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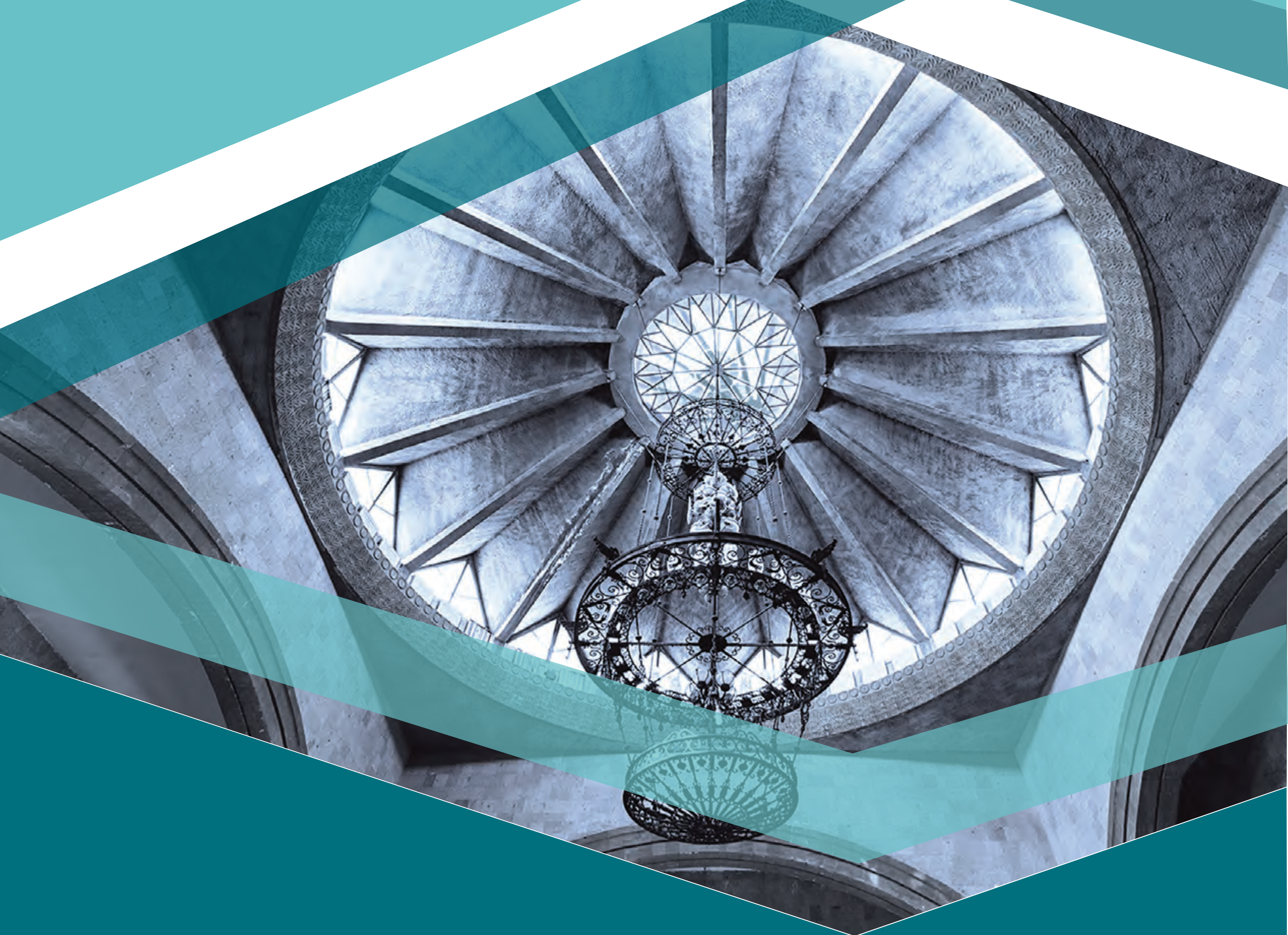

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CONTENT

MOISTURE PROTECTION OF RESIDENTIAL BUILDINGS INFLUENCE OF TYNES ON THE THERMAL-HUMIDITY REGIME OF THE BUILDING

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Abstract: *Moisture penetration into the building structures of residential buildings is caused by climatic conditions and has a negative impact on the operation of buildings. Since thermal insulation of structures directly increases the energy saving of buildings, it can also affect the energy saving of buildings, contribute to the durability of enclosing structures, reduce condensate zones, and reduce fuel consumption during measures to eliminate penetrating water vapor. Buildings in different climatic zones have different vapor permeability rates, which can have different effects on the physical condition and thermal properties of surrounding structures. Thermal insulation significantly reduces the intensity of thermal conductivity and heat transfer processes, reduces air and moisture permeability. The main goal of this study was to determine the construction the amount of steam passing through the structure due to its vapor permeability and its impact on the thermo-humidity regime of the building. The thermal and air-humidity conditions of two types of buildings widespread in the Republic of Armenia, 5-story tuff and 9-story RC panel cladding structures, were observed in different climatic zones of the republic. It has been proven that the type, thickness and installation method of thermal insulation material have different effects on the formation of condensate zones in external structures for different settlements of the Republic of Armenia. As a result of the research, it was found that in tuff cladding structures (in the cities of Yerevan, Gyumri, Hrazdan, Vanadzor and Sevan) a condensate zone forms, while in Kapan it does not. However, by using different types of thermal insulation materials, such a phenomenon can be avoided. Studies have shown that in order to ensure the required thermal resistance and avoid condensation in the mentioned cities, it is necessary to use a thermal insulation material with the minimum required thickness. The thickness of the foamed polystyrene thermal insulation layer in buildings with a tufa structure is: In Yerevan and Vanadzor - 5 cm, in Gyumri - 6 cm, in Hrazdan and Sevan - 7 cm, in Kapan - 4 cm, and in expanded polystyrene - 6 cm in Yerevan and Vanadzor, 8 cm in Gyumri, Hrazdan and Sevan, and 5 cm in Kapan. In the case of reinforced concrete panel construction, the thickness of expanded polystyrene will be 9 cm in Yerevan, 10 cm in Vanadzor, 11 cm in Gyumri, Hrazdan, and Sevan, and 8 cm in Kapan, in the case of expanded polystyrene: 7 cm in Yerevan, 8 cm in Vanadzor, 9 cm in Gyumri and Sevan, 10 cm in Hrazdan, and 7 cm in Kapan.*
Keywords: *air-vapor permeability, thermal insulation effect, minimum thickness of the insulation layer, energy efficiency of buildings, thermal load.*

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Introduction

The provision of thermal comfort conditions in residential buildings is largely determined by the provision of thermo-humid conditions in them. In the external construction, the thermo-humid regime of buildings changes under the influence of indoor and outdoor temperature, humidity, and wind speed. In particular, in the case of currently widely used almost absolutely hermetic "metal-plastic windows", excess humidity occurs in the air inside the building. To avoid this phenomenon, many European countries suggest using a "warm ventilation device - window" [1] for forced air movement and preheating of the incoming air. Quantitative and qualitative temperature-regulating heating/cooling re-users of the incoming air are also used: two-pipe, three-pipe, etc. [2]. In the cold season, as a result of the vapor permeability process of the building, depending on the indoor air temperature, the temperature on the inner surface of the external construction can equal the dew point temperature, causing condensation on the inner surface of the enclosing structure, which will disrupt the humidity regime of the building. To avoid such an undesirable phenomenon, it will be necessary to increase the indoor air temperature by increasing the thermal capacity of the heating system, as well as the consumption of additional organic fuel with hazardous emissions. If there is no danger of condensation due to the high indoor air temperature, then as a result of vapor permeability, the relative humidity of the indoor air will inevitably increase, instead of the required 40-60%, it will be in the range between the amount of penetrating steam and the internal moisture barriers. This is also a transient phenomenon, since the internal thermo-humidity regime is disrupted [3]. To avoid this phenomenon, it is again required to increase the thermal load of the heating system. In each case, the required heat quantity in the heating system will increase, and therefore the fuel consumption, and the ecological hazard will increase accordingly. The theoretical and experimental study of the heat and moisture transfer in building walls has been the target of a lot of important research work [4-7].

Materials and Methods

Moisture penetration into the building significantly affects its air humidity and thermal regime, since the moistening of building materials leads to an increase in their thermal conductivity coefficient and therefore to an increase in heat losses. In addition, the sanitary and hygienic properties of the building structure and buildings deteriorate: the relative humidity inside the building increases, and consequently, the risk of fungus and mold formation as well as the durability of the structure significantly decreases. Moisture can penetrate the building in various ways: as a result of groundwater, atmospheric moisture, and its condensation in the structure, internal moisture releases from people are possible, and in some cases as a result of the technological process. A significant part of the moisture can be removed, but moisture caused by atmospheric moisture penetration and condensation in the structure can periodically accumulate due to improper air humidity and temperature regime of the building. It occurs due to the temperature difference between the indoor and outdoor air [8,9], due to the difference in partial pressures or elasticity of water vapor, since there is a difference in partial pressures, diffusion process of gases and vapors [9-11]. The amount of water vapor will be determined as follows [11]:

$$G = \frac{e_{in}-e_{out}}{R_{vp}^{res}}, \tag{1}$$

where e_{in}, e_{out} are the elasticity of water vapor on the inner and outer surfaces of a building structure Pa, R_{vp}^{res} is the vapor permeability resistance of the layer, m^2 h Pa/mg.

The resistance to vapor permeability will be determined [11,12] by:

$$R_{vp}^{res} = \frac{\delta}{\mu}, \tag{2}$$

where μ is the moisture permeability coefficient of the layer, mg/m h Pa, δ- is layer thickness, m.

Then, according to [11,12] the numerical values of the saturation pressures at external and internal temperatures are determined:

$$E=1.84 \cdot 1011 \quad e^{\frac{-5330}{273+t}}, \tag{3}$$

where e is the base of the logarithmic function, t is the external or internal air temperature.

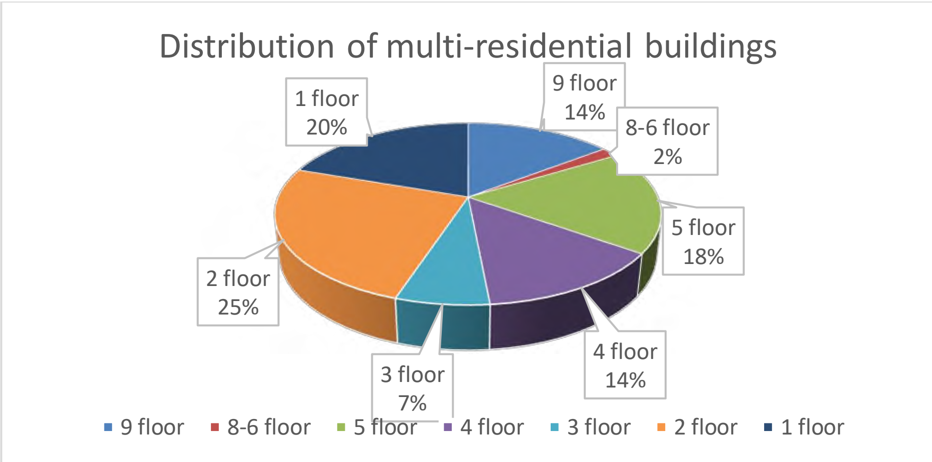
Having the indoor and outdoor saturation pressures and the numerical values of relative humidity, the specific laws of water vapor will be determined:

$$e_{in} = \frac{E_{in}}{\varphi_{in}}, \quad e_{out} = \frac{E_{out}}{\varphi_{out}}, \tag{4}$$

where E_{in}, E_{out} are the saturation pressures of the indoor and outdoor air, Pa, φ_{in}, φ_{out} are the relative humidities of indoor and outdoor air.

To prevent moisture condensation on the internal surface of a building structure, the following conditions must be met: E > e [9,13]. If this condition is not met, it is necessary to increase the thermal resistance of the structure by thermal or moisture insulation of enclosing structures. To select the necessary values in the above formulas and determine the calculated values, the parameters of the building are determined based on the thermo-humidity regime and the operating conditions of external building structures. Using the above methods, calculations were performed, and the results depending on the thermo-humidity regimes of the enclosing structures were determined for the cities of Yerevan, Gyumri, Kapan, Hrazdan, Vanadzor, and Sevan. Since the multi-apartment buildings of the main housing stock of the Republic of Armenia are 35-60 years old and the currently applicable energy efficiency standards did not exist during their construction, according to the calculations of various experts, the energy consumption per $1m^2$ of such buildings exceeds the same indicator in developed countries by about 30-50%, which is a consequence of the poor thermo-technical indicators of the enclosing structure.

According to studies[1], 56.1% of the apartments in the Republic of Armenia are located in cities, 43.9% in villages. About 70% of the total housing stock are private houses, and 30% are apartment buildings. About 70% of the external housing structures are made of stone, and 23% are panel buildings (Fig.1). According to the Cadastral Committee of the Republic of Armenia, the total area of the housing stock in the republic at the end of 2021 was 100.2 million m^2, including 55.9 million m^2 in cities and 44.3 million m^2 in villages. The distribution of 5- and 9-story buildings and their enclosing structures in 6 cities is also presented below[2].



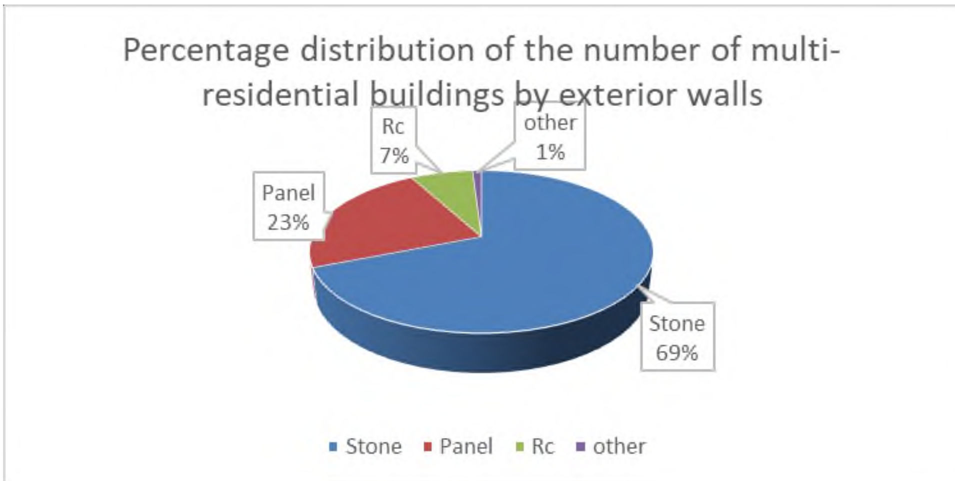


Fig. 1. *Distribution graphs of various buildings in the Republic of Armenia, 2021*

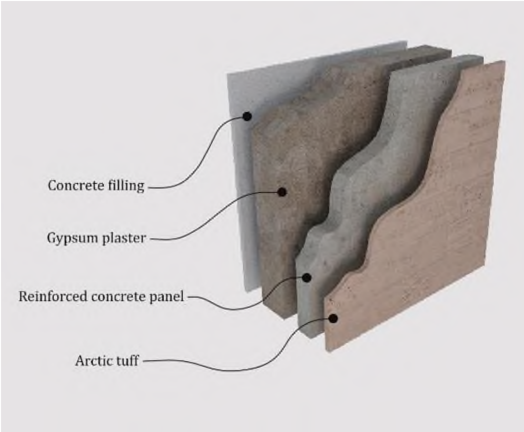
The cities mentioned above also have different climatic conditions which have a direct impact on the enclosing structures and their heat losses (Table 1).

Table 1. Outdoor air temperatures in cities during the heating season[3]

City	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Estimated outside air temperature, ^0C	-18	-19	-14	-14	-21	-9

[1] RA SC, Housing Stock and Public Utility in the Republic of Armenia.
[2] Ibid.
[3] "RA Construction Norms 22-01-2024 "Building Climatology". https://armmonitoring.am/page/1466

According to Figure 2, the calculation of the thermal resistance and heat transfer coefficient was carried out for the cladding structure.



Arctic tuff	$\delta_1 = 0.02m$,	$\lambda_1 = 0.52$ W/m^{0}C
Concrete filling	$\delta_2 = 0.1$m,	$\lambda_2 = 0.76$ W/m^{0}C
Reinforced concrete panel	$\delta_3 = 0.16$m,	$\lambda_3 = 1.92$ W/m^{0}C
Gypsum plaster	$\delta_4 = 0.02$m,	$\lambda_4 = 0.41$ W/m^{0}C

Fig. 2. *9 floor enclosing structure of a multi-story residential building*

Heat transfer resistance:

$$R_0 = \frac{1}{\alpha_{in}} + \frac{1}{R_s} + \frac{1}{\alpha_{out}} \quad , \tag{5}$$

where: α_{out} is the thermal conductivity coefficient of the external surface of the structure, W/m^2 ^{0}C,
α_{in} is the thermal conductivity of the internal surface of the structure, W/m^2 ^{0}C,
R_s is the thermal resistance of the enclosing structure, m^2 ^{0}C/W.

$$R_s = \frac{\lambda_1}{\delta_1} + \frac{\lambda_2}{\delta_2} + \frac{\lambda_3}{\delta_3} + \cdots + \frac{\lambda_n}{\delta_n} \quad , \tag{6}$$

where: λ_n is the calculated value of the thermal conductivity coefficient of the layer material, W/m ^{0}C,
δ_n is the layer thickness, m.

$$R_s = \frac{1}{23.2} + \frac{0.02}{0.52} + \frac{0.1}{0.76} + \frac{0.16}{1.92} + \frac{0.02}{0.41} + \frac{1}{8.7} = 0.46 \text{ m}^2\, {}^0\text{C/W}, \tag{7}$$

$$k_s = \frac{1}{0,46} = 2,17 \text{ W/m}^2\, {}^0\text{C} \tag{8}$$

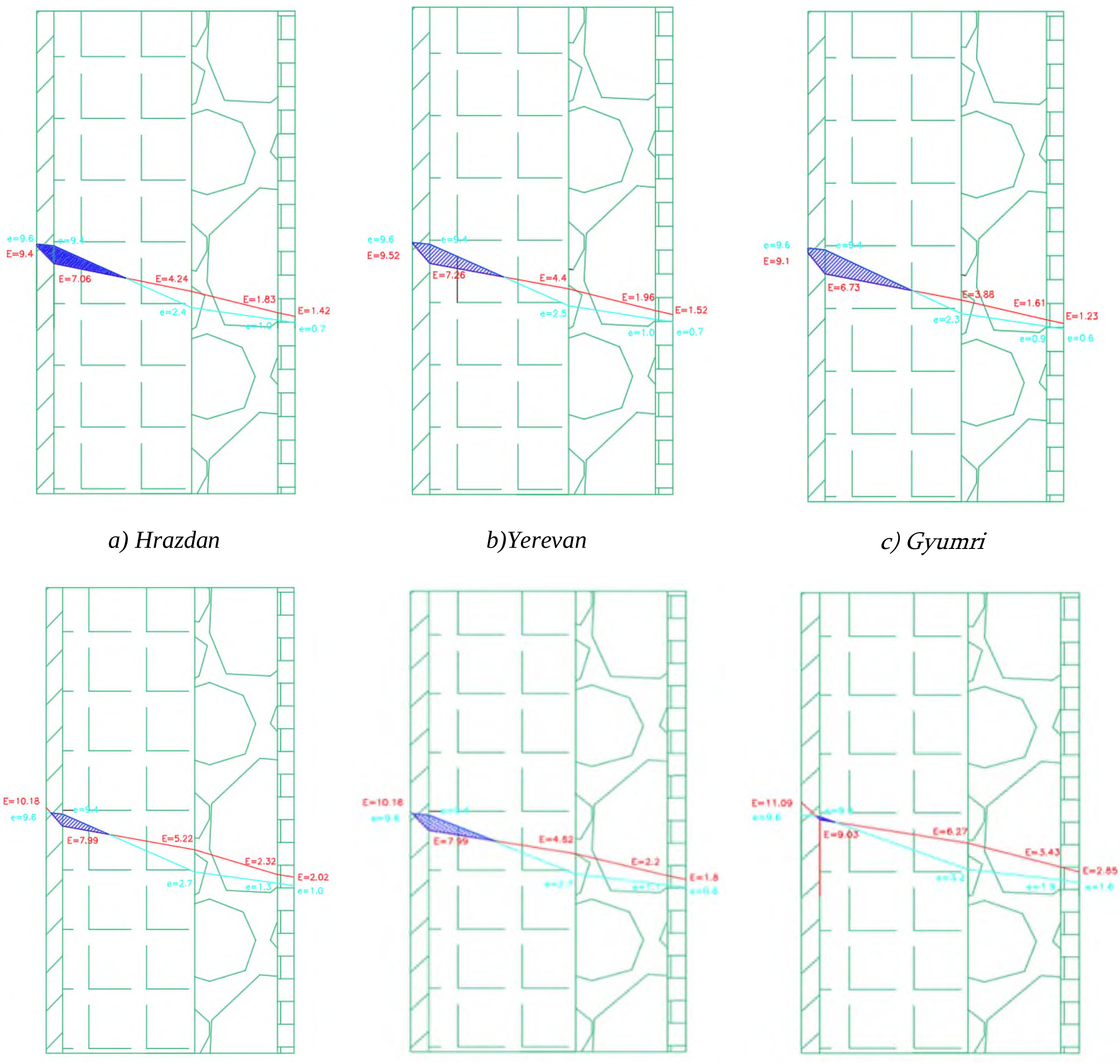
Accordingly, the heat losses of the building were calculated, and then the heat loads were determined under appropriate climatic conditions (Table 1), when the indoor air temperature is $t_{in} = 20^0$C. For each city, Table 2 provides the temperature and relative humidity of the outside air, saturation pressure, E, Pa, and mass amount of water vapor, mg/m^{2}h.

Table 2. Thermal load of a 9-story residential building and external air saturation pressure E, Pa, mass amount of water vapor, mg/m^{2}h

City / Calculated value	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Thermal load, kWt	178.1	182.8	159.4	159.4	194.0	135.9
Relative humidity of outside air, %	77	79	74	69	83	75
Saturation pressure of outside air E, Pa [6]	125.3	113.3	181.3	181.3	93.32	212.9
Mass amount of water vapor, mg/m^{2}h	168.9	170.7	160.8	160.8	173.6	145.8

Results and Discussion

To determine the mass amount of water vapor in the envelope, the relative humidity of the indoor air was assumed to be 55% [4]. Since the humidity is determined by the outdoor air temperature and is variable, the coefficient of elasticity for indoor air will be 2338 Pa [11]: The calculations of thermal loads were carried out according to the method[5], using conventional temperatures [9], and the mass amount of water vapor was calculated using the method given above (Fig.1). Figure 3 shows the graphs of the change in humidity due to moisture permeability in buildings in cities.



a) Hrazdan *b)Yerevan* *c) Gyumri*

d)Vanadzor *e) Sevan* *f) Kapan*

Fig. 3. *Graphs of humidity changes due to vapor permeability of a 9-story building*

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[4] "Thermal Protection of Buildings" RACN 24-01-2016 https://nature-ic.am/en/publications/%22thermal-protection-of-buildings%22-racn-24-01-2016

[5] "RA Construction Norms II-7.02-1995 "Building Thermophysics of Fencing Constructions". https://www.minurban.am/storage/Normative/1-II-7.02-95%20.pdf

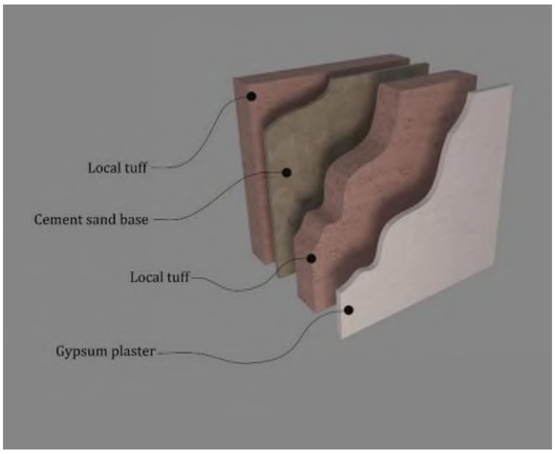
It follows from Figure 3 that in the given climatic zones, in the calculation mode, a condensate formation range can be obtained inside the enclosing structure. The latter largely depends on the calculation temperature of the external air and therefore on the vapor elasticity coefficient. As a result, the construction of buildings located in the given climatic zone. A condensate zone forms in the structure. As a result, the structure is subject to damage due to the resulting water ice. If it is close to the metal structure included in the structure, the metal will separate from the concrete and the structure will weaken, which is an undesirable or unacceptable phenomenon. This can be avoided if the outside of the structure is insulated with polystyrene foam when the minimum thickness of the insulation is: 9 cm in Yerevan, 10 cm in Vanadzor, 11 cm in Gyumri, Hrazdan, and Sevan, 8 cm in Kapan, and in the case of expanded polystyrene: 7 cm in Yerevan, 8 cm in Vanadzor, 9 cm in Gyumri and Sevan, 10 cm in Hrazdan, 6 cm in Kapan.

On the other hand, the massive flow of steam into the building endangers the sanitary condition of the internal structure - mold and unpleasant odors will appear. To avoid this, it is necessary to increase the temperature of the indoor air, and therefore the thermal load of the heating system, for the possible formation of condensate or evaporation of the penetrating steam. Increasing the load will lead to an increase in the power of the heat source and, therefore, an increase in the consumption of organic fuel. At the same time, it is necessary to increase the surfaces of the heating devices (Table 3).

Table 3. The effect of moisture permeability on fuel consumption

City / Energetic nature	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Gas consumption in January, m^3/month	20880	22263	20888	18210	18210	15532
Gas consumption in January, taking into account the effect of condensation, m^3/month	22350	24267	22768	19849	19483	16309

Then, the most common 5-story, tuff-lined, 2-entrance typical residential buildings in the Republic of Armenia were considered, for which the necessary thermal load and vapor permeability calculations were performed (Fig.4).



Local tuff $\delta_1 = 0.20$m, $\lambda_1 = 0.52$ W/m^{0}C

Cement sand base $\delta_2 = 0.08$m, $\lambda_2 = 0.76$ W/m^{0}C

Local tuff $\delta_3 = 0.20$m, $\lambda_3 = 0.52$ W/m^{0}C

Gypsum plaster $\delta_4 = 0.02$m, $\lambda_4 = 0.41$ W/m^{0}C

Fig. 4. *5 floor enclosing structure of a multi-story residential building*

The calculation was performed as before (formulas 5,6).

$$R_s = \frac{1}{23.2} + \frac{0.20}{0.52} + \frac{0.08}{0.76} + \frac{0.20}{0.52} + \frac{0.02}{0.41} + \frac{1}{8.7} = 1.23 \text{ m}^2\,{}^0\text{C/W}, \quad (9)$$

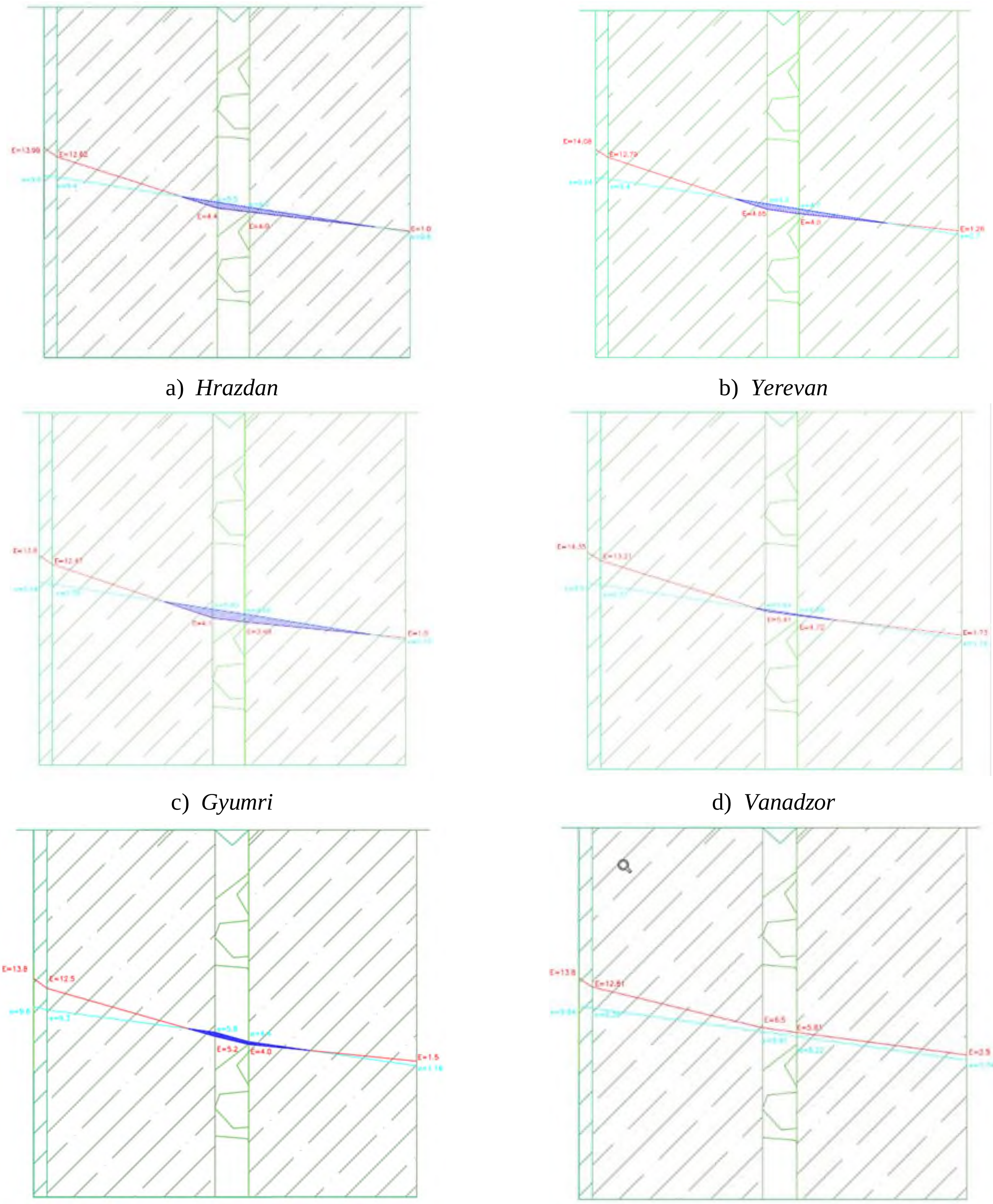
$$k_s = \frac{1}{1.23} = 0.92 \text{ W/m}^2\,{}^0\text{C}. \quad (10)$$

The outdoor air temperatures and relative humidity of a 5-story stone residential building, the heat load from the supporting structure inside, 20^{0}C, and the outdoor temperatures according to the calculated temperatures of the cities, the outdoor air saturation pressure E Pa, and the mass amount of water vapor, mg/m^{2}h are given in Table 4.

Table 4. Thermal load and saturation pressure of outdoor air and mass amount of water vapor of a 5-story residential building

Calculated value \ City	Yerevan	Hrazdan	Sevan	Vanadzor	Gyumri	Kapan
Thermal load, kWt	84.4	86.7	75.5	75.5	94.4	64.4
The relative humidity of the outside air, %	77	79	74	69	83	75
Saturation pressure of outside air E, Pa [11]	125.3	113.3	181.3	181.3	93.3	284.0
Mass of water vapor, mg/m^2h	214.8	216.1	208.0	209.7	218.3	193.8

Since moisture permeability for building construction is determined by the outside air temperature, the humidity change graphs in the calculation mode will be depicted in the form of Figure 5.



a) *Hrazdan* b) *Yerevan*

c) *Gyumri* d) *Vanadzor*

e) *Sevan* f) *Kapan*

Fig. 5. *Humidity change graphs due to vapor permeability of a 5-story building*

Figure 5 shows that for the city of Kapan, due to vapor permeability, there is no condensate formation zone. For the cities of Sevan and Vanadzor, the condensate formation zone is insignificant, but it falls on the clay-sand mortar. Since the duration of negative temperatures during the heating season is short, this zone cannot have a special effect. In the case of the cities of Hrazdan, Yerevan, and Gyur, such a zone falls on the clay-sand mortar itself, especially for Hrazdan, and represents a potential danger in terms of the formation of water ice and the destruction of the layer. In the climatic conditions of the city, the external tuff stone and the concrete mortar poured under it will weaken over time, and the weakening of the wall will be felt, especially on the upper 4th and 5th floors. As mentioned above, the area of condensation formation can be avoided by using a heat-insulating layer, especially in the climatic conditions of Hrazdan. In this case, the thickness of the heat-insulating layer, based on calculations, in the case of using foam-reinforced concrete, is 5 cm in Yerevan and Vanadzor, 6 cm in Gyumri, 7 cm in Hrazdan and Sevan, 4 cm in Kapan; in the case of thermal insulation with expanded polystyrene in buildings with a tufa structure, 6 cm in Yerevan and Vanadzor, 8 cm in Gyumri, Hrazdan and Sevan, 5 cm in Kapan.

Conclusion

1. Increasing the number of stories of a building leads to an increase of moisture permeability on the upper floors, especially in areas with cold climates, as the influence of gravitational forces and relative humidity in the outside air increases.
2. The negative and dangerous effects of moisture permeability can be avoided by insulating the exterior structure, depending on the building's thermal properties, geographical location, climatic conditions, barometric pressure, moisture buildup inside the building, etc.
3. The amount of moisture that penetrates due to moisture permeability can be avoided if a layer of heat- and moisture-insulating material is applied as close as possible to the outside of the structure.
4. The appropriateness of the above measures largely depends on the current and prospective fuel prices in the region.

Conflict of Interest

The authors declare no conflicts of interest.

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IMPROVEMENT OF THE CEMENT MORTAR CHARACTERISTICS REINFORCED WITH BASALT FIBERS

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Abstract: *Fibers derived from basalt rocks exhibit high strength and stability in aggressive environments and are environmentally benign. Consequently, in this study, basalt fiber (BF) was selected as a material to reinforce the mortar. The influence of BF content on the mechanical properties of cement mortars was investigated, and the optimal fiber concentration was determined to be 3.3 kg per 1 m³ of the mixture. The research was conducted on the filler-cement-fiber-water system, and the following results were obtained through analysis of experimental research: flexural strengths increased by 3.7-16.2% for mixtures prepared with river sand and 9.1-16.8% for those prepared with lithoidal sand. Additionally, compressive strengths increased by 3.1-13.7% when river sand was utilized as filler and 5.9-12.4% when lithoidal sand was employed. Developing cement mortar compositions incorporating basalt fibers up to 12 mm in length and lithoidal light and river sands, abundant in our republic, represents a scientific innovation that results in enhanced compressive and bending strengths.*

Keywords: *basalt fiber, cement mortar, flexural strength, compressive strength..*

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Introduction

Concrete science improvements at the end of the 20th century allowed for producing high-quality, high-strength concretes with compressive strengths of not less than 100 MPa. High-rise skyscrapers, oil platforms, and other remarkable structures in the seas and oceans are all constructed using these concretes [1,2]. However, with a significant increase in the compressive strength of concrete, the flexural strength of high-strength concrete increases only slightly, reducing its efficiency. Reducing costs and technological complexity, using materials and energy resources efficiently, and implementing new, cutting-edge materials and technologies are all aspects of modern construction that directly address the issue of improving the efficiency of construction product production. This type of material is known as distributed reinforced concrete, and it is being utilized extensively in many industries [3-5]. Increases in tensile and flexural strength, crack resistance, impact strength, durability, frost resistance, stability, water permeability, wear resistance, and shrinkage reduction are required for new architectural forms, thin-walled panels with complex relief, airport takeoff and landing zones, roads, and industrial building floor panels. Non-metallic composite reinforcement made of glass, basalt, and carbon fibers impregnated and reinforced with a polymer binder, fibrous reinforcement for dispersed reinforcement of concrete made of the same fibers (for fiber-reinforced concrete or, in other words, fiber-reinforced concrete) are used to improve the listed properties. Woven tapes and preparations for reinforcing the web and gutters are also widely used from the same fibers [6-9]. A common reinforcing material is dispersed reinforcement made of different fibers, such as steel, polypropylene, and basalt [10]. The fibers in the concrete mixture are evenly distributed throughout the material field to accomplish dispersed reinforcing. The latter can be considered a revolution in building materials for the twentieth century.

Today, all sectors worldwide are trying to use or develop environmentally friendly materials and processes due to the economic use of ecosystems and natural resources. Therefore, the construction industry should also contribute to producing and using sustainable materials with low CO_2 emissions. Basalt fibers, which have a high modulus of elasticity and tensile strength, were considered in this work [11-13]. Because of their high strength and varying sizes, these fibers greatly enhance the mechanical and physical properties of the final product under stress influences and during abrupt temperature changes. According to [14], 0.5-3.5% BF by weight of cement was added to the concrete mixture. At BF 2%, the strength increased by 10%, and a further increase in BF to 2.5 and 3% led to a decrease in strength by 12 and 21%, respectively. The reduction in compressive strength due to the addition of basalt fiber is explained by the formation of weak interfacial areas between the fibers and the cement mixture [15].

Another study [16] reported a maximum compressive strength increase of 10 % when 0.3% BF with a length of 22 mm was used. The effect of the fiber length on the compressive strength was studied. Four distinct fibers with lengths of 3, 6, 12, and 24 mm were employed at dosages of 0.1, 0.3, and 0.5% by volume of concrete [15]. The test results showed a significant improvement in compressive strength: composites with 12 mm fibers showed the highest compressive strength compared to other composites at all fiber dosages. In addition, a fiber content of 0.1% was considered the optimum content for fibers of any length. According to many studies, the optimum fiber content for compressive strength is approximately 0.3%. However, it is known [17-19] that using basalt fibers increases the tensile and bending strengths of concrete and mortar. In particular, the flexural strength increased by approximately 75% when 0.3% basalt fiber was used in the mixture. The optimum length was 3-12 mm fiber [20,21] owing to the creation of a concrete bridge effect, which contributes to a higher tensile strength and, consequently, an increase in flexural strength. This study explored how the type of filler material, lithoid-pumice sand and river sand, and the quantity of locally produced basalt fiber affected the primary mechanical and physical properties of processed cement mortars.

Materials and Methods

Raw Materials

M400 (Class B42.5) Portland cement manufactured by the Ararat cement plant was used as the binding material in the processed compositions. Laboratory studies of the main physical and mechanical characteristics were carried out according to the GOST EN 196-3-2002 standard[1] and are presented in Table 1. In addition to the characteristics defined by the aforementioned standards, the bulk density of the cement was also determined for practical use.

Table 1. Physical and mechanical properties of cement

N	Characteristics	Unit	Results obtained
1.	The residue on the 0.08 sieve according the fineness of grinding	% by mass	3.6
2.	Specific gravity	g/cm^3	2.89
3.	Bulk density	kg/m^3	1135
4.	Standard consistency	%	26.3
5.	Setting time	min	Initial - 75 Final - 216
6.	Compressive strength	MPa	42.23
7.	Flexural strength	MPa	6.12

This study aimed to develop and research cement mortars reinforced with basalt fibers. Therefore, large aggregates were not considered, and only small aggregates with a grain size of 0-2.5 mm were considered. River and lithoidal pumice sands, currently the most used sands in the construction industry in the Republic, are used as fine aggregates for fiber concretes. Moreover, pre-washed river sand was obtained from the Araksavan deposit and lithoidal-pumice from the Jraber deposit. The physico-mechanical characteristics of the

[1] GOST EN 196-3-2002. Methods of Testing Cement. Part 3. Determination of Setting Time and Soundness. GOST: Moscow, Russia, 2002. Available at: https://www.armstandard.am/en/standart/5558 (accessed on July 31, 2023).

selected sand samples were determined using the current GOST 8735-88[2] standard method. For the sand, the average bulk density, fine particles, and water absorption indicators were also determined, as shown in Table 2. The grain-size composition data determined by standard sieve analysis and the bulk modulus (Ms) are presented in Table 3.

Table 2. Grain size composition of sands

Name of rocks	**Balance type**	**Whole residues on the sieves, %**					
		2.5	**1.25**	**0.63**	**0.315**	**0.16**	**< 0.16**
River sand	Partial	9.96	14.9	32.65	31.2	9.24	1.99
	Total	9.96	24.86	57.51	88.71	97.92	99.91
Lithoidal pumice sand	Partial	12.10	21.45	17.51	17.04	21.25	8.24
	Total	12.10	33.55	51.06	68.10	59.35	97.59

Moreover, according to the values of size modules Ms = 2.54 and 2.79, according to GOST 8736-2014, they belong to the group of course (Ms = 2.5-3.0) sands.

Table 3. Main characteristics of sands

Name of rocks	**Bulk density, kg/m³**	**Dust content, % by mass**	**Water absorption, % by mass**	**Size Modulus, Ms**
River sand	1630	1.76	16.3	2.54
Lithoidal pumice sand	1020	5.63	30	2.79

In contemporary practice, lightweight concretes and construction mortars are in high demand and widespread use due to their numerous advantages. Consequently, this study considers not only river sand but also lithoid-pumice aggregate, which is currently extensively utilized in the construction industry. In contrast to river sand, lithoid-pumice aggregate exhibits high chemical reactivity and, through interaction with calcium hydroxide — a product of cement hydration — mitigates the alkaline environment that poses a threat to fibers. This interaction contributes significantly to enhancing the durability of the resultant products.

It is known that the fibers obtained from basalt rocks have high strength and resistance to many aggressive environments, including cement and calcareous alkaline environments, as well as the thermal effects of fires and other valuable features [22,23]. In addition, it is obtained from natural raw materials and is environmentally safe. Basalt fiber manufactured by "ArmBasalt" Continuous Basalt Fiber Manufacturing Plant CJSC was chosen as the dispersed reinforcement for this work.

Short-length fiber segments are often utilized for dispersed reinforcement, and the waste material generated during the production of basalt fiber roving is also appropriate for this purpose. In the compositions developed, fibers measuring between 10 to 12 mm in length were employed, and their effects on the key physicochemical and mechanical properties of the mortar were examined. Figure 1 presents an example of basalt fibers, while Table 4 summarizes their key characteristics.

Fig. 1. *Dispersed basalt fibers for cement mortar reinforcement*

[2] GOST 8735-88. Sand for Construction Work. Test Methods. GOST: Moscow, Russia, 2021. Available at: https://meganorm.ru/Index2/1/4294853/4294853080.htm (accessed on January 1, 2021).

Table 4. Main characteristics of basalt fibers

Basalt fiber	Characteristics					
	Raw material	**Density, kg/m^3**	**Diameter, μm**	**Melting temperature, ^{O}C**	**Alkali and corrosion resistance**	**Tensile strength, MPa**
	Basalt stone	2800	17	1450	high	450-600

Compositions and Specimen Preparation

To ensure a fair comparison between mortars made with lithoidal pumice sand and basalt fibers and those made with river sand and basalt fibers, we standardized the cost of cement in both cases. However, considering the differences in the average density of these two types of sand, we mixed them in the mortars using the same volumetric proportions rather than by weight. Taking as a basis that the bulk density with river sand is 1630 kg/m^3, and with lithoidal pumice, it is 1020 kg/m^3. Basalt fiber (BF) dosages were chosen according to the amount of content in 1 m^3 of the mortar, with a measurement unit of kg/m^3. BF = 0; 0.5; 1.2; 2.1; 3.3; 4.5; and 6.1 kg/m^3. Laboratory research was conducted using three identical size 40 × 40 × 160 mm test samples. The mortar was prepared in the proportion of cement — filler — water of 1:3:0.5, and the average density $\rho_{average}$ was determined by vibration in a standard 1 liter container. Ten different mortars were developed, as presented in Table 5.

Table 5. Quantites of starting materials for 10 different components

N	River sand, g	Lithoid pumice sand, g	Cement, g	Water, ml	Basalt fiber, g	The volume of the prepared mixture, cm^3	Fresh mix density, ρ_{av}, g/cm^3
1.	1650	-	550	275	-	1.124	2.201
2.	-	1030	550	395	-	1.1	1.794
3.	1650	-	550	275	0.562	1.124	2.248
4.	1650	-	550	275	1.349	1.124	2.232
5.	1650	-	550	275	2.36	1.124	2.187
6.	1650	-	550	275	3.709	1.124	2.151
7.	1650	-	550	275	5.058	1.124	2.201
8.	1650	-	550	275	6.744	1.124	2.172
9.	-	1030	550	395	2.31	1.1	1.774
10.	-	1030	550	395	3.63	1.1	1.789

The mixtures were prepared in a standard mixer for cement mortar (Fig. 2a), with basalt fiber pre-mixed with sand. The resulting mixture with basalt fiber is illustrated in (Fig.2b).

The test specimens were molded using a vibrating platform. After being cured in a normal curing chamber alongside the molds for one day, they were demolded and immersed in water for an additional two days. Subsequently, the specimens underwent heat treatment in a heat bath chamber (Fig.3a).

Fig. 2. *Electric mixer (a) for mortar and the resulting fiber mixture (b)*

The hydrothermal processing was conducted as follows:

- The temperature was slowly raised to 800°C over 1 hour.
- An isothermal treatment was maintained at 800°C for 3 hours.
- After the treatment, the thermo-humidity cell was disconnected, and the samples were allowed to cool until the following day.

Once removed from the heat sink, the test samples were oven-dried (Fig.3b) until they reached a constant mass.

(a) *(b)*

Fig. 3. *Humidity test chamber (a), drying oven (b), and the specimen*

After using the mentioned technology and applying accelerated strengthening through heat treatment, all prism-shaped test samples, measuring 40 × 40 × 160 mm and containing doses of 0.5-6.0 kg/m³ of both non-fiber and basalt fiber, were tested according to standard methods after drying (Fig.3a). Their halves were then also subjected to testing (Fig.3b).

Methods

Flexural Strength

The flexural strength of the specimens was tested using the Unitronic Compression/Tensile 50 kN testing equipment, which had a 50 kN maximum capacity and specimen sizes of 40 mm × 40 mm × 160 mm. A three-point flexural test on a poured prism formed the basis of the experiment using the standard EN 196-1[3].

Compressive Strength

In accordance with the Concrete Compression Machine 2000 kN automatic, Servo-Plus Progress, the compressive strength was determined by the average value of six test specimens, using the standard EN 196-1[4], and the specimen size was 40 × 40 mm. At a loading rate of 2.4 kN/s, compressive tests were performed on an automatic pressure machine.

Results and Discussion

Mechanical Properties

For each component, the final value of the flexural strength was determined by calculating the mean of three identical test samples, while the compressive strength was derived from the average of six halves obtained from the flexural test. The results are presented in Table 6.

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[3] GOST EN 196-1-2002. Methods of Testing Cement. Part 1. Determination of Strength. Available at: https://www.armstandard.am/en/standart/5556 (accessed on July 31, 2023).

[4] Ibid.

Table 6. The main physical-mechanical characteristics of cement mortars without basalt fiber and dispersed-reinforced with basalt fiber

N (Filler, BF consumption)	Average density, ρ_{av}, g/cm^3	Flexural strength, MPa	Compressive strength, MPa
N1 (with river sand, without fiber)	2.18	7.03	37.33
N2 (with lithoid pumice sand, without fiber)	1.7	4.7	29.64
N3 (with river sand, 0.5kg basalt fiber)	2.24	7.29	38.13
N4 (with river sand, 1.2kg basalt fiber)	2.21	7.58	38.80
N5 (with river sand, 2.1kg basalt fiber)	2.18	7.87	39.75
N6 (with river sand, 3.3kg basalt fiber)	2.19	8.17	42.43
N7 (with river sand, 4.5kg basalt fiber)	2.21	7.89	39.51
N8 (with river sand, 6.1kg basalt fiber)	2.17	7.59	38.50
N9 (with lithoid pumice sand, 2.1kg basalt fiber)	1.69	5.13	31.40
N10 (with lithoid pumice sand, 3.3kg basalt fiber)	1.66	5.49	33.32

Flexural strength

According to the data presented in Table 6, the analysis of flexural strength in test samples composed of river sand and varying concentrations of basalt fibers revealed that, in comparison to the flexural strength of the reference test sample N1 (7.03 MPa), the values increased by 3.7% (BF = 0.5 kg, N3 = 7.29 MPa), 7.8% (BF = 1.2 kg, N4 = 7.58 MPa), 11.9% (BF = 2.1 kg, N5 = 7.87 MPa), 16.2% (BF = 3.3 kg, N6 = 8.17 MPa), 12.2% (BF = 4.5 kg, N7 = 7.89 MPa), and 8% (BF = 6.1 kg, N8 = 7.59 MPa). For test samples prepared with lithoidal sand filler, the following data were obtained: the flexural strength of the reference sample was N2 = 4.7 MPa, while the flexural strength of samples made with composition N9, where BF = 2.1 kg was used, was N9 = 5.13 MPa. For composition N10, where BF = 3.3 kg was used, the flexural strength was N10 = 5.49 MPa, representing a 16.8% increase. Figure 4 shows a comparison of the flexural strength tests of reference samples (with a dashed line) and samples prepared with different concentrations of BF.

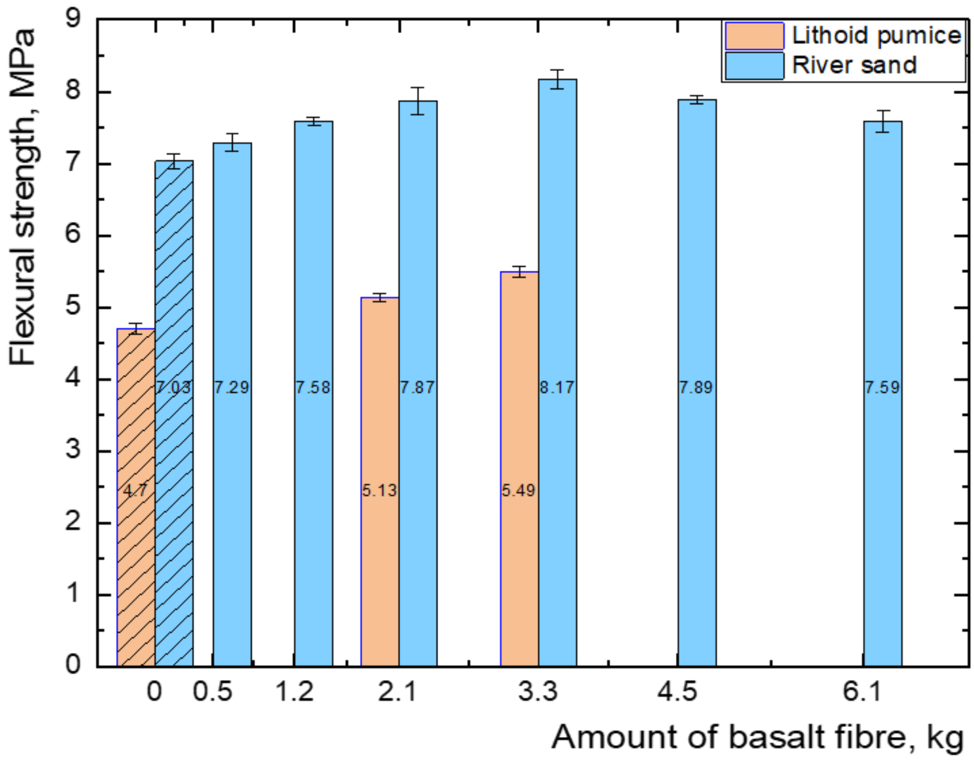

Fig. 4. *Effect of basalt fiber content on the flexural strength of cement mortar*

Compressive strength

The compressive strength testing of the samples yielded the following results (Table 6): For the reference sample utilizing river sand as a filler, the strength was N1 = 37.33 MPa. The compressive strength of the N3 composite post-heat treatment increased by 2.1% relative to the reference sample, reaching 38.13 MPa (BF = 0.5 kg). Sample N4 exhibited a 3.9% increase, attaining 38.80 MPa (BF = 1.2 kg), while N5 demonstrated a 6.5% increase, achieving a compressive strength of 39.75 MPa (BF = 2.1 kg). The N6 composition samples showed a 13.7% increase, reaching 42.43 MPa (BF = 3.3 kg). For compositions N7 and N8, although the strengths began to decrease, they remained elevated compared to the reference sample, with increases of 5.8% (39.51 MPa, BF = 4.5 kg) and 3.1% (38.50 MPa, BF = 6.1 kg), respectively. The compressive strength of the reference sample composed of lithoidal sand was N2 = 29.64 MPa. For N9, the results indicated a 5.9% increase to 31.40 MPa (BF = 2.1 kg), while composition N10 demonstrated a 12.4% increase, with a strength of 33.32 MPa (BF = 3.3 kg).

Figure 5 presents representative graphs illustrating the flexural and compressive strength of the tested samples, while Figure 6 depicts the relationship between the compressive strength values of samples derived from river and lithoid-pemza sands and various concentrations of BF.

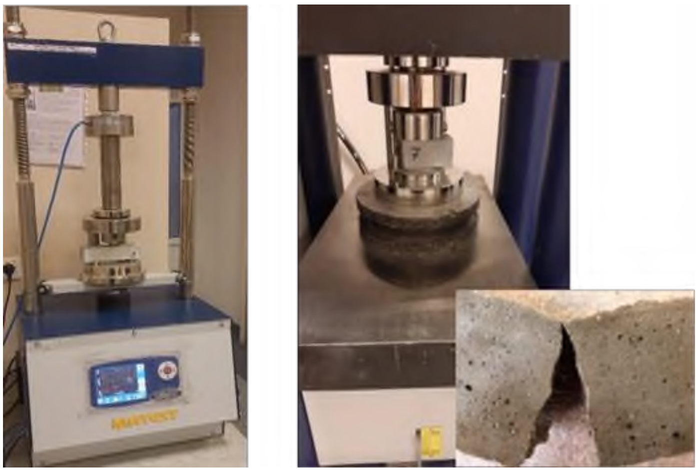

Fig. 5. *Flexural and compressive strength tests*

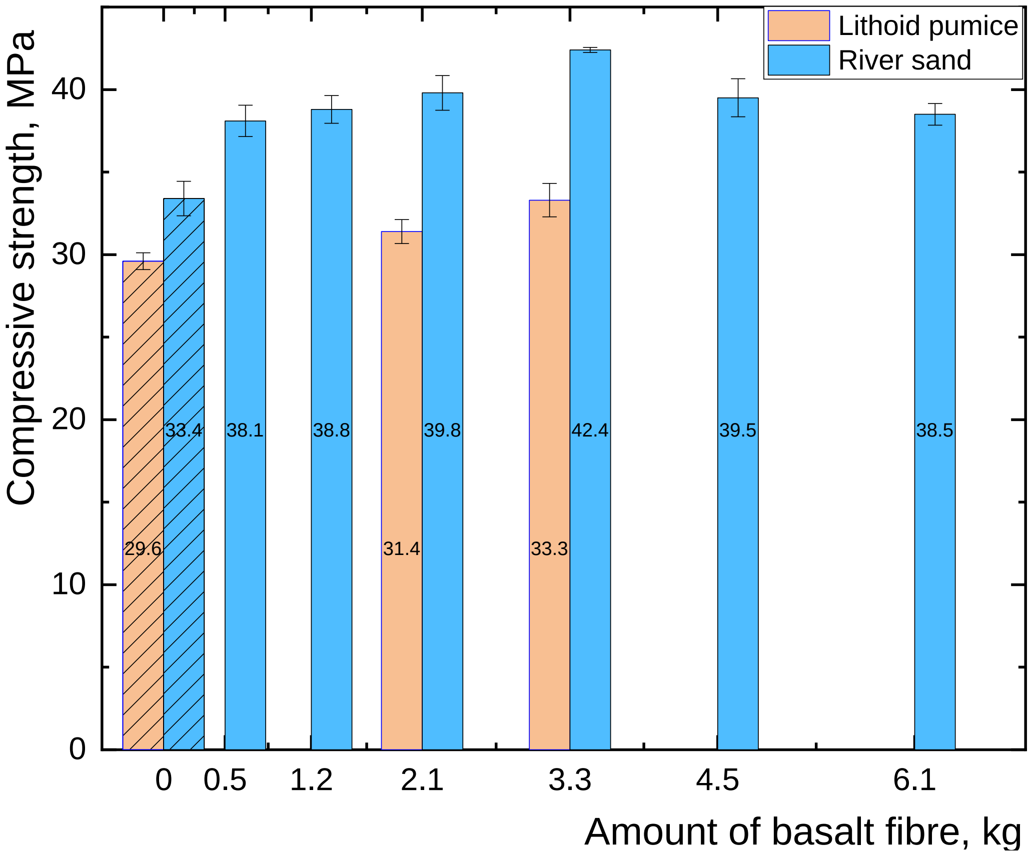

Fig. 6. *Effect of basalt fiber content on the compressive strength of cement mortar*

Basalt fiber can significantly enhance the mechanical properties of concrete due to its unique characteristics. Basalt fibers are known for their high tensile strength. When added to concrete, they enhance its ability to resist tensile forces, reducing the likelihood of cracking and improving its overall durability. By distributing the stress more evenly throughout the concrete matrix, basalt fibers increase the flexural strength of concrete. This is particularly beneficial in applications requiring high load-bearing capacity and resistance to deformation. Basalt fibers minimize shrinkage-induced cracking by acting as reinforcement at the micro level. They also have excellent thermal stability, reducing the risk of cracking due to temperature fluctuations [24,25].

Conclusion

The following conclusion can be made after examining the experimental measurement results from this study:

- Analysis of the obtained results indicates that the flexural strength of the fiber-reinforced mortar, within the range of 0-6.1 kg of fiber consumption per 1 m^3 of mortar mix reinforced with river sand filler and 10-12 mm long dispersed basalt fiber, demonstrates a notable increase. Specifically, at a consumption of 3.3 kg compared to the same mix without fiber, the flexural strength gradually increases from 7.03 MPa to a maximum value of 8.17 MPa, representing an enhancement of 16.2%. Subsequent increases in fiber dosage result in a diminished fiber effect, halting further improvements in bending strength. The flexural strength then begins to decrease gradually, reaching 7.59 MPa at the consumption of 6.1 kg, corresponding to only an 8% increase compared to the fiber-free product.
- The analysis of the obtained results indicates that an initial increase in compressive strength is observed within the range of 0-6.1 kg of fiber consumption per 1 m3 of mortar mixtures reinforced with river sand filler and dispersed 10-12 mm long basalt fiber. Specifically, up to a consumption of 3.3 kg, the compressive strength of the fiber-reinforced mortar compared to the non-fiber mixture gradually increases from 37.33 MPa to 42.43 MPa, reaching a maximum enhancement of 12.4%. However, further increase in the fiber dosage results in a diminishing effect, halting the increase in compressive strength and subsequently leading to a gradual decrease.
- The results presented in the aforementioned points demonstrate that for 1m^3 of dispersed cement mortars reinforced with basalt fiber 10-12 mm in length, the optimal quantity of fiber is 3.3kg. Concurrently, the experimental results obtained for flexural and compressive strength indicate that they vary according to a similar pattern; however, the influence of fiber on flexural strength is marginally greater than on compressive strength.

Basalt fiber mortars are utilized for strengthening and retrofitting existing structures (both concrete and masonry). This process may be implemented through basalt-based fiber-reinforced polymers and cementitious matrices. In plastering and rendering applications, basalt fiber mortars enhance crack resistance and impact strength. These materials are employed for structural and non-structural repairs, particularly in historical buildings.

Conflict of Interest

The author declares no conflicts of interest.

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EVOLUTION OF CITIES UNDER CLIMATE CHANGE: GREENING AND BLUE-GREEN INFRASTRUCTURE

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Abstract: *Every year the world's population moves more and more to cities. Today 56% of all people live in cities, the forecast for 2050 suggests an increase in this figure to 60%. Sustainability for urban development is critical, as it addresses such issues as water and air pollution, waste management and resource consumption. Green cities use environmentally friendly practices to promote the health of the urban environment and, as a result, improve the quality of life. Nature-based solutions represent an interdisciplinary issue, including the competencies of urban planners, landscape designers, engineers, hydrologists, ecologists, economists, etc. and are critically needed for climate change adaptation.*

The paper is focused on the role of blue-green infrastructure as key adaptation strategy for climate change. Innovative approaches and technologies as examples of the best urban management strategies promoting a more sustainable urban environment resistant to climate change will be presented and discussed.

Keywords: *urban development, climate change, mitigation and adaptation, blue-green infrastructure, ecosystem services.*

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Introduction

Cities have always attracted people, becoming economic engines, centers of trade, culture, and innovation. The benefits are also related to utilizing human capital, shared infrastructure, and division of labour [1]. Some 56% of the global population (4.4 billion inhabitants) already lives in cities, and by 2050, two-thirds of the world's population are expected to live in urban areas, which is projected to increase to around 9.8 billion[1] [2]. There is a strong relationship between urbanization and income: as countries get richer, they tend to become more urbanized. Therefore, urban populations tend to have higher living standards [3–6]**.** Today, megacities occupy about 3% of the earth's surface but at the same time consume two-thirds of the world's energy and other resources. The consumption of materials by the planet's cities (all raw materials mined in the territory per year plus imports minus exports) will increase from 41.1 billion tons in 2010 to 88.8 billion tons by 2030. The cities are the largest contributors to climate change, creating about 70–75% of anthropogenic carbon dioxide emissions. Despite all their power and wealth, cities are extremely vulnerable to climate disasters [7]. The modern process of urbanization is characterized, first of all, by a deterioration of the urban environment. The purpose of this paper was to analyse the development of blue-green infrastructure in the city of Krakow and its role in shaping the urban environment in terms of improving the quality of life of city residents and adaptation to climate change. The aim was achieved based on the case studies of the development and transformation of urban areas in Krakow, Poland.

Urban areas as techno-ecosystems

Urban population growth, especially in recent decades, turned out to be so rapid that the environment of many cities in the world is no longer able to satisfy many biological and social needs of the people. The big

[1] United Nations, Department of Economic and Social Affairs, Population Division, 2018.

cities change almost all components of the natural environment – topography, water resources, atmosphere, soils, and even climate. Cities concentrate people, infrastructure, and many other resources in a limited space – this makes them more vulnerable to natural phenomena. In addition, there are typical urban problems: air and water pollution and the generation of various types of waste. Dense urban development, urban transport, and a lack of green spaces contribute to the emergence of heat islands. This phenomenon is caused by sealed surfaces (asphalt, concrete) "absorbing" heat and not allowing surface runoff to pass through. This process is intensified by climate change: the average annual temperature is rising, and abnormal heat waves are occurring more frequently. At the same time, the demand for air conditioning increases, which means greater energy production, respectively. More hydrocarbons must be processed to meet demand, resulting in higher emissions of air pollutants and greenhouse gases (Fig.1).

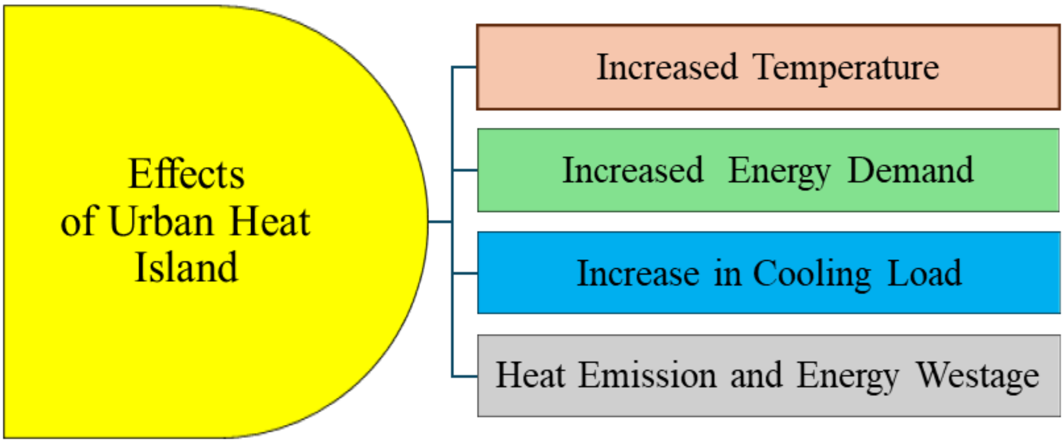

Fig. 1. *Negative effects of urban heat islands [8]*

Many cities also suffer from a shortage of fresh water. According to the World Resources Institute, 17 countries, home to a quarter of the world's population, have extremely high levels of water stress. The demand for energy and water is increasing due to population growth, socio-economic development, and urbanization, while climate change makes this problem even more critical. All this harms the comfort of life and health of the population. From an environmental point of view, a modern city is a tangle of acute contradictions with the need to seek difficult compromises. First of all, the process of urbanization deals a severe blow to the fragile ecological balance. The main problems in urban areas are presented in Figure 2 [9].

The urban environment becomes the basic condition for human life. A healthy urban environment favourable for people and nature ensures the physical, psychological, and social comfort of residents, harmonious and sustainable social and economic development of the city.

The urban ecosystem is an unstable natural-anthropogenic system, consisting of architectural and construction sites and severely disturbing natural ecosystems. If the first ones provide comfort of life for a modern city dweller, the latter, on the contrary, reduce its quality [10]. The city develops special microclimatic conditions inherent in individual areas of the urban area. The formation of the city's microclimate is also influenced by the conditions created by urban development, as well as city transport, thermal power plants, industrial and other enterprises. The major factors of city microclimate formation are the following: (1) topography changes; (2) difference in thermophysical properties of the surfaces of urban elements and natural environment; (3) difference in albedo of underlying surfaces of the city territory and surroundings; (4) artificial heat flows; (5) air pollution; (6) reduced evaporation due to sealed surfaces; (7) sharp decrease of surface area with vegetation and natural soil [11].

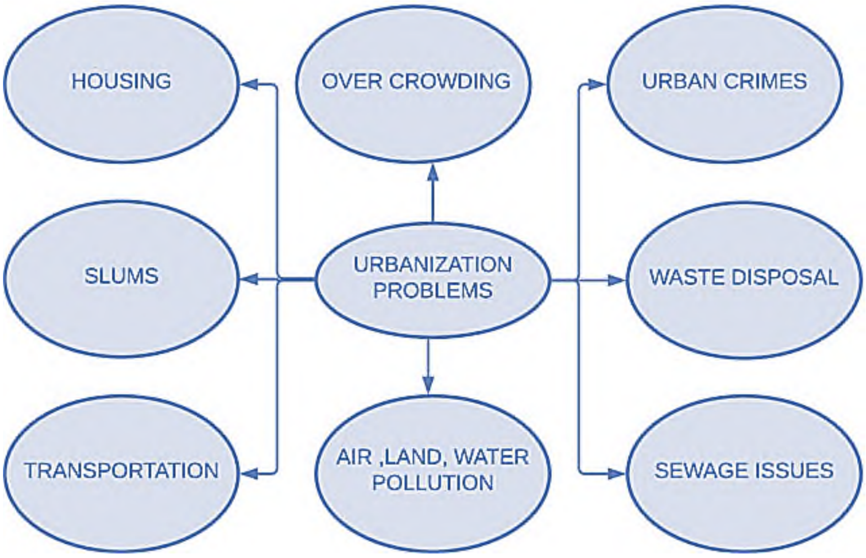

Fig. 2. *The main social and environmental problems in urban areas [9]*

Urban development vs climate change

Cities influence climate both at local and global levels and, in turn, are themselves subjected to the consequences of climate change. Cities contribute to global climate change by releasing greenhouse gases through heating, cooling, transport, and industry. As cities grow, they are increasingly exposed to the risks of climate change, especially in the absence of rational development planning. The new urban development program adopted at the third UN conference on housing and sustainable development defines sustainable cities as "providing protection, preserving, restoring, and shaping ecosystems, water resources, natural habitat, and biological diversity, minimizing environmental impact, and providing the transition towards sustainable consumption and production patterns"[2]. The number of activities required to achieve the goal of sustainable urban development is presented in Figure 3 [12].

Fig. 3. *The basic activities towards transformation to sustainable urban development (on the base of [12])*

Blue-green infrastructure

One of the tools for urban areas adaptation to climate change is creating blue-green structures. Urban green infrastructure planning (UGI) is a strategic approach to develop interconnected and multifunctional networks of blue and green spaces that potentially provide a wide range of environmental, social and economic benefits and simultaneously enhance the climate resilience of cities[3]. Already now, blue-green infrastructure" can act as a systemic approach to address the problems of pollution, habitat, recreation, and urban development. Integrating the green (soft areas, plants, and trees) with the blue (watercourses, ponds, lakes, and storm drainage) elements makes the urban spaces more resilient, pleasant, and healthy places to live, work, and

[2] Habitat III: New Urban Agenda. Quito, Ecuador, October 2016.

[3] Urban green infrastructure planning and nature-based solutions. DG CLIMA Project Adaptation Strategies of European Cities (EU Cities Adapt), Climate-ADAPT, 2024.

leisure. The development of such infrastructure in cities helps to increase the flow of benefits from ecosystem services and is an important trend in the formation of a "green" economy (Fig.4) [13].

Trees, parks, and gardens are not only compatible with cities but undoubtedly must be an integral part of densely populated urban areas. Trees and other plant species create many benefits, such as restoration of the water cycle, reduction of CO_2 emissions, and air purification, all of which have aesthetic value and improve the quality of life[4].

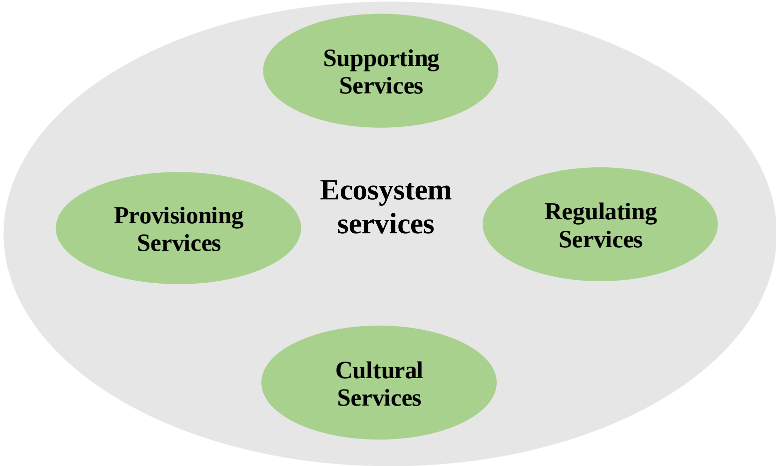

Fig. 4. *Ecosystem services in urban areas [13]*

The conservation and restoration of natural ecosystems has a long history but is not always perceived as a tool for climate change mitigation. One way to adapt to climate change is to use the stabilizing role of natural ecosystems. Modern large cities are practically devoid of natural ecosystems. They are trying to adapt to new conditions primarily through "grey" infrastructure (i.e., engineering structures and technologies) that require significant resources and are often mono-functional. It is cheaper, more efficient, and more durable for cities to turn to solutions created by nature itself. Such solutions can be implemented by replacing "grey" infrastructure with "green" and "blue" ones, that is, creating, preserving, and properly using green areas and water bodies.

However, in order to achieve the effect of "green" infrastructure, strategic planning is necessary taking into account local specifics, ensuring the creation and maintenance of a continuous water-green framework of the city as a single system. Spatial planning has a key role in addressing the causes of climate change.

Materials and Methods

To achieve the intended goal, the following research methods were used: the monographic method, document examination method, diagnostic survey method, and case-by-case method. The analysis was carried out based on data obtained from the Municipal Green Area Management Board in Krakow for the period 2018-2024 (statistical data on the number, types, and surface of urban green areas, urban greenery maps, and others).

Results and Discussion

Case Study: Approach to Urban Greening and Blue-Green Infrastructure in Krakow

Examples of urban greening, implementation of blue-green infrastructure, and Nature-Based Solutions (NBS) can be found in cities around the world that are actively pursuing sustainable development and adaptation to climate change. Krakow, a historic city in southern Poland with a population of approximately one million, is one of them. The actions taken in Krakow towards achieving climate neutrality and enhancing the city's resilience to the impacts of climate change can serve as a model to follow.

In recent years, the Municipality of Krakow (GMK) has implemented a series of policies, strategies, and plans aimed at creating an environmentally friendly and sustainable urban space in the city. These documents have redefined the goals to be achieved and the priorities for actions through 2050, with a particular emphasis on achieving climate neutrality. For this purpose, Krakow has decided to join the "Mission 100 Climate-Neutral and Smart Cities" by 2030. To reach this goal, the city has developed a "Climate Contract," which serves as an action plan for achieving climate neutrality by 2030. The target is to reduce CO_2 emissions by

[4] Summary of the 21st Session of the Committee for the Review of the Implementation of the Convention of the UN Convention to Combat Desertification. Earth Negotiations Bulletin, 4 (303), 2023

80% by 2030 compared to the base year of 2018. The city's efforts are currently progressing according to plan, making the achievement of this target seem realistic.

One of the city's main strategic objectives is to increase the proportion of green areas within developed spaces, enhance forest cover, and improve residents' access to these areas. To accelerate the achievement of environmental and climate goals, GMK established two specialized organizational units: the Municipal Greenery Authority (2015), focused on the development and management of green spaces in Krakow, and the municipal unit Climate-Energy-Water Management (2020), dedicated to reducing greenhouse gas emissions and adapting Krakow to climate change. As a result of the efforts of these two municipal units, supported by other municipal organizations, over 376,500 trees and more than 818,000 shrubs and climbers have been planted in Krakow since 2015. Since 2018, 28 new city parks have been opened to the public, and 24 existing parks have been modernized. Additionally, 27 new pocket parks, 18 new community gardens, and 6 "Krakowian Parks" have been established.

As part of the city's afforestation plan for 2018-2024, the forested area within the city's boundaries has increased from 4% to nearly 5%, with a target of achieving a forest cover rate of at least 8% by 2040. All investment activities undertaken to green the city simultaneously improve residents' access to recreational public green spaces, which now total 2,526,000 m². Currently, 85% of Krakow residents have access to public green areas larger than 0.5 hectares within a straight-line distance of no more than 300 meters. A summary of current data on parks and gardens located in Krakow is presented in Table 1[5,6,7,8,9,10,11].

Table 1. Summary of Basic Information on Urban Parks and Gardens in Krakow for the Years 2018 and June 2024

Type of Green Space	Number		Area
	2018	**June 2024**	**[ha]**
Parks	43	75	835,19
Pocket Parks (Krakowian Gardens)	16	43	11,65
Forests	-	-	1590,39
Community Gardens	3	21	-
Krakowian Parks	0	6	-

An essential parameter indicating a city's resilience to climate change is the biologically active surface area ratio. In Krakow, this indicator currently stands at 72% of the city's total area, which is 327 km².

Equally important as urban greening for building climate resilience is a city's ability to manage and absorb rainfall effectively to prevent localized flooding and manage drought conditions during dry periods. To achieve this, the city of Krakow continuously implements measures to restore natural retention systems in highly urbanized areas. The primary objective is to manage stormwater so that it is retained as much as possible at

[5] Zarząd Zieleni Miejskiej w Krakowie: Krakowska zieleń w liczbach. https://zzm.krakow.pl/?view=article&id=1606&catid=111
[6] Zarząd Zieleni Miejskiej w Krakowie: Lista parków miejskich. https://zzm.krakow.pl/images/pliki/PLIKI%20PDF/Parki.pdf
[7] Zarząd Zieleni Miejskiej w Krakowie: Lista parków kieszonkowych. https://zzm.krakow.pl/images/pliki/PLIKI%20PDF/parki%20kieszonkowe%206.24.pdf
[8] Zarząd Zieleni Miejskiej w Krakowie: Powierzchnia lasów miejskich. https://zzm.krakow.pl/nowe-lasy/1524-informacja-o-powierzchni-lasow-w-krakowie.html
[9] Zarząd Zieleni Miejskiej w Krakowie: Mapa krakowskich ogrodów społecznych. https://zzm.krakow.pl/dla-krakowian/ogrody/krakowskie-ogrody-spoleczne/1090-mapa-krakowskich-ogrodow-spolecznych.html
[10] Zarząd Zieleni Miejskiej w Krakowie: Lokalizacje parków krakowian. https://zzm.krakow.pl/wspoldzialanie/parki-krakowian.html
[11] Zarząd Zieleni Miejskiej w Krakowie: Mapy lasów zlokalizowanych na terenie Gminy Miejskiej Kraków. https://zzm.krakow.pl/lasy-w-krakowie-na-mapach.html

the point of precipitation (within the local catchment area), and where this is not feasible, to delay the outflow of stormwater from the local catchment area to the greatest possible extent.

To this end, Krakow is undertaking a range of investment activities focused on developing a comprehensive blue-green infrastructure. This includes the construction of retention basins, depressions, ponds, bioretention ditches, infiltration ditches, rain gardens, green roofs, facades, walls, permeable pavements, and structural soils. Where necessary, impermeable surfaces are being replaced with permeable ones. All these actions are preceded by thorough analyses of water flow in local catchments using advanced numerical hydrodynamic models. These models not only help to identify potential flood-prone areas but also optimize the placement of technical solutions to enhance the retention capacity of each catchment.

Examples of Developing and Transforming Urban Green Spaces

Railway Park in the City Center

In 2017, a railway link was introduced in downtown Krakow, connecting two separate railway lines into a unified system to serve regional and agglomeration rail services. The railway link comprises three viaducts with a total length of over one kilometer and two bridges with a length of 155 meters. The link is supported by 30 pillars up to 15 meters high and uses 28 steel spans with a maximum span of 81 meters (Fig 5). Beneath the viaduct, between the pillars, a new open space with an area of 20,000 m² was created. Following public consultations, this space has been designated as Railway Park, which will also serve as a pedestrian and bicycle route connecting two adjacent city districts (Fig.6).

Fig. 5. *Aerial view of the railway link, beneath which Railway Park is planned to be developed* [12]

Fig. 6. *Visualization of a section of the Railway Park beneath one of the viaducts* [13]

In accordance with the residents' wishes, the park has been divided into functional zones, determined by various spatial and architectural factors such as the height of the pillars, the width of the viaduct, and the surrounding environment. The design includes the creation of an educational trail focusing on the history of railway transport development in Poland, complemented by graphic elements that also serve to enhance the monochromatic pavement and concrete elements of the viaduct. Along the entire length of the railway link, a series of green zones with different functionalities will be developed beneath the viaducts. These will include, among other things: a playground in the form of a railway town, a sensory garden, a dog park, a recreational area, bicycle parking facilities, a meeting area, a multifunctional zone (including services, retail, and cultural spaces), a sports zone (featuring basketball, soccer, fitness areas, and a skatepark), and a community garden[14]. All these zones will be surrounded by tall and low greenery, as well as flowering meadows. The park is currently under development.

[12] Ministerstwo Infrastruktury: https://www.gov.pl/static/mi_arch/2-514324a4ec938-1798072-p_32.html
[13] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/
[14] Ministerstwo Infrastruktury: https://www.gov.pl/static/mi_arch/2-514324a4ec938-1798072-p_32.html

Zakrzowek Park – Urban Swimming Area

The park was established around a former quarry, now filled with crystal-clear water (Fig.7). It has become one of the city's favorite recreational spots. Zakrzowek Park covers an area of 50 hectares, and together with adjacent areas, the blue-green space spans approximately 100 hectares[15]. The park features charming walking trails, viewpoints, and running paths equipped with water fountains. It also offers extensive opportunities for cyclists and rock climbers. In recent years, the park has introduced Krakow's first public swimming area of this kind. The swimming facility consists of openwork pools on the surface of the reservoir, with varying depths, allowing for swimming both for proficient swimmers and those who are not, as well as a 40-cm-deep pool designed for children[16].


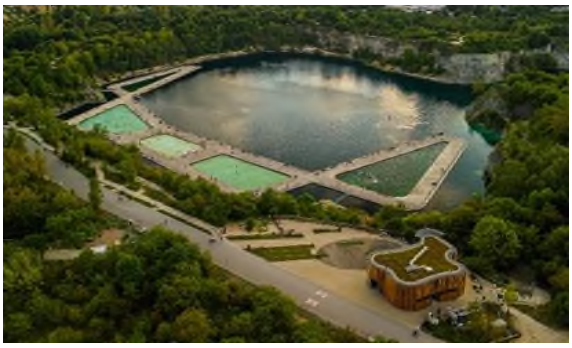

Fig. 7. *Zakrzowek Park [17,18]*

Pocket Gardens

Pocket gardens in Krakow are small green spaces developed in various parts of the city, primarily on previously unused or underutilized plots. This initiative aims to increase greenery in densely built urban areas, improve air quality, and create recreational spaces for residents. These gardens are often designed with environmental sustainability in mind, incorporating native plant species and sometimes including educational elements, such as informational boards about local fauna and flora.

Krakow features several unique pocket gardens, each with its own theme. The Fairy Tale Garden (Fig.8) draws inspiration from fairy tales, incorporating elements that evoke children's literature and create a magical atmosphere.

Fig. 8. *The Fairy Tale Garden [19]*

Fig. 9. *The Chess Garden[20]*

The Chess Garden (Fig.9) includes chess tables amid greenery, encouraging residents to engage in intellectual outdoor activities. The Weed Garden (Fig.10) showcases the beauty of wild plants and weeds, often undervalued, highlighting their role in the urban ecosystem. The Chestnut Garden (Fig.11) centers around

[15] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/
[16] Ibid.
[17] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/
[18] Zalew Zakrzówek i Uroczysko Skałki Twardowskiego. https://cudnapolska.pl/zalew-zakrzowek-i-uroczysko-skalki-twardowskiego/
[19] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/
[20] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/

chestnut trees, with their leaves and fruits forming a distinctive element, providing a tranquil space for elaxation under the tree canopies. These gardens enrich the urban landscape, offering diverse aesthetic and educational experiences[21,22].

Fig. 10. *The Weeds Garden* [23]

Fig. 11. *The Chestnut Garden* [24]

Community Gardens

Community gardens are shared green spaces created and maintained by residents. Their primary roles are to foster social integration, provide ecological education, and promote sustainable living. These gardens offer opportunities for growing vegetables, herbs, and flowers and serve as venues for meetings, workshops, and cultural events, thus strengthening community bonds.

One example is the Wild Explorers Space (Fig.12). This garden combines recreational and educational functions, particularly aimed at children. It features a variety of installations and natural elements designed to encourage young visitors to explore nature and learn through play. The space is designed to stimulate creativity and curiosity about the world while fostering ecological awareness from an early age.

Another community garden, located in Kurdwanow, is dedicated to the collective cultivation of plants by residents. This garden serves as a place that fosters integration and the exchange of experiences among its users (Fig.13).

The garden at the Kraków City Hall, on the other hand, offers a more tranquil setting where residents and municipal employees can relax amidst greenery and participate in various ecological initiatives (Fig.13).

Fig. 12. *Community Garden - Wild Explorers Space* [25]

[21] Zarząd Zieleni Miejskiej w Krakowie: Lista parków kieszonkowych. https://zzm.krakow.pl/images/pliki/PLIKI%20PDF/parki%20kieszonkowe%206.24.pdf
[22] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/
[23] Ibid.
[24] Ibid.
[25] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/

Fig. 13. *Community Garden – Kurdwanow (left) and Community Garden – at the Krakow City Hall (right)* [26]

Revitalization of Streets and Squares

One of the more notable projects undertaken by the city was the revitalization of Krupnicza Street, located in the heart of Krakow. The goal of these revitalization efforts was to create a space that is welcoming to all residents – pedestrians, cyclists, and businesses operating on the ground floors along the street. The guiding principle behind the changes was based on the concept of a woonerf – a street with traffic-calming measures where pedestrian safety is prioritized while still accommodating vehicular traffic. This goal was achieved by creating a shared space for all users through the elimination of curbs and the traditional separation of roadway and sidewalk. Traffic calming was further supported by the integration of street furniture and green spaces.

Rainwater harvesting systems were installed along the street, with collected water used to irrigate new plantings during dry periods. Additionally, rain gardens were established along the entire length of the street. The street surface is constructed from granite paving stones, occasionally supplemented by historical basalt cobblestones recovered during demolition work. Embedded within the paving are copper plates providing information on significant historical and cultural facts related to Krupnicza Street (Fig.14).

Fig. 14. *Krupnicza Street before (left) and after (right) revitalization* [27]

Another example of urban greening is the revitalization of the area around the Market Hall in Grzegorzki, Krakow. This project aims to transform the area into a modern and functional urban space. It involves updating infrastructure, enhancing the aesthetics of public spaces, and introducing new elements of street furniture. However, the most crucial aspect is increasing the amount of green space through tree planting, creating small parks and gardens, and constructing green roofs on tram stops. These measures are intended to modify the local microclimate and reduce the urban heat island effect (Fig.15).

[26] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/

[27] Whitemad. Available at: https://www.whitemad.pl/zniknely-auta-powstal-deptak-ulica-krupnicza-w-krakowie-po-metamorfozie/

Fig. 15. *The area around Market Hall in Grzegorzki before (left) and after (right) revitalization* [28]

Blue-Green Infrastructure

In Krakow, a variety of blue-green infrastructure solutions are being implemented to integrate vegetation with stormwater management systems. Examples of such solutions include urban parks and green spaces, such as the Park of Polish Aviators (Fig.16), which serve both retention purposes by storing stormwater and recreational functions, enhancing air quality. Other examples include green roofs on public buildings, residential blocks, office buildings, and public transport stops, as well as green walls. For many years, Krakow has been constructing retention tanks and rain gardens aimed at capturing stormwater and reducing runoff into sewage systems. These solutions support local biodiversity and contribute to cooling urban areas on hot days.

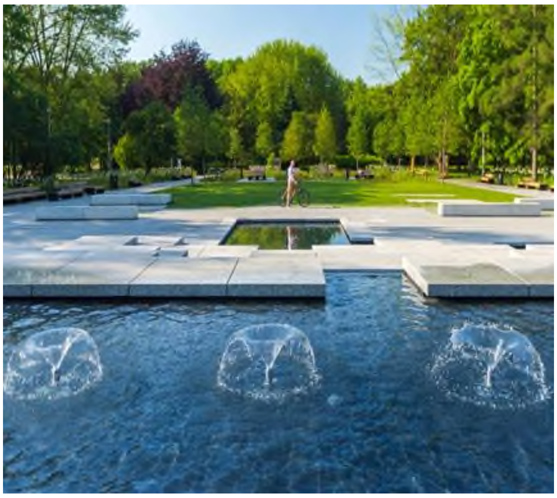

Fig. 16. *Park of Polish Aviators – an example of a pond as a component of blue-green infrastructure* [29]

Conclusion

Climate change necessitates innovative approaches to urban planning and development. Urban greening and the implementation of nature-based solutions (NBS) are becoming crucial components of adaptation strategies aimed at enhancing the resilience of urban environments to these changes. Effective adaptation requires an interdisciplinary approach, integrating knowledge from urban planning, hydrology, ecology, and engineering. An example of a city that has long pursued an ambitious pro-climate policy is Krakow. Through numerous initiatives related to greening and managing storm water, the city aims not only to improve the quality of life for its residents but also to enhance its resilience to climate change. The priority is retention, green and blue infrastructure, maintenance and revitalization of parks, afforestation, etc. The analysis of the presented examples of investments implementation in the field of blue-green infrastructure in Krakow clearly shows the city's commitment to the application of the "sponge city" strategy. Increasing biologically active

[28] Lovekrakow. Available at: https://lovekrakow.pl/aktualnosci/zdjecie/51359
[29] Zarząd Zieleni Miejskiej w Krakowie: https://zzm.krakow.pl/

areas plays an extremely important role in the functioning of urban ecosystems. Greening cities allows for the achievement of the following strategic ecological, economic, and social goals:

1) restoring the natural water cycle and water balance in the city,
2) mitigation of the urban heat island phenomenon,
3) shaping a comfortable microclimate of the city,
4) improving of the general ecological situation,
5) adaptation to the adverse effects of climate change,
6) improvement of the urban technical infrastructure functioning (e.g., wastewater networks, highways),
7) rational management of rainwater and its use for different municipal needs,
8) increasing the safety and life quality of residents,
9) social integration of residents,
10) creation of additional employment places.

Lack of funding is consistently cited as a barrier to green infrastructure implementation. However, one of the advantages that green infrastructure projects offer is that they bring so many benefits that they can compete for a variety of different funding sources. Some tax incentive programs administered by federal agencies can be used to attract funding for green infrastructure projects. The city of Krakow's long-standing commitment to the development of blue-green infrastructure was honoured in 2022 with an award in the Eco-City competition organised by the French Embassy in Poland and the UNEP/GRID-Warsaw Centre.

Conflict of Interest

The authors declare no conflicts of interest

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THE HISTORY OF SQUARE FORMATION AND PECULIARITIES OF COMPOSITIONAL FORMATION

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Abstract: *This work delves into the compositional aspects of urban space organization, aiming to provide an overview of the historical development of squares and elucidate the intricacies of their compositional formation through the analysis and comparison of various examples. The article draws upon published materials and employs scientific methods of generalization and analysis. It synthesizes the history of square formation and development while scrutinizing the key characteristics influencing square composition. By examining 40 squares at different times and locations, certain recurring features impacting compositional formation–such as perception of space, degree of enclosure, architectural and compositional imagery, and scale–have been identified. Furthermore, the study identifies additional factors affecting the formation of square composition, the further exploration of which promises to enrich and refine ongoing investigations on the subject matter. The insights gleaned from this study hold relevance for future scholarly endeavors concerning square composition and for researchers with an interest in the study of squares in general.*

Keywords: *square, spatial organization, compositional formation, proportionality, visual perception.*

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Introduction

Public squares hold significant importance as public spaces within urban environments. They serve as open areas that reflect the identity of cities and the cultural background of communities, acting as hubs for communal gatherings and urban activities since ancient times. As fundamental components of city structures, urban squares contribute significantly to a city's image and prestige [1]. Historically, public spaces have been central to population centers, tailored spatially and functionally to suit the needs of surrounding cities or towns [2]. Throughout history, squares have evolved, undergoing functional and compositional changes from Ancient Greece to the present day. One of the earliest examples of public squares is the Greek Agora, which played a vital role in Greek city life, serving as an open space in the city center for political, social, and economic activities [1]. Greek agoras hosted a variety of gatherings, including political meetings, athletic competitions, theatrical performances, and commercial activities [3]. The next significant period of square development occurred in Ancient Rome with the creation of the Roman Forum, which synthesized elements of the Greek agora and acropolis. Subsequent periods saw the emergence of trade squares in the Middle Ages, predominantly in European countries, followed by the dominance of Italian piazzas during the Renaissance and Baroque periods. The period of classicism also left its mark on square development. The 19th and 20th centuries were pivotal for the compositional and functional evolution of squares, leading to our current era, where squares seem to have lost their primary societal role without clear functional significance. Throughout different historical periods, theorists from Vitruvius to Francis Chin have examined the history and compositional development of squares in their works. Various researchers have dedicated studies to specific types of squares, such as the Greek Agora and Roman Forums. For instance, works by John McK. Camp, Jamieson C. Donati, Flavio Barbini, and others [4-11] have covered the Greek agora, while the Roman forums were first covered by Vitruvius, and notable contributions have been made by David Watkin [9, 12-17].

Additionally, there are various studies on squares from the Middle Ages, the Renaissance, Baroque, Classicism, and the 19th and 20th centuries [1, 4, 8, 9, 18-24]. However, existing research primarily focuses on the general history, design, and construction of squares, their societal role, and their relationship with surrounding buildings. There is a lack of comprehensive exploration of issues such as square composition, factors influencing spatial organization, and compositional principles, as well as limited research on proportional analysis and comparison of squares from the same or different eras and locations. This study aims to address these gaps by providing a comprehensive overview of the history of square creation and revealing the peculiarities of their compositional formation through analysis and comparison of various examples. The focus of this work is particularly on compositional principles, spatial organization issues, and proportionality factors influencing square formation.

Materials and Methods

This work has been developed based on material published on the subject, including scholarly articles and books, utilizing scientific methods of generalization and analysis. The first part of the study focuses on the general history of square creation, presenting the evolution of squares across different periods and locations. In the second part, a detailed analysis of typical characteristics influencing square composition is conducted. For this research, 40 squares from various eras and locations were selected for analysis and comparison, resulting in the creation of a relevant Table. The selected squares are chronologically arranged from the 6th century BCE to the 20th century CE and classified according to periods. During the analysis of square composition, three indicators were utilized: a) the ratio of square width to length, b) the ratio of square width to the height of surrounding constructions, and c) the ratio of lengths between open and closed parts of the square's construction perimeter. The examination of these selected squares allowed for the identification of certain characteristics influencing square composition, including the degree of enclosure, architectural and compositional imagery, and scale. Additionally, other characteristics influencing square composition formation were identified, with further study expected to enrich and clarify the research material on the subject. The insights derived from this study are pertinent for future scholarly endeavors concerning square composition and for researchers interested in the broader study of squares.

Results and Discussion

Emergence and formation of squares

Agora

Arguably the most renowned public space of all time, the ancient Greek agora served as the primary public square and meeting place of the town. Initially a marketplace, the agora transcended its commercial function to become a venue for assembly, ceremonies, and spectacles, where economic, political, and cultural activities intertwined, forming an integral platform for the city's social life [4]. Physically, the agora stood as the central node of an ancient Greek city, with significant roads converging here from various directions, facilitating the movement of people, money, goods, and ideas [5]. Agora, serving as both a market and the political center of Greek cities, typically featured a square surrounded by porticos in one or several colonnades [6]. The agora was typically a square or rectangular space [7]. In the 6th century BCE, Athens created its agora as a space for citizen assembly, where orators could address the populace and exchange ideas, reflecting Greek society's democratic principles [8] (Fig.1).

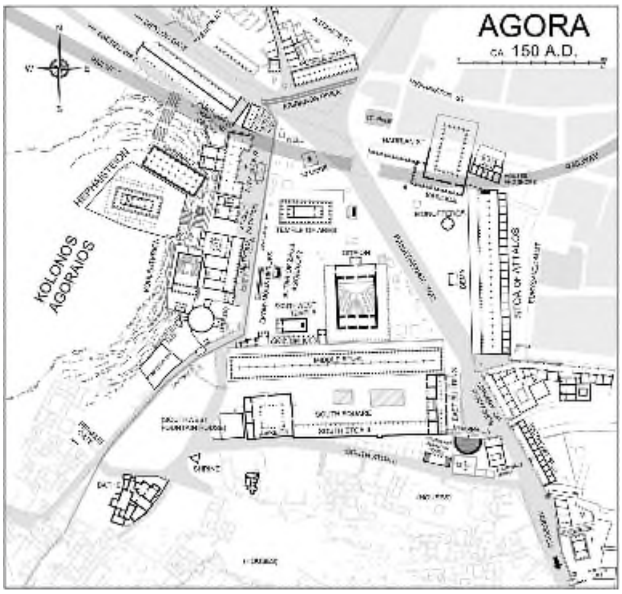


Fig. 1. *Plan of the Athenian Agora*

Table. Analysis of 40 selected examples

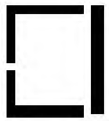
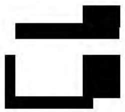
№	Period	Type of public square	Name of the public square	Plan	The ratio of width to length	The ratio of width to height	Compositional principle	The ratio of the lengths of open and closed sections along the perimeter
1.	Ancient Greece	Agora	Agora of Athens, 6th century BCE		1	12.09	asymmetric	0.51
2.			South Agora of Miletus, 3rd century BCE		0.8	-	symmetric	0.06
3.			Agora of Priene, 3rd century BCE		0.85	-	asymmetric	0.14
4.	Ancient Rome	Forum	Forum Romanum		0.4	1.7	asymmetric	0.21
5.			Pompeii Forum, 4th century BCE		0.2	-	asymmetric	0.28
6.			Ostia Forum, late 6th or early 5th century BCE		0.36	-	disymmetric	0.31
7.	Middle Ages	Medieval market square	Jemaael-Fnaa, Marrakesh, 11th century		0.58	-	asymmetric	0.38

Table (continued)

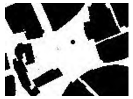
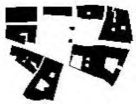
8.			Markt, Leipzig, 12th century		0.43	1.6	asymmetric	0.28
9.			Grand-Place, Brussels, 12th century		0.61	0.7	asymmetric	0.13
10.			Old Town Square, Prague, 12th century		0.61	0.92	asymmetric	0.42
11.		-	Piazza della Signoria, Florence, 13th century		0.5	0.97	asymmetric	0.22
12.		-	Piazza del Campo, Siena, 13th and 14th centuries		0.66	1.08	asymmetric	0.15
13.		Medieval market square	Main Square, Kraków,13th century		1	2.4	asymmetric	0.25
14.		Town square	Münsterhof, Zürich, 13th century		0.6	1.5	asymmetric	0.11
15.		Medieval market square	Raekoja plats, Tallinn,14th century		0.83	1.02	asymmetric	0.24
16.		-	Piazza Maggiore,Bologna, 12-15th century		0.49	1.19	asymmetric	0.24
17.		City's main public square	Piazza San Marco, Venice		0.3	0.70	asymmetric	0.13

Table (continued)

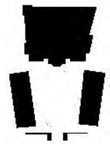
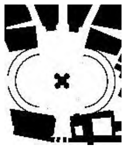
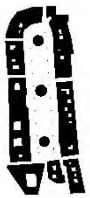
18.	16th century	Renaissancesquare	Piazza della Santissima Annunziat,Florence, 16th century		0.85	3	disymmetric	0.10
19.			Piazza del Campidoglio, Rome, 16th century		0.5	1.55	symmetric	0.4
20.			Piazza dei Signori, Vicenza, 16 century		0.22	0.33	asymmetric	0.21
21.	17th century	-	Nytorv, Copenhagen, 1610		0.49	-	asymmetric	0.24
22.		Baroque square	Saint Peter's Square (Piazza San Pietro), Rome, between 1656 and 1667		0.7	1.4	symmetric	0.11
23.			Piazza del Popolo, Rome, 17th century		0.6	3.6	disymmetric	0.2
24.			Piazza Navona, Rome, 17th century		0.2	0.8	disymmetric	0.07

Table (continued)

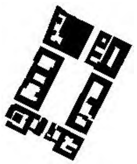
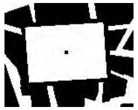
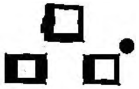
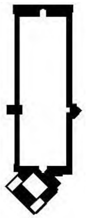
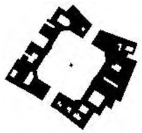
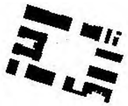
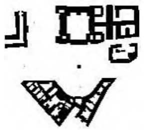
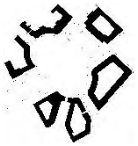
25.			Piazza San Carlo, Turin, 16-17th century		0.43	-	disymmetric	0.15
26.		-	Plaza Mayor, Madrid, built between 1617 and 1619			1.56	symmetric	0
27.		-	Registan, Samarkand17th century		0.84	1.93	disymmetric	0.66
28.		-	Naqsh-e Jahan Square, Isfahan,16th and 17th centuries		0.28	3.07	disymmetric	0
29.	18th century	Classicism square	Place Vendôm, Paris,1699		0.9	5	symmetric	0.1
30.		-	Wright Square, Savannah, 1733		0.87	-	asymmetric	0.59
31.		Classicism square	Place de la Concorde, Paris, 1757		0.6	8.58	disymmetric	4.66
32.		-	Praça do Comércio, Lisbon, 18th century		1	5.8	symmetric	0.44

Table (continued)

33.	19th century	-	Palace Square, Saint Petersburg, 18th and 19th centuries		0.87	6.5	disymmetric	0.47
34.		-	Place Charles de Gaulle (Place de l'Étoile), Paris, 1854		1	5.7	symmetric	1.73
35.		-	Trafalgar Square, London, 19th century		0.75	3.5	disymmetric	0.64
36.		-	George Square,Glasgow, 19th century		0.59	6.2	disymmetric	0.53
37.	20th century	Administrative Square	Republic Square, Yerevan, 20th century		1.1	4.8	disymmetric	0.44
38.			Three Powers Plaza, Brasília, 1956-1958		0.48	1.47	asymmetric	3.99
39.			Nathan Phillips Square, Toronto, 1965		0.93	1.15	asymmetric	0.04
40.			Empire State Plaza, Albany, 1965-1976		0.24	0.66	asymmetric	1.47

Within the city of Athens, three main components defined its urban structure: the acropolis as the ritual and spiritual core, the agora as the economic hub, and the surrounding urban fabric housing small shrines and temples [9]. The vast esplanade of the Athenian agora, encompassed by buildings representing political power and other structures like the Stoa, served as the preferred gathering place for citizens for meetings, assemblies, and markets [10]. The Agora of Athens stands as a testament to the city's rich history, functioning as the focal point of public life. Encircled by buildings on all four sides, the Agora's expansive open square epitomized the essence of the city center [11].

Roman Forum

The forum served as a central open space utilized for various purposes, including meetings, markets, political discussions, and demonstrations–a crucial location within the city for exchanging ideas and disseminating news [12]. Vitruvius, the author of *Ten Books on Architecture* in the first century BCE, the sole surviving ancient treatise on the subject, outlined the components of a forum, advocating for the inclusion of money-changers' shops, basilicas, a treasury, a prison, and a senate house [13]. The forum's size needed to be proportional to the number of residents to avoid being overly cramped or appearing empty due to a lack of people. Its width was determined by dividing its length into three parts, with two of these parts serving as the width, creating an oblong shape conducive to public events [14].

The Roman Forum, the nucleus of the Roman Empire and a reference point for the urban development of many classical cities, played a foundational role in classical architecture and the Roman practice of urban planning [15] (Fig.2). Initially, the Forum Magnum, or Forum Romanum, was merely a vacant space, gradually accumulating temples, halls, colonnades, and statues, evolving into the focal point of civic life [16]. According to Mumford (1961), the Roman forum amalgamated elements of both the Greek agora and acropolis, incorporating a wider array of activities, including shrines, temples, halls of justice, and council houses, within a more structured framework [17].

Fig. 2. *A view of the Forum Romanum (a painting by Jean Victor Louis Faure)*

Medieval square

With the decline of the Roman Empire, a notable transformation occurred in public spaces, influenced by the rising dominance of the church, autonomous city-states, and the burgeoning economic prowess of trade–markets and merchant guilds. These squares became focal points, adorned with significant structures, whether of religious significance, such as cathedrals, or political, such as palaces, town halls, and barracks [8]. In the Middle Ages, this dichotomy between sacred and secular spaces manifested prominently in the public squares of cities, where the realms of the temporal and the divine were clearly demarcated. Notably, in the urban milieu of Italy, distinct principal squares emerged, each tailored to specific functions. For instance, the cathedral square remained distinct from the primary secular square (signoria) and from the marketplace (mercato) [4] (Fig.3). Urban markets played a great role in middle-aged cities' lives. Usually, market squares were located near the cathedral and often adjoined with the cathedral square under the corner. Usually, in addition to the main market square, built up with monumental buildings of guild communities, a town hall,

Fig. 3. *The Piazza della Signoria, Florence (a painting by Giuseppe Zocchi)*

a church, and residential buildings of wealthy burghers, there were separate urban spaces for trading meat, fish, hay, firewood, etc. The architecture of market squares constituted a special theme in medieval town planning [18].

Renaissance square

The piazza, serving as a meeting place, a stage for religious and civic gatherings, and a hub for markets, typically emerges as one of the most significant focal points in cities, showcasing distinctive and refined architecture. The piazza plays a fundamental role within the irregular and dense urban fabrics of medieval European cities, seamlessly integrating with the surrounding streets where urban life thrives. These piazzas often feature grand temples, erected at the expense of Christianity, such as Christian cathedrals and episcopal palaces.

During the Renaissance, notable interventions, like those carried out by Brunelleschi in the fifteenth century on Piazza della Santissima Annunziata, endowed certain piazzas with remarkable regularity and architectural order [19] (Fig.4). In the warm climate of Italy, citizens frequently spent significant time outdoors in the open piazzas or squares, which served as communal spaces for cities and towns. In larger cities, multiple squares might exist, with some primarily serving as markets and others being associated with adjacent churches [20].

Fig. 4. *Piazza della Santissima Annunziata, Florence (a painting by Bernardo Bellotto)*

Baroque square

By the late 17th century, the Baroque style had come to define the architectural landscapes of major European capitals–Rome, Paris, London, and Vienna–leaving an indelible mark on their identities. However, this period also witnessed the transformation of numerous medieval structures, as they were renovated with Baroque facades and interiors, reflecting the era's modernizing tendencies [9, 22] (Fig.5). St. Peter's Square, situated in front of Saint Peter’s Basilica in Rome, underwent significant changes, including the installation of a four thousand-year-old Egyptian obelisk of red granite in 1568 by Domenico Fontana, an architect and engineer. Originally, the square's layout was quite different, but it was redesigned by Gian Lorenzo Bernini in 1657, almost a century later, with a colonnade envisioned to embrace visitors like the maternal arms of Mother Church. The colonnade frames a large area shaped like an 'ovato tondo,' a round oval with its long axis parallel to the basilica's front [21].

Fig. 5. *The Piazza del Popolo, Rome (a painting by Gaspar van Wittel)*

19th -century square

During the 19th century, the industrial revolution brought about dramatic changes in urban design and planning. The establishment of extensive railway networks led to a surge in urban populations, spurring the growth of cities. New industrial areas emerged near urban centers, drawing laborers into the cities [10]. In the latter half of the 19th century, squares served as venues for ceremonial processions and the display of statues, including those honoring reigning monarchs. Additionally, city squares assumed new functions as traffic hubs and green havens. In Paris, a variety of new square shapes emerged, such as the semi-circular Place du Trocadéro, the rectangular yet fragmented Place de la République, and star-shaped layouts with radial vistas like the Place de la Nation and Place Charles de Gaulle (Place de l'Étoile), where the concept of a traffic roundabout was first tested in 1907. These squares differed from their historic predecessors as they were not enclosed; instead, they were expansive, with monumental streets leading into them [8] (Fig.6).

Fig. 6. *George's Square, Glasgow (a drawing by John Fleming)*

20th-century square

The urban population continued to swell during the 20th century, leading cities to expand, diversify, and fragment (Fig. 7). Private car ownership experienced a rapid surge, resulting in cities increasingly dominated by motor vehicles and restricting pedestrian movement and freedom. In the latter half of the 20th century, many urban squares transformed into bustling crossroads, particularly in developing nations. Changing consumer habits and trends further diminished the use of open public spaces as shopping malls emerged as new hubs of leisure [1]. The ascendancy of automobiles, coupled with the establishment of out-of-town shopping centers and supermarkets, as well as business parks, resulted in many city centers languishing with vacant plots and derelict buildings, rendering them unattractive and, in some cases, hazardous. The decline in the quality of urban life and the use of squares and public spaces persisted, with numerous historic squares repurposed as car parks to accommodate the growing demand for vehicle space, such as the Praça do Comércio in Lisbon or the abandoned Grønttorvet vegetable market space in Copenhagen (later renamed IsraelsPlads) [8].

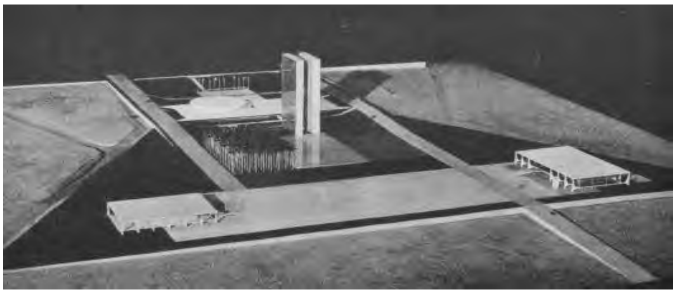


Fig. 7. *The Three Powers Plaza Model (Legislative, Executive and Judiciary Powers) presented in the article about Brasília's inauguration (RIBA Journal)*

Compositional analysis of squares

In this section, we aim to synthesize the findings from our research on the compositional structure of squares based on the analysis of 40 selected examples. Our analysis focused on identifying typical characteristics that influence the formation of square compositions.

Compositional principle

The compositional principle of each square serves as its foundation, dictating its architectural and structural solutions, as well as the layout of the area.

Research shows that approaches to the compositional principles of squares vary. There are symmetrical, dissymmetrical, and asymmetrical compositions. The choice of compositional principle depends on various factors. For instance, the urban development environment has often dictated the principles for many asymmetrical squares, where existing buildings, streets, or parks influenced and shaped the square's compositional framework. Consequently, most medieval commercial squares exhibit asymmetric compositions. However, during the Renaissance, Baroque, and Classicism periods, symmetric squares became more prevalent. Prominent examples of symmetric squares include Rome's Saint Peter's Square and Piazza del Campidoglio, Paris's Place Vendôme and Place Charles de Gaulle, Madrid's Plaza Mayor, and Rome's Caesar Forums. Asymmetric squares include Marrakesh's Jemaael-Fnaa, Prague's Old Town

Square, Siena's Piazza del Campo, Athens' Agora, and Rome's Roman Forum (Forum Romanum), known for their asymmetrical compositions from ancient times. Additionally, squares with dissymmetrical compositions are also common. These compositions are similar to symmetric ones but include certain deviations. Examples include Samarkand's Registan Square, Isfahan's Naqsh-e Jahan Square, Saint Petersburg's Palace Square, and Mexico City's Constitution Square.

Existence of a dominant feature

The presence of a dominant feature plays a significant role in shaping the area of a square, influencing its compositional image, as exemplified by Rome's Saint Peter's Square. When a dominant structure surrounds the square, it enhances the sense of enclosure, affecting the relationship between the height of the surrounding development and the width and length of the square.

An analysis of various examples reveals different types of squares depending on the presence of a dominant structure and its relationship to the surrounding development. For example, Piazza San Carlo in Turin and Place Charles de Gaulle (Place de l'Étoile) in Paris feature uniform building heights in their surroundings and prominently defined dominant structures. During the Classical period, squares such as Place Vendôme and Place de la Concorde in Paris were examples with uniform building heights but lacked a prominent central feature. Madrid's Plaza Mayor and St. Petersburg's Palace Square also reflect this approach. Nearly all medieval squares are characterized by surrounding structures of varying heights and a clearly defined dominant element. Examples include Leipzig's Market Square, the Main Market Square in Kraków, Münsterhof in Zurich, Raekoja plats in Tallinn, and Old Town Square in Prague. Ancient examples, such as the Athenian Agora and the Forum of Pompeii, are examples of squares where the surrounding structures vary in height and lack a central dominant feature. Among 20^{th}-century examples, the Empire State Plaza in Albany and Nathan Phillips Square in Toronto are marked by such a composition.

Existence of a Central Element

In certain squares, central elements such as columns, obelisks, statues, fountains, or triumphal arches also play a significant role in composition. Squares featuring a central column include Paris's Place Vendôme (Vendôme Column), London's Trafalgar Square (Nelson's Column), and Saint Petersburg's Palace Square (Alexander Column). Rome's three Baroque squares–Piazza del Popolo, Saint Peter's Square, and Piazza Navona–are notable for their obelisks, with the latter two squares also featuring fountains on either side of the obelisk. Paris's Place Charles de Gaulle stands out with its central Triumphal Arch. Statues serve as central elements in Madrid's Plaza Mayor (statue of Philip III), Prague's Old Town Square (Jan Hus Memorial), Rome's Capitoline Hill (Equestrian Statue of Marcus Aurelius), and Piazza della Santissima Annunziata (Equestrian Monument of Ferdinando I).

Studies indicate that squares with central elements were prevalent during the Renaissance, Baroque, Classicism, and 19th-century eras. These squares often exhibit symmetrical or dissymmetrical compositions.

Degree of enclosure

The degree of enclosure plays a pivotal role in how a square area is perceived. To determine this degree, we found it reasonable to analyze the ratio of the lengths of open and closed sections along the perimeter of the square's development. Naturally, a smaller ratio indicates a more enclosed square.

Based on the degree of enclosure, squares can be categorized into three groups: open, semi-closed, and closed. Squares with a ratio greater than 1.5 are considered open; those with a ratio between 0.5 and 1.5 are semi-closed; and those with a ratio below 0.5 are closed.

Examples of open squares include Paris' Place de la Concorde (ratio: 4.66), which features buildings only in its northern part, and Brazil's Praça dos TrêsPoderes (ratio: 3.99). Semi-closed squares include Registan Square in Samarkand (ratio: 0.66), Wright Square in Savannah (ratio: 0.59), Trafalgar Square in London (ratio: 0.64), George Square in Glasgow (ratio: 0.53), and Empire State Plaza in Albany (ratio: 1.47). Closed squares include Naqsh-e Jahan Square in Isfahan (ratio: 0) and Madrid's Plaza Mayor (ratio: 0), which are among the most enclosed examples we reviewed. Other closed squares include Siena's Piazza del Campo (ratio: 0.15), Krakow's Main Market Square (ratio: 0.25), Brussels' Grand Place (ratio: 0.13), and Rome's Piazza Navona (ratio: 0.07).

The data suggests that the majority of observed squares belong to the closed or semi-closed type. Yerevan's Republic Square, for instance, falls into the semi-closed category with a ratio of 0.44. However, it's important to note that open squares can present a challenge in terms of perception of space, as they blend into the surrounding urban environment and may not be perceived as distinct areas. Brazil's Praça dos TrêsPoderes, for example, has encountered this issue.

Proportional relations

To conduct a proportional analysis of squares, we find it pertinent to consider two indicators:

- The ratio of the square's width to its length (where the smaller dimension is considered the width).
- The ratio of the square's width to the height of surrounding development (if there is a dominant structure, its height is used; otherwise, the height of the tallest structure within the square).

These indicators are crucial for understanding the spatial characteristics of the area. Regarding the first indicator, a ratio closer to one indicates a more balanced square. Examples of squares with ratios close to one, resembling square layouts or nearly equal-sided squares, include Trafalgar Square in London (0.75), Palace Square in Saint Petersburg (0.87), Right Square in Savannah (0.87), Place Vendôme in Paris (0.9), Registan Square in Samarkand (0.84), Piazza della Santissima Annunziata in Florence (0.85), Raekoja plats in Tallinn (0.83), as well as the agoras of Priene (0.85) and Miletus. Squares with smaller ratios, indicating a more elongated shape, include Leipzig's Markt (0.43), Piazza San Marco in Venice (0.3), Piazza Maggiore in Bologna (0.49), Piazza dei Signori in Vicenza (0.22), Nytorv in Copenhagen (0.49), Piazza Navona in Rome (0.2), Piazza San Carlo in Turin (0.43), Naqsh-e Jahan Square in Isfahan (0.28), and Empire State Plaza in Albany (0.24), as well as the forums of Rome (0.4), Pompeii (0.2), and Ostia (0.36). Remarkable squares with a ratio equal to one, forming square layouts, include Main Square in Krakow (1), Praça do Comércio in Lisbon (1), Place Charles de Gaulle in Paris (1), and the Athenian agora (1).

Regarding the second indicator, a larger ratio indicates a more open square area. Squares with larger ratios include Piazza del Popolo in Rome (3.6), Republic Square in Yerevan (4.8), Naqsh-e Jahan Square in Isfahan (3.07), Place Vendôme in Paris (5), Place de la Concorde in Paris (8.58), Praça do Comércio in Lisbon (5.8), Palace Square in Saint Petersburg (6.5), Place Charles de Gaulle in Paris (5.7), George Square in Glasgow (6.2), and the Athenian agora (12.09). Notable squares with smaller ratios include Grand-Place in Brussels (0.7), Old Town Square in Prague (0.92), Piazza della Signoria in Florence (0.97), Piazza San Marco in Venice (0.70), Piazza dei Signori in Vicenza (0.33), Piazza del Campo in Siena (1.08), Münsterhof in Zurich (1.5), Piazza Navona in Rome (0.8), Saint Peter's Square (1.4), Campidoglio Square (1.55), Plaza Mayor in Madrid (1.56), Empire State Plaza in Albany (1.15), Nathan Phillips Square in Toronto (0.66), as well as the Roman Forum (1.7).

Functional purpose

Squares have had diverse functional roles. In ancient times, they served as spaces for gatherings, discussions, and trade. Agoras in Priene and Miletus, as well as forums in Pompeii and Ostia, fulfilled such purposes. During the Middle Ages, squares primarily served trade functions, exemplified by places like Jemaa el-Fnaa in Marrakesh, Markt in Leipzig, Main Square in Krakow, and Raekoja plats in Tallinn. In the Renaissance, squares took on more administrative and religious functions, as seen in places like Piazza della Santissima Annunziata, Piazza del Campidoglio in Rome, and Piazza dei Signori in Vicenza. Noteworthy squares from the 20th century include Yerevan's Republic Square and Brasília's Praça dos Três Poderes. The former became the administrative center during the capital's reconstruction, while the latter serves as the focal point of a newly constructed capital, housing relevant administrative buildings. Naturally, the functional purpose significantly influences a square's architectural and compositional identity. For instance, the intended function often dictates the scale of a square. This explains why squares with administrative and religious purposes tend to be larger in scale, such as Mexico's Constitution Square and Isfahan's Naqsh-e Jahan Square. The functional purpose also greatly influences the selection of architectural solutions and styles.

The purpose of dominant structures

Throughout history, the dominant structures within squares have served various purposes. In the Greek agoras and Roman forums of antiquity, these structures were primarily religious or administrative. During the medieval era, dominant structures in trade squares served administrative, religious, and residential functions, such as town halls, cathedrals, and palaces. In Baroque squares, the main structures were often religious, as seen in Saint Peter's Square, Piazza del Popolo, and Piazza Navona. Similarly, during the Renaissance period, religious and administrative buildings predominated, exemplified by places like Piazza della Santissima Annunziata, Piazza San Marco in Venice, and Piazza del Campidoglio in Rome. In the 20th century, the dominant structures in the squares that we have observed have typically served administrative and cultural purposes, as evidenced by landmarks like Three Powers Plaza in Brasília, Nathan Phillips Square in Toronto, and Republic Square in Yerevan. The purpose of the dominant structure significantly influences the composition of the square and contributes to its architectural identity. Certain types of squares consistently feature specific dominant structures, such as cathedrals or basilicas in Roman forums, town halls in medieval trade squares, and churches in Baroque squares.

Conclusion

This research aims to provide a comprehensive overview of squares' historical development and to elucidate the intricacies of their compositional formation through the analysis and comparison of various examples.

Studying squares built in 40 different periods and locations, selected to represent the general history of square emergence and compositional formation, has allowed us to identify typical characteristics that influence square composition formation.

These include:

- **Compositional principle**: Depending on the type, this principle plays a fundamental role in architectural and compositional solutions and in the formation of square areas. Various compositional principles have been employed in different historical periods: asymmetric, symmetric, or dissymmetric.
- **Existence of dominant structure**: Squares have been classified into four types based on the existence of a dominant structure and its ratio to the surrounding development:
  a. same height surrounding development with a clearly defined structure,
  b. same height surrounding development with no clearly defined dominant structure,
  c. different heights surrounding development with a clearly defined dominant structure,
  d. different heights surrounding development with no clearly defined dominant structure.
  Squares belonging to these types exhibit different compositional designs and area characteristics.
- **Existence of central elements**: Central elements alter the perception of space within a square. They serve a unifying purpose in composition, shaping the square's layout.
- **Degree of enclosure**: This factor significantly influences the perception of a square's environment, categorizing squares into three types:
  a. open,
  b. semi-closed,
  c. closed.
  Squares falling into these categories exhibit distinct compositional formations and perceptions of space.

- **Proportional relations**: Squares were classified into three types based on width and length ratio indicators:
  a. condensed,
  b. extended,
  c. square layout.

Squares were classified into two types based on the width and height ratio of the surrounding development:

a. with a high ratio, indicating openness,
b. with a low ratio, indicating enclosure.

- **Functional purpose**: This aspect significantly influences a square's architectural and compositional image and scale choice. Squares with administrative and religious purposes tend to have larger scales and stricter or more monumental architectural images.
- **Purpose of dominant structure**: The intended function of a dominant structure greatly influences a square's composition and architectural image, often correlating with the square's purpose.

In conclusion, the study of characteristics influencing square composition demonstrates that each of these factors influences the perception of space of the square, degree of enclosure, architectural and compositional image, scale, and other properties.

We believe that these findings may prove useful for future scholarly works related to square composition issues, as well as for researchers interested in the broader study of squares.

However, we acknowledge that the characteristics presented may not fully encompass all aspects of square composition formation. Future research should address topics such as the perception of space in pedestrian and vehicular movements, the functional structure in modern conditions, and the influence of changes in surrounding urban development environments on composition and perception of space. Exploring these areas will further enrich and clarify our understanding of the peculiarities of square composition formation.

Conflict of Interest

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THERMAL PERFORMANCE EVALUATION OF TRADITIONAL BUILDINGS FLAT ROOFS IN A HOT AND ARID CLIMATE OF ALGERIA

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Abstract: *This investigation aims to apply the analytical method of admittance for determining the thermal performance of composite flat roofs in traditional houses located in the southern region of Algeria, characterized by hot and arid climate conditions. The effect of adding insulation to the composition of flat roofs in traditional houses is studied by varying its, type, location and thickness. In this study, nine configurations of composite flat roof systems were manufactured using multiple layers with five types of insulations. Moreover, different dynamical thermal parameters are analyzed in this study, namely time lag (TL), decrement factor (DF), admittance (Y), transmittance (U), and surface factor (SF). The main results revealed that the roof configuration of R8 with insulation based on formaldehyde board presents a high value of TL (9.94 hours) and the lowest value of DF (0.1). In contrast, the configurations without insulation addition (R1, R2, and R3) display the lowest values of TL (4.91, 4.74, and 4.81, respectively) and the highest values of DF (0.59, 063, and 0.62, respectively). This research is useful for clearly understanding the thermal performance of composite flat roofs for the improvement of the energetic efficiency of traditional buildings.*

Keywords: *Thermal insulation, flat roofs, dynamic thermal properties, decrement factor, time lag.*

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Introduction

In Algeria, the general construction rules and the choice of suitable materials for manufacturing buildings mainly depend on the climate conditions of the considered region [1,2]. However, the use of the same building concept and materials in different regions of the north and south of Algeria, which are characterized by different climates – Mediterranean in the north and the Sahara of hot and arid climates in the south, creates an uncomfortable situation for the sustainability of building elements [3,4]. The main solution adopted to improve the thermal comfort of Algerian construction is the use of heaters and air conditioners, particularly during the summer and winter seasons, which involves a high energy consumption [5-8].

Recently, the use of thermal insulation in wall or flat roof configurations has been proposed as the most economical and sustainable solution for buildings located in regions characterized by arid and hot climates [7,9,10]. In contrast, there are few experimental works about the position of thermal insulation in wall or flat roofs configurations and its optimal thickness adequate for the traditional houses located in hot and arid regions [4,11,12]. On the other hand, much attention has been focused during the recent decades on the role of thermal insulation in regulating heat transfer and on researching the analytical methods to be used to analyze the thermal performance parameters of heat transfer through the building envelope [6,13-15]. For this purpose, there are several methods applied for deducing the values of DF and TL, each with its physical interpretation [16,17].

These analytical resolution methods provide exact solutions and represent a suitable approach for computerized applications [13,16]. However, it cannot be extended with numerical approaches, which are generally approximate solutions to a physical problem [13,18]. The most interesting analysis is mainly focused on studying the dynamic thermal properties of walls using the Fourier complex analytical method [13,14].

Indeed, there are several analytical methods, such as the transfer function method (TFM), the cooling load temperature difference method (CLTD), and the total equivalent temperature difference method (TETD), that have been used in the study to model heat transfer and the thermal inertia of composite walls and roofs [19-21]. Accordingly, an efficient analytical solution based on the Fourier analysis (Fast Fourier Transform-FFT) with periodic boundary conditions for the translation of the behavior of heat transfer in composite walls (marble, concrete block, plaster) has been reported by Daouas *et al*. [22], which investigated the best thermal performance of walls according to the hot climatic zones of Tunisia. In addition, Kameni Nematchoua *et al.*[23] investigated the thermal modeling of a building located in the equatorial and tropical climate of Cameroon by using a periodic solution Fourier analysis for the propagation of heat flux through a composite wall. The theoretical methodology on time-varying heat gains through the walls and flat roofs of buildings was initially developed by Yumrutaş et *al.* [24]. Different configurations of walls and flat roofs were studied to determine the TETD values of various configurations of walls and flat roofs in the context of Turkey's climate. The sinusoidal variation was considered for explaining the external temperature diffusion using the finite Fourier transform (FFT). Subsequently, much research work was carried out using the Fourier complex method to assess heat transfer through multilayer walls and roofs [25]. This method was also used by Kaşka et al. [26] to analyze the TL, DF, and the TETD parameters for multilayer walls and flat roofs of buildings made of different materials and insulation (concrete, plaster, sandwich XPS).

In the case of Algeria, the use of insulation and the investigation of the thermal performance of flat composite roofs investigated in traditional buildings are weakly explored. Nowadays, the building of external flat roofs based on the insulation and local materials carried out in arid and hot regions of Algeria generally meets different problems due to the absence of scientific research about this subject. The review of the current state of knowledge in the field of heat transfer in composite flat roofs based on insulations (cork, polystyrene, polyurethane, etc.) and local materials (earth blocks, plaster, lime mortar) revealed that there are very few studies focused on this subject [5]. For this purpose, the present study aims to determine the thermal performances of composite flat roofs of traditional houses in Algerian climatic conditions by using an analytical method of admittance. Compared to other analytical methods of resolution, the admittance method, based on the transmission matrix, has advantages, in particular a format of the matrix favorable to the storage of databases and analysis of modelling information [26-29]. This method takes into account the effects of dynamic conditions on heat transfer through the wall or roof and the calculation of heat flows on the inside and outside of a wall or roof as a function of surface temperatures [29-31]. Thus, as a main objective of this study, the analytical method was applied in order to investigate the dynamic thermal parameters of external composite flat roofs of traditional constructions located in the Southern Algeria regions characterized by hot and arid climates. During this work, the best combination of composite flat roof systems can be found using the determination effects of different factors, such as the influence of the insulation layer, their position, thickness, and the variation effect of the thermal insulation layer in composite roofs on the thermal dynamic parameters like TL, DF, Y, U, and F over a 24-hour period.

Methodology

The cyclic-response admittance method

This study is based on the analytical method of admittances, which is based on complex Fourier analysis [14]. This method focuses on one-dimensional transient thermal conduction through a flat roof with two time-dependent boundary conditions and an initial condition.

$$\rho C_p \frac{\partial T(x,t)}{\partial t} = \lambda \frac{\partial^2 T(x,t)}{\partial x^2} \qquad 0 < x < L,\ t > 0\,, \tag{1}$$

λ, ρ and C_p are the thermal conductivity, density and specific heat, respectively.

The boundary conditions are given:

$$-\lambda \frac{\partial T}{\partial x}(0,t) = h_i[T(0,t) - T_i] \quad \text{for } x = 0, \quad t > 0\,, \tag{2}$$

$$-\lambda \frac{\partial T}{\partial x}(L,t) = h_0[T_o(t) - T(L,t)] \quad \text{for } x = L, \quad t > 0\,, \tag{3}$$

where (h_i, T_i) and (h_0, T_0) are respectively the heat transfer coefficient and the temperatures on the inside and outside surface [1,5].

The initial condition is as follows:

$$T(x,0) = T_0 \quad \text{for} \quad t = 0, \quad 0 \leq x \leq L\,. \tag{4}$$

A space- and time-independent solution is used for the resolution of equation (1) with boundary and initial conditions (2), (3), and (4). It allows describing the dependence in the imaginary domain of temperatures and thermal flows on both sides of an opaque wall. The solution is sought in the following form [13,14]:

$$T(x,t) = A.\exp\left(x/_\xi \right)\exp\left(t/_\zeta \right) \quad , \tag{5}$$

where ξ and ζ have units of distance and time, respectively.

The combination of both equations (5) and (1), the relation of: $\xi^2 = \alpha\zeta$ can be deduced. Where α is the thermal diffusivity of the roof. For a structure subjected to periodic excitation of period P, periodic solution becomes:

$$\xi^2 = \frac{\alpha P}{2j\pi}, \quad \text{where} \quad j^2 = -1 \tag{6}$$

Thus, it can be obtained a periodic solution with-period P.

$$\frac{x}{\xi} = \frac{x}{\pm\left(\alpha P/_{j2\pi}\right)^{1/2}} = \pm(i+j)\left(\frac{\pi\rho C_p x^2}{\lambda P}\right)^{1/2} \tag{7}$$

In this case, the matrix relationship between flux and internal and external temperatures is given [13].

$$\begin{bmatrix} T_{pi} \\ q_{pi} \end{bmatrix} = \begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix} \begin{bmatrix} T_{pO} \\ q_{pO} \end{bmatrix}. \tag{8}$$

T_{pi}, q_{pi}, T_{pO} and q_{pO} indicate the temperature and heat flux at both internal and external surfaces, respectively. R_i and R_O represent the inside and outside of each studied configuration.

The transfer matrix is defined below:

$$\begin{bmatrix} E_{11} & E_{12} \\ E_{21} & E_{22} \end{bmatrix} = \begin{bmatrix} 1 & -R_i \\ 0 & 1 \end{bmatrix} \begin{bmatrix} (A_1 + jA_2) & (A_3 + jA_3)/a \\ a \times (-A_4 + jA_3) & (A_1 + jA_2) \end{bmatrix} \begin{bmatrix} 1 & -R_0 \\ 0 & 1 \end{bmatrix}. \tag{9}$$

The cyclic thickness z and the characteristic of the admittance slab are the two parameters that appear in the definition of the transmission matrix (Eqs. (10) and (11)):

$$z = \sqrt{\frac{\pi L^2}{\alpha \mathrm{P}}} = \sqrt{\frac{\omega L^2}{2\alpha}}\,, \tag{10}$$

$$a = \sqrt{j\omega\lambda\rho C_p}\ . \tag{11}$$

The thermal transmittance, U, is calculated using

$$U = \frac{1}{R_i + R_c + R_O} = \frac{1}{R_i + \left(\frac{L_1}{\lambda_1}\right) + \left(\frac{L_2}{\lambda_2}\right) \ldots\ldots\ldots + R_O}\,, \tag{12}$$

where L_1 *and* L_2 are the thicknesses of the roof layers.

The thermal admittance, Y, is calculated as:

$$Y_c = -\frac{E_{22}}{E_{12}}; \qquad Y = |Y_c| \,. \tag{13}$$

The DF *f is* calculated using the following equation:

$$f_h = \frac{Y_{12}}{\mathrm{U}} = -\frac{1}{UE_{12}}\,; \quad f = |f_h| \,. \tag{14}$$

Φ presents the TL obtained between the timing of the peak inside temperature and the peak heat transfer out of the outer surface, calculated using the relationship:

$$\phi = \frac{12}{\pi} arctan\left(\frac{Im(F_c)}{Re(F_c)}\right) = \frac{12}{\pi} arctan\left(\frac{Im\left(-\frac{1}{UE_{12}}\right)}{Re\left(-\frac{1}{UE_{12}}\right)}\right) . \tag{15}$$

On the other hand, the surface factor (F) is calculated as follows:

$$F_c = 1 - R_{int}\frac{E_{11}}{E_{22}}\,, \quad F = |F_c|. \tag{16}$$

In this investigation, the dynamic thermal parameters of composite roofs (TL, DF, U, Y, F) are calculated using the Matlab program. The different calculations are performed for a different system roof subjected to an external sine excitation period of P=24h and an internal temperature of Ti=25°C. The values of the internal Ri and external RO thermal resistances are Ri = 0.045 and RO = 0.11 m^2KW^{-1} [5]. The effect of the humidity parameter of flat roofs was not considered in the analysis.

Climatic conditions

The Adrar region, located in southern Algeria, is characterized by a hot and arid climate. The buildings of this region generaly present a traditional character, particularly those manufactured with local materials such as earth, stone, and plaster (Fig.1) [2,3].

Fig. 1. *A traditional house example with a flat roof in the Adrar city*

On the other hand, in this region of Southern Algeria, the climate is extremely arid, with winter cold at night and the days remaining hot (25-27°C) [32]. The annual temperature evolution from 2006 to 2016 in the Algerian arid regions, such as Adrar city, located in southern Algeria, is summarized in Figure 2. In addition, given the climatic context of this region, the roofing system used in house construction is flat, utilizing materials available in the region (Fig.2). As a result, the maximum temperature increases to 46°C in summer, and the minimum to 5°C in winter, and the general rainfall is very low, rarely exceeding 40 mm annually but sometimes reaching a maximum of 80 mm. The relative humidity ranges between 10% in summer and 40% in winter. Sandstorms are generally frequent and blow at high speeds exceeding 70 km/h [33].

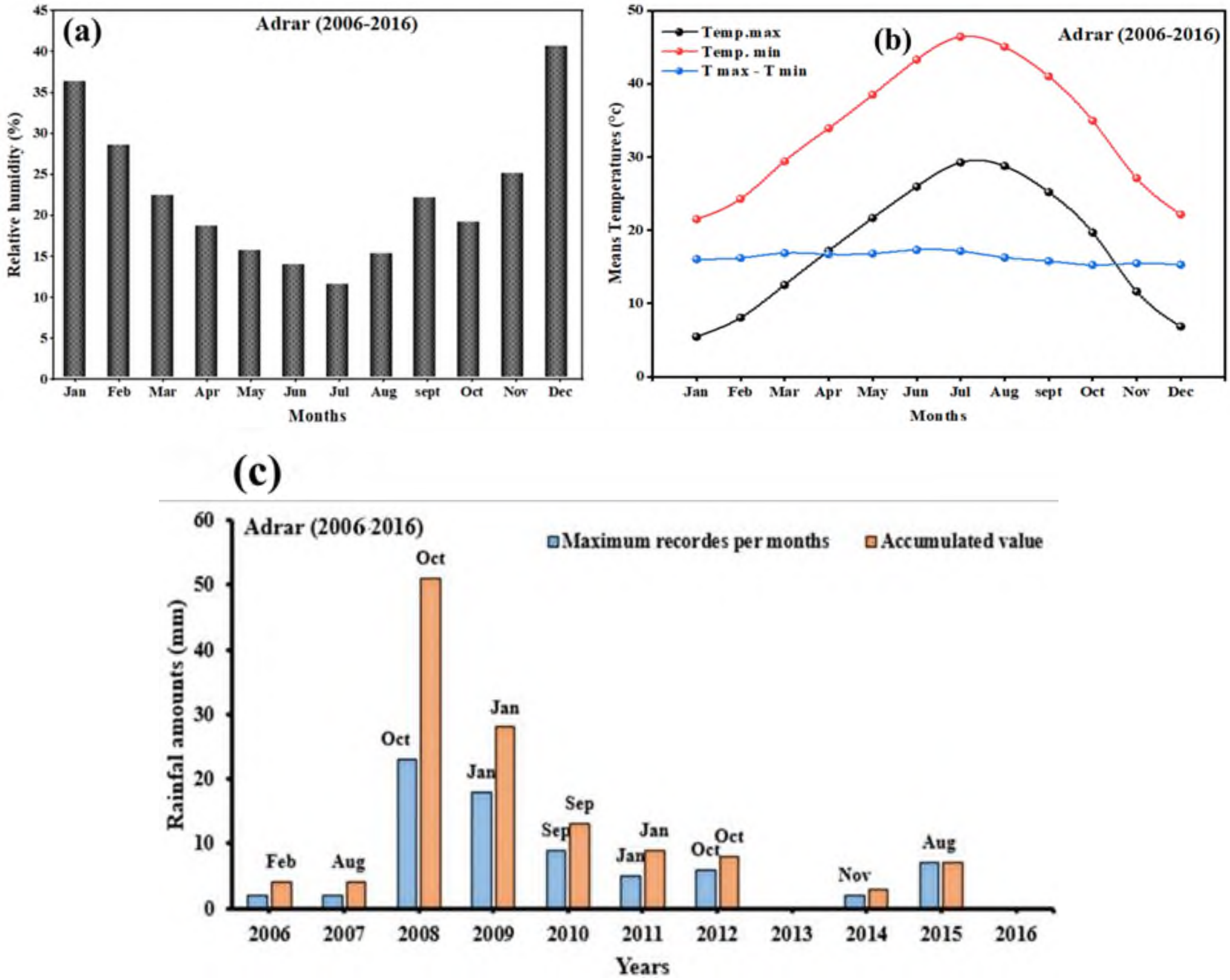


Fig. 2. *Evolution of annual temperature from 2006 to 2016 in the Adrar city: (a) relative humidity, (b) mean temperatures, and (c) rainfalls* [33]

Thermo-physical properties of materials

In the present study, dynamic parameters of Y, U, DF, TL, and F are examined for different building materials that compose the flat roofs of traditional constructions located in the hot and arid climate of southern Algeria. For the technical aspects of the construction, the fundamental principle of Saharan flat roof design is the use of local raw materials. In general, the rules of construction in southern Algeria consist of laying a layer of mortar (a mixture of cement and lime) as a protective waterproofing layer, followed by another local material (plaster concrete, volcanic ash, lime, pozzolanic concrete, clay, tuff, sand, clinker, etc.) as a reinforcement layer, CNERIB-DTR E-4.1[1].

The schematic roofs indicated in Figure 3 illustrate the horizontal reinforced concrete that may incorporate thermal insulation layers and other mortar layers in their exterior or interior surface. The reinforced concrete layers have a constant thickness of 0.15 m, and they may be put in two layers of thickness x = 0.075 m. The total thickness of this type of flat roof is usually 0.23 m.

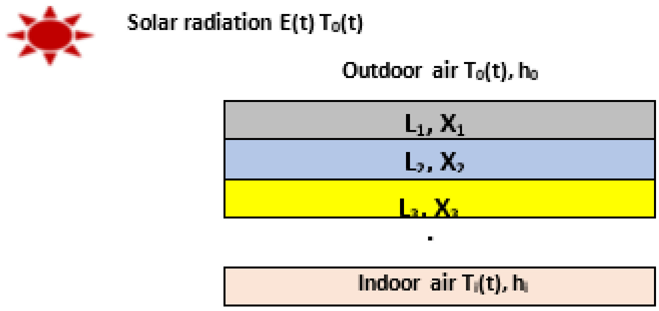


Fig. 3. *Schematic representation of a flat roof*

[1] DTR E 4-1. Travaux d'étanchéité Des Toitures Terrasses et Toitures Inclinées-Support Maçonnerie. *CNERIB*, 2018 Algiers.Algeria.

The waterproofing of these flat roofs is ensured by a layer of lime mortar, which is a type of mortar not accessible to terraces typical of the climate of arid regions. The thermal insulation consists of a material ensuring thermal inertia, placed so as to give a slope of 0.5 to 1 %. According to DTR E 4.1, there are three categories of flat roofs in Algeria, classified according to slope[2].

Table 1 summarizes the thermophysical characteristics of the investigated materials of thermal conductivity, specific heat, and density. The properties of materials selected in the present study for the configuration of different flat roof systems are the same as those used in the construction of traditional house roofs in southern Algeria[3] [5,17]. The common materials used for the construction include lime mortar stabilized (LM), reinforced cement concrete (RC), gypsum plaster (GP), and mortar stabilized. Five insulation materials such as expanded polystyrene, cork, date palm, and mineral wool, were selected. The insulation used in this work is noted by IS.

Table 1. Thermophysical properties of some common construction materials of flat roofs[4] [17].

Materials name	Code	Thermal Conductivity λ (W/m K)	Specific heat (J/Kg,K)	Density (kg/m^3)
Lime mortar stabilized	LM	0.720	840	1800
Reinforced cement concrete	RC	1.37	880	2076
Stabilized earth concrete	SC	1.15	936	1700
Inside gypsum plastering	GP	0.35	936	750
Polystyrene board	IS1	0.040	1400	30
Palm Fiberboard	IS2	0.040	840	80
Foam Glassboard	IS3	0.055	700	160
Formaldehyde board	IS4	0.030	1674	30
Polyurethane board	IS5	0.027	1400	55

Configurations of composite flat roofs

This work focuses on studying different composite flat roofs built with cement-based materials and thermal insulation. In order to give more details about the best combination of composite configuration roofs, different layers of insulating materials have been integrated into the flat roofs compositions to assess a possible improvement in thermal performance. Table 2 summarizes the different configurations considered for the composite roofs proposed.

Table 2. Configurations of the flat roofs

Roof	Thickness of the roof from outside to inside (m)
R1	0.15 RC + 0.03 GP
R2	0.025 SEC + 0.15 RC + 0.005 GP
R3	0.025 LM + 0.15 RC + 0.005 GP
R4	0.025 LM + 0.15 RC + 0.04 IS + 0.015 GP
R5	0.025 LM + 0.04 IS + 0.15 RC + 0.015 GP
R6	0.025 LM + 0.075 RC + 0.04 IS + 0.075 RC + 0.015 GP
R7	0.025 LM + 0.02 IS + 0.15 RC+ 0.02 IS + 0.015 GP
R8	0.025 LM + 0.075 RC + 0.02 IS + 0.075RC + 0.02IS + 0.015GP
R9	0.025 LM + 0.02 IS + 0.075 RC + 0.02 IS + 0.075 RC + 0.015GP

[2]DTR E 4-1. Travaux d'étanchéité Des Toitures Terrasses et Toitures Inclinées-Support Maçonnerie. *CNERIB*, 2018 Algiers.Algeria.

[3]DTR C3-2/4. Réglementation Thermique Des Bâtiments d'habitation, Règle de Calcul Des Déperditions Calorifiques, Algiers, Algeria. *CNERIB*. Algiers 2017, Algeria.

[4] Ibid.

Figure 4 presents the configuration of different flat roofs considered with different combinations and positions of insulation materials in the wall system. To achieve this, nine (09) configuration systems of flat roofs with different traditional and durable building materials based on thermal insulation are considered in this work. The different insulating materials of the study were placed in different positions inside and outside the roofs. A total thickness of 4 cm of insulation was placed as one or two layers (each one 2 cm) at different locations in the 23 cm total-thickness composite roof system.

In this study, the contact between layers in the case of flat composite roofs is considered to be perfect. It can be noted that the considered roofs are subject to heat transfer in just one direction.

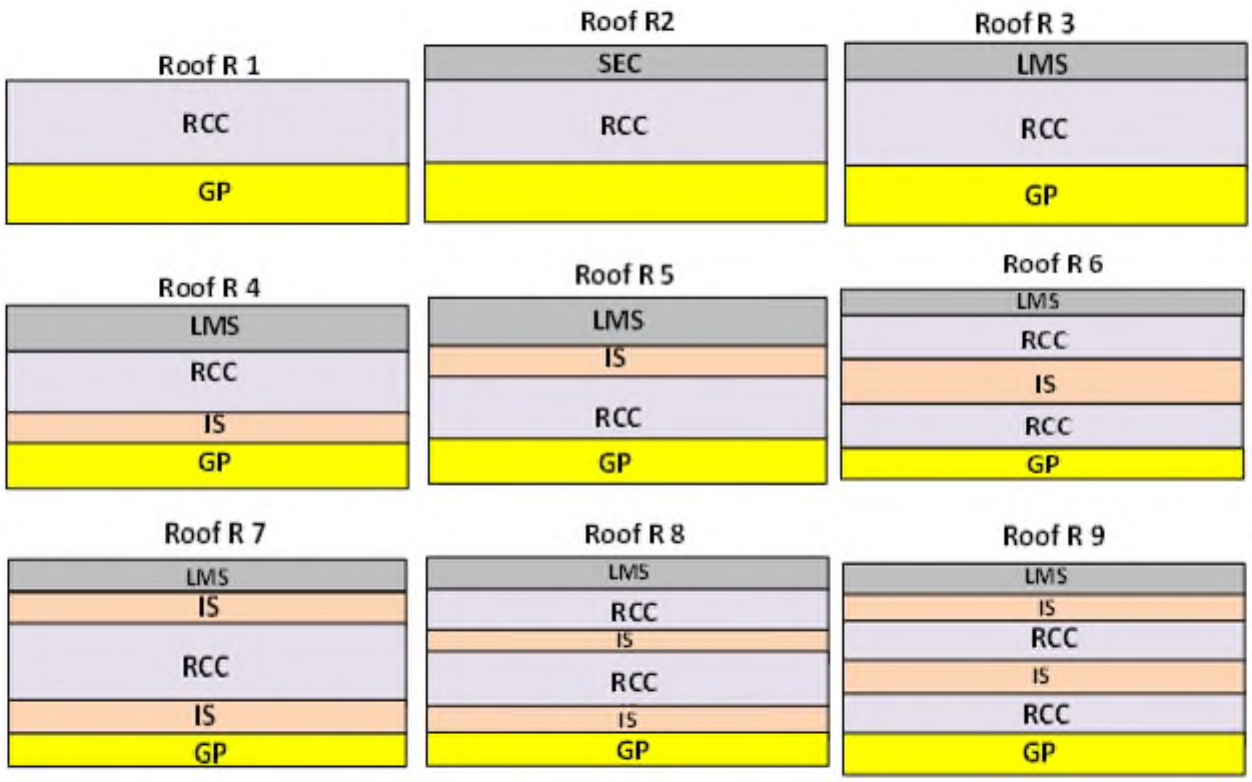


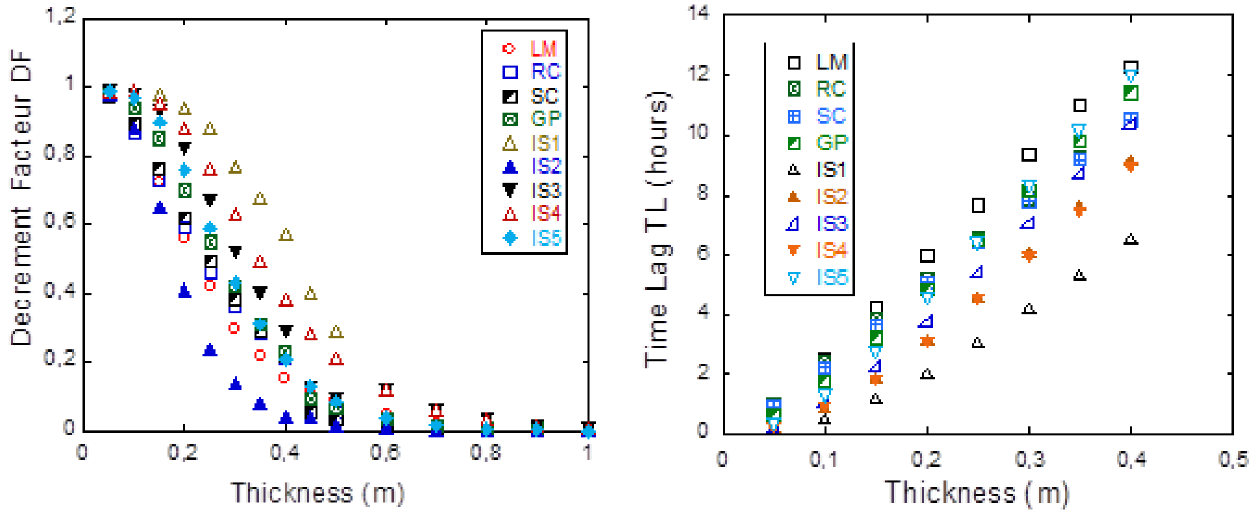
Fig. 4. *Configuration of the composite flat roofs*

Results and Discussion

Thermal inertia parameters

Figure 5 shows the effect of the thickness of the considered materials on the variations of DF and TL results. The findings of this study indicate that the DF values of different studied materials decrease with increasing their thicknesses, which is not the same for the TL parameter; the increase of material thickness increases linearly its values of TL. This is because the variation in thickness involves a phase change in the temperature distribution of the interior and exterior spaces.

Indeed, it appears that out of the five (05) insulators studied, the results showed that both thermal insulation of foam Glassboard (IS3) and formaldehyde board (IS4) have the lowest values of DF and the highest value of TL (Fig.5). For the thickness of 40 cm, the values for DF vary in the range of 0.21–0.29, and TL values increase from 0.41 to 11.98 hours. It was also revealed in this study that the thermal inertia parameters TL and DF depend mainly on the intrinsic properties of the materials making up the roof, like thermal conductivity, specific heat capacity, density, and thickness. Similar findings are obtained by previous works which studying the relationship between thermo-physical properties and thermal inertia parameters [13,34,35]. The same conclusion is obtained by Balaji et al. (2019) [14], in particular with regard to the relationship between the time lag and the decrement factor with the thermal properties of materials and the thickness of insulating materials.

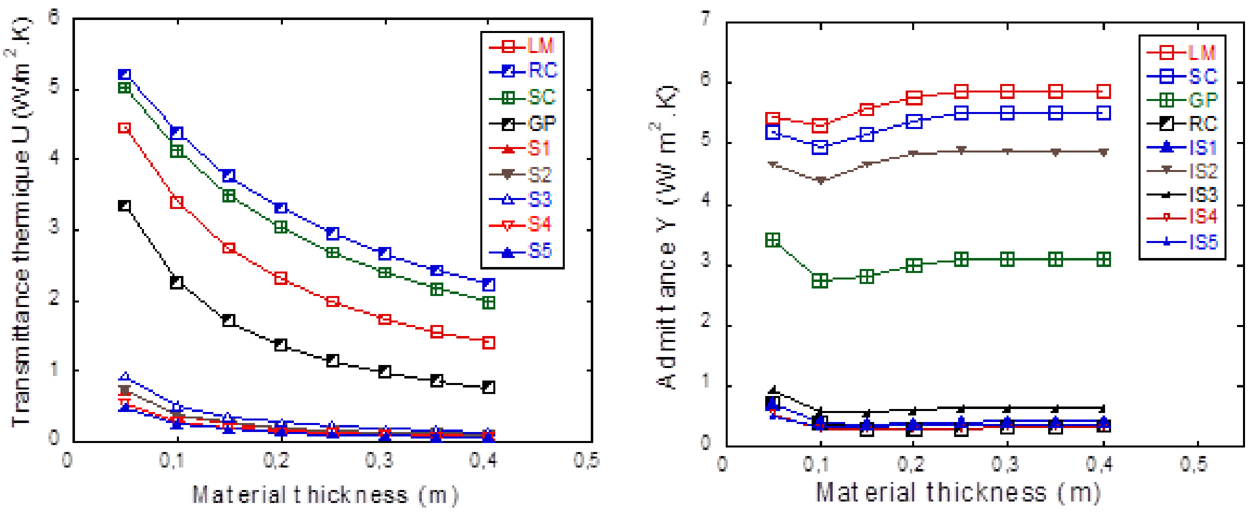


(a) (b)

Fig. 5. *Effect of thickness on (a) the DF and (b) TL of building and insulating materials*

Transmittance and thermal admittance

Figures 6 (a) and (b) indicate the variation of the values of thermal transmittance and thermal admittance as a function of different fixed thicknesses of investigated materials.



(a) (b)

Fig. 6. *Effect of thickness on the U (a) and (b) Y of building and insulating materials*

The Y values explain the relationship between the complex magnitude of the change in heat flow on one side of the structure and the complex magnitude of the temperature fluctuation on the same side of the structure. The thermal transmittance defines the ratio of individual physical quantities on one side of the wall to the other [13]. As a result, increasing the thickness of the materials significantly decreases the values of both parameters of Y and U. This is mainly due to the great capacity of materials/insulators to absorb and store heat. The Formaldehyde board (IS4) insulation has the lowest values of Y for all thicknesses among the five materials studied, followed by IS3 and IS5. On the other hand, the U values of IS4 insulation decrease from 0.28 to 0.14 W/m^2K for thickness from 10 to 20 cm.

Indeed, the best dynamic thermal performances are obtained for IS4 and IS5 insulation. Thus, these insulations exhibited almost the same thermal performance. Similar results are also observed in the literature [18] on thermal admittance and thermal transmittance values.

Surface factor

Figure 7 shows the variation of the surface factor values as a function of the thickness of the studied materials and insulations. This factor generally explains the capacity of the surface element to absorb the incident radiative heat and to estimate if using equation (16). According to the obtained results, the F-factor values of the insulation are much higher than the other studied materials of LM, RC, SC, and GP. In the case of the thermal insulation materials, the formaldehyde and polyurethane board (IS4 and IS5) are characterized by high thermal performance, which translates to the high values of surface factors, 0.95 and 0.96, respectively. This could be attributed also to the high density and surface heat capacity properties of this insulator, which shows significant variations in physical properties compared to other materials. In the case of materials such as lime mortar and inside gypsum mortar (LM and GP), the calculated surface factor F is in the range of 0.46 and 0.65, respectively. These results have been in previous searches proved by Balaji et al. [14] and Kalinović et al. [28].

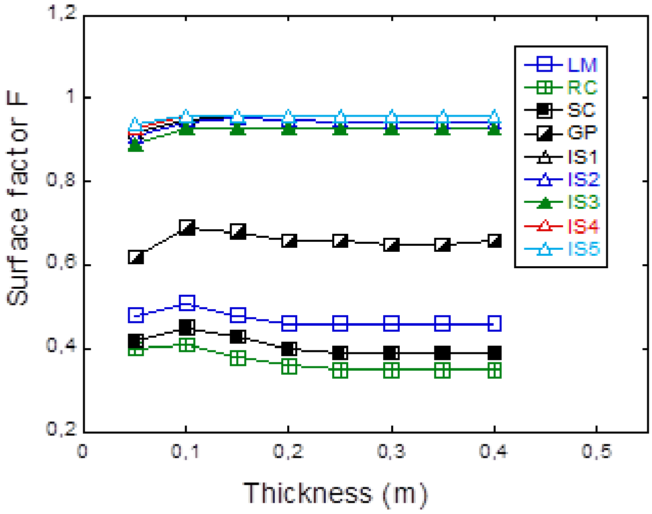
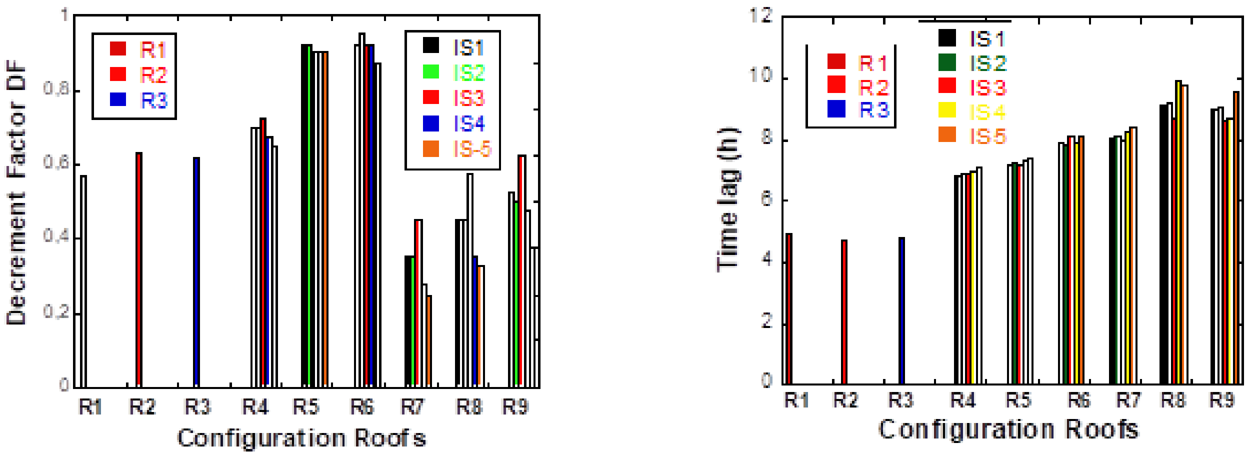


Fig. 7. *Variation effect of thickness composite roofs on the surface factor values*

Insulation configuration on the composite roofs

The selected materials in this work are mainly those most commonly used in the construction of roofs for traditional buildings, such as those made of earth blocks or natural stone, located particularly in southern Algeria (Table 2). The dynamic thermal performance of the respective composite and roof systems is shown in Figure 8.



(a) (b)

Fig. 8. *Effect of insulation position on the DF (a) and (b) TL parameters for different configurations*

The values of these two factors mainly depend on the exterior and interior temperatures as well as the thermo-physical properties of the materials taken into account in the configuration of studied roofs. Figures 8 (a) and (b) indicate that the thermal inertia parameters of flat roofs, namely the DF and TL, strongly depend on the thermal characteristics of the insulating materials used and their position in the configuration system (towards the outside or inside) as well as the relative proportion of the material layers inserted in the roof. As a result, the highest values of TL occur in the case of the configuration of roofs (R7, R8, and R9), and the lowest value is obtained for the roof (R1) without insulation. This confirms the importance of insulation incorporation in the flat roof system for improving the thermal performance of buildings.

The application of a lime-based plaster (LM and GP) with concrete blocks (RC) in a configuration with six layers (R8 and R9) in two concrete layers 0.075 m thick, respectively, and associated with two insulation layers with a thickness of 0.02 m represent the configurations with the best insulation characteristics and have given the best thermal dynamic performance. Indeed, flat roofs with two layers of insulation of 0.02 m based on formaldehyde board or polyurethane board (IS4 and IS5) give a good result. These systems (IS4 and IS5) are characterized by TL (9.94 and 9.76 hours) and DF factors (0.14 and 0.13).

On the other hand, the values of DF decrease significantly (65%) for configurations with insulation, which is not the same for configurations without insulation, and especially with roofs based on IS4 and IS5 insulations. This reduction of DF values is associated with an increase of TL values of about 3.5 to 4.50h for all systems of R3 (IS1, IS2, IS3, IS4) in comparison with the R3 configuration.

Conclusion

In this article, the thermal performance of composite flat roof systems used in traditional houses has been analyzed by studying their dynamic thermal parameters. An analytical method of admittance is proposed in order to define the dynamic thermal characteristics of the investigated composite flat roofs. The conclusions drawn can be summarized as:

- The adequate choice of building materials and their appropriate position in flat roof design plays an important role in the thermal comfort of the construction. Based on the analysis performed, it can be observed that the thermal inertia of some flat roofs selected reduces and delays effectively the effect of external conditions (temperatures) and is particularly suited to the climate where the temperature difference between day and night is important, as in the climatic conditions of the hot and arid regions of Algeria.
- The change in the roof configurations (R1 to R9) has a significant impact on the thermal performance of buildings, in particular the values of DF and TL. Thermal inertia parameters (TD and DF) improve with increasing thermal capacity and material layers to design the composite flat roof configuration. The flat roof systems with six layers and the insulations applied located in inside/middle or outside/middle positions were found to be the most appropriate configurations among the nine combinations tested to minimize the DF and maximize the TL. In addition, it was revealed that the thermophysical properties of materials and insulators (thermal conductivity, thermal capacity, and density) and their thicknesses have a very significant effect on the dynamic thermal characteristics as well as the admittance and transmittance parameters.
- The value of the surface factor is highly dependent on the thermal properties and thickness of the materials. Consequently, it can be noted that the insulating materials with low thermal conductivity applied to flat roofs have a higher surface factor and a high time lag.
- The formaldehyde and polyurethane board with a thickness of 0.04 m revealed better performance than the other selected thermal insulations, and they can be the suitable materials that can improve the thermal performance of buildings. According to most results, it can be noted that for a flat roof with the same structure and same total thickness but with different thicknesses of individual layers within the structure of the roof, the two configurations (R8 and R9) are the flat roofs with the best insulation characteristics. The values for DF in these configuration systems (R8 with IS4-IS5) oscillate in the range of 0.14–0.13 and have the highest TL, which varies between 9.94 and 9.76 hours, respectively. These configurations of flat roofs could be a viable and effective alternative to conventional roofs in hot and arid climatic regions. They were found to be useful and more efficient configurations that are capable of dampening the thermal waves of the outdoor environment exposed on the external face of the roof.

- Consequently, it has been concluded that the configuration with two thermal insulation layers with respective thicknesses of 0.02 m (outside) and 0.02 m (inside) placed between reinforced cement concrete RC with thicknesses of 0.15 m and exterior lime mortar LM (0.025 m) and with inside gypsum plastering GP (0.015 m) presents a higher time lag and lower decrement factor.

At the end of this work, it has been concluded that it was perfectly possible to design high-performance composite roofs with energy savings in the regions characterized by the arid and hot climate of Algeria. In future research, based on the methodology proposed in this work, evaluation of the dynamic thermal performance of roofs and walls of buildings can be performed in other climates of Algeria, both technically and economically.

Conflict of Interest

The authors declare no conflicts of interest.

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THE EFFECT OF DIFFERENT MULTI-WALLED CARBON NANOTUBES ASPECT RATIO ON THE COMPRESSIVE STRENGTH OF THE CEMENT-BASED CONCRETE

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Abstract: *In recent years, there has been extensive research on the mechanical and physical properties of composite cement-based building materials containing nanosized carbon particles, particularly multi-walled carbon nanotubes (MWCNTs), owing to their mechanical and physical advantages. This study investigated the effect of purified multi-walled carbon nanotubes (MWCNTs) with different aspect ratios on the compressive strength of cement-based concrete. This study aimed to enhance the mechanical properties of the composites by optimizing the MWCNT dosage and type. The novelty of this study lies in comparing three MWCNT types (TNM2, TNM3, and TNM7) with aspect ratios ranging from ~250 to ~4347. Concrete samples with 0–0.2 wt.% MWCNTs by the weight of cement were tested after 7 days of curing. The results show that the compressive strength increased by 9.41% (TNM2 at 0.2%), 2.80% (TNM3 at 0.05%), and 12.13% (TNM7 at 0.05%). High-aspect-ratio MWCNTs showed consistent improvement with increasing content, whereas low-aspect-ratio MWCNTs peaked at 0.05%. This effect is attributed to the nanotube dispersion, reinforcement efficiency, and porosity control. A standardized ultrasonic dispersion technique was used to ensure the homogenous distribution of nanotubes in the cement matrix. These findings support the development of nano-engineered concrete with improved early strength for structural and precast construction applications.*

Keywords:*. carbon nanotubes, cement based concrete, compressive strength, aspect ratio, outer diameter*.

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Introduction

Concrete is among the most widely utilized materials in construction, attributed to its notable workability and mechanical properties. Enhancing these attributes, particularly compressive strength, presents a significant challenge. Numerous studies have investigated the incorporation of additives and nanoparticles, such as nanofibers, carbon graphene, single-walled carbon nanotubes (SWCNTs), and multi-walled carbon nanotubes (MWCNTs), to augment the mechanical properties of concrete, thereby achieving superior compressive and tensile strengths [1,2,3,4]. Multi-walled carbon nanotubes (MWCNTs) are among the most extensively employed and robust nanoparticles. Their one-dimensional fibrous nature contributes to a broad range of outer diameters (spanning from 0.4-3 nm to 1.4-100 nm, contingent on the number of layers) and aspect ratios (ranging from 100 to 1000) [5]. MWCNTs exhibit high tensile strength (50-200 GPa) and Young's modulus (1 TPa), which significantly impact the fundamental properties of concrete [5]. This is primarily due to their capacity to function as crack bridges, thereby inhibiting the propagation of microcracks within the matrix [5,6]. Consequently, they enhance various characteristics of concrete, including compressive and tensile strength, as well as crack resistance. Research indicates that the incorporation of carbon nanotubes (CNTs) in concentrations ranging from 0.01% to 0.5% by weight of cement can enhance compressive strength by up to 30% [7,8]. While this finding highlights the potential for improved material properties, a critical area of inquiry is the optimal aspect ratio of multi-walled carbon nanotubes (MWCNTs) in concrete. Variations in the diameters and lengths of MWCNTs can differentially affect the mechanical properties, such as compressive, tensile, and flexural strengths, of cement-based materials, including concretes and mortars. Notably, modifications in the diameter of the nanotubes can significantly influence their compressive characteristics [9,10,11,12]. However, there is a scarcity of studies examining the impact of different aspect ratios (length-to-outer diameter) of MWCNTs on the mechanical properties of concrete. This paper investigates the influence of various aspect ratios of CNTs on the compressive strength of concrete and the optimal concentration of three types of MWCNTs by weight of cement.

Materials and Methods

Materials

Ordinary portland cement with the class 52.5 (M500) made and fabricated by the Factory of Ararat Cement, was used as a binder in the concrete mixture. For the selected cement, sand, and coarse aggregate physical and mechanical properties are detailed in Tables 1, 2, and 3, respectively [5]. Figure 1 illustrates three MWCNTs (TNM2, 3, 7) with different lengths and outer diameters, which were procured from Zhengzhou University, China, and synthesized via the chemical vapor deposition (CVD) method. The requisite technical properties of the MWCNTs are presented in Table 4.

(I) (II) (III)

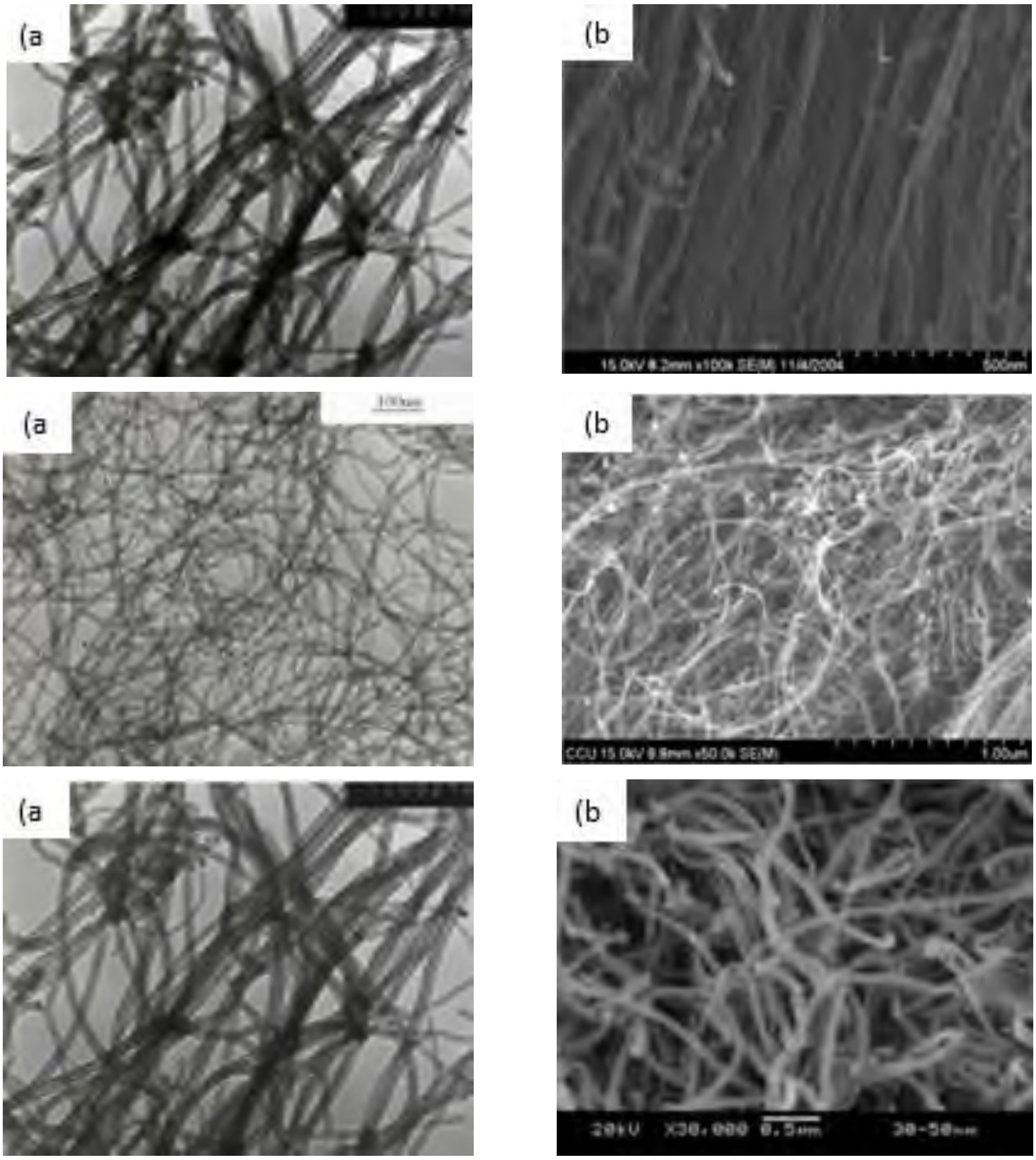

Fig. 1. *(a) Transmission Electron Microscopy (TEM), (b) Scanning Electron Microscopy (SEM) of I) TNM2, II) TNM3, III) TNM7*

Table 1. Physival and mechanical properties and chemical composition of portland cement

(a) [5]				(b) [5]	
Physical and mechanical properties of porland cement (Class 52.5)				Chemical composition of porland cement (Class 52.5) (wt.%)	
Characteristics			Testing results	SiO_2	21.6
Standard consistency (%)			27	Al_2O_3	4.5
Specific gravity (g/cm^3)			3.1	Fe_2O_3	2.2
Blaine fineness (m^2/kg)			328.3	MgO	1.1
Compressive strength of cement specimens (MPa)		3 curing days	20	CaO	61.9
		7 curing days	36	SO_3	2.1
		28 curing days	52	Loss on ignition	3.2
Setting time (min)		Initial	45	Insol. Resid.	1.9
		Final	315	Free CaO	1.5

Table 2. Physical properties of Coarse aggregate

Particle diameter (mm)	Specific gravity (kg/m^3)	Bulk density in Loose state (kg/m^3)
5-10	2650	1830

Table 3. Physical properties of sand (fine aggregate) [5]

Fineness modulus (FM)	Specific gravity (kg/m^3)	Bulk density (Loose state) (kg/m^3)	Bulk density (Compact state) (kg/m^3)
3.4	2450	1700	1925

Table 4. Technical datas of MWCNT

TNM2			TNM3			TNM7		
Outer diameter 8 – 15nm	Length ~50μm	Purity >95wt%	Outer diameter 10– 20nm	Length 10 - 30μm	Purity >98wt%	Outer diameter 30 – 50nm	Length < 10μm	Purity >98wt%

Dispersion of MWCNTs

Various techniques for dispersing MWCNTs have been reported in the literature. In this study, MWCNTs were continuously mixed with water using ultrasonic dispersion. The sonication process was conducted with the ultrasonic device UP400S under ambient temperature conditions for 30 minutes. To enhance the simultaneous plasticizing and dispersing effects of MWCNTs, Mapefluid N200 was employed. The dispersion was performed across all types (TNM 2,3,7) and concentrations (0.05, 0.1, 0.15, 0.2 wt.%) of MWCNTs selected for this research. The mobility and workability of concrete, including those incorporating multi-walled carbon nanotubes, are critical technological attributes that significantly influence the stability and operational characteristics of the material. To enhance these properties, a plasticizing chemical additive can be introduced into the concrete mix to reduce water consumption. In this study, we employed the Italian-manufactured superplasticizer "Mapefluid N200." This product is a 40% active polymer solution that improves concrete strength, decreases water permeability, enhances durability with reduced water usage, and imparts the necessary plasticity to the concrete mix. The solution is brown and constitutes 0.5% to 1.5% of the cement mass in the concrete. According to the provided data, its density is (1.20 ± 0.03) g/cm^3 at 20°C. The solution is free of chlorides and has an alkali content (Na_2O equivalent) of less than 6.0%, ensuring its safety for human use. The superplasticizer is available in containers with capacities of 10 kg, 25 kg, and 200 liters.

Mixing and Sample Preparation

The water-cement, cement-sand, and cement-coarse aggregate ratios applied in this research were 0.45, 0.58, and 0.47, respectively. Ordinary portland cement with a mixture of MWCNTs, superplasticizer, and water was blended using a 1400W handheld electric concrete mixer for 2 minutes. During continuous mixing, the sand and coarse aggregate, already in a mixed state, were added gradually and blended for an additional 5 ± 1 minutes. Specimen cubes with outer dimensions of 100 mm × 100 mm × 100 mm were selected. A vibrating table was employed for approximately 30 seconds to vibrate the molds of the samples. The mixing and preparation process for ordinary concrete (without MWCNTs) was carried out in the same manner as the composite concretes. After 24 hours, the composite samples were demolded and placed into a curing tank at a temperature of (20 ± 2)°C and (95±2)% humidity (Fig. 2).

Fig. 2. *Sample preparation steps, curing and testing processes*

Experiment. Compressive Strength Testing

To assess the average compressive strength of MWCNTs concrete, three specimens were prepared for each batch and evaluated using the automatic Compression Machine (C089) (Matest, Treviolo, Italy) 2000 kN Servo-Plus Progress, in accordance with the standard GOST 10180-2012[1]. The testing of specimens with dimensions of 100 mm × 100 mm × 100 mm was conducted at a loading rate of 0.6 MPa/s at a curing age of 7 days, as per the same standard[2].

Results and Discussion

Figure 3 presents the compressive strength of concrete incorporating three types of purified MWCNTs, categorized as TNM 2, 3, and 7, and varying MWCNTs percentages by weight of cement over 7 days. For the three types of carbon nanotubes, the designations C0, C1, C2, C3, and C4 correspond to 0%, 0.05%, 0.1%, 0.15%, and 0.2% of nanotubes by weight of cement, respectively.

According to the test results shown in Figure 3, the reference sample (C0) exhibited a compressive strength of 60.7 MPa at the 7-day curing age. The following results occurred when concrete mixtures were treated with various quantities of MWCNTs: compressive strength of the concrete increased by 9.41% for TNM2 at 0.2 wt.%, compared to the compressive strength of the reference sample (C0), 2.80% for TNM3 at 0.05 wt.%, and 12.13% for TNM7 at 0.05 wt.%.

As illustrated in Figure 3, the compressive strengths of the selected material composition structure attain their peak values at varying percentages of MWCNTs by weight of cement. Specifically, the data presented in Figure 3a (TNM2) demonstrate that, for a high aspect ratio (approximately 4347), the compressive strength increases with the rising percentage of MWCNTs in the concrete. In contrast, for a small aspect ratio (approximately 250) of nanotubes, as depicted in Figure 3c (TNM7), the compressive strength diminishes beyond 0.05 wt. %. A comparable pattern is evident in Figure 3b (TNM3). However, upon comparing TNM3 and TNM7, in the case of TNM3 the experimental results are approximately analogous, with minimal differences between C0 and C1.

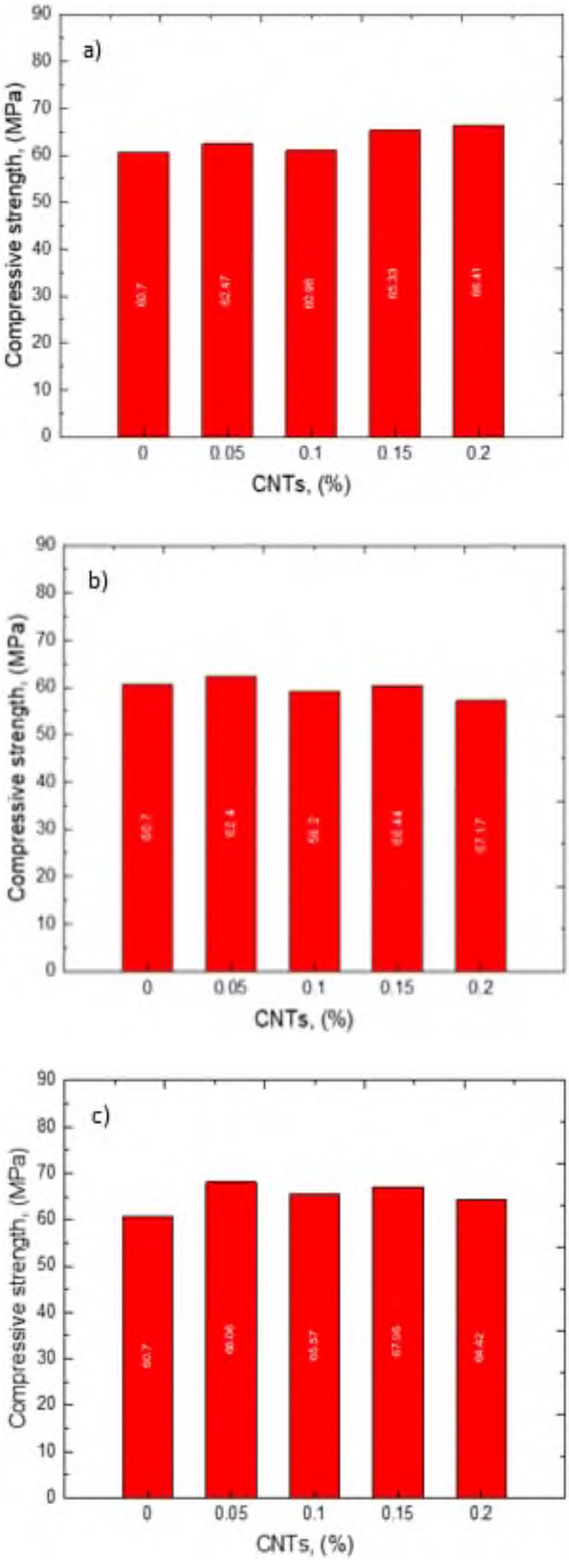

Fig. 3. *Compressive strength of concretes with different amount and types of nanotubes for 7 curing days, (a) TNM2, (b) TNM3, (c) TNM7*

[1] GOST 10180-2012. Betony. Metody opredeleniya prochnosti po kontrol'nym obraztsam. Moscow, Standartinform. 2018.

[2] Ibid.

For all types of multi-walled carbon nanotubes (MWCNTs), the results can be analyzed separately. Based on the references reviewed and the test results, there are significant differences in how various diameters and lengths of MWCNTs affect the compressive strength of concrete [9,10,11,12]. MWCNTs with a smaller diameter and a higher aspect ratio provide better filling and have a more effective reinforcing influence within the matrix, provided that the dispersion process is carried out well [9,10]. As shown in Fig. 3a, there is no evidence of agglomeration. Additionally, it's important to mention that the sonication time and power can damage the particles, possibly reducing their length to less than 50 μm.

In the case of nanotubes with a small aspect ratio, the dispersion effect is more favorable; however, the filling properties and specific surface area are low, which generally decreases the interaction between the nanocarbon and the cement matrix. Some pore structure test results indicate that porosity increases with the diameter of the nanotubes, which can affect the compressive strength of the specimen. In contrast, smaller-diameter multi-walled carbon nanotubes (MWCNTs) effectively increase pore size distribution and reduce porosity in concrete.

Conclusion

This paper investigates the effect of the aspect ratio of different carbon nanotubes on the compressive strength of cement-based concrete. The experimental results show that the average compressive strength of concrete samples cured for 7 days reaches its maximum at varying concentrations of nanotubes, depending on the type of MWCNTs used. Specifically, the compressive strength increased by 9.41% for TNM2 at 0.2 wt.%, 2.80% for TNM3 at 0.05 wt.%, and 12.13% for TNM7 at 0.05 wt.%. For samples with a higher aspect ratio (approximately 4347), an increase in the concentration of nanotubes (0.05%, 0.1%, 0.15%, and 0.2%) results in an enhancement of compressive strength. In contrast, for samples with smaller aspect ratios (approximately 250), the compressive strength decreases after reaching a concentration of 0.05% nanotubes. These results can be explained by considering several factors, including the filling effect of nanotubes, effective reinforcement within the concrete matrix, good dispersion, the agglomeration effect, sonication time, and the distribution of porosity and pore size in the concrete. These findings support the development of nano-engineered concrete with improved early strength for structural and precast construction applications.

Conflict of Interest

The authors declare no conflicts of interest.

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DEAF SPACE IN BAZNAS DKI JAKARTA PESANTREN TAHFIZ DIFABEL COMPLEX

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Abstract: *The Tahfiz Islamic Boarding School (Pesantren) for the hearing impaired is a significant innovative step in overcoming the challenges of access to religious education for individuals with disabilities in Indonesia. This research aims to thoroughly explore and analyze the application of deaf space architecture in the KH. Lutfi Fathullah BAZNAS DKI Jakarta Pesantren Tahfiz Difabel Complex, which is exclusively designed to meet the needs of deaf people. This research was conducted using a qualitative approach with two elaborations. The first is through interview and observation. The second examines deaf space architecture through literature studies via the internet. This research provides an in-depth description of how the architectural design of the boarding school complex has taken into account aspects of inclusivity for deaf people. The results highlight that the main buildings, such as classrooms, places of worship, dormitories, and other public areas, haven't been designed by considering the accessibility and safety needs of people with disabilities by integrating passive design in the form of other supporting facilities effectively. However, this research also highlights the need for continued efforts in monitoring and evaluation to ensure the sustainability and effectiveness of inclusivity in practice in order to meet the needs of the disabled holistically.*

keywords: *inclusive architecture, deaf space, Pesantren.*

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Introduction

The Quran must be read and learned by all, including people who are deaf or hard of hearing. Recite what has been revealed to you, the Quran (Al-Kahf: 27). Learning the Quran provides important religious values and helps in the development of cognitive and language skills of deaf students.

One method of education for deaf children is through the segregation system, which provides special education separate from hearing-able children [1]. The government has attempted to provide Quranic education services for children with special needs in a segregated manner, including boarding schools specifically for people who are deaf or hard of hearing. One example is the Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) Jakarta (Fig.1), which is located in Jakarta City and organizes special religious education programs for children with special needs, such as deaf children.

Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta was established in 2022 and is located at Jl. Manunggal Jaya, RT.8/RW.4, Lebak Bulus, Cilandak, South Jakarta. The name of this pesantren is taken from the name of a figure of the National Amil Zakat Agency, KH. Lutfi Fathullah, who is known as a renowned hadith scholar. Due to the limited teaching staff, this boarding school only accommodates female students. So this pesantren has yet to be able to add classes for male students. With

Fig. 1. *Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

a total area of 2400m², this pesantren provides various facilities that support learning activities for female students with special needs. These facilities include three classrooms, two gazebos, a laundry room, a prayer room, a student (santri) dormitory, student toilets, an administration room, a VIP toilet, a kitchen, a management room, a warehouse, and a dining room. There are two deaf-friendly classrooms for junior high and high school, with 23 deaf students in junior high school and 7 in high school. The deaf-friendly classroom for junior high school has a total area of 70 sqm and can accommodate ten students per class.

The pesantren is strategically located close to the village office. Access to the pesantren can be through Lebak Bulus III road, then enter Manunggal Jaya road for about 300 meters (Fig.2).

Fig. 2. *Block Plan of Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Deafness is a hearing disability that varies from mild to severe and is classified into two categories: deafness and hard of hearing [2]. Hearing loss causes individuals to rely heavily on their sense of sight. This results in how they interact with their surroundings being slightly different from people with normal hearing, especially regarding space awareness, communication, and attempts to protect themselves. One example of a common adaptation is using sign language.

The activities of students at the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta last about five hours a day every week. Two learning subjects help deaf students communicate: the Quran memorization program and the general curriculum, like in schools. Learning the Quran not only provides religious value but also helps develop the cognitive and language skills of deaf students. The theoretical learning method here is more passive compared to pesantren in general, with more use of pictures and writing.

Individuals who have hearing can communicate verbally from one place to another, while individuals who are deaf can only communicate through sight. The limitation in hearing causes deaf children to tend to rely on visual and sensory abilities [3]. The difference in human sensory and auditory abilities allows hearing individuals to capture the sounds around them more than deaf individuals, who can only see within their visual range. Research by Sirvage in 2012 and by Chiambretto and Trillingsgaard in 2016 highlighted that the body movements of deaf humans can only be seen within a 180-degree visual range (Fig.3).

In the context of space experience for deaf individuals, a concept of space design guidelines can be used. This concept includes five main aspects, namely 1) space and proximity, 2) sensory reach, 3) mobility and proximity, 4) light and color, and 5) acoustics [4,5].

The reach of deaf individuals is limited to visual. Although this is one of the means used by deaf individuals to gain information about their environment, they also use vibration, touch, and shared or social cues to achieve the 360-degree sensory reach that hearing typically provides [4].

The five concepts aim to expand an individual's ability to respond to space by considering the limitations in the 180-degree visual range, with the hope of increasing space awareness to 360 degrees [5]. From this, it is essential to note that the prominent ability of deaf individuals lies in the sensory range of the eyes (visual) [6].

The boarding school building is generally oriented in an east-to-west direction, as shown in Figure 4, so it is exposed to the most sunlight in the morning and evening. The sun moves from east to west from around 5:00 am to 6:00 pm. In the deaf classroom building, the sun is directly above at around 12:00 am to 2:00 pm, with the highest intensity between 10:00 am and 3:00 pm. For visual comfort, the orientation of the deaf

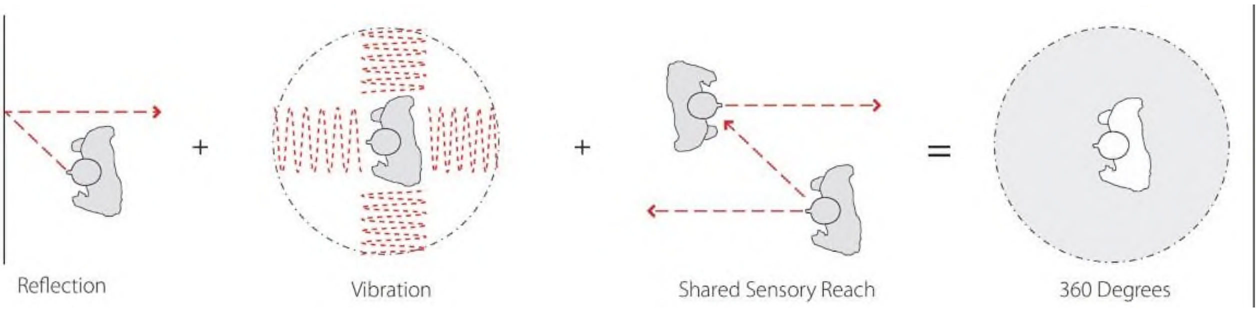


Fig. 3. *Deaf Humans Visual Range [4]*

boarding school building follows an east-to-west direction rather than north-to-south. This orientation allows daylight and glare control along the long side of the building and minimizes glare from sunrise or sunset. The deaf pesantren building receives optimal daylight, which is not allowed to enter the building directly. There is a corridor in front of the building, a facade, and many windows on the sides so that the natural sunlight does not give direct glare to the students.

One of the main elements of visual range is color. Color not only plays a role in aesthetics or creating a particular atmosphere in a place, but it can also be used to identify specific areas, divide the space into zones, and draw attention to certain areas of the room. For example, a white-painted ceiling with a black floor will give the impression of greater height than otherwise [7].

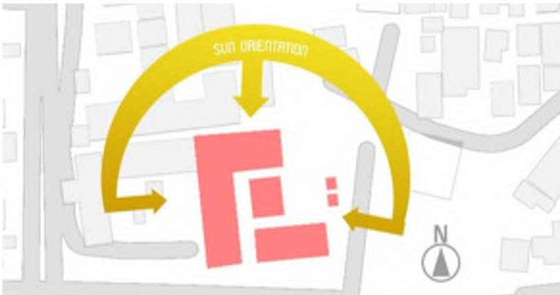


Fig. 4. *Orientation of the Building Mass Order of Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Although deaf students experience limitations in hearing and verbal communication, they are expected to be able to carry out daily activities independently without relying on the help of others; this depends on the environment in which they live, which also has a significant impact on the process of forming their independence. In this context, the design of the pesantren environment has a vital role in shaping the character of deaf santri. Based on theory and direct observation of the behavioral characteristics of people who are deaf or hard of hearing indoors, their needs include spaces that allow movement according to human body size and utilize visual access capabilities to recognize the environment. When interacting or communicating, they must face each other. Therefore, the environmental factors where they live and live need to be arranged according to the behavioral activities of deaf students as users to apply interior deaf space in the pesantren environment effectively.

Based on the explanation above, it can be concluded that the concept of deaf space has a significant impact. Therefore, applying this concept in the environment of Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) Jakarta is worth considering. The hope is that using the idea of deaf space can help deaf students develop and improve their ability to overcome challenges that may arise in their surrounding environment and find solutions to various problems. So this research aims to examine the concept of Deaf Space in the pesantren environment.

Based on the problem formulation described above, the objectives of this study are 1) to examine the concept of deaf space in the permanent environment and 2) to provide an understanding of the need for deaf space in the boarding school environment.

This research is new to a previous study by R. Permadi et al., which focused on designing a Deaf Special School (SLB-B), a general education institution. This research focuses on Hansel Bauman's five deaf space concepts applied to the Boarding School for the Disabled, which has an Islamic curriculum, so that the idea of Hansel Bauman's deaf space will acculturate with the Islamic learning system, especially in the Quran memorization learning system.

Methods

The research method chosen is descriptive qualitative. This research will utilize interviews, observations, and literature analysis data. This research focuses on the Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) in South Jakarta, with research subjects being the teaching staff from the pesantren. And this observation and interview was conducted in May 2024.

The data in this study are divided into two types: primary data obtained directly from respondents through interviews and secondary data derived from literature studies such as books and scientific journals. The sampling technique used was purposive sampling, namely interviewing teaching staff who have taught at the pesantren since its inception.

The data collection techniques include literature study, interviews, observation, and documentation. Data analysis was conducted qualitatively by processing data from various sources such as notes, photos, and interview results. The results of this analysis were then used to conclude the research problem, such as the chart in Figure 5.

This research applies the data analysis technique developed by Miles and Huberman [8], which consists of three main stages: data reduction, data presentation, and conclusion drawing. Data reduction is done by collecting information about deaf space in pesantren through interviews and observations. The data was then presented in various forms, such as tables, graphs, stories, and documents, to facilitate understanding and conclusion.

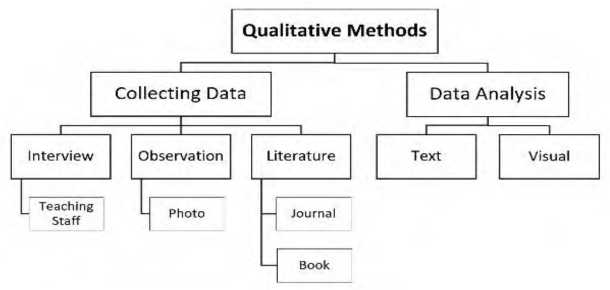


Fig. 5. *Research Method*

Data verification and conclusion drawing are based on valid and consistent evidence so that the research results can be accounted for.

Results and Discussion

This chapter presents the results of research conducted regarding applying the concept of deaf space in the environment of Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta. Five deaf space concepts were studied in this research. These five concepts underlie the design of deaf space: space and proximity, sensory reach, mobility and proximity, light and color, and acoustics [7].

These five concepts are guidelines designed to create an environment that is more inclusive and responsive to the needs of deaf students:

1. *Space and proximity* – examines how space is organized and optimized to enable effective interaction between deaf students and facilitate their daily activities [7].
2. *Sensory reach* – explains how space design allows deaf santris to maximize their sense of sight, extending their visual range and improving navigation within the pesantren environment [7].
3. *Light and color* – examines the use of light and color in the interior design of pesantren to improve visual comfort and assist deaf students in space orientation and learning activities [7].
4. *Mobility and proximity* – discusses how movement and accessibility within the pesantren are organized to facilitate the mobility of deaf santris, including pathways and furniture arrangements that support affordability [7].
5. *Acoustics* – evaluating the acoustic aspects in the pesantren environment. Although deaf santris do not rely on hearing, minimizing sound disturbances that affect comfort and concentration is vital [7].

The results of this research are expected to provide a deeper understanding of how the application of deaf space concepts can support the independence and well-being of deaf santri in the pesantren environment. A detailed analysis of each idea will be presented in the following subsections, showing the relevance and effectiveness of deaf space design in the specific context of Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta.

Sensory Reach

Deaf children have limited speaking and hearing abilities, so visual media is a suitable learning medium. The way to explain visual media to deaf children is with lip language or lip movements [9], which makes them need cues that can stimulate other visual and sensory abilities in the form of signs, labeling, use of materials, etc. Spatial orientation and awareness of the activities around us are essential for maintaining well-being. Visual connection, openness, and transparency are vital to expanding the sensory range of deaf students but must be balanced with considerations of privacy and comfort, as well as "degree of enclosure." Setting the degree of openness appropriate to the situation is necessary to balance visual availability, privacy, and safety [4].

According to Hansel Bauman, the standard angles used in deaf space design include oblique, curved, transmission, or curvatures that provide a more comfortable visual appearance. The space in the Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta still has right angles or sharp corners in the corridor (Fig.6), creating blind corners, so students must be careful not to bump into others when crossing the intersection (Fig.7).

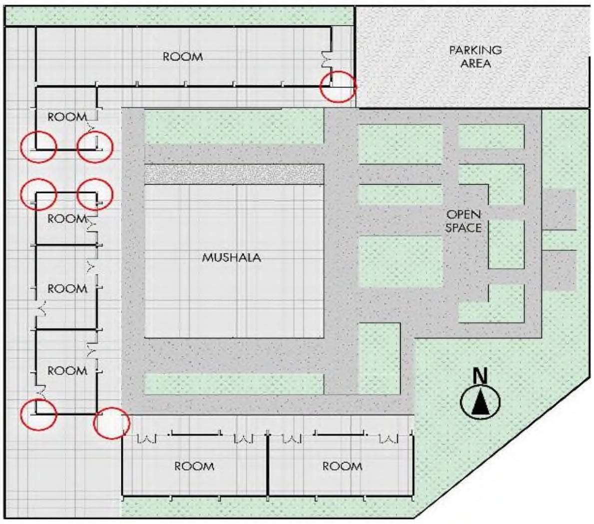


Fig. 6. *Blind corner at the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Fig. 7. *The corner of the room at the KH. Lutfi Fathullah BAZNAS Jakarta Tahfiz Difabel Pesantren*

This characteristic of deaf psychology is applied to help or even increase the stimulation of the senses that deaf people have. By using other senses, deaf students are expected to be able to read different situations through existing visuals. For example, the wall elements use transparent glass accents on the door so that students who are in the classroom can find out if there are people at the door; the addition of glass material to the interior accents so that students can quickly respond if there is a call from behind [10].

The door in the deaf pesantren room at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta uses a wooden door without a layer of transparent glass on both sides (Fig.8). This condition increases the risk of deaf students colliding when opening the door because they cannot see who is behind it. In addition, the door opening in this pesantren room leads out, so students must be careful not to bump into other people. This risk can be minimized by adding transparent glass to the door so that deaf students can see the person behind the door.

In the building of Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta, windows are placed almost throughout the building. Nearly all rooms use transparent glass material. The use of transparent glass aims to give deaf students a broad view and allow them to clearly see the situation outside and inside the room.

The windows used in this pesantren are almost the same as the window system in general, which uses a type of nako glass window (Fig.9). The window is made in such a way that students with special needs, especially blind students, do not hit it when walking. If the window can be opened with the addition of swing window hinges, there is a high probability that students with special needs can hit the window when passing by.

Fig. 8. *The Door at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Fig. 9. *Window at the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Nako glass windows have advantages in regulating airflow according to the desired conditions of the occupants and are easy to maintain [11]. With nako glass windows, air circulation in the room can be optimized.

The seating arrangement in the study room for deaf students is adjusted to the learning needs because the furniture is portable (movable). This classroom's table and chair model can be easily arranged according to learning needs. Seating arrangements are arranged in rows and parallel apart (Fig.10). This seating arrangement is intended so that deaf students can focus on paying attention to the material delivered by their ustadz (teacher).

When deaf individuals are seated in groups, it is essential to arrange the seating so that they can see each other's faces and maintain eye contact with all participants. Square and rectangular tables become problematic for groups larger than four, with the issues worsening as the group size increases. Therefore, round and horseshoe-shaped tables are preferred [4].

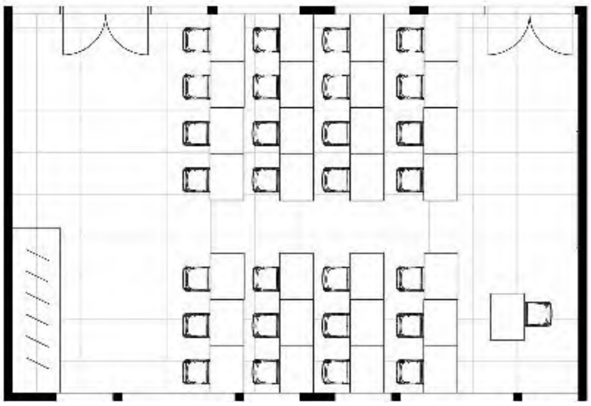


Fig. 10. *Seating arrangement at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

There is a comparative optimization of seating arrangements in the deaf space literature. A "U" or horseshoe-shaped seating arrangement effectively gives everyone equal visual access [4,12]. The semi-circular arrangement is usually used for more than four students, for example, seven students, and requires a larger room size, usually applied to a square room. At the same time, the "U" - shaped arrangement is often used in classrooms with four students. However, the "U" - shaped seating arrangement has disadvantages if applied in this deaf pesantren class because it can divert the concentration of the students. They may be unable to focus on the ustadz and are easily distracted by other deaf students. The seating arrangement currently applied in this pesantren classroom is lined and parallel (Fig.11). So that students can see and focus on the ustadz during the learning process.

Fig. 11. *Classroom at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Space and Proximity

Deaf people need more space than hearing people to attend to their environment freely. Large and spacious visual spaces facilitate communication and environmental awareness for deaf people. For example, two deaf students communicate more visually than with sign language or spoken speech. The space and proximity characteristics of the deaf form a comfortable space for them to do their activities. The language and communication skills of deaf students often require visual skills in communication.

Deaf people are more dominant with face-to-face characteristics to more easily understand messages through spoken or sign language. They need ample space to demonstrate sign language, so wider walkways and ramps are essential. Wider walkways allow communication with the interlocutor while walking safely. This boarding school has no walkways, but almost all areas use 1500 mm wide corridors. The best practice chosen by Universal Design experts is 1200 mm for barrier-free pedestrian width. However, in areas with higher frequency, it is recommended to use a width of 1830 mm [13]. After reviewing the universal design standards, we see that the road corridor in this pesantren is sufficient for just a pedestrian path.

The shape of the proposed room considers the psychological characteristics of people who are deaf or hard of hearing, such as resembling a circle, to be more flexible and facilitate the view between students. This circular shape provides positive value for deaf psychology, especially in reducing fatigue due to communication activities. The design of the communal area in the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta is dominated by a circular shape, which is applied to the gazebo, prayer room, garden, and so on, to support the function of deaf people.

However, the existing learning space must be revised because it cannot adjust to learning needs. For example, during certain learning activities, such as Al-Quran memorization deposit activities, students move from the classroom to the mushala or gazebo to carry out teaching and learning activities in a circle (Fig.12).

Fig. 12. *Learning at Mushala Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Light and Color

Lighting is one of the critical factors in space design that supports user comfort [14], given the dependence of deaf people on their visual abilities. Of course, adequate lighting is needed to keep the room illuminated and avoid its adverse effects. The negative effects of poor lighting include 1) eye fatigue, 2) mental fatigue, 3) damage to the visual apparatus, 4) complaints of soreness around the eyes, and 5) increased risk of accidents [15].

Visual comfort is closely related to the lighting standards that have been set. SNI 03-6197-2000 sets visual comfort standards tailored to specific activities and needs: general classrooms require lighting of 250 lux, computer rooms require 500 lux, drawing rooms require 700 lux, and wood workshops require lighting between 200 and 1000 lux [16].

The Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta places the spaces around a garden in the center of the site so that each room can access natural lighting because other structures block no side of the building. The corridor in front of the room ensures that sunlight does not directly daze the students. Even and adequate lighting in the classroom of deaf students facing the park is obtained from the many windows on the side of the building. Artificial lighting in each classroom uses downlight-type lamps (Fig.13) with 40 watts of power and a light temperature of 4000K cool tone. Cool light (4000K) produces a higher ability to concentrate, and warmer light (3000K) can improve communication [17]. Lighting conditions like this can give a bright impression and increase concentration and productivity in learning. This lighting is by SNI standards[1], where the optimal minimum lighting level for classrooms is 250 lux with color rendering group 1 or 2 and cool white or daylight temperature (Table 1). With this lighting, deaf students can read sign language, lips, and body language during learning.

[1] SNI 03-6197-2000 Standar Nasional Indonesia Badan Standardisasi Nasional Konservasi energi pada sistem pencahayaan

A bright window behind a person or a focal point in space causes a high contrast between the subject and the environment (backlight) (Fig.14). A person standing in front of a bright window will be silhouetted, causing difficulty reading facial expressions and eye contact [4].

Fig. 13. *Lights in the Classroom of Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

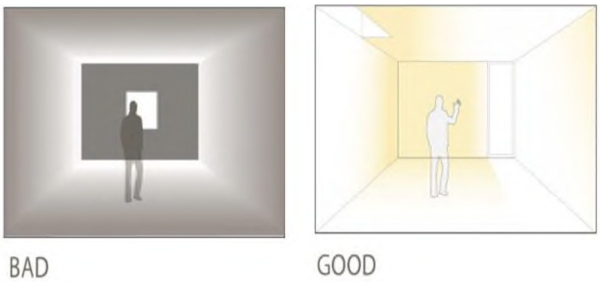


Fig. 14. *Backlight Illustration [4]*

Table 1. Room Lighting Standards [14]

Material	Light Levels (Lux)	Color Rendering Group
Library	0.09	1 or 2
Lobby, Corridor	0.07	1
Storage Room	0.02	3

The condition of the disabled boarding school space is considered feasible according to Hansel Bauman's regulations because it meets the lighting standards that do not cause backlight, according to Hansel Bauman's inclusive design principles, which emphasize the importance of even lighting to avoid glare and shadows that interfere with vision. The classrooms in this pesantren have lighting from all directions, which ensures uniform light distribution throughout the room and prevents overpowering light sources from one direction, which can cause backlighting and harsh shadows and reduce visibility (**Fig. 15**).

Color selection can undoubtedly affect the characteristics and behavior of deaf users. According to Witabora et al., a color scheme combines several colors chosen with aesthetic harmony in mind, capable of conveying a specific message or meaning and related to particular emotions or impressions [18]. Choosing colors that contrast with the skin can improve visual focus for users with difficulty paying attention to the other person. Since communication between deaf and hard-of-hearing people depends heavily on visual clarity, colors that contrast and match the skin tone are best for sign language backgrounds. Blue and green are colors that contrast with most skin tones. In addition, blue and green colors visually prevent overstimulation of the eyes and provide a background against which the eyes can rest [4].

Fig. 15. *Classroom Openings at Tahfiz Pesantren with Disabilities KH. Lutfi Fathullah BAZNAS Jakarta*

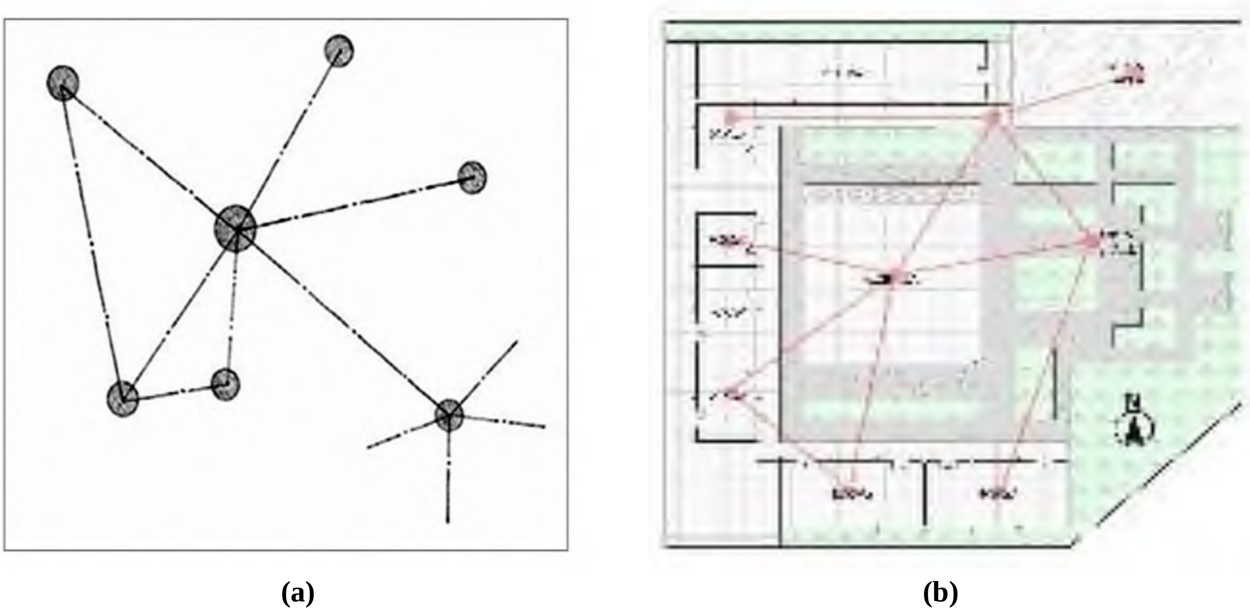
The walls in this pesantren are dominantly colored with white and brown bricks, the floor uses white ceramic tiles, and the ceiling is painted white. The furniture uses a combination of brown, gray, white, and black colors from wood materials. The whiteboard contains the alphabet and numbers on the top. The color of the tiles and ceiling in this classroom is white, which creates the impression of a spacious, open, and shiny room, which positively affects the condition of the room's occupants, especially deaf people who need high concentration in the learning process. The vigorous intensity of the white color on the tiles gives a calm and spacious impression, supporting the necessary atmosphere for concentration without pressure. The wall paint colors chosen are white and brick brown. Psychologically, white symbolizes success, light, goodness, purity, innocence, and simplicity [19]. However, brown is less than ideal because it matches the color of human skin, making it difficult for deaf people to focus on sign language that uses hand gestures. On the other hand, aesthetically, the combination of brown with white, wood, and black furniture creates a good atmosphere for the learning process. The furniture in this classroom is painted in black, white, grey, and brown (**Fig. 16**).

Fig. 16. *Building Color Accents at the Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Mobility and Proximity

This principle is similar to the principle of space and proximity but focuses more on the movement of deaf students. The communication characteristics of people who are deaf or hard of hearing use their imagination, so they tend not to pay much attention to their surroundings, especially when concentrating on talking to each other. Their ideal space is spacious, open, and wide, allowing them to focus on the road and their interlocutors. Space from this principle includes walking areas, classrooms, and access to corridors and ramps that need to be considered for deaf people. They need wider circulation paths to accommodate conversations with signs while walking, mainly when two or more deaf students communicate while moving. The path they walk on should have good circulation and visibility, be visible from a distance, and be free of obstructions, abrupt transitions, or angles. Any obstacles to the movement of deaf santris can disrupt their conversations, so these pathways should be as clear as possible (Fig.17a).

The circulation system in the deaf pesantren complex is closely related to the activities carried out by the deaf santris. This system affects the smooth running of activities and provides flexibility for deaf santri. The furniture arrangement is essential in arranging circulation patterns to create adequate flow with clear directions. This circulation pattern becomes a direction that provides continuity for users of the room to the function of the space. In the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta, the circulation pattern applied is a networking pattern [20]. With 30 deaf female students, a minimalist open space arrangement fills the middle area of the site so that circulation outside the building feels wide and the view of deaf students is not blocked (Fig.17b).



(a) **(b)**

Fig. 17. *(a) Circulation Networking [17],*
(b) Circulation Patterns at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta

Users with hearing loss need ease of movement and activity. In addition to movement space, tools and movement systems must also be considered. For example, ramps in boarding schools for people with other disabilities. Ramps should be configured to create an adequate deaf space environment so that movement and conversation while walking can occur smoothly and reduce the risk of tripping. Ramps should be used primarily in the central circulation paths, such as the access path to the 2nd floor. Ramp width varies from 900 mm to 1220 mm, with the best practice being 1000 mm for one person [13]. Intersections must be carefully designed to maintain ease of access and communication for deaf students. There is a difference in elevation between the park and the pedestrian walkway, with the park contour being about 5-10 cm lower than the pedestrian walkway, as shown in Figure 18(a). The ramp is made with a width of about 1000 mm, as shown in Figure 18(b), which is sufficient for the circulation of one person, with the top of the ramp merging with the floor to minimize the risk of tripping.

(a)

(b)

Fig. 18. *(a) Elevation of Pedestrian Path at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta [Author, 2024], (b) Ramp at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

The corridor in this classroom is about 1500 mm wide, as shown in Figure 19, enough for two people to walk side by side. However, this width could be improved for students who communicate while walking. Deaf students need more space to move comfortably and freely when communicating. The circulation path in the corridor in front of the deaf classroom is considered less than optimal due to the narrow width of the corridor and the presence of large pillars that block the view of the deaf students. Hence, this path needs to be more visible from a distance.

The relationship between existing elements and mobility affects the emotional state of people who are deaf or hard of hearing. The distance between objects and individuals is well-considered so as not to disturb the atmosphere. The classroom area for deaf students in this pesantren is 70 m², which is considered optimal for activities because it is only occupied by fifteen deaf students and one teacher. Furniture and furnishings in this classroom are applied minimally along the walls with a small amount so that the space does not feel claustrophobic. The ceiling is not too prominent and is accented with a matte white color that does not readily reflect light that dazzles the eyes.

Fig. 19. *Corridor at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

Acoustic

Buildings for deaf users require quiet acoustic conditions with minimal background noise to prevent distractions, especially for deaf students who use hearing aids. Deaf students need quiet spaces, although not all spaces need to be so. Some rooms that require low noise levels should be designed to be soundproof. The acoustic system in classrooms used by deaf students is essential to note. Rooms that are too noisy will produce sound echoes, one of the primary sources of distracting background noise, and should be avoided, given the limited hearing of deaf santri.

The Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta is located next to the local village office. Vegetation around the garden and corridor of the pesantren helps reduce classroom noise. The garden in this pesantren has enough vegetation to muffle outside sounds, including those from the urban village office. As the deaf santri need a low-noise environment, the vegetation in front of the deaf classrooms reduces noise. Some deaf santris have varying residual hearing, so it is crucial to maintain low noise levels in the classrooms. The large amount of vegetation in this pesantren helps minimize outside noise, especially with the vegetation along the corridor in front of the deaf classroom (Fig.20).

Fig. 20. *Vegetation at Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS Jakarta*

The rooms in the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta generally use gypsum material for partitions and ceilings, while the walls are made of concrete, brick, and plaster and finished with white paint. The floors are tiled, the doors are wooden, and there are glass windows in every room. These materials have a low level of sound absorption, making them less effective in reducing noise from outside (Table 2). In general, porous materials tend to absorb sound energy more effectively than other materials. The pores allow sound waves to enter the material [21]. Classrooms for deaf students require a room that is well-maintained and easy to clean. Ceramic tile flooring was chosen because it is where the students do their activities, and they are still vulnerable to disease. Ceramic tile is a strong and durable material, making it easy to clean and ideal for use. However, ceramic tile is considered less able to reduce noise. Because ceramics are reflective of sound, they can cause unwanted reflected sounds, such as echoes or excessive reverberation [22].

The wall structure of this classroom consists of concrete, brick, and plaster, finished with a layer of white paint. Concrete was chosen because it is permanent, durable, and resistant to weather conditions, thus ensuring a sturdy and long-lasting building. Concrete walls provide vital protection for residents on the move for long periods. This material is chosen based on the conditions in Cilandak, which is close to Depok and has a mild temperature with a tropical climate, so the building remains resistant to various weather conditions. However, Indonesia's tropical architectural style has a light structure and open external walls, making it challenging to dampen sound [24].

The structural arrangement of the ceiling has an impact on the height or lowness of a room in the building. The ceiling functions as a sound distributor in acoustic systems, so it usually uses more reflective materials than absorbent. However, the shape of the ceiling itself must be considered to direct the expected sound reflection [22]. For this reason, the choice of material on the roof also impacts the room's acoustics; research revealed that the amount of sound reflected from the roof is constant, both when the building is complete and empty. In empty and full conditions, the direct sound value obtained with absorbent material is the same as that obtained without. However, the value of the sound reflected from the roof is lower than that without the absorbent material, showing that the purpose of placing absorbent materials on the roof is to control the intensity of sound caused by roof reflection [25]. The high or low sound is also influenced by the shape of the ceiling structure, such as curves, sloping, or flat. The Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta adopts a ceiling structure made of gypsum material without any additional sound-absorbing ornaments. Gypsum should be applied by filling the gaps using sound-absorbing materials such as glass wool to prevent sound propagation to other rooms. However, gypsum is now available that can reduce sound effectively [22].

The windows in this pesantren are made of wood and clear glass, with frames painted dark brown and finished with varnish to maintain the wood's color. Clear glass is chosen so that natural light can enter the classroom, creating a comfortable environment for deaf students to do their activities. The placement of windows almost across the entire building wall allows visual access for visually impaired people who pass by.

Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta adopts wooden doors. The general structure of the door consists of a frame and a door leaf, all made of wood. These materials are used in many common types of doors, including double doors. Wood has sound-absorbing properties, making it suitable for supporting sound absorption. However, if combined with some hard finishing, it can reduce the absorption [22].

Table 2. Acoustic Material Sound Absorption Coefficient [23]

Material	Frequency (Hz)				
	125	**500**	**1000**	**2000**	**4000**
Gypsum Board	0.29	0.05	0.04	0.07	0.09
Wood	0.15	0.10	0.07	0.06	0.07
Glass	0.18	0.04	0.03	0.02	0.02
Concrete	0.01	0.02	0.02	0.02	0.03
Brick	0.03	0.03	0.04	0.05	0.07

The furniture elements in the Pondok Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) DKI Jakarta are mainly made of wood, such as chairs, tables, and shelves, with furniture finishes that are safe and comfortable for deaf students. The selection of wood materials for these pieces of furniture aims to reduce the negative impact of chemicals and increase the durability of the furniture. Classroom furniture includes tables, chairs, cabinets, display shelves, bookshelves, and notice boards.

The furniture is intended to encourage positive learning experiences and increase social interaction among deaf students. The function of the furniture includes reducing noise from inside and outside the room. When an object produces sound and is blocked by a boundary plane, the sound will likely be reflected. The speed of sound propagation and the characteristics of the barrier (such as density, shape, and smoothness of the surface) will determine the magnitude and direction of the reflected sound [22]. Although the space in this deaf boarding school is not very large, the furniture placed in the classroom is quite numerous and spread out around it, helping reduce the duration of reverberation or excessive sound reflections that can cause disturbance for deaf students or those with hearing loss.

Conclusion

Based on the analysis of deaf space in the Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) Jakarta, the researcher concluded the following.

The space needed by deaf children must allow movement appropriate to the human body's size and rely on visual access to recognize the environment and to interact or communicate with each other. Therefore, the environment in which they live and move should be arranged according to the behavior of deaf children so that they can effectively apply interior deaf space in the classroom.

Some areas in the Jakarta Pesantren Tahfiz Difabel KH. Lutfi Fathullah BAZNAS (BAZIS) complex are not by the deaf space interior principles developed by Hansel Bauman. The shortcomings lie in the principles of sensory reach, mobility and proximity, and the use of color. Visibility and circulation could be more optimal because there are still right angles, doors with openings leading out, narrow corridor widths, many large pillars that interfere with the view, and the absence of standard background colors. However, the other deaf space principles have been implemented well enough to support santri learning effectively.

Conflict of Interest

The authors declare no conflicts of interest.

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LANDSCAPE AND CITY PLANNING DEVELOPMENTS IN THE CONTEXT OF CONTEMPORARY ARCHITECTURE

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Abstract: *In shaping the contemporary era of architecture, the essential roles have been the primary criteria for architectural insight, among which the most important are the development of settlement types and the emergence of new building types specific to the time. The main problem is the description of the town planning crisis inherited from the 19th century, a fixation of town planning structures developed until globalization at the end of the 20th century. Objectives are the increase of population and the formation of megacities, challenges of planning regulation, and regionalization of the world, which have changed the capacity of transportation means. The state of the art is the urgency of systematization of mega settlements and the crisis of overcrowding of the population. Besides different building types, in a new sense, megacities, megastructures, and corporate and regional communication buildings have been formed. In the conclusion, climate change and newly developed environmental conditions are emphasized.*

Keywords: *Contemporary city planning, types of 21st century settlements, metropolises, cosmopolitan cities, suburban layouts, megacities, small cities of great and limited capabilities.*

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Introduction

Although all the above-mentioned aspects have been continuously developing over the past two centuries, there are still many critical and unresolved issues with landscape and city planning. They are eager to be resolved; otherwise, they obstruct the planning regulation of the settlements more and more each day. The state of the art of the study is the determination of contemporary settlements, including the new megacities [1], as well as comparatively small cities having great and limited financial capabilities. The main problem of the presented study is the critical study of the new cities created and the performance of their detailing from the point of contemporary architecture (CA). Objectives of the study include the following aspects: a/ A glance at urban planning and the formation of preconditions for new settlement types in the XXI century. b/ Description of town planning regulation of overcrowded mega settlements. c/ Documental study of existing and newly formed cities in the XXI century and their differences.

Materials and Methods

Methodically, at first, the above-mentioned classification of megacities performed by UNESCO over the past decades of the XX-XXI centuries has been analyzed. The new settlements of the XXI century have been described, along with qualitative details about them. The properties of the existing and newly listed cities from the period were matched in a comparative method.

In conclusion, the new types of settlements from the XXI century are derived. The latter is the novelty of this research, which focuses on the following cities of the CA era, such as Singapore, Mumbai, Shanghai, Guangzhou-Dongguan-Shenzhen, New York, Hong Kong International Finance Center, Vienna, Los Angeles, Frankfurt, Dubai, Yerevan, and others. There is plenty of research held considering the new landscape and city planning situation formed in the XXI century. They are possible to be grouped in the following profiles of activities, such as formulation of relevant data banking of the study, analysis of landscape and city planning studies related to preconditions of CA consolidation, planning regulations held, and documental studies of the settlements from the XXI century.

Results and Discussion (clarified in the following **a, b,** and **c** factors**)**

a. The landscape and city planning studies related to the preconditions of CA consolidation[1]

The preconditions of modern city planning go back to XIX century developments (1800 onwards), which is after the London reconstruction and Haussmann's remodeling of Paris[2] [2], as well as Barcelona, Vienna, Berlin, the undertaking of facts of industrialized cities, etc. The XIX and XX centuries were full of theories, including linear cities, organic town planning, and the garden cities of Ebenezer Howard and other scholars of the field, etc. In the 1920s, the ideas of modernism began to surface in urban planning, particularly promoted by the "Congrès internationaux d'Architecture Moderne" from 1928. The influential modernist architect Le Corbusier presented his scheme for a "Contemporary City" for three million inhabitants in 1922[3,4]. In 1925, he exhibited his Plan Voisen[5,6]. In 1935 Le Corbusier reformulated his ideas on urbanism, eventually publishing them in the "La Ville radieuse" (the Radiant City), etc.[7] [3]. However, it is important to notice that "contemporary" urban planning was in the role of a reaction against town planning modernism from the 1960s and early 1970s. As well as the facts of New Urbanism and its charter, which mentions "It is an approach for successfully reducing environmental impacts by altering the built environment to create and preserve smart cities that support sustainable transport in order to concise the measures of sprawling suburbs"[8]. These facts, wanted or not, lead the attitudes to increase the existing cities into megacities. The mentioned fact happened very urgently within the end of the XX century and promoted a planning crisis. Actually, according to records of city space use, this runs out of legislative control in the XXI century. Consequently, there came into existence plenty of ways of reforms that converted into different types of mega and minor settlements associated with the XXI century, which have the following 6 aspects of preconditions:

1. The initialization of historicism in architecture, which was promoted by the Rational South's activities from 1960 [4]; the development of postmodernism and deconstructivism in architecture by Francois Leotard and Jacques Derrida [4]; and the spread of international style and Hi-Tec architecture, which urged the change of the modernist career into postmodern.
2. The settlements caused changes in the planning and landscape. The main reason for this precondition is the result of overpopulation. In fact, at the pass of the XX-XXI centuries, 50 megacities have been formulated, 33 of which are from India and China. However, the population of megacities, as usual, started from 5-10 million and has now arrived at 30-40 million. Such famous cities are Tokyo-Yokohama, Shanghai, Guangzhou, and others, forming a zonal development of 3 megacities in the area.
3. The next precondition is in behalf of forming a new regional world network, which was formed because of the overcrowding of the population of certain cities, as well as the world trade reform declared in the 1995s. That is because of the increase in transferred cargos and the need to create super large airports, which led to alterations in the regional network of transportation in the world.

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[1] Compare the matter with: Landmarks Architects, "What are the 5 Major Trends in 21st Century Architecture?", as well as "What are the 5 rules of Modern Architecture?" etc.
[2] History of urban planning. Wikipedia. https://en.wikipedia.org/wiki/History_of_urban_planning.
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[4] Ville Contemporaine. Wikipedia
[5] Hoog, The weird plan for Paris. 2023. Available at: https://www.youtube.com/watch?v=BP2qaqojsEY. Accessed on January 10, 2024.
[6] Compare: Plan Voisen. Wikipedia.
[7] La Ville radieuse - Wikipedia
[8] History of urban planning. Wikipedia.

4. The other preconditions led to alterations in the system of megacities are in behalf to environmental alterations, urging to adapt of new measures of problematic architecture focusing on sustainable, eco, energy-conservative, green architecture, world climate changes, etc.
5. No less important precondition for the alterations in the planning is globalization, such as clustering attitudes, as well as the rise of new capitals on the Asian continent, changes in computer and digital technologies, etc.
6. In addition to the above-mentioned is the formation of different types of cities having different financial capabilities, which became urgent because of the rise in the environmental problematic architecture trend of research from the end of the XX century.

b. Megacities' planning regulations or town-planning reconstruction undertakings

Bearing in mind the content of the megacities' list mentioned above and comparing it with several lists of cities from CA, as well as the information provided from the study of CA preconditions, it is possible to fix the supply of the following regulation orders of the megacities by the means of adding megastructures or satellite cities to the existing areal context.

In reality, by means of megastructures, it is possible to investigate the reasons for the enlargement of the settlements in their various aspects. The existing agglomerations are increasing or decreasing according to the potential of the free area surrounding them. The mechanism used is the optimization of population density. In this way, regional world centers have been created that control the delivery of enormous transfers, as well as the overcrowding of the population. This is all taking place by means of recombination of free spaces among the existing settlements. Hereby, for this reason, the megastructures are used as auxiliary satellite city parts to free the residing territories. Indeed, the megastructures are self-sufficient city parts helping to unload the density of the existing cities; meanwhile, the satellites are possible business centers, neighborhoods, skyscrapers of different functions, or some other additions helping to unload the overpopulation in the area. A good example of the mentioned is Moskva-City, the nearby Russian capital, Moscow[9].

c. Documentary study of contemporary settlements in CA

There are plenty of methods to study and classify the cities in the world. In order to do a comparative analysis of the cities, it is reasonable to use the table accompanying the information available for each city in Wikipedia. In this way, it is possible to rearrange the list of the cities mentioned above into the following kinds of settlements. Hereby, principal analysis should be carried out according to the number of inhabitants in the area, the demography of the population, the residential density, and UNDESA (United Nations Department of Economic and Social Affairs)[10] [5] or the sustainability of the environment. Matching the indicated information, there are the following types of CA settlements that meet in the world.

1. The first group of cities, of course, are the technically developed settlements. Important examples are Dubai, Brisbane from Australia, London from the UK, Madrid from Spain, New York from the USA, Singapore from the Republic of Singapore, Taipei from China, Amsterdam from the Netherlands, etc. These cities are usually called smart cities. As a typical example, see Singapore[11] [6] (Fig.1).

Fig. 1. *Singapore as technically developed settlement*

[9] City of Capitals. https://en.wikipedia.org/wiki/City_of_Capitals.
[10] United Nations Department of Economic and Social Affairs. Wikipedia.
[11] Singapore. Wikipedia.

2. The second group of cities is formulated as a result of an uncontrolled, overcrowded population having high residential density. These are usually called megacities, having 5-10 million, which gradually extended into 30-40-56 million. Here, the population density begins at 2000 inhabitants and so on. The critical part in such cities is the 30-50% part, which increased in a disorderly way. Due to the drive, the attention here is the existing high level of air pollution. Renowned megacities are Mumbai, Bangkok, Thailand, Cairo, Chengdu in China, Hyderabad in India, Istanbul, Lahore, Tehran, etc. As a typical example for the study, see Mumbai[12] [7] (Fig.2).

a.

b.

Fig. 2. *The planning situation of Mumbai mega city.*
a. *The irregularly developed part of Mumbai*, **b**. *The regularly planned part of Mumbai*

3. Apart from the former, there are other megacities formed from existing central and other peripheral cities, converting the area into one enormous settlement, usually called intermediary cities. Renowned examples of the type are Shanghai, Beijing, New Delhi, etc. As a typical example for the study, see Shanghai[13] [8] (Fig.3).
4. Parallel or twin cities are special types of intermediary cities having a certain area composition. Such renowned examples are Paris-Defiance, Tokyo-Yokohama, "City of Bela Horizonte, capital of Minas Gerais" in Brazil, Minneapolis and St. Paul of Minnesota, and so many others. As a typical example for the study, see Guangzhou[14]-Dongguan-Shenzhen from China (Fig.4), or Tokyo-Yokohama[15] from Japan.

Fig. 3. *Shanghai as intermediary mega city*

Fig. 4. *Guangzhou-Dongguan-Shenzhen from China as joined cities in one*

[12] Mumbai. Wikipedia.
[13] Shanghai. Wikipedia.
[14] Guangzhou, Dongguan, Shenzhen (Wikipedia).
[15] Both of the cities from Wikipedia.

5. Megacities have vertical urbanization, including individual cities. This type of settlement is renowned as a "conurbation". They are, as usual, agglomerations consisting of the combination of many metropolitan cities, each of them having a high-rise concept. New York is a typical example of a conurbation, including 30 urban centers (Fig.5), where the population of each is more than 25 million, such as New Jersey and Pennsylvania. Other renowned examples are Puerto Rico, including the Caribbean area, and the coastal part of San Francisco, which includes metropolitan cities of San Francisco, San Jose, and Oakland, etc. As a typical example for the study, see the conurbation of New York[16]. See the added high-rise buildings in the existing environment.
6. Cosmopolitan settlements are a special type of conurbation that consists of several large corporations. A striking example of the type is "Hong Kong International Finance Centre". Whereas Hong Kong is usually named a cosmopolitan or global city. It is an uncial example to be presented individually as a typical example[17] [9] (Fig.6).

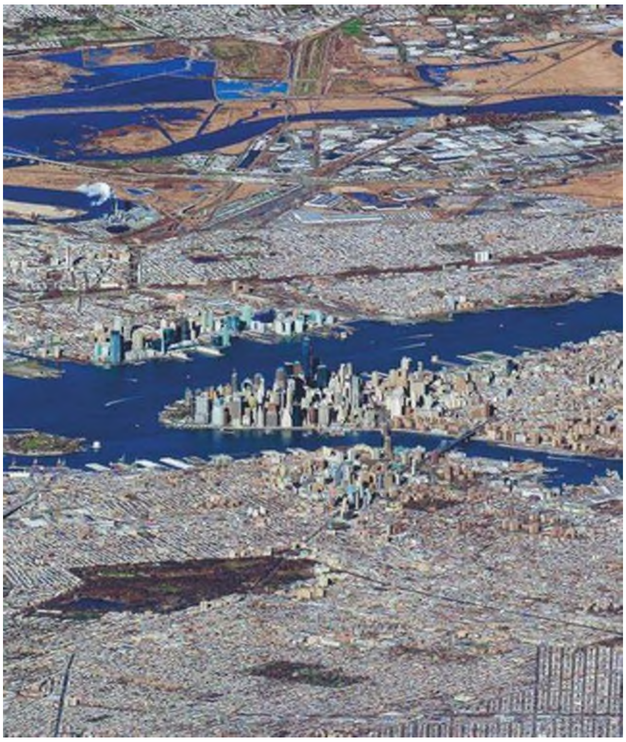


Fig. 5. *New York as vertical conurbation city*

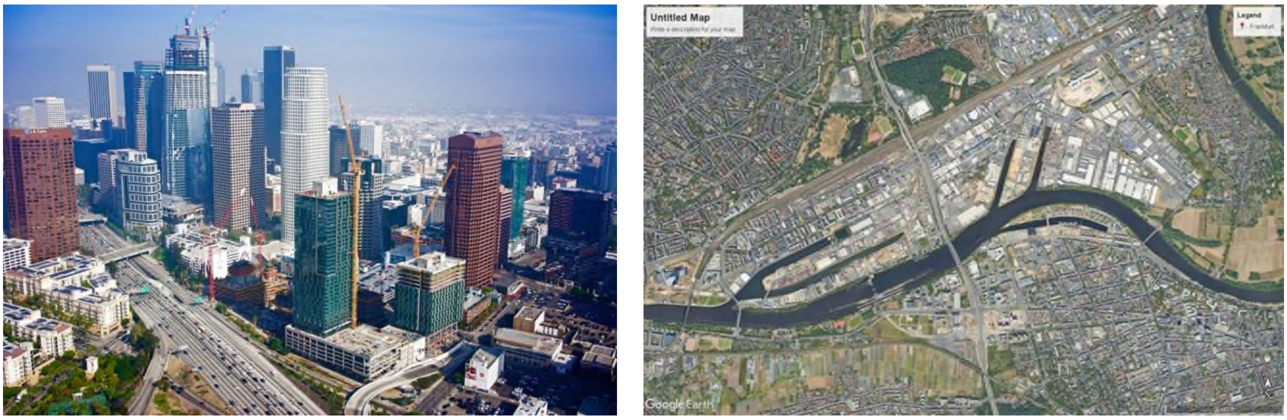
Fig. 6. *Hong-Kong or cosmopolitan city having global center*

7. Individual cultural republic cities. These are cities that have special traditions within the world culture. Among them, special indication has world historical capitals: Athens, Rome, Venice, Milan, Florence, Antwerp, Brussels, Vienna, etc. For a typical example, see the Austrian capital Vienna[18,19] (Fig.7).

Fig. 7. *Vienna as Cultural republic city*

[16] Conurbation. Wikipedia.
[17] Hong Kong. Wikipedia.
[18] UNESCO World Heritage Centre; Historic Centre of Vienna inscribed on List of World Heritage in Danger.
[19] Vienna.Wikipedia.

8. The metropolis cities of the USA and Europe are the continuation of the former cultural republics, which have a civilizational indication in the world. From the USA, such renowned cities are New York, Los Angeles, Chicago, Dallas, Houston, Washington, etc. As a typical example for the study, see Los Angeles[20] [10] (Fig.8). What concerns the European metropolises, striking examples are the political and business capitals, such as Berlin, London, Paris, Frankfurt, Rome, Madrid, Barcelona, Amsterdam, etc. As a typical example for the study, see Frankfurt[21] [11].



a. **b.**

Fig. 8. *The American and European instances of metropolis cities.*
a. *Los Angeles metropolis-city in the USA*, **b.** *Frankfurt metropolis-city in Europe*

9. The realm of small cities. These are mainly divided into two groups. The first group includes cities as new metropolises from Asia. Besides great centers of East Asia, the cities of the UAE caught important attention, which in a short time converted into leading centers of contemporary architecture. Such as Dubai, Abu Dhabi, Kuwait, Doha, Oman, etc. Being comparatively not big cities, they have great financial capabilities, which gave new progress to the architecture of the 21st century. As a typical example for the study hereby included the city of Dubai[22] [12] (Fig.9).

The other types of cities included are the settlements having limited financial capabilities. Special instances of them are the cities of the former Soviet Union or the UIC countries. They are being scientifically efficient. Because of limited capital, their architectural implementation preferably underwent a multi-cycle regeneration trend. Such cities are Yerevan, Tbilisi, Kishinev, and Vilnius, etc. The study of them kept in touch with Yerevan capital of Armenia[23] (Fig.10).

Fig. 9. *The realm of minor but rich cities as Dubai*

Fig. 10. *Limited income minor cities as Yerevan*

[20] Los Angeles. Wikipedia.
[21] Frankfurt am Mine. Wikipedia.
[22] Dubai-Wikipedia.
[23] Yerevan-Wikipedia.

Conclusion

1. For almost half a century, beginning in the 1980s of modern architecture, the development of settlements passed certain accomplishment periods, including the following phases: a/ the spread of megacities, b/ regulation attempts of existing megacities and their trends, c/ development of the cities regarding the climate changes and other environmental regulations, and d/ formation of original types of non-megacities, which include planning methodologies of regeneration.
2. In the context of contemporary architecture, besides the above-classified megacities, notable are agglomerations consisting of system settlements centered by 1, 2, or many cities (e.g., Shanghai, Guangzhou, Dongguan – Shenzhen, Tokyo–Yokohama, etc.).
3. The planning regulations of the megacities in the XXI century were performed on behalf of the creation of megastructures of various sizes, as well as satellite-like new city parts or individual skyscrapers or groups of skyscrapers of conurbation style.
4. Because of environmental developments, small cities have been created that have great and limited financial capabilities. The first took the role of an oriental metropolis in contemporary architecture, such as the cities of the UAE. The others adopted the development way of regeneration, such as the small cities of the former Soviet Union, on the example capital of Armenia: Yerevan.

Conflict of Interest

The author declares no conflicts of interest.

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