, i.e. their common trihedral solid angle portions. To do this, it is possible to conceive of the yang polyhedra as made up solely of their faces - and the vin polyhedra solely of their vertices. This leads us to design and represent the two tetrahedral supports/shells of the organon (inner and outer) - in expressing their structural dualization, and then to give them a name. The outer tetrahedron, created solely by means of its faces - using plates (as defined by Wester [45]) - I called it a *tetraplate*. The inner tetrahedron made only with its vertices uses an embedment of its solid angles, a structural mode that I decided to call podes: it will be called a tetrapod (Fig.14).



Fig. 14. The tetrapod on the left and the tetraplate on the right with the tetrapod inside (personal drawings)

Fig. 13. In a 1987 preprint article entitled "The plate-lattice dualism", T. Wester highlights the difference between the purely geometric aspects of duality (the two central columns of the figure, where he already identifies a difference in the size and orientation of the dual tetrahedra) and the fact that materiality is taken into account, where he distinguishes between a "vertex tetrahedron" and a "face tetrahedron" (in the peripheral columns)

The whole organon is then made up of yang polyhedra made up of plates and yin polyhedra made up of advantage of this podes. The conception of Plato's system is that the transformation of a polyhedron into its dual transforms not only the general shape of the polyhedra, but also the functioning of its components: plates can be transformed into podes and vice versa. We can thus define two fundamental structural modes in structural morphology: polyplates and polypodes.

To these two modes can be added a 3rd intermediate mode - corresponding to the *central element* in Chinese way of thinking - which ensures their relationship and which is made up of two force members with dual functions - traction or compression. This makes it possible to rethink structural morphology, as well as its various architectural applications and the teaching of structures [46].

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Two organon modes: centred/yang and off-centre/yin

On the basis of the founding *tetraplate/tetrapod* pair just as there is 2 *wuxing* diagrams - temporal and spatial [47] - I have highlighted a variant of the *centred organon*, which I have called the *off-centre organon*. The 2 *organon* I propose share the same structure of 2 nested tetrahedra; but in the case of the *off-centre yin organon*, the 4 other polyhedra are located in the 4 free spaces of the large tetrahedron (Fig.15).



Fig. 15. *Temporal and spatial diagrams of wuxing (Wikipedia, GNU Free Documentation License)Below. Starting from the tetrahedral core/shell: the centred organon on the left - the off-centre organon on the right*

The advantage of this off-centre - spatial - expression of the *organon*, in keeping with the correspondences of the *wuxing*, is that it makes it possible to differentiate the polyhedra by attributing to them the colours of the Chinese elements - the red octahedron, for example - and to take into account a process of materialisation for these volumes [48]. Moreover, the fact that this *yin* organon was envisaged as a formal matrix for designing an architectural project [49] has raised the problem of the general orientation of the *organon* between *sky* and *ground* (Fig.16).



Fig. 16. Architectural project based on the off-centre organon

As the edge is the *central component* (dual to itself) in relation to the dual face/vertex pair, it is logical to position the external tetrahedron on an edge. The choice of the lower East-West edge allows us to have an upper North-South edge - which may correspond to the 2 *celestial* and *terrestrial axes* defined in Traditional Medicine [50] - and to orient the 4 volumes in plan, with the octahedron to the South.

Third stage: reciprocally, the organon as a resource and hypothesis of an isomorphism

From the outset, the aim of this thesis was to develop the hypothesis of M. Serres (and perhaps also of his mentor G. Bachelard [51]) of a general *organon* summarising the sciences - even if this remains a very ambitious objective! According to this study, if the *organon* transposes all the properties of the *wuxing* and vice versa, by analogy - or *isomorphism*, if we consider it as an ideal form of analogy [52] - there is nothing to

prevent us from hypothesising that the *organon* could shed light on the structure of the *wuxing* and hence on the foundations of TCM - TCM being based on the *yin/yang-wuxing* foundation [31].

It is therefore conceivable that the *off-centre organon* could provide a map of the various TCM subsystems. This bold hypothesis is possible by considering a perfect analogy [53] between:

the ratio "*face of a regular polyhedron*"/"*polyhedron of the organon system*" in their ability to characterise, by a number n of boundaries, the limit of a closed space (2D and 3D),

and the ratio "*sub-system of the TCM associated with a pole*"/"*pole of the large wuxing system*" in their capacity to organise a cyclical system of a type of man-environment relationship with a number n of polarities.

This analogy and the orientation of the two *celestial* and *terrestrial axes* make it possible to classify the various TCM sub-systems - such as the meridian systems (8 extraordinary and 12 standard) or the 6 energy system - according to the general logic of the *wuxing* (Fig. 17, right) [54].



Fig. 17. The 2 celestial and terrestrial axes and the classification of the different TCM systems

Results and Discussion: wuxing and organon, the same general system?

This thesis proposes a *geometric organon* that complements the Chinese *5 element* energy system. If these two symbolic halves find their meaning - once brought together - and respond to the four major functions of the *symbol* identified by G. Durand [55], is it reasonable to think that they constitute what can be considered a *general system* [56]? Firstly, the *organon/wuxing* correspondence provides an answer to M. Porkert's remark that *wuxing* cannot be considered a scientific theory - and it is difficult not to consider *wuxing* as a *general system* in its cultural context. And at the same time, this correspondence, thanks to the *minimality* of the *organon*, answers R. Rosen's problem [52]:

[To establish the most adequate definition of a "general system"] One can study modelling in the context of an arbitrary equivalence relation imposed on a class (or category) of systems; such an equivalence relation says precisely that any two systems in the same equivalence class are indistinguishable with respect to a certain property P that defines equivalence. (...) One of the fundamental problems of modelling is to extract from this equivalence class a certain canonical representative, characterised by an additional property of simplicity and minimality.

It thus becomes possible to hypothesise the same *equivalence class* and an *isomorphism* between these *wuxing* and *organon* representatives. This thesis ultimately proposes several models for the knowledge of this *general system*, the truth of which only emerges through these different interpretations [57] - others could be the narrative structure of certain films or the *C-K Design Theory* [58]. Can we conclude from this that this *general system* ultimately needs no further - additional - demonstration? Yes - by *correlative reason* [59] - because it exists by itself, defined by the interplay of its Chinese correspondences and its *minimal geometry*.

Conclusion - Greek unthought: geometry?

"*Geometry has no colour*", as Jean Dhombres so aptly pointed out in his thesis report: that is the problem. Because geometry retains only the state of things - having chosen to abstract them - it forgets how they work. This is one of the *unthought* of Greek culture, as F. Jullien has developed in his work. This choice has had

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consequences for the whole of Western culture. Geometry can be seen as the origin of Greek thought, with its capacity for modelling. It is the power of the Western world, with Newton's science applied to mechanisms [60] - the *major mode* of science. But if geometry had developed in China, it would very likely have had different colours. Geometry alone cannot account for the living world. And our space-time, because it is inhabited, is part of the living world. The association of polyhedral geometry with the correlations of the *five elements* - thus linked to the human body and its environment - makes it possible to qualify these pure forms to think and design a habitat *in resonance* - in H. Rosa's meaning [61] - and finally to open the way for a *correspondence* between China and Greece cultures.

Conflict of interest

The author declares that there is 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.

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INVESTIGATION OF FINE-GRAINED CONCRETE PROPERTIES WITH A MIXED BINDER AND VARIOUS FILLERS



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Abstract: The goal of this work is to investigate the properties of finegrained modified concrete using various aggregates and blended binders. Considering that there is a tendency to reduce the use of Portland cement worldwide, the goal was to develop fine-grained concrete compositions with low clinker binders (mixed binders), which would preserve and even improve the physico-mechanical properties of fine-grained concrete. River and lithoid pumice sands were investigated and used as fillers. Superplasticizer, microsilica, and quicklime were used in different quantities to modify fine-grained concrete. The research results show that, depending on the type of fillers used, the compressive strength of the river sand-based mortar increased by 15.33% after 28 days, and by 6.34% with lithoid pumice, compared to the reference sample. The use of lime resulted in an increase in the density of cement stone for heavy aggregates but a decrease in density for light aggregates, with no significant increase in strength observed.

Keywords: fine-grained concrete, mixed binder, mineral and chemical admixtures, compressive and flexural strengths, carbon dioxide, aggregate activity.

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Introduction

New approaches and innovative technologies used to develop modern composite binders aim to increase the quality of the finished product and reduce the cost, but not at the expense of quality. The quality of cement stone, mortar, and concrete can be increased by controlling the structuring processes through the introduction of various mineral and chemical additives [1].

In the modern construction industry, effective plasticizers and microdisperse active mineral additives are required for obtaining concrete with high-quality operational characteristics, that is, mixed binders with complex additives. Another incentive for using various active mineral additives is the problem of reducing carbon dioxide emitted into the atmosphere [2], which occurs in large quantities during the production of Portland cement, which is a co-construction binder [3,4].

Fine-grained concretes based on mixed binders are widely used in construction in different countries: gypsum-cement, cement–lime, and lime cement. Cement-limetious mortars are widely used for several reasons. First, lime lower the cost of the binder and its carbon traces. According to [5-12], the use of large amounts of Portland cement in concrete and construction mortars leads to the emission of greenhouse gasses and affects the ecology of the environment.

The cement-lime binders increase the material's eco-friendly qualities, and the constructions based on them are more durable because low-base calcium silicates and aluminates are synthesized in the binding stone. Lime increases the plasticity of the concrete mixture but reduces the curing rate at the initial stage. Over time, lime, as an oily binder, improves the mechanical properties of artificial stone [13,14] because the contact zone, especially in the case of amorphous fillers, is better adhered. If the strength of concrete with dense and inactive fillers is determined by the tensile strength of the bonded surfaces (adhesion) and the strength of the binder

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(cohesion), then in concrete with active fillers, in addition to the two factors mentioned, the unique form of adhesion due to the interaction of the filler and the binder plays a significant role.

Methods and Materials

Study of the physical and mechanical properties of fine-grained concrete with the same mixed binder and different fillers

The composition and properties of the cement binder greatly influence the structure of the resulting cement stone and concrete. Concrete properties also depend on the type and amount of fillers [15-17]. The effect of a binder with complex additives was studied in this article, with fillers having different origins and chemical activities.

The interaction of the additive with the inorganic binder takes place in the contact zones of the component particles. The optimal content of the mineral additive corresponds to the amount at which its particles will participate in the pozzolanic reaction, as is possible with the calcium hydroxide formed from the clinker minerals [16,17]. In the case of a small amount of the additive, we will have a decrease in the effectiveness of the impact, and in the case of high content, the contact of the particles of the additive with each other will also lead to a decrease in its impact.

On the other hand, the importance of filler material on the properties of concrete is also known, which is determined by its grain structure, grain porosity, pore shape and size, strength, structure, pozzolanic activity, and strength of adhesion with cement stone [16].

In this study, lime and microsilica were used as mineral additives. Air-setting lime expands several times in volume during lime slaking. In contrast to free super-burnt and very slow lime slaking contained in Portland cement, it slakes quickly, so it does not cause internal stresses during the mortar's hardening process. The import of lime is also due to the activity of vitreous rocks of RA [17].

Lime interacts with the glassy phase of volcanic rocks, determining the mineralogy, phase composition, and structure formation of the resulting artificial conglomerate.

It actively interacts with the vitreous phase of volcanic rocks and determines the mineralogy, phase composition, and structure formation of the resulting artificial conglomerate.

Amorphous volcanic rocks, endowed with energy potential by nature and interacting with lime, produce calcium hydro silicates, hydro aluminates, and other new formations that ensure properties of the artificial stone material. These interactions with different rocks proceed with different intensities because of the difference in the chemical activity of these rocks and the specific surface, which is presented in Figure 1.



Fig. 1. Activities of volcanic rocks of RA

RA is rich in effusive rocks, including tuffs, slags, and pumice. Lithoid pumice, the most active rock, was selected as a light filler after considering the most applicable types of these rocks and taking into account the obtained results.

Unlike rocks containing volcanic, porous, and glass phase, quartz, river, quartz-feldspar, carbonate, and other structured fillers used in artificial aggregates, calcium hydroxide practically does not interact with the base of the rock. However, mortars have certain and sufficient strengths.

The preservation of mineral reflexes in rocks (labrador, oligoclase, pyroxene, olivine, quartz, etc.) up to one year of age in limestones examined by X-ray phase means that they do not undergo chemical interaction with lime crystals [16-18].

Therefore, it became interesting to study the behavior of different fillers in concrete with different types of mixed binders: river sand with a crystalline structure from the Ranchpar mine and lithoid pumice from Jraber with the most active vitreous structure in RA.

Portland cement

A mixed binder was used in the study, in which M500 or CEM II/A-P 42.5 N (EN 197) class Portland cement produced by the Ararat plant was used. The properties and chemical compositions are given in Table 1 and Table 2.

Indicator	Results
water requirement, % by mass of cement	31
real density, g/cm ³	3.1
bulk density, kg/m ³	1081
fineness of grinding, cm ² /g	3550
Compressive strength, MPa	
at 3 days	21
at 7 days	38
at 28 days	52
Setting time, minutes	
start	60
end	330

Table 1. Characteristics of Portland cement

 Table 2. Chemical composition of Portland cement (oxide content in %)

SiO ₂	Al_2O_3	Fe_2O_3	MgO	CaO	SO_3	Loss on ignition
21.9	4.5	2.17	1.1	62.2	2.1	3.2

Micro silica

Micro silica is the most commonly used active mineral additive, with an average particle size of 0.1 microns. It is approximately 100 times smaller than the average size of cement particles. Owing to the large dispersion and the structure of the amorphous state of the particles, micro silica has high pozzolanic activity and is considered an effective micro filler.

The use of micro silica is appropriate for the introduction of additives and superplasticizers. Being a highly dispersed material, it absorbs a large amount of water, and without the superplasticizer mineral admixture, the effectiveness will be reduced to a minimum, which can sometimes lead to a decrease in the strength characteristics of the concrete. Table 3 lists the characteristics of the micro silica.

Characteristics	Results
particle size, micron	0.1
specific surface, m ² /g	pprox 20.0
SiO ₂ ,%	89.1
loss on ignition, %	4.07
bulk density, kg/m ³	332.5
Cl ⁻¹ , %	< 0.1
pH	5.5 ° 1.0
Color	Grey

Table 3. Characteristics of micro silica

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Superplasticizer

Sika Visco Crete 225P was used as the superplasticizer. It is a powdered organic material of the carboxylate group, has a bulk density of 592 kg/m³, and is intended for mortars and concretes.

Quicklime

"Effect Group" CJSC lime was used in the work to increase the workability index of the mortar. It is a dustlike material with a bulk density of 703kg/m³, average lime slaking rate (12 minutes), and high exothermicity (84°C).

Fine fillers

River sand of Ranchpar mine and lithoid pumice sand were used in the study.

The bulk density of river sand is 1765 kg/m³, and lithoid pumice sand is 1066 kg/m³. The chemical compositions and sieve analysis results are given in Tables 4, 5 and 6.

SiO ₂	TiO ₂	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	SO3	Loss on ignition
57.26	0.56	14.68	6.22	-	8.33	4.8	trace	4.56

Table 4. Chemical composition of river sand

			Table 5. (Chemical	composit	ion of lith	oid pum	ice sand		
SiO ₂	Al_2O_3	TiO ₂	Fe_2O_3	CaO	MgO	MnO	R_2O	SO_3	H_2O	Loss on ignition

0.23

7.22

0.15

0.38

3.70

Table 6. Sand residue

0.28

Sieve number	2.5	1.25	0.63	0.315	0.16	< 0.16
River sand, partial residue %	12.81	14.56	26.66	16.98	27.6	1.39
River sand full residue, %	12.81	27.37	54.03	71.01	98.61	100
Lithoid pumice sand, partial residue, %	19.75	20.35	12.06	13.02	15.88	18.94
Lithoid pumice sand full residue, %	19.75	40.1	52.16	65.18	81.06	100

Water

71.15

Water quality meets the requirements of the interstate GOST23732 standard.

1.46

Results and Discussion

14.64

0.13

1.14

In RA, river sand is widely used for heavy aggregate concrete because the choice of heavy sand is limited, which cannot be said for lightweight filler. Jraber lithoid pumice sand was chosen as an active filler in this study.

The binder was modified by adding varying amounts of microsilica and quicklime. Sika Visco Crete 225P super-plasticizer by 0.3% weight of cement was added to heavy concrete (1.5 kg) and light concrete (1.2 kg). 10 batches of specimens were prepared for testing, with 5 batches containing heavy sand and the other 5 containing light sand.

The mortar was prepared with a mixer of MATEST E094 in the following order: cement, micro silica, and lime were mixed for 2 min, sand was added, and mixing was continued for another 2 min. Superplasticizer and water are added to the resulting dry mixture, and the mixing process was continued for another 5 min. In the reference sample, the mass ratio of the binder to sand is 1:3.32. The components of fine-grained concrete with a mixed binder for 1 m³ are given in Table 7.

40x40x160mm test samples were molded from the obtained homogeneous mixture and compacted on a MATEST vibrator with a frequency of 3000 oscillations/min (Fig. 2).

Number	Cement	Superplasticizer	Microsilica	Quicklime	River sand	I ithoid sand
INUITION	kg	kg	kg	kg	< 5mm, kg	< 5mm, kg
1	500	-	-	-	1660	-
2	500	1.5	-	-	1660	-
3	450	1.5	50	-	1660	-
4	400	1.5	50	50	1660	-
5	350	1.5	100	50	1660	-
6	400	-	-	-		1328
7	400	1.2	-	-	-	1328
8	360	1.2	40	-	-	1328
9	320	1.2	40	40	-	1328
10	280	1.2	80	40	-	1328

 Table 7. Compositions of fine-grained concrete

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The peculiarities of the effects of chemical and mineral additives used in the study on the formed stone material are determined by the type of filler used. Mortar made with composite (mixed) binder due to lime slaking were heated during the mixing process. Based on the results obtained, it was observed that the average density and compressive strength of samples made with mixed binder and river sand did not show a significant change when compared to the reference samples (components 1 and 4). However, in the case of flexural strength, a 2.8% increase was recorded which allowed for a saving of 100 kg cement per $1m^3$. Additionally, when the amount of microsilica was increased, there was a 3.6% increase in density and a 15.33% increase in strength which allowed for a saving of 150 kg cement (components 1 and 5) (Fig. 3).



Sand



4x4x16 cm mold with mixture



Quicklime



Mortar mixer

Water





Sika Visco Crete 225P



Cement

Curing tank 550 liters capacity (20° 2)°C temperature, (98° 2)% humidity



Flexural and compressive strenght testing

Fig. 2. Concrete production technology



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Fig. 3. The results of the experiment: average density, flexural strength and compressive strength of heavy concrete

For samples with lithoid pumice, with the addition of lime, compared to the reference sample (compositions 6 and 9), a decrease in density of 2.5% is observed, which hardly affected the durability indicators. By increasing the amount of micro silica, the density of concrete decreases by 2.6% compared to the reference sample. By increasing the amount of micro silica, the density of concrete decreases by 2.6% compared to the reference sample, but the strength increases by 6.32% (compositions 6 and 10), which is explained by the formation of a contact layer (crust) on the surface of the light aggregate (Fig. 4).



Fig. 4. The results of the experiment: average density, flexural strength and compressive strength of lightweight concrete

In river sand mortar, the increase in volume due to lime slaking leads to the compression of the binder particles, because of which the cement stone becomes dense, creating contact zones with the sand.

The test results of concretes made based on river sand showed that both with using a plasticizing additive (component 2) and microsilica (component 3), an increase in strength was observed compared to the reference sample, but it decreased with the introduction of lime, because of SiO_2 low quantities.

This leads to a significant excess of $Ca(OH)_2$ (component 4), and with an increase in the amount of silica, pozzolanic reactions between lime and silica again occur, and the strength of the formed stone increases (component 5).

With lithoid pumice, exactly the opposite phenomena occur. The developed specific surface of pumice, which has open and communicating pores, enables the penetration of slaked lime grains into them, which leads to a decrease in the average density of the cement stone, creating a contact layer rather than a contact zone between the cement stone and the aggregates. Because of the decrease in the density of cement stone, the strength of concrete decreases (component 9), which according to [16-18] will continue to increase over time, which is explained by the chemical interaction processes to bind the lime due to the pozzolanic property of pumice, which does not develop quickly, but over tens of years, synthesizing low basic calcium hydro silicates and hydro aluminates (helenite hydrate and hydrogarnet).

The addition of micro silica in this case also leads to an increase in strength, but if it reaches the maximum with a similar composition made of river sand, the result obtained with a composition made of lithoid sand is not the highest strength (the highest: composition 8).

Conclusion

The lime increases the plasticity of the concrete mixture, but reduces the strength at the initial stage of hardening, which is not so convenient in monolithic construction, but the hardening process of the binder, which lasts for tens of years, leads to an increase in the strength and durability of concrete, because low-base calcium hydro silicates and hydro aluminates are synthesized.

Lithoid pumice, which has a vitreous structure and developed surface, when used as a filler, forms a deeper contact zone with the cement stone. Because the grain of slaked lime, which is finer than the grains of Portland cement, penetrates into the smaller pores of the filler and, endowed with activity by nature, it takes place in the structure formation process.

With river sand, the filler is inert, and the strength of concrete increases mainly due to the pozzolanic reactions of $Ca(OH)_2$ and quicklime with the mineral additive micro silica.

This leads to an increase in the strength of cement stone and, as a result, of concrete. As a result, the strength of concrete with river sand increased by 15.33% compared to the reference sample.

Using lithoid pumice, for modification of the binder with microsilica and quicklime, the strength of concrete increased by 6.3%, but cement consumption per 1 m³ decreased by 120 kg.

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Conflict of interest

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FOLLOWING ARMENIAN MEMORIES: IN THE MYTH OF VENICE. IN SEARCH FOR DETERMINANTS OF ARCHITECTURAL FORM



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Abstract: To invoke Mnemosyne (goddess of memory in Greek mythology) is to invoke her daughter muses? If so then memory is always behind the imagination. The idea of the research grew out of interest to understand if architecture can be recognized as a physical manifestation of memory. The work is an attempt to demonstrate how remembering is experienced through architectural forms. Literature, psychological and architectural narratives provided a necessary guidance to understand where the conjunctions between the theory and empirical studies of memory lie. After the exploration of different theories comes the time to respond to the question whether memories can be matters of architecture and if they can become principal tools of form finding. That weightless transitional forces making the unconscious to travel back in time and space, somewhere and sometime that you are not anymore. What can we do with them? To seize the forces of our mind and later to submit them to control of our reason as Andre Breton was saying in "First Manifesto of Surrealism". Images, associations and all what is remembered, let them serve as paraphernalia for creative act. The discussion proceeds with a real act of memory connected to Armenian traces of Venice, an architectural experimentation with cultural, personal and contextual memories for definition of new forms on the island of San Lazzaro degli Armeni and in Armenian College Moorat-Raphael.

Keywords: Memory, architecture, forms, images, words, associations.

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Introduction

"Generally people's memories are precious to them. It is no accident that they are coloured by poetry..." Andrey Tarkovsky [1]

The enigmatic relationship between memory and space was a theme that has always inspired intense interest of scholars and artists. In ancient times the idea of remembering was more than just an act "to think of again". It was conceived as the reverse side of imagination and as one of five canons in rhetorical culture. The *art of memory* (Latin: ars memoriae) in ancient Roman and Greek oratorical treatises, was a technique to accurately recall facts and stories with support of places and images, and so architecture was perceived as a mnemonic device for remembering dialogues, narratives and thoughts. The idea of the research grew out of interest to understand if architecture can be recognized as a physical manifestation of memory. The following ideas will seem far from realms of architecture, but in this distant perspectives lays the key to understanding the true creative forces of our minds.

Was the same *ars memoriae* to find it's expression in complex architectural theories and also literary works centuries later. *Q la Rrecherche du Temps Perdu* by Marcel Proust was one of the exemplary novels of 20th century regarding remembrance. This work was an obvious resonance of John Ruskin's extended essay named *Seven lamps of Architecture*, that Proust was translating at times. He believed that memory is hidden beyond the reach of intellect, it is in some material objects and in sensations that they give to us. Remembering is always an impromptu experience, all of a sudden "search of lost time". As in the novel, just tripping against

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two uneven stones makes to recall St. Mark's Baptistery and Venice, "it's profound azure intoxicating the eyes, impressions of coolness and the dazzling light" [2]. Architecture is the *aide-memoire* that helps to remember the moments once lived, and are the forms to trigger the mind to weave together the images and emotions. French philosopher and art historian Georges Didi-Huberman in his book "Images in Spite of All: Four Photographs from Auschwitz" affirms the importance of visual imagery for the *act of memory*: "For in each testimonial production, in each act of memory, language and image are absolutely bound to one another, never ceasing to exchange their reciprocal lacunae. An image often appears where a word seems to fail; a word often appears where the imagination seems to fail" [3].

The four photographs, around which Didi-Huberman composes his narrative, are suffice to retell about the history and to affirm their power, the ability to transmit *in spite of all*. And, indeed, what gets imprinted within us are the images; all that we recall are *snapshots* that memory retrieves from the depths of it's infinity. Time makes these images fade and get intertwined with others, and all what is remembered are not the exact same happenings but blurry reminders of former times.

These theoretical explorations posed another question that was more about practice and performative power of images. What if we take advantage of that weightless transitional forces and start to follow fragments of past that appear in mind? Will they be able to construct new tangible narratives? Here has to be remembered that in Greek mythology Mnemosyne is not just the goddess of memory, but also the mother of nine muses. To invoke Mnemosyne is to invoke her daughter muses. Thus the memory is always behind the imagination. The following is a trial to prove this on the grounds of architecture, manifesting all the traditional conventions of form-finding and letting the memories out of any sequence to tell the direction of a travel, forging new connections, new logic and meanings.

This whim reminds the notions of Aldo Rossi about his *Analogous City* for Venice Biennale of Architecture in 1976 and in particular his definition of Canaletto's *Capriccio with Palladian Buildings* as a "remarkable collage, an imaginary Venice built on top of the real one", the construction of which "takes place by means of projects and things, invented or real, quoted and put together, thus proposing an alternative within reality" [4,5]. Venice was the backdrop also for abstractions proposed in this work, for imaginary collages and practical verifications of the aforementioned statements. As Brodsky says, this place has a molecular affair with each of us and there is a moment when we all spot the elements of our own chemistry in this city. Its myth is not merely about the magical apparition from the waters of the Adriatic Sea, or of historical reputation as an exemplary republic. It has something to do with its non conventional essence, with sensations it creates. And thus there is no better place than Venice to host the mentioned experiments. Besides the mythical nature of this city, there was another important factor that made the choice of the site stronger. The presence of own cultural memories. The connection of Armenians with this place has a long history. This work depicts two important nodes of this relation. The following projects are situated in Armenian Island of Venice and in College Moorat-Raphael. Personal, cultural, contextual remembrances became the performers of presented creative acts.

Method of Parallel Coexistance

The film *Mirror* of Andrey Tarkovsky was, perhaps, an implicit reference for all the experimentations that came to happen after theoretical explorations of remembering. That confusing and without equilibrium sequence of scenes and ideas is the state in which our mind is when remembering the things past. This work attempts to demonstrate this within the field of architecture. To start consciously with memories, leaving them free to begin the process, to collide, to prevail and thus lead to the definition of new forms. While it is true that the latter are always emerging from the depths of our experience and memories are inherent matters of art and architecture, the question is that this usually happens unconsciously, and we only recognize the familiarity of certain elements in the end or during the creative process. The logic here is to inverse the rule and start to put the images appearing in mind on a paper since the beginning, allowing everything remembered to serve as paraphernalia for creative act.

One of the prominent figures in the architectural discourse of the 19^{th} century, EugAne Emmanuel Violletle-Duc, in his series of lectures entitled *Entretiens sur l'Architecture* has offered a methodological explanation of creative act and its link to memory. He states throughout the *Entretiens* that architecture is never an invention *ex-nihilo* and there is always a need to "recourse to the past in order to originate in the present" [6]. This return to the architectural past is not about reclamation or revival, but an act of critical imagination — an analysis to reconfigure the material structures of former times into architecture for the present. Hence, memory is the first faculty to be exercised, and after has to be made an analytical step by active imagination, that comes to compare, choose and order the confused mass recalled by mind.

When dealing with that confusion of intertwining images and thoughts, it is impossible to pass by their psychological narratives. A strong scientific foundation for the studies of memory was the work of Sigmund Freud. As he affirms, psyche is a subterranean archive where memories press their claims on the conscious mind influencing the way it deals with present reality and all what once happens to us never gets cancelled or erased but encoded within us. We carry all the truths in the depths of our unconscious till arises a need to recall one of them. With comparison to Rome he explains the infinity of our mind, and the way it saves all what has once been experienced:

"Now let us make the fantastic supposition that Rome were not a human dwelling-place, but a mental entity with just as long and varied a past history: that is, in which nothing once constructed had perished, and all the earlier stages of development had survived alongside the latest" [7].

He endeavors to compress all the layers of history into one simultaneous depiction. "Where the Coliseum now stands we could at the same time admire Nero's vanished Golden House" [7]. This Rome is perhaps new one, emerging from the superimposition of all the layers of past, without losing any sign of history. It exists all at once. 'Roma Quadrata' of the Palatine, the Rome of the 'Septimontium,' the Rome enclosed in the Servian Wall, and the other images of the eternal city of successive emperors.

This idea of parallel coexistence got it's reflection in works of contemporary artist Idris Khan. His layered artworks are similar to Freud's Rome. These are condensed cultural artifacts, or better to say, melancholic reminders of the passage of time. Pages of books, musical notes, photography are becoming elements of nostalgia in his works. One of the most fascinating examples is his series in homage to iconic couple of photographers of 20th century Bernd and Hilla Becher, who for decades documented types of industrial structures. This series makes to reflect not only of passing time but also of creative power of images. The amalgamation of these industrial types renders them anymore individually recognizable. There are no longer the precise and sharp outlines of industrial architecture documented by Becher, but fluctuating forms on unclear background — new architectures perhaps, emerging from layering one above the other carefully captured figures of past.

Arises a question what if to turn this into a method and to start experimenting with described compression of types, images, associations on the grounds of architecture? Liberating all the confusion of images within us on the outset of form finding process and letting the active imagination to perform further analytical steps. "To seize the forces of our mind and later to submit them to control of our reason" as Andre Breton was saying in *First Manifesto of Surrealism* [8], recognizing also the *geist* hovering over the place, that provides initial cues to the memory about where to meander.

Results and Discussion

As already stated Armenian Traces of Venice were to host the architectural experimentations of this work. Isola di San Lazzaro degli Armeni or Armenian Island of Venice, once a leper colony during Middle Ages, has been home to the Armenian Catholic Monastery since 1717, the headquarters of Mekhitarist Order and a prominent center of Armenian cultural studies. Here is where the *act of memory* started, and as in the aforementioned notion of Georges Didi-Huberman *words and images* were the ones to perform it.

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When thinking of monastic complexes, the first images appearing in mind are blurry memories of *Sanahin and Haghpat*. Massive columns of medieval libraries, the narrow pathway between the churches and those old manuscripts, which are the only witnesses of times when we never were. The weightlessness of words in those writings contrasts the heavy, primordial shapes guarding them. Dedications, prayers or testimonies inscribed on both papers and walls evoke the essence of these ancient monasteries. These monasteries are enclosures, formal and ideological definitions of order, codes to demarcate borders. The shape of the Armenian island and that of Mekhitarist monastery affirm this notion. Enclosed around itself to establish order in the infinity of the Adriatic Sea, safeguarding the accumulated cultural inheritance and its spiritual essence.

These reflections evoke disciplinary memories, recalling in mind the plans of Armenian enclosed monastic complexes, coming from 4th till 12th century. Amaras, Tade, Haghpat, Geghard, Ktskonq, Havoc Tar, Sqanchelagorc, Horomos, Hreshtakapetavanq... Why exactly this nine? There is no precise answer to this question. Some because of their architectural appearance, the others because of personal emotions, and some simply because they now exist just in pages of books or in minds of those who has had a chance to see them. Unique clusters of architectural monuments; several churches, chapel, library, gavit and other buildings for monastic living.

After acknowledging these memories as tools to proceed with, their formal homology helped to find a way for superimposing them. These enclosures share geometric and semantic similarities. A circular or a rectangular tower in the corners of enclosure for observation of surroundings is common in all the compositions. This detail is recognizable also on the plan of San Lazzaro island. A little polygonal terrace on the north-western corner for following the movement towards the monastery from the sea. This element has become a constrain, a *hinge* for placing all the nine remembered plans one above the other (Fig.1).



Fig. 1. The process of superimposition of nine plans and final collage of fragments, model by the author

This was an operation of compressing all these types into one plane as the layered artworks of Idris Khan. After was another contextual reading that suggested the following steps. In his renowned *Fondamenta degli Incurabili* Brodsky writes: "There is nothing Freudian to this fantasy [...] the anarchy of water that spurns the notion of shape. It is as though space, cognizant here more than anyplace else of its inferiority to time, answers it with the only property time doesn't possess: with beauty. And that's why water takes this answer, twists it, wallops and shreds it, but ultimately carries it by and large intact off into the Adriatic" [9].

To twist, to wallop and to shred. It Probably will sound Dadaistic, but if to translate these verbs into formal operations, they will be to rotate, to overlay and to cut. This were the steps with which the act went on. After overlaying of plans just knowing these three operations one unconsciously starts to search for an order. While rotating the plans, the shapes of the monastery were somehow giving hints for directions. And as Aldo Rossi was wondering while looking to Punta della Dogana how the figure of fortune on the golden sphere moves [10], this plans were also finding themselves and their places by *fortune*. But this does not mean that the control was totally relinquished. In the mass of these geometries later the *logic* was to search for new meanings and *to cut or to choose the pieces of the whole* for establishing new connections, sometimes forcing to stay together things that are not supposed to (Figs. 2,3).



Fig. 2. Final composition with remaining fragments, model by the author

Fig. 3. *Axonometry of final composition by the author*

After all the mentioned operations all the former unities result into fragments, pieces of a mechanism whose overall sense is lost^[10]. The monasteries are no more recognizable, but there are still some signs recalling back to them. Gavit of Haghpat or the chapel of Khtskonq. They partially remained as they appeared to be, thus becoming elements of nostalgia within new composition. This new narrative from reassembled pieces is, perhaps, that space designated by Rossi as laying *between logic and biography* [10].

Another verification of creative potential of memories took place in the Armenian College of Venice. A prominent educational institution that has hosted thousands of pupils till the end of last century and that is still and silent today. With every step in this splendid palace memory gets into some tension. Classrooms, scientific, artistic rooms, canteen, chapel...Opening the doors of sequential rooms, even just touching the decorated handles one seems to be in a long forgotten jewel box. And the most precious piece here is the Mirror Hall or Sala Nobile, with immersive paintings of Louis Dorigny and Tiepolo. Upon entering to this room, there is a moment when consciousness gets lost in time. One sees his own reflection but thinks about those who previously stood in front of these mirrors. Memory transfers somewhere back in time and brings some images laying in the depths of the mind. This is perhaps when surreality, that absolute reality comes to happen. You are in a certain space now but mind floats in another time, "memory takes pleasure in weakly retracing for him the circumstances of the dream, in stripping it of any real importance, and in dismissing the only determinant from the point where he thinks he has left it a few hours before" [8].

This space triggers the machine of memory to get accelerated, working with constant collision of images. Taking distant fragments of time and putting them together *according to the law of chance*. The snapshots redrawn here are of different nature, from Parajanov's allegoric shots, appearing in this emptiness burdened with memory, till the arches of the cathedral of Ani and stones of those monuments left back in time and history.

All these images laying between imagination and present moment are laying one above the other amounting to abstraction. "*The metaphysical will find it all the more interesting to* migrate, for whoever wants to follow it, into the space between one image and the other. In the BETWEEN, in the conjunction AND lies the sense of any new juxtaposition" [11]. The measure of this distance is transparency, which, as Colin Rowe defines, is the synonym of words "space-time, simultaneity, interpenetration" [12]. It makes their collision stronger and after suggests different geometrical possibilities for new order (Fig.4). It allows ambiguity and ambivalence. And here is not the chance to decide but logic to recognize new forms.

The collage of this images is similar to the state of mind, to the pathways and chains of that machine which gets into tension when recognizing some elements in space recalling own history. That memory machine itself is not constructed of anything else then the same instants it triggers. From memories and for memories; for that eternal collision and remembrance to happen (Fig.5).



Fig. 4. The chart of recalled images and their collision on the backyard of Armenian College Moorat-Raphael, by the author



Fig. 5. Axonometry of the Machine of Memory on the backyard of Armenian College Moorat-Raphael, by the author

This Machine is a proposal for an installation in the courtyard of Collegio Armeno Moorat-Raphael (Fig.6). The forms derived from this experimentation are all serving for projections of memories starting from the ones of famous alumnae's of the college, visible from interior, till experimental works of Armenian modern artists - surreality by projecting and reflecting images and texts accompanied with notes of Armenian chants.



Fig. 6. The Machine of Memory on the backyard of Armenian College Moorat-Raphael, Projection of "Land" by Martiros Saryan and typographical experimentations of Fred Afrikyan, visualization by the author

Conclusion

There was a constant recourse to Aldo Rossi's *Scientific Autobiography*, when carrying out this investigation around memory and its relevance in architecture. The memory is nothing else but our own biography, as all what we have lived gets imprinted within our cells, encoded in our biological tissue. These inscriptions are laying dormant in the depths of our unconscious till that instant of time when by the help of appropriate reason we reactivate them and force them to become part of new narratives.

These trials, with surrealistic desire to take an advantage of those forces within us, are as already said between own history and logic. Perhaps this is also where the imagination resides. The images and thoughts from own formal background are getting directly manifested within architectural creative acts. These attempts might have resembled to whims, forcing to stay together disparate images or exhausting possible operations from the pages of books. The experimental steps might have seemed irrational, sometimes aggressive and violent, as they are challenging nowadays understandings of design process, making a return to *critical imagination with forms of past*[6] described by Viollet-le-Duc. May be judged the final content of this *surreality* and may be questioned the *logic of this dream* [1], that is far from any functional diagrams and has something to do with more sensitive side of architecture. All this was just to restate that there are still better truths for the form to follow, and concerns that we give to us today are leaving in shadow the real values that architecture has to convey. Has to be remembered that all what we create is an embodied dimension of meanings and understandings of the time. Ruskin once said that there are two strong conquerors of the forgetfulness, poetry and architecture, and the latter in some way includes the former [13].

Whether foreshown attempts to prove the creative potential of images and the infinite search for the shapes of poetry were successful or not has to be judged by others, but there is a certain feeling after this process. "A desire to remake, not in order to effect some change but out of a strange profundity of feeling for things" [10], a certain satisfaction remaining after the end of all these acts, when seeing that resulted forms are not merely old fragmented remembrances but new narratives and new meanings for places strongly linked to cultural history.

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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.

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THE QUALITY OF SOCIAL HOUSING: EVALUATION OF USER SATISFACTION. THE CASE OF THE 670 SOCIAL HOUSING UNITS IN ORAN, ALGERIA

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Abstract: Improving people's quality of life depends on the quality of their housing. Nowadays, countries around the world attach great importance to this issue. This article aims to analyze the discourse of social housing residents in Oran. Using the qualitative method of Post Occupancy Evaluation, the goal is to highlight the gaps between the representations that users have of their apartments, which they aspire to have, and the architectural quality of the housing they live in. The objective is to help propose responses that contribute to enhancing the architectural quality of housing. The analysis of our survey, carried out using SPSS statistical software, enabled us to conduct various analyses relating to qualitative variables. It also enabled us to evaluate the influence of various aspects of housing on satisfaction.

Keywords: Post Occupancy Evaluation, quality, residents, social housing, users.

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Introduction

The home is the first place where inhabitants can truly blossom, renew, and reconnect with themselves. It reveals part of the occupant's personality, "like a skin that breathes, separates and exchanges" [1]. Contrary to the ideas defended and imposed by the proponents of the modern movement, such as Le Corbusier, who advocated the internationalization of a universal concept of housing, this research is in line with the current of thought asserting that housing is a veritable cultural receptacle [2-5], that must be designed to accommodate and reflect the unique lifestyle of each family.

The user-related architectural space implies a social fact that only takes on meaning when placed in a specific context. This context defines it as a physical and cultural design object [6]. Hence the question of the spatial organization of housing, particularly from modern history to the present day, is based on the assumption of coherence between the designed space and the values of society. The dialectical relationship of the private spatial unit and the collective housing unit to their immediate environment is considered in a social dimension that considers the household and daily practices [7]. It is in this context that the interior space of the dwelling and the surrounding space constitute a spatial register¹ encompassing the needs and expectations of users, which plans and facades materialize. Examples of this are the paintings and photographs that decorate interiors and provide information about the objects of civilization². Of course, several parameters highlight the potential gap between designed and lived space, such as how rooms are laid out and arranged, their relationship with the outside world, how the home is accessed, joint ownership, etc [8].

Whether socialist or capitalist, public housing policy differs from country to country, its production depends

¹ The term spatial register is used here to describe how the various spaces fit together to meet the requirements of the home's inhabitants.

² Common civilization objects refer to material items frequently used in the daily life of a given culture, such as traditional tools, decorative objects, handicrafts, etc. They represent important aspects of a society's culture and traditions.

mainly on government initiatives. Thanks to the public housing strategy, the institutions concerned have established the right of Algerian families to own their own homes in Algeria [9]. This right is one of the results of the housing policy implemented by the country's authorities since the 1980s. It turns out, however, that mass-produced social housing absorbs a significant proportion of the State's cash flow, which it has difficulty making profitable [10].

Moreover, from the 1970s onwards, the demand for housing became large and urgent [11]. To meet this demand, the state resorted to the industrialization of construction; several construction mechanisms and techniques were imported to build many houses during this decade. However, the social housing built in Algerian cities does not yet meet the needs and desires of the Algerian family [12]. The ZHUN³ formula is implemented as part of urban planning without considering users' socio-cultural characteristics [13]. The non-correspondence of collective housing with the Algerian family's way of life has been raised from then until now, not to mention the cramped conditions of the dwellings and the often-high number of people per household, which remain among the basic causes of their unsuitability [14].

Users have tried to be flexible with this production by making modifications that give them more surface area both inside and out [15]. On the inside, these transformations were appreciated by the occupants. From the outside, this remodeling has harmed the city's image as a whole. The quantity-quality factor was not taken into consideration, even though rapid construction aimed to de-clutter the housing stock [16], as confirmed by C. Moley [17], "Housing construction is one of the most important factors entering into the composition of the human environment and especially the urban environment".

To assess residents' satisfaction with their housing, the approach adopted in this study is the Post Occupancy Evaluation approach, based on the three crucial socio-spatial dimensions that qualify collective housing, namely micro-space: the interior space of the dwelling and its relationship with its occupants. Meso-space: this encompasses the common areas shared by the occupants, and macro-space: this is the immediate environment that includes the individual and the city's human environment. Post-occupancy evaluation is used to study and assess a constructed space that has been previously exploited over a given period, facilitating the task of deciphering the transformations induced between the mutual interaction of man and his space to be inhabited [18]. This article aims to arrive at results that can shed light on the vulnerabilities of the designed space and how to modify them concerning the lifestyle of the target society. Indeed, our concern is with the following question: what factors influence inhabitants' satisfaction with their housing?

Given that housing represents the essential locus of social and family interaction, the occupant appears as someone who inhabits a whole environment even before occupying a particular building [19]. Through recent studies, we aim to highlight that the relationship between space and habitat naturally flows from another interaction: that between space and inhabitants. Thus, our study emphasizes the confrontation of two relationships: the relationship between the design of housing and the relationship between the use of its space. This implies that our inquiry is built around two interdependent concepts. The conclusions drawn from a postoccupancy evaluation provide a solid basis for making appropriate decisions regarding improvements to the building in order to better satisfy the needs of the occupants.

The object of this study is the 670 housing estates $(LPL)^4$ in Hai El Sabah. Inhabitant questionnaires and direct observation were used as a technique for gathering information and finding out how satisfied households were with their housing [16]. The housing studied was selected using the systematic sampling method, which selects a representative sample of the target population by choosing items at regular intervals from a random starting point. This ensures a fair distribution of individuals in the sample to facilitate data analysis.

³ ZHUN (Zones d'Habitat Urbain Nouvelles - New Urban Housing Zones) ZHUNs in Algeria are housing zones designed to create new residential districts to meet the urgent housing crisis and offer modern infrastructure.

⁴ Logement Public Locatif (LPL) in Algeria is a program established by the government to provide housing for low- and moderate-income households on a long-term rental basis.

Materials and Methods

As early as the 1960s-1970s, countries such as the United States, Great Britain, Canada, and France began to collect information on Post Occupancy Evaluation (POE) through questionnaires, interviews, analyses, and in-depth observations, which they made available to researchers to study users' impressions of their homes [20]. However, Post Occupancy Evaluation was not considered a discipline in its own right until the 1980s. Since then, theory in this field has undergone a remarkable evolution in analysis procedures, and techniques, including in terms of applications [21].

While architectural critics tend to focus on aesthetics and construction evaluation, POE focuses on the evaluation of occupant satisfaction, taking into account their needs and desires. POE aims to integrate the design process for the built environment into the scientific research cycle. Occupants express any architectural aspects of the building that do not correspond to their needs. This feedback is taken into account by specialists when making improvements or designing future architectural projects [22].

This being said, in our case study, the POE approach is carefully adopted in a social housing context; to assess certain parameters of satisfaction and dissatisfaction of households in the 670 social housing estate, and to determine the strengths and weaknesses of the design in its social and environmental context.

Satisfaction, as a subjective element, is based primarily on the confirmation of users' desires. The paradigm for conceptualizing satisfaction comprises three parameters: comparison, expectations, and perceptions. Based on this consensus, dissatisfaction arises when the quality experienced is lower than the quality expected; in other words, satisfaction will be confirmed in cases where users state that the quality experienced is higher or outstanding compared to the quality expected; the third position is that of equality between the quality experienced and the quality expected, where users express their satisfaction to a rather normal degree [23].

The survey process

The survey was conducted in January 2022 in a social rental housing estate in Oran. Built in 2009, the housing estate comprises nineteen blocks, ranging in height from the ground floor plus five stories to the ground floor plus ten stories. The majority of units have suffered tangible damage⁵, both inside and out, affecting even the spatial configuration of living spaces.

Our survey aims to examine in depth the link between the user satisfaction variable and the other variables in the various sections that make up our questionnaire. These variables are organized as follows: physical, behavioral, and environmental, in relation to the housing studied. The information collected was analyzed using SPSS⁶ statistical analysis software (statistical processing software for the social sciences). This software is used by researchers to analyze and interpret statistical data in the social sciences. It enables a variety of statistical analyses to be carried out and the results to be presented in a visual and comprehensible way once the questionnaire has been encoded.

The questionnaire has been organized into five distinct sections, each of which includes questions focused on measuring satisfaction, thus facilitating data analysis. The first section is devoted to user identification, while the second deals with the degree of household satisfaction with the design and layout of the interior space. In the third section, questions are asked about the immediate environment and the social life of the inhabitants, while the fourth section deals with user needs and various spatial modifications. Finally, the fifth section deals with socio-spatial and cultural practices. We have chosen questions that are consistent with the Post Occupancy Evaluation method and also compatible with the principles of the SPSS software. We applied the systematic sampling method (10% of the population was surveyed), which means we selected a sample of

⁵ Over time, multi-family dwellings suffer a variety of degradations, including those caused by dampness (mold, mildew, stains), damaged interior finishes (walls, paintwork, floors), problems with equipment (plumbing, heating, ventilation) and natural wear and tear due to lack of proper maintenance.

⁶ (Statistical Package for the Social Sciences), a software package used for statistical analysis.

67 dwellings in our survey⁷. The dwellings ranged from two-roomed to three-roomed, and the selection of dwellings studied in this housing estate enabled us to obtain more reliable results. When the individuals were interviewed, 87% were men and 13% were women, with an age difference ranging from 23 to 77. Each dwelling comprised a single household, with the number of people per household ranging from 1 to 7, shared between men and women. The households surveyed stated that they had always been tenants, from the time the dwellings were distributed in 2009 to the present day.

The degree to which people are satisfied with their housing is crucial in the housing evaluation process. It also helps define the mutual interaction between the user and his housing. Satisfaction analysis enables us to determine one or more groups of inhabitants living in their homes in different ways, with distinct positions according to certain factors such as monthly salary, cultural level, neighborhood and socio-professional status [24].

Case study: 670 social housing estates

The 670-unit housing estate, initially a social rental project, is now part of the 1.000-unit social rental housing program. It is located in the Hai El Sabah commune, Daura Bir El Djir, to the east of the city of Oran. The housing estate comprises 19 blocks (4 angular blocks and 15 linear blocks), with the main and rear facades treated differently. The blocks were designed on the principle of four dwellings per level, with identical shapes and living areas ranging from 45.25 mU(square meter) to 72.4 mU(Table 1). Construction work began in 2003, under the responsibility of the project owner OPGI (Office de Promotion et de Gestion Immobili(re)⁸, and the first completed units went into operation in 2009. The buildings have a self-supporting reinforced concrete skeleton.

N	Headings	Building	Building	Building	Building	Building	Building	Building	Building
14	ficadings	type	type	type	type	type	type	type	type
1	Туре	В	B trade	С	C trade	D	Ε	A trade	Total
2	Number of blocks	2	5	5	3	2	1	1	19
3	Number of levels	Six-storeys building, with ground floor	Six-storeys building, with ground floor	Eleven-storeys building, with ground floor	Eleven-storeys building, with ground floor	Eleven-storeys building, with ground floor	Eleven-storeys building, with ground floor	Six-storeys building, with ground floor	
4	Form of blocks	Bar	Bar	Bar	Bar	Angular	Angular	Angular	
4	Number of housing per level	4	4	4	4	4	4	4	28
5	Number of housing Ground floor	4	4	4	2	4	4	4	26
6	Number of housing per block	24	24	44	42	44	44	24	246
7	Total number of housings	48	120	220	126	88	44	24	670
8	Average living area F2	45.25	45.25	45.25	45.25	55.04	49.85	55.04	
9	Average living area F3	60.05	60.05	60.05	60.05	70.91	72.40	70.91	
10	Number of commercial premises per block	0	5	0	5 6 7	0	0	4	27
11	Number of commercial premises	0	25	0	18	0	0	4	47

Table	1.	Tvr	e of	buil	ding	35
1 ant		I y L		oun	um	50

⁷ To do this, we divide the total number of dwellings in the housing estate by the desired sample size, giving us a systematic interval. We then select a dwelling at random as a starting point and survey all the dwellings at regular intervals defined by the systematic interval until we reach the desired sample size.

⁸ OPGI (Office de Promotion et de Gestion Immobili∩æ) in Algeria is a public institution responsible for promoting and managing real estate projects, particularly public housing.

The total surface area of the plot is 22954.6 mU of which the built area is 11975.9 mUand the open space is 2093.9 mU with the remainder devoted to parking space with a surface area of 885.5 mU The housing estate is located in a district with a somewhat strategic position, as the presence of public transport (bus lines and the tramway line) facilitates travel to the various districts, particularly the city center, plus the factor of being close to the university and surrounded by all the necessary equipment (Figs. 1,2).



Fig. 9. Site plan and mass plan, 670 LPL housing estate, Oran



Fig. 2. Views of the facades, 670 LPL housing estate, Oran

Questionnaire survey: residents' first impressions

According to the questionnaire, residents of the 670 housing estate report anomalies and shortcomings not only in their interior spaces but also in the immediate exterior landscape. On the inside, the designed spatial configuration raises the concern of inadequacy for different spatial and social activities. The cramped nature of the rooms, the poor orientation of the wet areas, and the number of rooms, which is often insufficient for the number of people per household, led users to make certain transformations to the floor plans, which had an impact on the quality of the dwellings envisaged by the practitioners⁹, yet the operation of concordance put in place by the inhabitants was done primarily to meet a need for a socio-spatial practice. The transformations to the layout that we were able to reveal during our observations inside the dwellings, were carried out by the inhabitants with two important measures in mind: family structure and social requirements that evolve with changing lifestyles.

The immediate exterior landscape has been affected by several problems due to a lack of regular maintenance. According to residents, the appearance of the outdoor environment is of paramount importance to their physical and moral well-being. They hope to one day see better-maintained green spaces, offering play areas that meet safety standards for their children. Indeed, improving these outdoor spaces would go a long way toward creating a more pleasant environment conducive to their quality of life.

"We hope one day to have a well-appointed outdoor space with play areas for our children. The presence of green spaces in our housing estate comforts me" (a resident of the 670 housing estate).

Results and Discussion

Post-occupancy evaluation is the foundation of our study and is valid for a building in a cycle of use, which is the case of this study. The gap between design and use of the space to be inhabited requires some kind of evaluation to make it comprehensible. To this end, POE makes it easier for us to grasp the complexity of designing a space that must meet users' needs, with a logic that respects their expectations on both scales: interior and exterior. The mechanism of this approach makes it possible to determine the quality of housing by knowing the constructive parameters that must be adapted to the doctrines of residential satisfaction.

The "SPSS" software enabled us to carry out several analyses, namely the bi-variate analysis of qualitative variables through correlation, and the bi-variate analysis of qualitative variables through cross-tabulation. The notion of correlation is used to determine whether there is a relationship between two variables, whether quantitative or qualitative. Spearman's correlation coefficient is a non-parametric statistical measure used to

⁹ Practitioners refer to professionals involved in housing and urban planning, such as architects, urban planners, civil engineers, property developers, construction project managers, real estate agents, and other professionals in the sector.

assess the relationship between two ordinal variables. It compares rankings of observations rather than actual numerical values and ranges from -1 to 1. It is robust to outliers and non-normal distributions, making it suitable for non-parametric data analysis. The two-tailed significance of Spearman's Rho Test assesses whether or not this correlation is statistically significant.

Evaluation of initial rent typology with housing satisfaction

The cross-tabulation (Table 2) helps us assess residents' satisfaction with the variable (type of initial rent). Analysis of the results shows that residents who previously lived in multi-family dwellings are divided into two groups: one group, who lived in dilapidated dwellings, is fairly satisfied and finds the current dwelling better than the old one; the other group, who lived in dwellings that were in average condition, is very dissatisfied, as the current dwelling is no more comfortable than the old one. On the other hand, those who have lived in individual dwellings are rather dissatisfied, declaring that they lived in living conditions (hygiene, size of dwelling, state of outdoor environment, etc.) more suited to their lifestyle than the collective dwelling. This result confirms that the initial rent has a strong influence on residents' satisfaction. As for legal status, all users are tenants, so it's unlikely to have much influence on resident satisfaction.

		51 C5	e			
Type of initial rent	Housing satisfaction					
	Very dissatisfied	Somewhat dissatisfied	Somewhat satisfied	Totai		
Individual	19	22	10	51		
Collective	6	4	6	16		
Total	25	26	16	67		

Table 2. Cross-tabulation of initial rent typology and housing satisfaction

Evaluation of housing satisfaction with the initial rental location

The results in Figure 3 show that all the residents of the 670 housing estate lived in the city before moving to the new estate. As a result, the majority of users are dissatisfied with their current dwellings, as they used to live in inner-city areas where the majority of public services are available. In this sense, the situation of the old home has a very strong impact on user satisfaction.



Fig. 3. satisfaction with the housing in relation to the location of the initial rent

Evaluation of housing satisfaction in relation to housing cost, year of installation, income of the head of household

In relation to the correlative analysis between satisfaction and the cost of rent (Table 3), the two-sided significance is less than 5%, so we have a positive correlative relationship between these two variables, with Spearman's correlation coefficient equal to 37%, at which point the correlation is medium. On the other hand, the correlation between satisfaction and the other two numerical variables (year of installation and monthly income of the head of household) is not significant, as the two-sided significance is greater than 5%, so these two variables do not have a significant influence on user satisfaction (Tables 4,5).

			Cost of rent	Housing atisfaction
Spearman's Rho	Cost of rent	Correlation coefficient	1.000	0.373**
		Sig (bilateral)	•	0,002
		N	67	67
	Housing satisfaction	Correlation coefficient	0.373**	1.000
		Sig (bilateral)	0.002	
		Ν	67	67

Table 3. Bivariate correlation a	nalysis:	Spearman's	Rho	test
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**. The correlation is significant at the 0.01 level (bilateral).

Table 4. Bivariate correlation analysis: Spearman's Rho test Correlations

			Housing satisfaction	Year of installation
Spearman's Rho	Housing satisfaction	Correlation coefficient	1.000	0.206
		Sig (bilateral)		0.094
		N	67	67
	Year of installation	Correlation coefficient	0.206	1.000
		Sig (bilateral)	0.094	•
		N	67	67

Table 5. Bivariate correlation analysis: Spearman's Rho test

Correlations

			Housing satisfaction	Monthly income
Spearman's Rho	Housing satisfaction	Correlation coefficient	1.000	0.153
		Sig (bilateral)		0.215
		N	67	67
	Monthly income	Correlation coefficient	0.153	1.000
		Sig (bilateral)	0.215	•
		N	67	67

Correlation between regret at leaving the housing and satisfaction with the housing

According to the results obtained in (Table 6), regret at leaving the housing has a certain influence on housing satisfaction. Bilateral significance is less than 5%, so we have a negative correlation between these two variables. The strength of this correlation is medium, with a coefficient of 40%. In other words, residents who are dissatisfied with their cells will not regret leaving their homes. For those who are quite satisfied, they will regret leaving their homes. This is mainly due to the suitability of the interior configuration of the dwelling to their needs, although this attachment has no relation to the immediate external environment, according to the residents' statements.

"I live in a housing that doesn't meet all my needs, and I'm dissatisfied with it. That's why I'll never regret leaving it" (a resident of the 670 housing estate).

"I've adapted the spatial layout of my home to suit my needs, and right now I'm pretty happy with the reconfiguration. That's why I'll have regrets if I have to leave my housing, but these regrets are in no way

linked to the neighborhood or the immediate external environment of the housing estate" (a resident of the 670 housing estate).

			Housing satisfaction	Regret about leaving the housing
Spearman's Rho	Housing satisfaction	Correlation coefficient	1.000	-0.402**
		Sig (bilateral)		0.001
		N	67	67
	Regret about leaving the housing	Correlation coefficient	-0.402**	1.000
		Sig (bilateral)	0.001	
		N	67	67

Table 6. Bivariate correlation analysis: Spearman's Rho test

**. The correlation is significant at the 0.01 level (bilateral).

Evaluation of interior space satisfaction

The correlative analysis between housing satisfaction and room satisfaction in (Table 7) confirms that there is a strong relationship between these two qualitative variables, with a two-sided significance of less than 5% and a correlation coefficient of 76%. In other words, user satisfaction in the various rooms has a remarkable impact on satisfaction with housing. According to the respondents' statements, representative spaces such as the living room and kitchen are more important than other spaces in terms of satisfaction; it is through the spatial distribution of these spaces, and their surface areas, that a certain level of interior satisfaction can be achieved.

"I spend more time in the kitchen and living room because these are the two spaces where I carry out the majority of my activities. For me, these two rooms are of considerable importance for our socio-spatial practices" (a resident of the 670 housing estate).

			Housing satisfaction	Satisfaction with interior space
Spearman's Rho	Housing satisfaction	Correlation coefficient	1.000	0.769**
		Sig (bilateral)		0.000
		N	67	67
	Satisfaction with interior space	Correlation coefficient	0.769**	1.000
		Sig (bilateral)	0.000	
		N	67	67

Table 7. Bivariate correlation analysis: Spearman's Rho test

**. The correlation is significant at the 0.01 level (bilateral).

Evaluation of satisfaction with spatial distribution, room grouping, shape, and surface area

The cross-tabulation (Table 8) shows that residents are quite satisfied with the spatial distribution, although a significant number are very dissatisfied with their housing. They did, however, express satisfaction with the room layout. When it comes to grouping rooms together, we have a number who are rather satisfied with the hall as a connecting space between the different areas. The rest of the users also prefer to have a hall in their housing, but on the other hand, they are rather dissatisfied with the housing they currently live in. Respondents are quite satisfied with the shape of the rooms, and at the same time very dissatisfied with their area. Users' statements affirm that the area of rooms poses a major concern in their daily lives, and all three variables influence satisfaction with housing, knowing that the ratio between them is high, especially in the case of the composition of the Algerian family, which demands more spacious rooms with a central articulation space that slightly resembles the patio of the traditional house, based on very clear spatial geometric forms.

"The rooms are well distributed, the shape of the spaces is not bad, but what bothers me most is the cramped nature of the rooms" (statement by a resident of the 670 housing estate).

		1	-		0				
Housing satisfaction	Spatial	Spatial	Room	Room	Room	Room	Room	Area	Area
	distribution	distribution	grouping	grouping	grouping	shape	shape	(no)	(yes)
	(no)	(yes)	(corridor)	(hall)	(both)	(no)	(yes)		-
Very dissatisfied	3	22	5	17	3	2	23	25	0
Somewhat dissatisfied	4	22	1	18	7	2	24	26	0
Somewhat satisfied	0	16	3	9	4	0	16	16	0
Very satisfied	0	0	0	0	0	0	0	0	0
Total	7	60	9	44	14	4	63	67	0

Table	8. Cross-	tabulat	ion of spa	atial dist	ribution,	
om grouping	element,	shape,	and area	with hou	using satis	faction

Degree of boredom in the 670 housing estate

ro

Based on the results of (Fig. 4), users who are rather dissatisfied with their housing find it very boring due to several factors that have hurt the quality of the immediate environment, including dirtiness, lack of outdoor lighting, and lack of security. These are the main reasons for the deterioration of the exterior. This state of affairs has led to the emergence of another factor that has exacerbated the further deterioration of the estate's external landscape: the gathering of young people at the foot of buildings at all times of the day, a behavior perceived as a source of moral deviance¹⁰. For these reasons, residents are calling for a cleaner environment that meets their needs for a healthy social life, free from harmful factors.

"The outside environment of the housing estate presents several problems, including a permanent lack of maintenance, which has led to a situation of dirtiness. It leaves me with a feeling of deep boredom with the estate" (statement by a resident of the 670 housing estate).



Fig. 4. Satisfaction with housing and degree of boredom in the housing estate

¹⁰ The term (moral deviance) suggests that this behavior is considered to go against accepted social and cultural norms in society. This may include disruptive activities, harmful behavior, breaking the law, or any other action deemed inappropriate by the local community or society as a whole.

Relationships between neighbors: the impact of relationship type on social life

Graph (Fig. 5) shows that 94% of respondents have a relationship with their neighbors. This relationship varies from friendly to helpful. They declare their satisfaction with this social aspect, despite the existence of several shortcomings in the social environment of this housing estate. Good neighborliness has helped to consolidate the social structure of the estate, with the majority cooperating to solve many of the estate's sometimes technical problems on their own.

"We often help each other to solve certain technical problems, strengthening the bonds between us. The relationship of mutual aid in our housing estate is really strong, and we maintain good relations with our neighbors" (statement by a resident of the 670 housing estate).



Fig. 5. The existence and nature of a relationship between neighbors

Explaining the results: an interpretative action

User satisfaction remains a preliminary estimate based on their needs and expectations. Each household expressed its level of satisfaction by answering the question "very dissatisfied, somewhat dissatisfied, somewhat satisfied, very satisfied".

We followed the process of the Quebec Statistical Institute. It is the users who participate in the testimonial on usage, satisfaction, and desires. The main objectives of the survey were, firstly, to identify the most and least satisfying points, and secondly, to gather the necessary information to enable us to carry out a study of the relationship between household satisfaction and certain socio-spatial parameters [25]. None of the respondents answered "very satisfied", which reflects the quality deficit in collective social housing, and the latter needs to be restructured around the measures and requirements of the inhabitants.

Housing quality: between theory and experience

The main parameters of theoretical housing quality can be summed up in functional, technical, architectural, aesthetic, and socio-environmental quality. In terms of functionality, users criticized the grouping of rooms, the positioning of wet areas, and the lack of closet space in some units. Technical quality remains inadequate, with dampness in some rooms due to the poor orientation of the blocks, the lack of lighting, and natural ventilation in the bathrooms, including the lack of maintenance for sewage disposal. In terms of architectural and aesthetic quality, the residents have managed to resolve some of the criticized aspects on their own by making interior alterations, repaining the various rooms, repairing cracks, renewing flooring, installing earthenware in kitchens and bathrooms, etc. The socio-environmental quality has been criticized too much in terms of the lack of green space and play areas, but on the other hand, they have appreciated the location of the housing estate, the availability of public transport, as well as the neighborly relationship based essentially on cooperation and mutual understanding. The comparison between theoretical quality and the elements criticized by users shows us the gap between designed and lived housing. As D. Picho [26] stated, "A quality architectural program for a building must be based on a good understanding of the needs of the people and organizations housed in it, as well as the interrelationships woven by the latter with the physical environment in the daily uses they make of it".

Conclusion

Evaluation of user satisfaction is not an end in itself. However, this study has shown that improving housing programs requires taking into account the desires of future residents. It is important to define the various needs and desires to achieve their satisfaction. From the initial results of this evaluation, it's clear that housing quality boils down to the quality of the spaces and the quality of use. All quality-measurement operations take users' perceptions as their starting point; listening to users is the only way to define their level of satisfaction with any given product. The questionnaire itself will not improve the quality of the housing, but rather the analysis of the information and results obtained will enable us to deduce the weaknesses and advantages of the housing as perceived by the residents.

After gaining their independence, families from different backgrounds and with varying incomes set about transforming their housing to suit their respective lifestyles [27]. A person who feels satisfied with their housing situation will maintain it as long as it continues to meet their needs. In the event of dissatisfaction, this can lead to two alternatives: either an adaptation or reorganization of the current situation or a relocation or change in attitudes towards the current housing. This leads to a mismatch between housing-related attitudes and behaviors [28]. From the results of the analysis, it emerges that a large number of residents express dissatisfaction with the layout of their housing. The most criticized aspects of housing interiors are related to technical problems, use of space, functionality, and behavioral aspects. An analysis of the external and social environment reveals that the majority of residents surveyed have an unfavorable opinion. Families are particularly sensitive to damage to communal areas such as playgrounds and green spaces, and to sewage disposal, which can be explained by the fact that social housing is often perceived as a secondary option to individual housing. In terms of architecture, the relentless repetition of the same cell type in social housing creates a regrettable rigidity and monotony. These aspects have led to harsh criticism of the social life in housing estates.

Nowadays, it is crucial to pay greater attention to the links between households and their material and social environment when planning housing. It would be insufficient to simply propose different types of habitats without considering the actual inhabitant when designing the space he or she will inhabit. In this context, involving residents in the design phase to find out about their needs and desires, while developing a spirit of communication between them and practitioners and decision-makers, helps to provide effective responses to the problem of the gap between the housing designed and the housing experienced. Researcher C. Belbacha-

Merouche [29] stresses the need to improve the quality of social housing to avoid the constant changes it undergoes, which hurt the building and the urban environment. This study highlights a crucial new line of thinking: exploring effective mechanisms for encouraging resident participation. To implement this approach, it is imperative to integrate a new dimension - that of the user - into the decision-making and management processes of housing, to ensure optimal housing performance.

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.

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