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Dear colleagues and friends,

In 2022, the Saint Petersburg State University of Architecture and Civil Engineering (SPbGASU) — the oldest Russian university training specialists for the construction industry — is celebrating its 190th anniversary.

The university preserves the traditions of the well-known school of Russian civil engineers. More than 80,000 specialists in architecture and urban planning, reconstruction and restoration of architectural heritage, civil engineering, housing and utility infrastructure, and automobile and road-building sphere have graduated from SPbGASU throughout its history. The efforts of its graduates contribute significantly to the development and prosperity of Russia and facilitate the achievement of the national goal to create a comfortable and safe living environment.

SPbGASU is the largest architecture and civil engineering university in Russia. Currently, there are more than 11,000 Russian and 800 international students, 200 PhD and DSc students enrolled at SPbGASU. The university has six faculties with more than 500 professors, associate professors, and lecturers. Its departments and research centers perform studies in highly demanded areas for the development of economy and the construction sector.

The university ranks high in Russian and international subject and university rankings, which shows a public acknowledgment of its contribution to the social and economic development of Russia in general and the North-Western Federal District in particular, and speaks for the high performance of its staff.

SPbGASU continues developing, sets new goals, and adequately meets new challenges. It actively cooperates with authorities, employers, and various research and educational organizations.

In the days of new challenges, the university, as always, will make every effort for the development and prosperity of Russia, for Russians to live in comfortable conditions and well-maintained cities.

Congratulations on the glorious anniversary to all the veterans, graduates, lecturers, employees, and students of the university! I am confident that the university will develop further.

Rector of the Saint Petersburg State University of Architecture and Civil Engineering (SPbGASU)
DSc in Economics, Professor
Evgeny I. Rybnov

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SEMIOTICS AS AN APPROACH TO THE ANALYSIS OF SYMBOLISM IN ISLAMIC ARCHITECTURAL ARTS

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Abstract

Introduction: There is a large gap in the studies and literature dealing with the concept of denotations and connotations in Islamic architecture, whether in terms of a purely geometric or artistic and aesthetic aspect. However, studies addressing these works from the ideological point of view and inferring values are scarce. This gap is a direct result of the problematic method of reading the Islamic artistic plane and its visual reading tools. **Purpose of the study:** We aimed is to reduce the gap between many European and Muslim researchers in understanding the symbolic connotations of various elements and the aesthetics of abstract vision in the apparent form focusing on the "spiritual component", and relate to the conscience of the Muslim and his mind without the need for stereotypical visual representation. **Methodology:** By adopting semiotics as a tool for modern criticism in reading and implicit analysis of the Islamic architectural text, we linked it with the fixed ideological component present in every place and at any time — the spiritual content. **Approach:** In the course of the study, we interpreted analytical and implicit reading of some Islamic architectural elements and their symbolic connotations. **Results:** We discuss three design trends that recently appeared in the Islamic world: the direct copying of traditional elements, the contemporary trend, and distinguishing and innovating new design elements based on traditional symbolic connotations. **Novelty:** Contemporary buildings have lost their identity and value and have turned into soulless creatures. Therefore, it is necessary to highlight the need for returning to cultural and architectural artistic heritage and benefiting from it in finding new and contemporary design solutions using modern digital technical means.

Keywords

Semiotics, Islamic architectural arts, denotations, connotations, implicit critique, symbolization, abstraction, visual text.

Introduction

Most studies, literature, and theoretical references have applied the concept of semiotics within the scope of Islamic architectural arts from a purely architectural standpoint or in terms of the geometric analysis of architectural forms. The studies dealing with the architectural concept from the perspective of the semantics, symbolic aspect, and spiritual content are scarce. Manieri-Elia (1996) studied architectural arts from the perspective of the geometric and formal aspects only and argued that the size, space, and characteristics of a building must relate to its function (Grabar, 2003; Manieri-Elia (1996). Other researchers dealt with pre-prepared models for semiotic analysis, e.g., the Gervereau model for the semiotic analysis of architectural and artistic works in terms of two aspects: formal and technical (Gervereau, 2020). However, it does not represent architecture as much as it represents a composition void of soul and life.

In his paper, Kononenko (2018) pointed out this gap between scholars studying architecture and stated that authors from Muslim countries put emphasis primarily on the "spiritual component", ignoring the architectural realities, while many European researchers routinely build on specific monuments, ignoring their religious component.

In the system of Islamic principles and standards, the art of personification does not have prime importance as is the case with the West (given skepticism about personification, and preoccupation with the universe in general). Trying to distance themselves from portraying people, artists turned their eyes to calligraphic, geometric, and ornate decoration, which are the areas where Islamic arts flourished. Perhaps one of the most prominent obstacles that prevented research methods from being able to develop a systematic theory of Islamic architecture is that some researchers mistakenly believe that its function is limited to serving religion only as explained by Grabar (2003), Titus (2009), and others who employed the metaphysical, mystical, and spiritual aspects in explaining Islamic arts, based on Western critical methods. Their works were unable to crystallize any visual readings that would reveal the functions and connotations of Islamic arts, proceed from the text itself without any spiritual and mythological projections coming from outside, and operate beyond this text of aesthetic and social concerns. Although Islamic arts — in contrast to Western arts — include what is sacred and secular in the life of a Muslim and everything related to their livelihood, behavior, and moral and social values, they do not aim to tell religious stories about monasticism and glorification of holy wars, like Western arts have been doing with regard to the Middle Ages.

One of the most popular and well-accepted critical approaches, which proved its efficiency in studying and analyzing the artwork of the last decades of the last century, is the semiotics approach. It is considered one of the most relevant Western critical approaches to the Arab-Islamic heritage. This approach allows us to study linguistic and rhetorical connotations, poetic symbols, and other matters related to literary work. Semiotics was developed by the linguist Ferdinand de Saussure. As a contemporary Western term, it derives from two Greek words: "seme", which means sign, and "logos", which means science. It is mainly concerned with the generation of meanings in addition to how meanings communicate (Chandler, 2007; Eco, 1984; Leach, 1997; Lune and Berg, 2017).

Islamic architecture is a mixture of modern and religious architectural designs. It has been developing since the establishment of the Islamic faith, which directly affects construction in Islamic culture (Hamid, 2010). Contemporary scientific research lacks adequate studies on Islamic architecture, addressing the significance of forms and inner semiotics of their elements, with account for the analysis of philosophy. Semiotics is discussed in works looking into the distribution of meaning in architects' communication (Medway, 1996), addressing built environments as the physical representation of semiotic styles (Cameron and Markus, 2002), and considering construction as a complex of signs (Medway and Clark, 2003). The formal and symbolic aesthetic values of architecture (as, above all, a language of communication through visual elements including signs and intellectual, aesthetic, and social connotations, which guarantees the continuity of the movement of meaning in architecture) represent the identity of society, and there is no need in a pictorial narrative to reveal the meanings (Porphyrios, 1981), which is what this study seeks to explain semiotically by analyzing visual components and their denotation and connotation implications. According to Eco, if semiotics is really to be a science studying all cultural phenomena as if they were systems of signs, then one of the fields in which it will undoubtedly find itself most challenged is that of architecture (Leach, 1997). Therefore, the purpose of this study was to adopt semiotics as a tool for modern criticism in reading and implicit analysis of the Islamic architectural text, which goes beyond the superficial concept of Islamic artistic creativity and its abstract aesthetics to its deep internal perception that the study seeks to achieve, and analyze models of visual text and their denotation and connotation implications.

1. Architecture semiotics: a critical review

Semiotics is the study of signs and symbols, which includes semantics and can be used as a method to analyze the meanings of the artwork (adopted from linguistics) and interpret visual language (directly or indirectly). Semiotics emerged as a result of various studies in linguistics. Being a system of signs that represent culture, it is closer to metaphysics since it shows what is behind the artwork, with its patterns of semantic interpretations. Architecture is an unspoken language that seeks to convey a certain meaning. It can establish new sources of knowledge by shifting the focus from styles and techniques to content and meaning (Ramzy, 2013).

A building may evoke particular feelings and ideas in recipients, such as a sense of transcendence or loftiness. Therefore, semiotics is compatible with the study of architecture. Wang and Heath (2011) noted that the use of semiotics can produce a universal language of the built environment. Just like a spoken

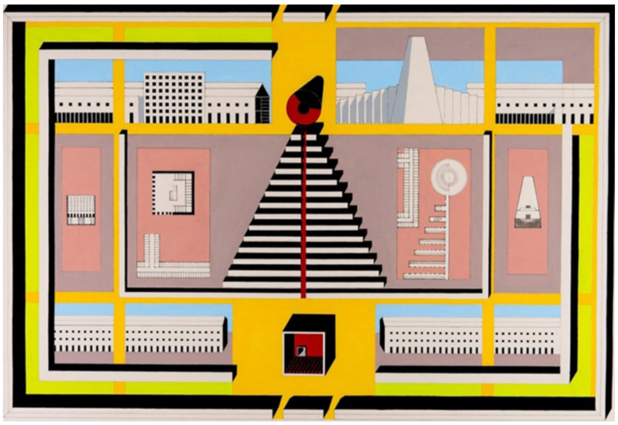


Fig. 1. Aldo Rossi (1931–1997), composition with Modena Cemetery, 1979 (https://drawingmatter.org/peter-eisenman-on-aldo-rossi/)

language, the visual language of architecture has its own vocabulary and carries meanings intended for the recipient. Thus, the semiotics approach can be used to thoroughly study architecture. Meaning in architecture can be understood in different ways depending on a recipient due to their differences in cultures and experiences.

In his design for a cemetery in Modena, Italy, Rossi (1984) suggested abstract symbols with distant meanings. These symbols appeal to the memory of the observer, trying to evoke some feelings. In Rossi's theory, memory is an important component in the formation as well as reading of symbols and their architectural expressions.

The bounding wall with openings around the site symbolizes containment (Fig. 1). The "abandoned" house without a roof or windows indicates the other life. The huge cone reminds an idle factory. The general layout of the cemetery was based on the symbolic expression of a city plan. In other words, the cemetery is a city but of a different category and a different time.

Accordingly, the semiotics approach considers that architecture has a communicative function, and, thus, the architectural "sign" is studied in connection with that function, and architecture is addressed as an art or a means of preservation and valuable communication. According to Norberg-Schulz, the terms "sign" and "symbol" are synonymous (Collins, 1967).

The architectural symbol is devoid of any independence from the process of social symbolization; the sign is characterized by being shared and usable, and it is created through social interaction. For this reason, social upbringing is based on traditions that include the entire complex of signs, systems, and symbols. Hence, a symbol has content. A denoted sign gives a direct, uncomplicated message to be understood. First-level significations (denotations) act as a basis for second-level significations (connotations). Implicit meanings, or "second-order meanings", are cultural. Thus, first-level semantics serves as a basis for second-level semantics (Collinge, 2019).

No element or form is abstract from the meaning; a form must be associated with a meaning behind it. Besides, there is no intellectual or moral content without being linked in some way. The human brain seeks to assimilate these symbols by reading the shapes (Cassirer, 1953).

Architecture is a form of non-verbal communication, so its function is associated with the message of religious beliefs and holiness, and those encrypted messages are understood as a real language. It does not contain any letters or paragraphs, but their synonyms are tangible in spaces and interfaces that differ in terms of shapes, dimensions, and colors. Therefore, through its semantic dimension and its objects, architecture represents a means of communication with its writing system, and a building can be considered a language of its speech, a language of architecture. According to Eco (1986), architecture has two functions: denotative and connotative. The denotative aspect is related to functional uses, while the connotative aspect is related to broader social (or systemic) uses of the object. He also stated that although we tend to associate semantic functions with things, semantics (understood as their social and cultural meanings) are just as important (Broadbent et al., 1980; Eco, 1986).

Semiotic understanding contributes to the realization of the meanings and connotations contained in the artistic aesthetics of Islamic architecture from a different angle to the study of architectural forms and their changes through the history of Islamic arts. For instance, the mosque as a religious building has invisible symbolic connotations, different from its physical characteristics based on the style of the building and architectural elements. Our vision of the mosque through the lens of aesthetic values makes it possible to discover the semiotics of cultural and ideological symbols, i.e., the integration of the structural body with the architectural elements and geometric motifs. It generates an integrated vision of the mosque, highlights the aesthetic aspect, clarifies the philosophy of its structure, and ensures the realization of its meanings and connotations.

Architecture is the noblest but also one of the most mysterious and contradictory arts, and that is evident in the architects' attempts to harmonize buildings (which constitute the basic physical framework for our daily activities and interests) considering the aesthetic and expressive value. Hence, two basic and complementary tasks of architecture can be distinguished: the functional value of a building and the formal expression that refers to the implicit meaning. These two tasks, i.e., the utilitarian function and expressive function, are contradictory. The utilitarian function of a particular building is that it is an institution based on technical knowledge, and its evaluation depends on the criteria of functional efficiency. The formal expression is, on the contrary, a fruit of artistic creativity, and its evaluation is based on technical criteria as well as connotations and cultural contexts of the building. Thus, symbolism in architecture makes a turn different from other arts, and the shape of a building is not formed only according to a need for some benefit or functional, material, and economic influences, but it also works together with it affecting the social heritage of architecture, and so symbolism in architecture is not a goal but a result. According to Ball, "designs are embodied in ways that go beyond their function or even symbolism, and comically or critically reflect cultural meaning" (Saidi, 2019).

Different buildings have different forms and perform different functions that serve to meet human needs. The relationship between the form and the function is not a direct but rather a dialectical relationship that depends on the linking element between these two concepts, which is the human being.

The form has two states. One of them is form as a material. It represents physical properties, which are the sum of the formations, such as shape, color, structure, and texture, that can be directly perceived. It represents the state of translating the materials used and organizing them in a stable state, in an entity that has a space of existence and is aware of the human sense.

Another one, form as a signifier, represents a deeper perceptual level, visual expression characteristics. If we consider architecture a language, its elements are a vocabulary and can be linked to form a sentence. These characteristics are represented by mass, space, and other aspects with a deeper perceptual level, such as proportions and measurements. In their comprehensive sense, characteristics represent a system based on the relationships between the parts of the same substance, while the form is generally arranged in terms of aesthetic and utilitarian aspects.

Here it becomes clear that the symbolic form is everything that transforms the material into a signifier, and it works together with the material to form a support for the sign. Architectural forms act as symbols and signs of cultural or social functions, connotations, or any other meanings. Some researchers noted the semiotic character of a city in its entire being and defined the city as a typical sign that consists of a signifier and signified (Jansson, 2004; Leach, 1997; Martin-Jordache, 2002).

These symbols help a person to treat the site in the appropriate cultural and social manner, according to what is dictated by their culture and education. Symbols inside a building also help a person understand whether it is a religious building, a hospital, or a museum.

2. Modern methodologies for the implicit critique of Islamic architectural text

2.1. Symbolism approach to the connotations of Islamic architecture

The important question that we ask in the beginning in this context is: Are there symbols specific to Islamic architecture that have conclusive and exclusive indications? How did they acquire their symbolic character? Is it a form or function? What is the theoretical philosophical framework that places these shapes in connotations specific to this culture, or negates their affiliation with the global human culture, if this assumption is possible and correct?

The concept of symbolism in the context of Islamic architecture will be studied from a philosophical point of view regarding its repercussions related to culture and civilization within the framework of the philosophy of urbanism. In general, in the field of contemporary Islamic architecture, this raises an important question regarding the legitimacy and control over historical metaphors, "abstracting", re-reading, and interpreting them.

Besides, it is an important topic that requires a conscious philosophical interpretation of the idea of symbols in Islamic architecture, the associated connotations and signals that emanate from the forms used, and the relationship between the art form and the function, especially in cases of function transformation over time, required by the current stage, cultural and civilizational conditions, and humanistic needs. Many scholars and thinkers addressing the symbolism of Islamic architecture, including, for example, Oleg Grabar, claim that Islamic architecture is full of meanings, symbols, and connotations hidden in the frequently used forms. In his article "Symbols and Signs in Islamic Architecture", Grabar (1980) mentioned that no one had tried to identify an Islamic visual sign-symbol system in any serious way. Despite this, we found some studies presented by Ardalan and Bakhtiar (1973) in their book "The Sense of Unity: the Sufi Tradition in Persian Architecture" and others, which touched on the geometric system in Islamic architecture. Without going into deep analysis of the implications of the form and symbol, they linked the geometric shapes used in mosques and the content carried by the use of those shapes and provided corresponding examples. For instance, cubic shapes are repeatedly used in mosques as a symbol of balance and perfection in terms of engineering, while in terms of content and symbolism they refer to the shape of the honorable Kaaba; octagonal shapes are used by Muslims to connect a spherical or hemispherical shape — a dome — with a cube to reflect the throne of God as the latter is known to be based on eight ribs, where the dome symbolizes the vault of heaven. Some architects applied these concepts to the design of mosques like, for example, the Italian architect Paolo Portoghesi did with the Islamic Cultural Center and its mosque in Rome.

In his paper, Grabar (1980) pointed out the following basic idea: there are semantic connotations related to forms, especially in Islamic architecture. He also clarified the basic difference between a symbol and a sign. For Grabar, a sign indicates something or refers to a certain impression while a symbol defines something and connotes it but does not circumscribe it as does a sign or an image. Many studies deal with the formal and artistic aspects of the mosque elements, individually or as a whole, such as a minaret, the symbol of Islam. For instance, Jonathan Bloom reviewed the historical origins of minarets and their connection with the structure of mosques and considered them a symbol of Islam and Muslims in terms of content (Williams, 1992).

This trend led many architects to study the formal and artistic aspects of Islamic architecture, and thus they linked the formal and artistic dimensions of the architectural mosque elements with the spiritual content. For example, in its form and meaning, the minaret is linked to the concept of guidance and reasoning. It is also a symbol of access to the mosque, which, in spiritual terms, guides people to the right track and keeps them away from misguidance through prayer. Architects also see that many of the forms of architectural elements used in mosque buildings deviate from their formal framework to their symbolic framework. Let us consider the following example: the central dome in a mosque refers to the rotation of a square shape, which symbolizes the four directions and physical components of the universe (water, earth, fire, and air).

To clarify Grabar's theoretical approach, we will adopt three geometric shapes for buildings that are considered to be related to Islamic architecture for an unclear reason (it is not clear if the form or the function is directly related to it). For the sake of argument, let us suppose that we do not know anything about these three shapes and what they symbolize. The first one is a huge cubic building located in Mecca, the second one is a building in Jerusalem topped with a hemispherical gilded dome, and the third one is a domed edifice surrounded by four vertical towers that rises above a terrace in India. The question is: What are the indications that make us realize that these monumental buildings belong to Islamic architecture?

In other words: What makes us understand that the first one is the Kaaba (Fig. 2A), one of the most important symbols in Islamic architecture, that the second one is the Dome of the Rock, which some critics consider the jewel of Islamic architecture, and that the third one is the Taj Mahal in India? What are the connotations or meanings that these buildings impart — if we exclude Quranic verses or writings — that classify these forms as pertaining to Islamic architecture? Do these forms have an Islamic connotation? If so, what is the connection between the cube and Islam or the hemispherical shape of the dome and Islamic architecture? Is the connection the "function"? If so, what is the function of the hollow cube, and what makes it Islamic? Does it have other cultural or theological connotations? It raises questions about its significance from a functional point of view, which makes its connection with Islam urgent and necessary.

The Dome of the Rock is a monumental building built by Abd al-Malik bin Marwan around a rock (Fig. 2B) in the place where the Prophet Muhammad (peace and blessings of God be upon him) ascended to the heavens on the night of Isra and Mi'raj. Thus, it does not have an Islamic function like, for example, a mosque intended for prayer, but rather it is a building linked to a historical event. The most controversial is the third building (Fig. 2C). What is the relationship between this building erected as a tomb to the wife of the Maharaja and Islamic architecture or Islam? The Taj Mahal was built by Emperor Shah Jahan in memory of his third wife who passed away while giving birth to their fourteenth child (Allen, 1988). In addition, some of these edifices almost contradict the teachings of Islam in their function. So, what makes these forms Islamic or associates them with Islamic culture and architecture? To answer this question, we will consider another important example, which is the minaret, despite the controversial issues it raises on the subject of symbolism. This example was given by Grabar (1980) in his paper "Symbols and Signs in Islamic Architecture". He believed that it is a sign suggesting a function, but it becomes a symbol when it reminds one of Islam, and it can become a symbol that has indications of a cultural product or a certain cultural identity as, for example, the minaret of the Samarra Mosque does when it reminds one of the city of Samarra. In more general philosophical terms, "while the sign attribute is fixed, the symbol attribute is a variable". When reviewing Grabar's work, we found that it is not sufficient to understand the dialectical relationship between the symbol and the function, especially when the function is changing or subject to a continuous transformation as is the case with most of the vocabulary, shapes, and architectural symbols in Islamic architecture. The most prominent of the examples is the minaret with its "contemporary" function, which has nothing to do with its "traditional" function established for it in the early days of Islam when it was the place for the

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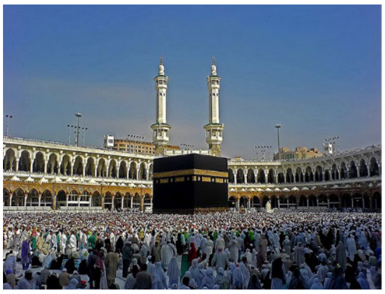

B

C

Fig. 2. A. Honorable Kaaba, Mecca (https://www.masrawe-b.com/2018/07/Photos-Kaaba.html) B. Dome of the Rock, Old City of Jerusalem. (https://www.pikist.com/free-photo-vzacq) C. Taj Mahal, Agra, India (https://www.pikist.com/free-photo-sofpi)

muezzin to announce the call to prayer.

There is another philosophical dilemma regarding the shape in the case of the minaret — especially in contrast to minarets in their traditional form — in such cities as Cairo, which is usually topped with a crescent. What gives the minaret of the Giralda in Seville, Spain, as a square vertical tower ascending to the sky the Islamic character (Fig. 3B)? Or the Savior (Spasskaya) Tower in Moscow (Fig. 3C) or even the Tower of Pisa (Fig. 3A) (as an abstraction of the idea of a minaret)? Here, it can be assumed that the minaret in its contemporary form, after changing its original function, could be represented by any vertical tower topped with a loudspeaker, and even the Savior Tower could be that building. Would then the Savior Tower acquire the Islamic character if a call to prayer was announced from it or if its shape was borrowed in the structure of a mosque? Along with the others, these examples represent an architectural and philosophical dilemma regarding the relationship between the form and the function, symbolic connotations, and the legitimacy of recognizing a symbol with a particular cultural significance, especially in the case of function transformation or even absence.

Perhaps, in our case, the minaret falls within the cultural and civilizational dimensions, which are greater than the issue of the relationship between the form and the function, and within the scope of issues related to culture, civilization, and identity. Therefore, the minaret — whatever its shape — has become a symbol of a certain identity of Islamic character, different from other cultures, as indicated by the building on which it is erected and not by its form or function. In other words, the symbolism of the form in Islamic architecture — e.g., that of the minaret — determines the tripartite relationship between the form, the function, and the third and most important element, which is the content (the cultural, social, and historical content imposed by the nature of the relationship between these three determinants).

These three determinants do not dictate a “fixed” pattern. It is rather that their output is subject to the nature of the interaction between the form, the function, and the identity content. It would be wrong to attribute the form to culture or identity. Its significance is rather determined by its relationship with the tripartite system in the cultural framework, which gives it its symbolism within the particular culture. Hence, the minaret is more than just a functional relationship implemented through the call to prayer via loudspeakers, and it is not related to the shape or height (whether it is an abstraction or an actual architectural transfer of traditional models into Islamic architecture). We are rather talking about an issue rooted in the cultural dimension of identity, which defines the characteristics of the symbol and what the minaret symbolizes.

The repetition of many elements in architecture throughout history has led to the consolidation of these forms in the Muslim mind, i.e., a perceptual system is formed, which operates as an electronic brain that utilizes many sources of information, and then makes a choice, combines, divides, and compares them, and also gets them duplicated as needed. In the eyes of many, the mosque has become a building that includes such specific elements as, for example, a minaret, a dome, and arches. These forms shifted from the formal to the symbolic concept in the mentality of Muslims and became for them a formal and moral language of

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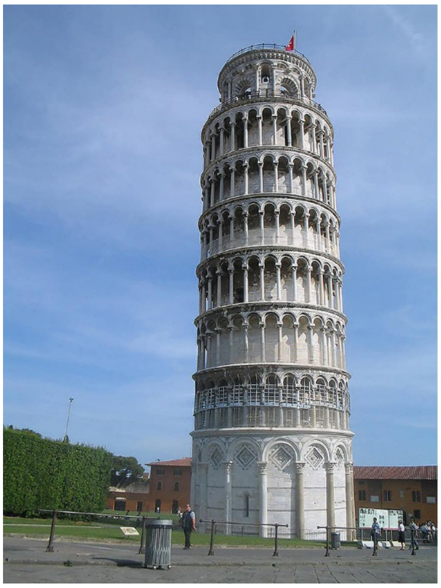

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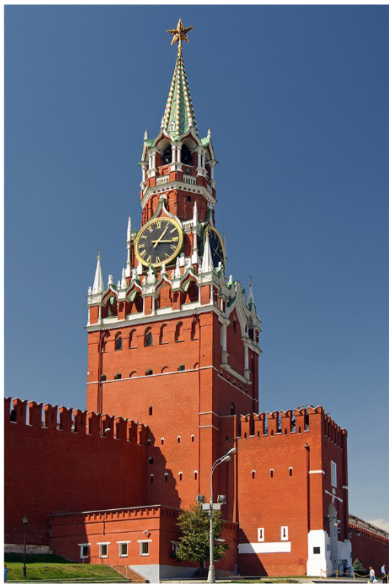

Fig. 3. A. Tower of Pisa. (https://www.pikist.com/free-photo-iazog)

B. Giralda Tower, Seville. (https://www.pikist.com/free-photo-iialt)

C. Savior (Spasskaya) Tower, Moscow (https://pixabay.com/ photos/ moscow-the-red-square-4572132/)

communication. In terms of form, it is an indication of a building for prayer, and in terms of meaning, it is related to Islam as an identity of the Islamic community at the general level.

The association of some architectural forms with the structure of the mosque, and their repetition transformed the concept in the Muslim mind into intellectual meanings and connotations related to the building of the mosque. Thus, sometimes it is difficult to introduce changes in these forms, especially as they relate to a religious establishment. The majority believes that they are "fixed" elements and the mosque takes its architectural identity from them.

2.2. Abstraction approach to the connotations of Islamic architecture

Abstraction and symbolism are among the most important features of Islamic arts. The Muslim artists did not care about the details of the things they depicted or drew. They were more connected to their essence, to what they referred to or symbolized, trying not to use perspective or embodied images and moving toward complete flatness in order to move away from the idea of representing what God created. According to Islam, all living creatures with the ability to move fall within God's domain and should not be replicated in any way including arts (Akkach, 2012).

Abstraction in Islamic arts is a fruit of a spiritual vision of the world or reality beyond the universe, and this can only be achieved by taking Islamic arts out of the world of perspective to the world of symbols and intuition, moving away from simulation and embodiment. If we look at abstraction in Islamic architecture, we will find that it represents its general feature, stemming from the Islamic concept of existence, which appeals to the absolute value who is God Almighty, who is the creator of this universe and is free from imagination or representation. Thus, the reference and value framework in the Islamic perception transcends the nature perceived by the senses, and this is because it is based on the concept of revelation from God to the Messenger, may God bless him. Therefore, the constants are paradoxical to the world of matter because they are unseen. The concept of abstraction in the Islamic artistic plane is a result of aesthetic and scientific spiritual thought, transcending the issue of depth and emptiness, which is one of the meanings of abstraction, to deal with the artistic visual plane as an artistic plane replete with connotations, signals as well as geometric, ornamental, calligraphy, and chromaticity signs behind every visual element, including story and significance, whether spiritual, aesthetic, cultural, or social. The Islamic architects pegged their creativity on evoking their inner beliefs through the use of abstract forms that produced magnificent works of art (Ghasemzadeh et al., 2013). The Muslim artists excelled by condensing and reducing it in Islamic arts into pure abstract visual signs and signals according to the Islamic and not Western perspective of abstraction. Based on the above, we can establish the reason for the generality of the abstraction approach in Islamic arts where the use of perceptible visual forms in a work of art has an invisible message, and that is due to moving away from the simulated approach. The simulated approach, born in Greek civilization and revived during the Renaissance, is intended for representing and imitating what is natural and perceptive, from man and nature to all other creatures, thus focusing on the apparent tangible part only, without hinting at the unseen motive power.

Perhaps Hegel's statement serves as an explanation for the motive of this mimicry approach among the followers, which did not find acceptance in Islamic civilization. As for the embodied or unembodied image in previous civilizations, the goal was to, first of all, defend against death since death is the demise of the body and the annihilation of the human trace from existence. Therefore, the ancient men resorted to the image in its various forms (statues, inscriptions on tombs, and other common manifestations) so that they could cling to life. The goals of abstraction have varied and include visual, spiritual, and aesthetic. Despite the agreement between most of the models that adopted abstraction, this is a way to ostracize classic fine visual simulation entirely or in part. Various artistic styles and means have been dealing with abstraction, e.g., by recording it in the semi-abstract symbolic form as in the arts of the Byzantine era and the Middle Ages. Although they adhered to the pictorial representation of religious stories, preserving flat depth, dimensions, and anatomical proportions, the artists neglected shadow and light in their depictions in harmony with the teachings of Christian theology (Fig. 4A) or reduced the details of visual elements, deconstructing such elements and preserving the pure essence of their components as in the case of Islamic abstract art. Those abstract components are reshaped again in an abstract plane where the dimensions are flattened, and the spatial image and its narrative meaning are destroyed. Thus, the components of the Islamic visual text in the Islamic abstraction approach, whether they are geometric, calligraphy, or botanical, are transformed into signs and obtain reduced functions (Figs. 4A, 4C). Their connotations vary between what is symbolic and pure contemplative aesthetics since these connotations and signs reduced with all their meanings are intended to revive hearts, brighten eyes, and nurture conscience. The Muslim artists expressed these meanings without the need to use the spatial image and replaced it by creating new visual solutions making it possible to achieve the goal. Besides, the interweaving of geometric and botanical elements as well as inscriptions is one of the prominent ways of Islamic abstract surface formation, in addition to the

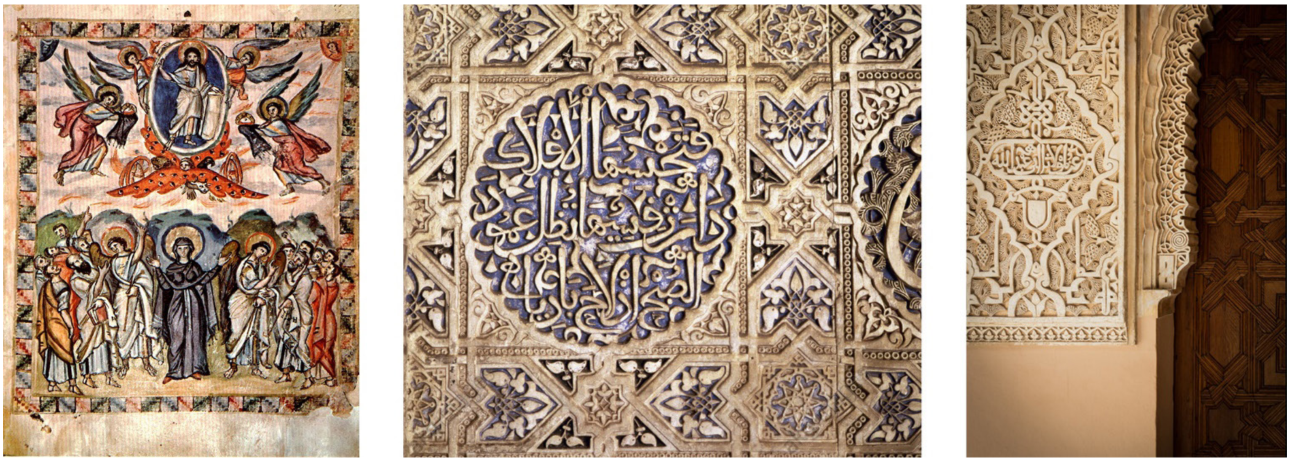

Fig. 4. A. Ascension, from the Rabbula Gospels. The most abstract and symbolic nature of Byzantine art (https://thevcs.org/ascension)
B. Islamic Art, 14th century, Alhambra. (https://www.akg-images.com/archive/-2UMDHUYGOPH6.html)
C. Arabesque at the Alhambra, Granada. (https://www.flickr.com/photos/alex-david/5316969135)

diversity and repetition in the distribution of visual elements. The Muslim artists were keen to keep these components coherent and interconnected in the eyes of the viewer (Fig. 4B, 4C). There is no doubt that these signs of visual entanglement hide behind them indications related to the idea of the nation's cohesion and solidarity, including the good of society

It is necessary to mention here an important factor that reinforced the position of the Muslim artist moving away from embodiment, and it is related to the goals of art, stemming from a deep understanding of Islam. Unlike other religious and non-religious arts, Islamic arts did not seek to express religious and secular stories such as those pertaining to the lives of prophets and saints, the glorification of conquests, and the heroism of politicians, which, for example, the Egyptians had to express in a narrative way using embodied images. Hence, it is important to understand the philosophy of abstraction in Islamic arts, which sought to delve deeper into the contents, and distance away from the superficial literal understanding of certain orientalists and others, especially since we are facing an art that considers the understanding of religion by man and the world. This understanding is translated into an aesthetic philosophy that has spiritual, intellectual, and aesthetic components reduced to pure abstract visual signs, functions, and connotations. Hence, the decorative and ornamental aspects of Islamic art emerge, which, as Burckhardt (2009) pointed out, do not contradict the privacy of thought.

The use of abstraction in Islamic arts was based on how the religion viewed nature and the goals of its imitation, which was far from the philosophy and goals of Western abstraction, completely different from its Islamic counterpart in terms of the form and substance; the difference between them is that the source of abstraction in Western arts is sensual, realistic, and visible, while the source of abstraction in Islamic arts is unreal and invisible.

In other words, Islamic abstraction does not seek to express the physical concept of the visible origin as it is in the natural reality that Western arts preserve, no matter how severe abstraction is. It rather seeks to express the pure reduced invisible components within nature. This means that Islamic abstraction expresses its connotations from within the visual text itself. The use of abstraction in Islamic arts resulted from the spiritual, scientific, philosophical, and intellectual richness of the Muslim artists, inspired their faith and deep understanding of religion, creed, monotheism, worship, values, and behavior. This understanding was translated and represented artistically — by the inspiration of faith — with a purely aesthetic vision, and artistic abstraction at a distance from any reaction, or exclusion of other aesthetics; the goal was to create new aesthetics and visual solutions going beyond the spatial image with its expressive and aesthetic concepts, especially since embodied images — from the Islamic point of view — do not serve the concepts of goodness, benefit, and beauty, and do not reveal the aesthetics of cosmic geometry and the inventiveness of creation. There was no need to use scenic representation in the classical and Renaissance manner to narrate the cosmic aesthetics, although Islamic arts (unlike other religious arts) never had a religious function, but attempted — through the social and intellectual role — to transcend the self and reality and reveal the aesthetics of cosmic geometry and the inventiveness of creation without resorting to this type of representation, which was replaced by Islamic abstraction with reduced visual signs and connotations inspired by the components of nature and the universe, such as the stars, the shapes of plants, etc., and that serves as a basis for the Muslim artists in accurate analysis based on thorough calculations, in an effort to move toward the hidden meanings.

To express the spiritual content of faith in the form of visual values, the Muslim artists needed mathematics as a method to achieve the goal of art, and since the content and idea were targeted, the artwork was not just decorative. Muslims excelled the most in four areas of arts: interlaced decoration, architecture, painting, and calligraphy. Interlaced decoration (Fig. 5) — an amazing authentic Arab art — is called arabesque by Westerners.

As mentioned above, Islamic architecture relied on the principle of abstraction with all its numerous symbols since it addressed both the mind and the conscience. The Muslim architects found that the content of the means they used to achieve abstraction included connotations representing the divine order, and metaphysical values, and thus, geometric shapes with a symbolic content appeared, emanating from the culture of society or inspired by previous arts in line with the Islamic faith, or emerging through formal and aesthetic structures, and that content expressed the values of rhythm and abstraction.

The equivalence of geometric heights is a visual sign that is evident in most Islamic abstract formations (Fig. 5), whether they are geometric, botanical, or in the form of inscriptions. Behind this visual sign, social and spiritual connotations with aesthetic motives are hidden, which the Muslim artists tried to convey to the viewer without the use of embodied images, expressing the ideas of justice and equality in direct pictorial mimicry. For instance, they were used by religious iconographers in Byzantine and medieval art. The characters of the saints and apostles were embodied in figurative icons and carved in sculptures so that the characters would have equal size and height to express the concepts of justice and equality between human beings, which are an integral part of the concepts of truth, goodness, benefit, and beauty, shared by all monotheistic religions.

Fig. 5. Great Mosque of Cordoba. The equivalence of geometric heights (https://books.openedition.org/pup/3601?lang=it)

2.3. Visual approach to the connotations of Islamic architecture

Islamic arts are in contrast to the arts of the Christian Middle Ages, which tended to enclose the visual text inside churches and Christian architecture in general, by using closed frames and determinants. Through incarnate symbolic visual representation, they would attract the viewer's attention to a specific central icon inside the church or an architectural place using a specific visual direction.

This requires space enclosing to focus on Christ, peace be upon him, and the religious stories told, whether they are in the images with individual frames and icons isolated from outside influences, or in the secular and religious architectural space. Designs are usually performed in a geometric style that isolates the inner space from the outer space; and that keeps the viewer's gaze confined within it, in harmony with the spiritual and theological philosophy that the visual discourse of those periods sought to express. Perhaps this justifies the small size of interior windows in this architecture, not allowing natural light to enter the place and replacing it with artificial lights and candles creating shadows, which have become necessary to visually embody a statue of Christ according to the Christian aesthetic and spiritual perception.

Meanwhile, Islamic architecture is characterized by removing the frame and keeping the visual text open on various types of abstract surfaces (so that the viewer's gaze would not be confined to the interior only), by distributing the visual signs in the text in all directions. The viewer's gaze is also distributed in multiple directions going beyond the boundaries of the drawn surface. Perhaps employing this in the Islamic abstract surface indicates particular significance related to the liberation of Muslims, their conscience, mind, and feelings, from the limitations of the physical place toward an open mental vision, clearly reflecting their rejection of rigidity and closure in their spiritual, moral, and social behavior. Maybe one of the most prominent creative solutions devised by the Muslim architects was to transfer their vision from inside the building to the outside, in all directions, and not to enclose it in the architectural space, by expanding and inclining the windows to become open to the sky so that natural light could enter and glow on all surfaces. The associated message and architectural visual discourse indicate the importance of the believer's insight into the face and light of God in every place and in every direction.

From the Islamic point of view, God Almighty is not confined to a specific place or space. The One Creator is present in every place and time, and this can be seen in the abstract formations (decorative, geometric, epigraphic) on the surface of the interior walls of a building. Its visual elements attract the gaze of the viewer and cause it to wander around the surface and follow its multiple directions, especially to the outer space with harmonious visual rhythms. According to Kress and van Leeuwen (2020), visual semiotic concepts are used to examine what an image represents and the nature of this representation. It gives a deep meaning, represented in the expression of the secular meeting the spiritual and the earth meeting the sky, and thus, the aesthetic discourse mixes with the spirit and social aspects through this openness.

3. Symbolic connotations of shapes and elements in Islamic architecture

From the perspective of Islamic thought, symbolism is a method of moving from the realm of reality to the world of post-reality, i.e., from life to the afterlife, or transition from the realistic physical image to the spiritual image. Therefore, the light symbolizes God Almighty, the Creator of the universe as He described Himself. The symbolic thought was adopted in Islamic architecture through abstraction to allude to and distance from the statement, and the architects intended to emphasize some meanings such as the contact with the sky, the principle of monotheism, and the belief in the oneness of the Creator, by designing the inner courtyard open to the sky, and using minarets and a parapet, referring to an attempt to connect the earth with the sky.

Symbolism appeared in most spaces of buildings oriented in two directions, a horizontal plane linking it to the Kaaba in Mecca through the mihrab and the crescent, and a vertical plane with domes, minarets, and a parapet. Throughout history, Islamic arts used basic geometric shapes as symbols in religious buildings. Thus, pyramidal, cylindrical, cubic, spherical, and hemispherical shapes appeared in the formations of religious architecture. Islamic architecture can be analyzed in terms of the following aspects.

3.1. Connotations of geometric shapes

The individual point expresses the unity of the Creator, extending to the universe and life.

The straight line is a symbol that indicates straight thinking and uprightness in religion and behavior.

The square, with its equal sides, symbolizes justice, stability, perfection, and constancy, and represents the four cardinal directions or the four elements of nature.

The circle, inspired by the sun, the full moon, and the vault of the sky, is a representation of cosmic laws such as the rotation of night and day, death and resurrection. Some art theorists link the circle as a form with a religious dimension, the circumambulation around the Kaaba. The circle generates spiral shapes that indicate the movement of celestial bodies, and these shapes are also present in Islamic architecture (e.g., they can be found in the minarets of the Samarra Mosque and the Mosque of ibn Tulun).

The octagon symbolizes the divine throne carried by eight angels. The shape generated by the overlapping of two squares, as in the horizontal projection of the necks of domes in many mosques, indicates a religious and spiritual meaning. The eight-pointed stars consisting of two squares also represent the universe composed of a square symbolizing the four cardinal directions (east, west, north, and south) and a square symbolizing the four elements of nature (water, air, fire, and earth).

The triangle is also associated with religious meanings since it indicates the close relationship between the sky and the earth and refers to the relationship between the soul and the prayer that ascends to the sky (base-down triangle) or indicates divine mercy (base-up triangle). The six-pointed star expresses the merging of two shapes representing the sky and the earth through the overlapping of two triangles, where the base-down triangle represents the earth, and the base-up triangle represents the sky.

3.2. Connotations of architectural elements

Islamic artistic and architectural elements often have more than one function (in addition to the symbolic goal under the influence of Islamic faith and thought). Below we present an analytical and philosophical interpretation of some Islamic architectural elements, where we mention the goal of each element and its symbolic connotations.

- **Minaret**

The minaret expresses spirituality and transition from the material to the spiritual with the use of a visual image as the eyes travel from the bottom of the minaret to its top, which makes it a symbol of the earth meeting the sky through the gradient in height. It is also a symbol and sign of the mosque's presence. The use of two identical minarets in the same mosque symbolizes the arms extended to God in prayer, trying to get close to Him (Fig. 6).

- **Domes**

The dome is one of the best types of ceiling covering large square areas, ensuring enough light and ventilation inside the building. Its shape makes it possible to have windows both in the neck and the body of the dome.

It is a symbol of the vault of the sky and the spiritual realm. Its spherical shape symbolizes the universe, and its orientation toward the sky shows where the believer's heart and mind must be directed. Besides, it is related to the movement of the universe through its infinite rotation as if it was a circumambulation and a heavenly quest, an infinite circle to reach God. Currently, electric lights of various colors are used to highlight the aesthetics of the domes and attract attention (Al-Ubaidi, 2021).

- **Pendants**

Pendants (also called muqarnas) are architectural ornaments resembling beehives, that can be seen in the Arab Islamic buildings, hanging in layers on

Fig. 6. Use of two identical minarets in the same mosque
(https://almashhadalaraby.com/news/287785) (https://www/ensonhaber.com/yasam/dua-ederken-nelere-dikkat-edilmeli)

top of each other. They are used for architectural decoration (Al-Ubaidi, 2021). They represent a complex series of arches and reversed pyramids in continuous rows. By employing such pendants, the Muslim architects intended to emphasize repetition, succession, spread, and continuity in creation despite that it is due to one source.

- **Arches and vaults**

Arches and vaults are used extensively for architectural and aesthetic purposes inside and outside buildings, above windows, doors, entrances, and niches. They symbolize the welcome and the invitation to enter the spiritual world and leave the materialistic world, separating the sacred and the secular. Currently, they serve as a symbol of distinguished architecture.

- **Pillars**

Pillars are one of the significant elements in Islamic architecture. They performed an important function in ancient buildings, where floral and geometric ornaments were used in the crown, indicating growth and ascent to the top in contrast to earth's gravity, and this was a reference to the absolute. If the architects attempted to impart an artistic touch, the crowns could be in the form of a truncated or inverted pyramid.

- **Courtyard**

Courtyards are open or exposed spaces and semi-exposed hallways helping protect the building against the sunlight in summer and the rain in winter and regulate air currents in the whole building. They refer to the inward orientation of life as well as purity and stillness.

- **Ornaments**

Ornaments are a spiritual expression of the idea of monotheism, represented by geometric shapes that have no beginning or end and originate from a single central point. The use of ornaments with vertical lines symbolizes the Muslim cap. The ornament design is based on vegetal shapes and shows the dynamism that can exist in floral patterns (Hillenbrand, 2003).

- **Parapet**

The parapet symbolizes unity and equality through repetition. It also reminds those praying as they stand in a row (Fig. 7).

- **Crescent**

The crescent is one of the architectural elements that top the walls of a mosque. It indicates the qibla and Islamic calendar. Crescents are always placed on the top of domes and minarets.

4. Privacy and identity of symbolic connotations in contemporary Islamic architectural design

The interest in studying the formal aspect of the elements of architectural buildings as well as the symbolism and meanings of these elements clearly emerged after the industrial revolution when architectural patterns underwent changes since the construction industry and architecture started using machinery. Contemporary technologies and modern manufacturing methods imposed new architectural forms and solutions, which in some cases conform to traditional forms and in other cases break from them. Based on those changes and the formal interest in architecture, particular trends emerged with regard to the forms and their concept.

For the arts to be distinguished, there must be signs, connotations, and symbols that distinguish the origin of one type of art and its features in a particular place from the other, with account for the difference in time as well as historical and cultural transformations. The Islamic heritage enjoys distinctive privacy and identity that have their own impact on contemporary arts, literature, and sciences. Privacy and identity are quite concentrated in terms of the humanity in Islamic thought, the principles of monotheism and the greatness of God, and so the Muslim artists (especially the Arab and non-Arab contemporary designers) in general were


Fig. 7. A part of the parapet symbolizing the physical and moral aspects, the body and the soul
(https://egymonuments.gov.eg/monuments/ibn-tulun-mosque) (https://mugtama.com/theme-showcase/item/72760-2018-05-29-11-39-53.html)

affected by those limitations.

Therefore, controversy emerged over the possibility of benefiting from these Islamic heritage elements in creating a contemporary design trend that would reflect the cultural identity. To address architectural forms in design, or the so-called modularity and change, three design trends appeared in the Arab and Islamic world.

4.1. Direct copying of traditional elements

Some architects adopted a commitment to traditional heritage architecture and convey its symbolic connotations in terms of using traditional construction techniques and methods as well as the direct use of traditional architectural forms and elements (see, for example, the Mosque in Amman, Jordan (Fig. 8) so that it would give people confidence in their culture. These forms are a language of their own just like other types of folk arts (the clothes, the tools used, etc.).

For an architectural work to have symbolic implications, it is important to consider history or adapt historical values and their uses in architecture. The architect Robert Venturi preferred the visual aspect to the form, where in the confirmation of the visual image the architectural identity is highlighted since, for Venturi, architecture is a shelter with symbolic connotations (Venturi and Brown, 1986).

According to Cassirer (1953), copying a symbol completely distances the element from the symbol, and no new value is created.

Copying architectural patterns from the past is not the best solution. Contemporary technology should be properly used, and the resulting architectural forms should be in line with the identity of the community when a contemporary structure is designed. Hence, the designer must focus on the importance of studying the social environment before designing and identifying the meanings and symbols associated with them when trying to change the architectural patterns.

4.2. Contemporary trend

This contemporary trend is a call for change and consolidation of Arab-Islamic architecture features, with new meanings in terms of the form and the content, as was seen by the pioneers of contemporary architecture at the beginning of the 20th century. Those pioneers had an absolute belief in the futility of the traditional method of design and the need to create architecture representing the zeitgeist. The events of that period reflected ideological and political changes. This trend resulted in architecture with symbolic connotations, which is also quite new (to the point of trying to find the features of contemporary international architecture).

The dissatisfaction with the functional approach in architecture provoked several attempts to use architectural symbols borrowed from ancient buildings in the design of modern buildings for various purposes. This trend sparked a great debate about the relationship between the form and the function. While the belief was that the function should give a certain identity to the volume, and the volume should express the function, the issue of the moral significance of architectural elements appeared as a product of other natural factors. The architectural writer Alan Colquhoun mentioned that the fundamental dialectic no longer seemed to be that between the form and the function but rather that between the form and other entity (Hays, 2000).

The neo-architectural movement led to the emergence of buildings that lacked expressive and recognizable symbolic connotations as can be seen in the Mosque in Rijeka, Croatia (Fig. 9) as an example of contemporary design. The trend resulted in a high number of people complaining about their architectural surroundings. During that period, the designer focused on the natural function, and the economic and technical considerations pertaining to the building, while the symbolic connotations were neglected.

As for the local architectural identity, the architects tried to reject it on the pretext that it did not meet the demands of modern life. Many residential and administrative buildings in fact refer to technical progress in construction and

Fig. 8. Mosque in Amman, Jordan
(https://umroh.com/blog/inilah-masjid-king-hussein-bin-talal-di-amman-yordania/)

Fig. 9. Mosque in Rijeka, Croatia
(https://ilmfeed.com/mosque-croatia-world/)

contemporary management methods rather than a living environment with specific customs, traditions, and culture.

4.3. Distinguishing and innovating new design elements based on traditional symbolic connotations

This trend is based on systematic research (with its various means of induction, analysis, and inference) addressing local conditions, and contemporary cultural and religious data of the time, including the role of the traditional form in the creation of a modern form. The traditional form can be used as one of the appropriate solutions to develop or discover a modern form and then the old form can be fused with the new form. The Kul Sharif Mosque in Kazan, Russia, is a great example of a new design that preserves Islamic traditional symbolic connotations (Fig. 10).

Fig. 10. Kul Sharif Mosque, Kazan, Russia
(https://www.pikist.com/free-photo-xvaeg)

Thus, compatibility between heritage and contemporary authenticity is achieved in design by revealing heritage aesthetic values, their philosophical and artistic features, and their connection to the Islamic faith as resources for design.

A local design should be brought in line with particular concepts and traditions and should preserve the culture and privacy of the local environment. This creative and innovative trend depends on development through understanding the content of Islamic heritage and corresponding engineering systems and borrowing its elements and ornaments, followed by re-building, formulating, and employing them in an innovative way with modern materials and techniques while exploiting modern technology such as computers. Therefore, it can be noted that, despite certain differences, controversy is focused on the need to enrich the architectural work by providing designs with a moral value and civilized connotations. This is what the architects Robert Venturi and Aldo Rossi advocated for, despite their different styles.

In his writings, Robert Venturi emphasized the importance of local values in architectural work. He believed that architectural work should act as a symbol in the space and not merely a form without meaning as was the case in the works of his contemporaries, which, according to Venturi's opinion, were just a translation of functional programs and construction requirements (Venturi et al., 1977).

Here it is necessary to confirm the presence of privacy and Islamic identity in contemporary design by deducing Islamic symbols in design and the possibility of achieving an Islamic identity in contemporary design.

Conclusion

This research was based on semiotics as a tool of modern criticism via a deep implicit analysis of symbols and their connotations in Islamic architecture through content, abstraction, and visual text. The results show that the tools for reading the visual text from the Western point of view are not compatible with Islamic peculiarities and the view of this form of art on the universe and the Creator.

Perhaps one of the cognitive factors related to Islamic architecture is the large number of scholastic approaches that to a greater extent are based on historical narratives and to a lesser extent are based on the religious description. These approaches rarely use modern critical methods such as semiotics, which today is almost the most attractive method for studying Islamic arts as a pristine creative space in critical studies, amenable to further analysis and theorizing.

Hence, our critical attempt was based on observing the superficial and deep structural relations between the visual functions of Islamic arts and their symbolic implications in the semiotic field. The results of this critical approach manifested clearly in the conscious implicit interpretation of each symbol in Islamic architecture, the associated connotations and signals that emanate from the forms used, the relationship between the art form and the function, and the expression of the spiritual content of faith, especially in cases of function transformation over time, required by the current stage, cultural and civilizational conditions, and humanistic needs.

We presented three contemporary design models and showed that there is a great discrepancy in the application of the symbolic elements of buildings as a result of discrepancies in the philosophical thinking of the modern Muslim designers, which resulted in defects and loss of the identity and privacy of the features of architectural buildings. Therefore, it was necessary to highlight the need for returning to cultural and architectural artistic heritage and benefiting from it in finding new and contemporary design solutions using modern digital technical means in order to keep pace with contemporary thought and strive toward development as well as renewal and achieve cultural communication. This modest study of the semiotics of Islamic architecture is more like a recommendation or a call for more sophisticated critical approaches in modern methodologies going beyond the superficial concept of Islamic artistic creativity and its abstract aesthetics to its deep cognitive layers full of meanings, connotations as well religious, philosophical, and scientific concepts.

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IDENTIFYING VALUES OF CONSTRUCTIVIST HOUSES AND PALACES OF CULTURE IN LENINGRAD

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Abstract
Introduction: This paper is a result of a long-term comprehensive study of Houses and Palaces of Culture in Leningrad, designed or constructed in the 1920s–1930s. It provides proofs and clarifications for those intermediate studies and conclusions that we previously performed and drew. Our main finding is a refined methodology to establish grounds for the protection of a special type of buildings — Houses and Palaces of Culture in the style of constructivism — both at the urban-planning and facility levels. **Materials and methods:** In the course of the study, we examined archival as well as published scientific and reference sources, including illustrations, on the subject, analyzed the master plans of Petrograd/Leningrad, performed on-site investigations and office processing of the obtained results, and compiled detailed graphic models. **Results:** We identified all the planned, partially constructed, and implemented designs of a special function — Houses and Palaces of Culture — in the territory of Leningrad in the 1920s–1930s, tracked prerequisites for their creation at the urban-planning level in the Leningrad development system of the time, grouped the facilities according to the main urban-planning, architectural-and-artistic as well as cultural features, and found examples of such buildings that developed the most. Based on the identified facilities, we propose methodological approaches to identify the values of Houses and Palaces of Culture in the style of constructivism, clarifying the existing structure of grounds for protection, established for such facilities. The study showed that some of the most significant architectural-and-artistic as well as urban-planning features of Houses and Palaces of Culture are very vulnerable. **Conclusions:** The proposed methodology to identify (clarify) values (grounds for protection) of such facilities will ensure a more holistic, comprehensive approach to the preservation of unique architectural-and-artistic, space-and-planning as well as urban-planning features of cultural heritage facilities of the avant-garde period.

Keywords
Grounds for protection, cultural heritage facility, constructivism, Palace of Culture, House of Culture, Soviet architecture, restoration, adaptation.

Introduction

The growing interest in Soviet architecture of the 1920s–1930s, on the one hand, and the poor condition of many unique constructivism monuments, on the other hand, determine the relevance of this research. There are numerous Russian and foreign studies on architectural trends of the first third of the 20th century. For instance, Dayanov and Zalmanzon (2018), Kirikov and Stieglitz (2018), Sementsov (2012), Slavina (2019), Stieglitz (2020), and Vaitens (1995) addressed the urban planning and architecture of Leningrad (including individual monuments of architectural avant-garde) during the period under consideration.

Slavina (2019), Sementsov (2012), Mikhailov (2017), and others analyzed issues of determining the values of cultural heritage facilities and evaluated methodological approaches to the protection of architectural heritage.

The urban-planning role of Houses and Palaces of Culture in Leningrad (Dubrovina, 2020b), the main issues of their operation and preservation (Dubrovina, 2019), as well as the specifics and current issues of establishing grounds for protection of such facilities (Dubrovina, 2020a) were briefly discussed in various research papers. We suggest an in-depth study of the main values of Houses and Palaces of Culture in Leningrad — their urban-planning role in city development of that period, the historical shape design, and the historical function of buildings as a whole and their individual premises — as significant features, which, when lost, may result in irreversible changes in original historical architectural-and-artistic solution as well as space-and-planning design.

To give consideration to all the Houses and Palaces of Culture of the avant-garde period (as a unique type of buildings), designed or constructed in the territory of Leningrad, we needed to identify all the facilities and their spatial location. This paper presents a comprehensive list of all the Houses and Palaces of Culture in Leningrad in the 1920s–1930s.

Methods

Our research was based on a comprehensive study of the architectural heritage of the 1920s–1930s: Houses and Palaces of Culture in Leningrad (currently Saint Petersburg). We examined archival as well as published scientific and reference sources, including illustrations, on the subject, analyzed the master plans of Petrograd/Leningrad and identified urban-planning patterns in the arrangement of Houses and Palaces of Culture, performed on-site investigations and office processing of the obtained results, and compiled detailed graphic models. To develop a methodology to determine the values of Houses and Palaces of Culture in Leningrad, we needed to solve the following tasks in due sequence: A). Identify all Houses and Palaces of Culture designed and constructed in Leningrad in the period under consideration, and determine their urban-planning role. B). Group all the identified facilities according to the main urban-planning, architectural-and-artistic as well as cultural features so as to identify those that developed the most. C). Identify the main issues of their operation and preservation in Saint Petersburg. D). Determine their most significant (consolidated) values. E). Compare the obtained results with the available and applicable grounds for protection, established for the identified facilities.

Results

A). Identify all Houses and Palaces of Culture designed and constructed in Leningrad in the period under consideration, and determine their urban-planning role. Based on the collections in the State Museum of the History of Saint Petersburg and Schusev State Museum of Architecture as well as reference sources on the subject, we compiled a list of 23 Houses and Palaces of Culture designed or constructed in the territory of Leningrad in the 1920s–1930s, which is by far the most comprehensive.

In the 1920s, district centers began to form in Leningrad. They usually included a square, administrative buildings, educational institutions, department stores, as well as Houses and Palaces of Culture. An intention to create a system of interrelated district centers was captured in the master plan of Leningrad of 1935 and was most prominently featured in the master plan of 1939. For various reasons (a "floating" system of zoning, the lack of funds, particular urban-planning conditions, flaws in design), the idea was only partially implemented. The most thorough ensemble appeared on Stachek Avenue (Stachek Prospekt). In fact, many district centers were outlined, even though they were not so thorough. When comparing the layout of district centers with the arrangement of Houses and Palaces of Culture, we can deduce that Houses and Palaces of Culture were most often designed as part of a complex of district buildings. The largest stand-alone Houses and Palaces of Culture having a special purpose were designed as significant fragments of an architectural and urban-planning ensemble or a complex of buildings forming the centers of new city districts (Fig. 1).

List of facilities in Fig. 1:

1. Vyborgsky Palace of Culture with two residential buildings (architects: A. I. Zazersky, V. V. Starostin, G. A. Simonov, 1913–1916, 1924–1927);
2. Krasny Putilovets House of Culture (architect: A. S. Nikolsky, 1925–1926; formed as a result of Putilov Plant church alteration);
3. **Gorky Palace of Culture** (architects: A. I. Gegello, D. L. Krichevsky, V. F. Railyan, 1925–1927) — *selected to identify building values*;
4. Club at the Leningrad Commercial Port (architect: A. A. Ol, a project of 1925; the wooden building was constructed no later than in 1926; not preserved);
5. **Textile Workers' House of Culture** (architect: S. O. Ovsyannikov, 1926–1927) — *selected to identify building values*;
6. **Lenin Palace of Culture at the Bolshevik Plant** (architects: V. A. Shchuko, V. G. Helfreich, 1927–1929) — *selected to identify building values*;
7. Orlov Metal Workers' Club (architects: N. A. Miturich, V. P. Makashov, 1928–1929; destroyed in 1943);
8. First Five-Year Plan House of Culture (architects: N. A. Miturich, V. P. Makashov, 1929–1930; demolished in 2005);
9. House of Culture of the Kapranov Union of Leather Workers (architect: M. S. Reizman, 1930–1931; demolished in 2006);
10. **Ilich House of Culture** (architect: N. F. Demkov, 1930–1931) — *selected to identify building values*;
11. Aviation Workers' House of Culture (architects: G. V. Maizel, Ye. V. Tseits, B. Ya. Karamyshev, 1930–1933);
12. **Gaza Palace of Culture** (architects: A. I. Gegello, D. L. Krichevsky, 1930–1935) — *selected to identify building values*;
13. **Kirov Palace of Culture** (architects: N. A. Trotsky, S. N. Kozak, Ye. A. Ilin, 1931–1937) — *selected to identify building values*;
14. **Lensoviet Palace of Culture (architects: Ye. A. Levinson, V. O. Munz, 1931–1938)** — *selected to identify building values*;
15. Communications Workers' Palace of Culture (architects: P. M. Grinberg, G. S. Raits, 1932–1939);
16. Water Transport Workers' House of Culture – Sailors' Palace of Culture (architects: N. D. Saburov, Ye. I. Chilingarova, 1932–1933);
17. Movie Palace — Gigant Movie Theater (architects: A. I. Gegello, D. L. Krichevsky, 1934–1936);

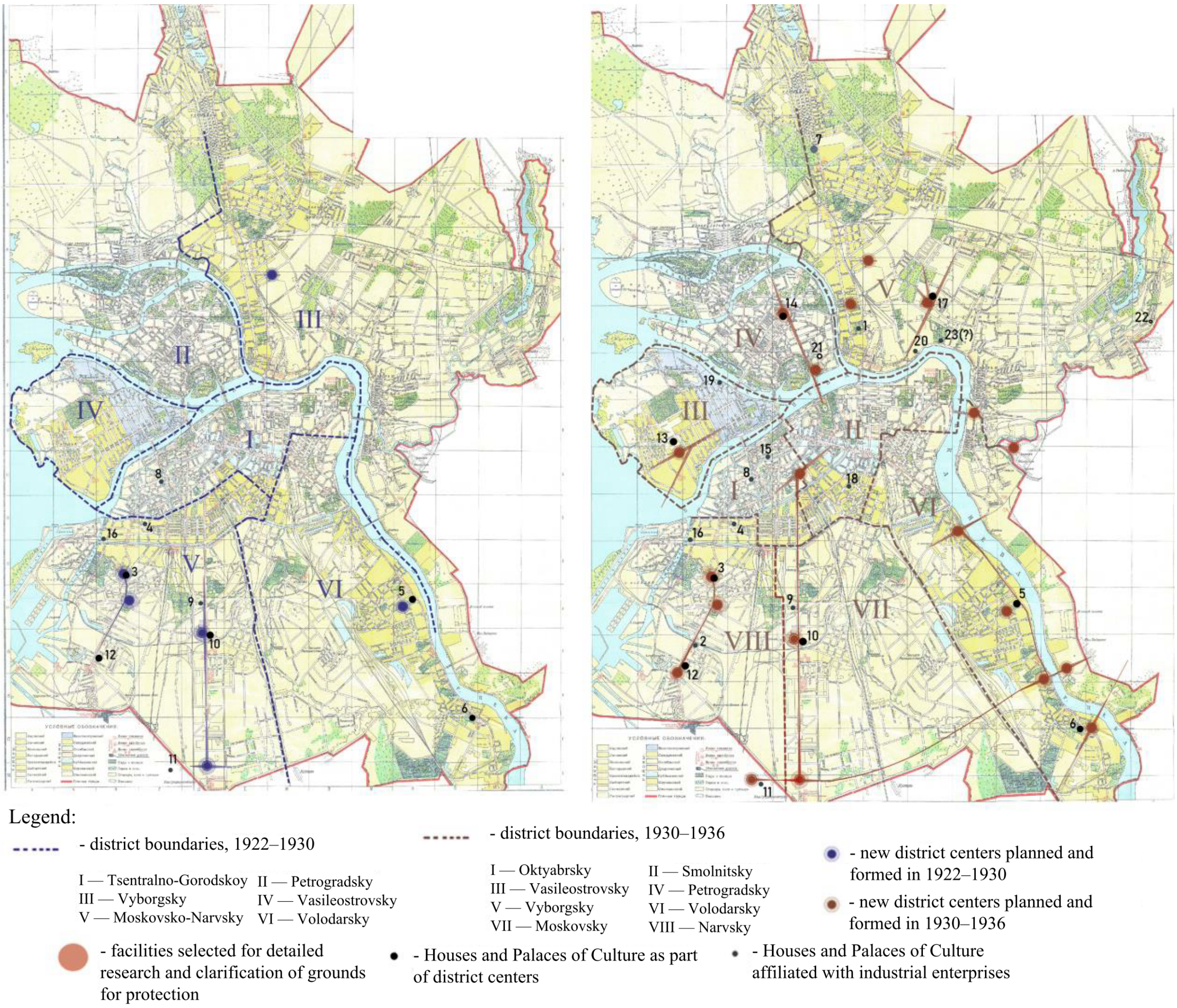

Fig. 1. Petrograd/Leningrad zoning plan, 1922–1930 and 1930–1936, with new district centers

18. Railway Workers' Club, Food Industry Workers' House of Culture (architects: A. G. Golubkov, V. P. Makashov, V. K. Krylov, 1912–1913, 1935–1937);
19. Kozitsky Plant. Plant Club (architects: M. I. Brusilovsky, D. P. Buryshkin, 1938–1940);
20. Cultural Education Complex (Club) of Krasny Vyborzhets Plant, 1939—1941 (architect: D. L. Krichevsky, finishing, 1945–1953);
21. Design of the theater (for 750 people) affiliated with the club of the Utility Workers' Union on Derevenskoy Bednoty Street (currently Michurinskaya Street) (architects: A. I. Gegello, D. L. Krichevsky, 1927) — *not implemented;*
22. Design of Porokhovskoy House of Culture of the Chemical Industry Workers' Trade Union in Leningrad (architects: N. A. Miturich, V. P. Makashov, V. V. Danilov, 1929) — *not implemented;*
23. Design of the House of Culture of the Metal Workers' Trade Union in Polyustrovo (architects: N. A. Miturich, V. P. Makashov, V. K. Krylov, V. V. Danilov, 1931) — *not implemented.*

B). Group all the identified facilities according to the main urban-planning, architectural-and-artistic as well as cultural features so as to identify those that developed the most. The list of all the identified facilities includes not only stand-alone Houses and Palaces of Culture having a special purpose, built in original (for that time) shapes, but also Palaces of Culture formed as a result of the alteration of existing buildings and introduced in the existing historical development of Leningrad. In these facilities, the distinctive features of the Palace of Culture (a new type of buildings) are represented only partially since the space-and-planning design as well as architectural-and-artistic features of the original buildings prevail. Some of the identified facilities were re-built or lost. Thus, it became necessary to analyze all the identified facilities and group them according to the main urban-planning, architectural-and-artistic as well as cultural features (Fig. 2).

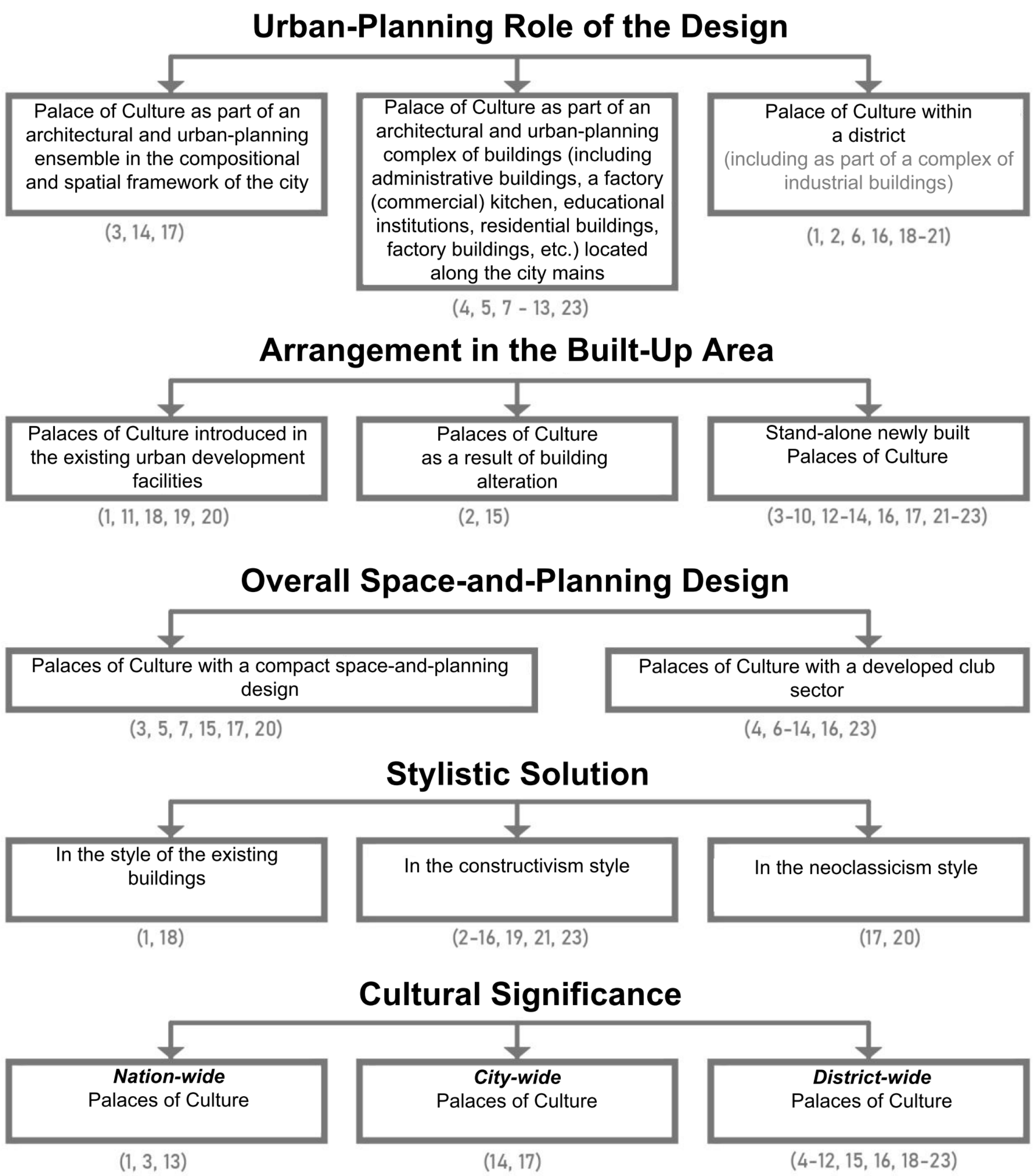

Fig. 2. Classification of Houses and Palaces of Culture in Leningrad in the 1920s–1930s:
(*) — No. of a facility from the list to Fig. 1

To determine the values of buildings, we selected the following stand-alone preserved facilities newly built in the constructivism style, having particular grounds for protection: the Lensoviet Palace of Culture (a cultural heritage facility of regional significance), the Kirov Palace of Culture (a cultural heritage facility of federal significance), the Gorky Palace of Culture (a cultural heritage facility of federal significance), the Gaza Palace of Culture (a newly identified cultural heritage facility), the Ilich House of Culture (a newly identified cultural heritage facility), the Textile Workers' House of Culture (a newly identified cultural heritage facility), and the Lenin Palace of Culture at the Bolshevik Plant (a newly identified cultural heritage facility).

C). Identify the main issues of their operation and preservation in Saint Petersburg. Based on the results of on-site investigations of the preserved Houses and Palaces of Culture, we defined issues of their operation and preservation, including the following:

– the relationship between the historical function of the main premises and the most significant urban-planning, shape design, architectural-and-artistic features of individual premises and the building as a whole. Changes in the function result in the loss of building values (e.g., when auditoriums and entrance lobbies are used as beauty salons, shops, trade fairs with individual entrances, randomly arranged partitions, walls and ceilings cladded with plasterboard);

– the effect of using substandard materials and technologies during construction, which resulted in buildings falling into a dangerous condition right in the middle of operation;

– imperfect components of the state heritage protection system, including activities aimed at preserving, maintaining, and ensuring the successful operation of Palaces of Culture;

– insufficiently clear requirements, formulated at the legislative level and within the operation system, for maintenance and operation of cultural heritage facilities; the lack of detailed methodological recommendations to establish grounds for protection.

D). Determine their most significant (consolidated) values. Based on the results of historical and cultural studies as well as on-site investigations, we identified the following features of Houses and Palaces of Culture as a unique type of buildings to be unconditionally preserved or — in case of their loss — reconstructed (if sufficient historical illustrations and technical capabilities are available):

– the urban-planning role of a Palace of Culture within the structure of urban development (as part of a district center);

– the overall historical space-and-planning design of a building (including elements not implemented and late additions): a compact space-and-planning design with a theater as a core component and a space-and-planning design with a developed club sector;

– the historical structural concept with the use of a reinforced concrete framework, wooden trusses, metal structural members, brick structures (including vaulted ceilings), etc.;

– the historical space-and-planning design of the main premises, based on the principle of “flowing space”;

– the historical function of a building as a whole and individual premises: theater sector premises (entrance halls, lobbies, auditorium, restaurants, cafeterias, etc.), libraries, club sector premises (rehearsal rooms, dance halls, recreation rooms, etc.), sports sector premises, movie halls, etc.;

– the historical architectural-and-artistic solution of facades in the constructivism style (in some cases, with the use of elements in the Stalinist classicism style);

– the historical decorative-and-artistic solution of interiors, showing the structural concept, with the use of concrete, metal, natural stone, fine wood, rich wall colors, decorative panels, etc.

E). Compare the obtained results with the available and applicable grounds for protection, established for the identified facilities. For this purpose, we performed a graphic analysis of the applicable grounds for protection, established for the selected facilities (Figs. 3, 4). It showed that currently only preserved historical elements of buildings, related to the construction period, can be considered eligible for protection. Grounds for protection depend on the integrity of a building. Usually, when grounds for protection are established, a formal approach is used. In all the studied and analyzed documents, they are identified in isolation, a building is “divided” into individual elements, and the most important features of Palaces of Culture are not considered eligible for protection.

– the urban-planning role — one of the most important features of this type of buildings;

– the space-and-planning design based on the principle of “flowing space”. In most of the examples considered, the space-and-planning design of a House or Palace of Culture within the boundaries of bearing walls is considered eligible for protection. However, even in this case, it is impossible to preserve the unique historical space-and-planning design of buildings with a developed system of entrance halls, lobbies, grand staircases, halls, recreation rooms, libraries, and other premises (e.g., to ensure preservation of bearing walls, formal rooms can be divided by numerous partitions with the arrangement of individual entrances, and that interferes with the historical shape design);

– the historical architectural-and-artistic solution of interiors. It was established that it is necessary to include the historical interior solution of some premises in the list of grounds for protection, especially when its reconstruction implies revealing and removal of late additions having little value in the form of random partitions, cladding, stretch ceilings, etc.;

– the function of premises. It was established that it is necessary to preserve the overall function of buildings (Palace of Culture), the general functional division into theater and club sectors (a compact design or with a developed club sector), as well as the function of individual premises (entrance halls, multi-level lobby system, auditorium, corridors, libraries, sports complexes, grand halls, etc.) since changes in the function of a building as a whole or the main premises of all the facilities under consideration transform significantly the space-and-planning design and the decorative-and-artistic solution of interiors.

Discussion

The study showed that to ensure more holistic preservation of the basic values of Houses and Palaces of Culture, it is necessary to determine grounds for protection at the urban-planning and facility levels, including both tangible and intangible components (urban-planning role, function of some premises, and, in some cases, those designs that were not implemented).

Currently, grounds for protection are mainly established at the facility level. In rare cases, specifics of Houses and Palaces of Culture’ location in the structure of urban development are briefly determined. Such an approach results in a gradual loss of the significant urban-planning role of Houses and Palaces of Culture, which can be observed in such unique facilities as the Kirov Palace of Culture, the Textile Workers’ House of Culture, and the Lenin Palace of Culture at the Bolshevik plant. Those

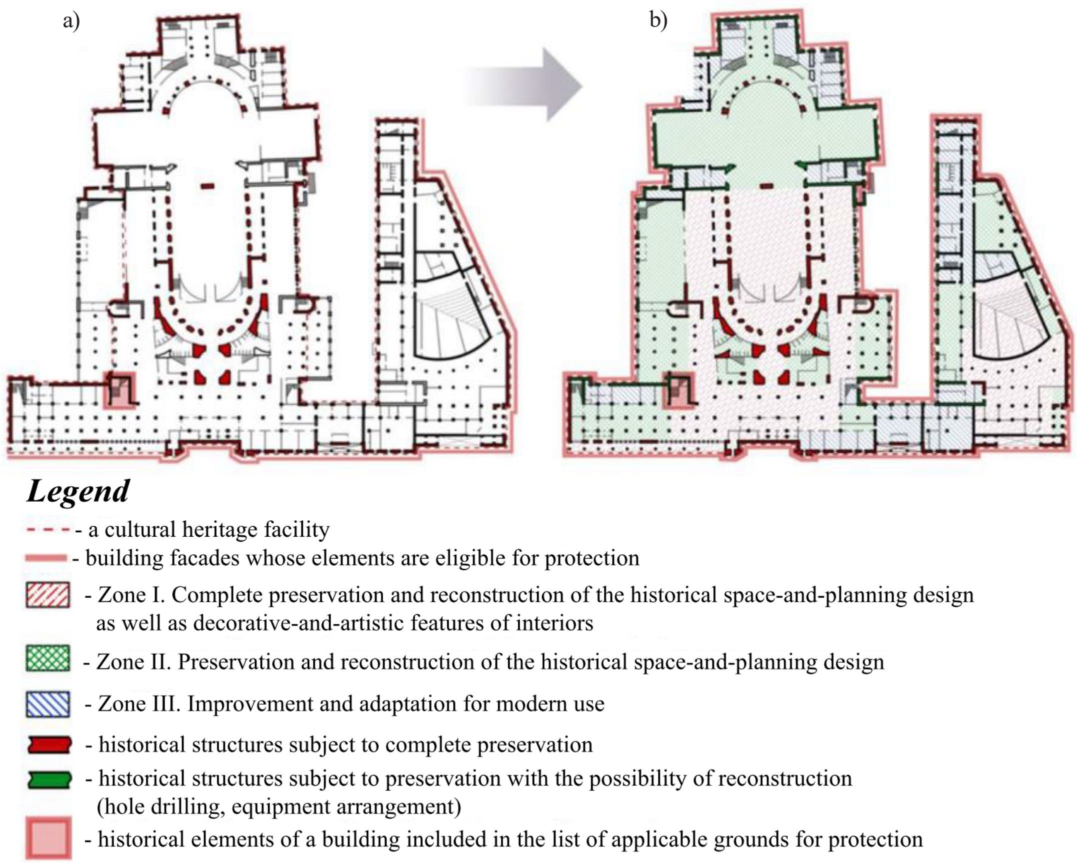

Fig. 3. Floor plans of the Lensoviet Palace of Culture:
a — a graphic analysis of the existing object under protection; b — a scheme of the proposed object to be protected

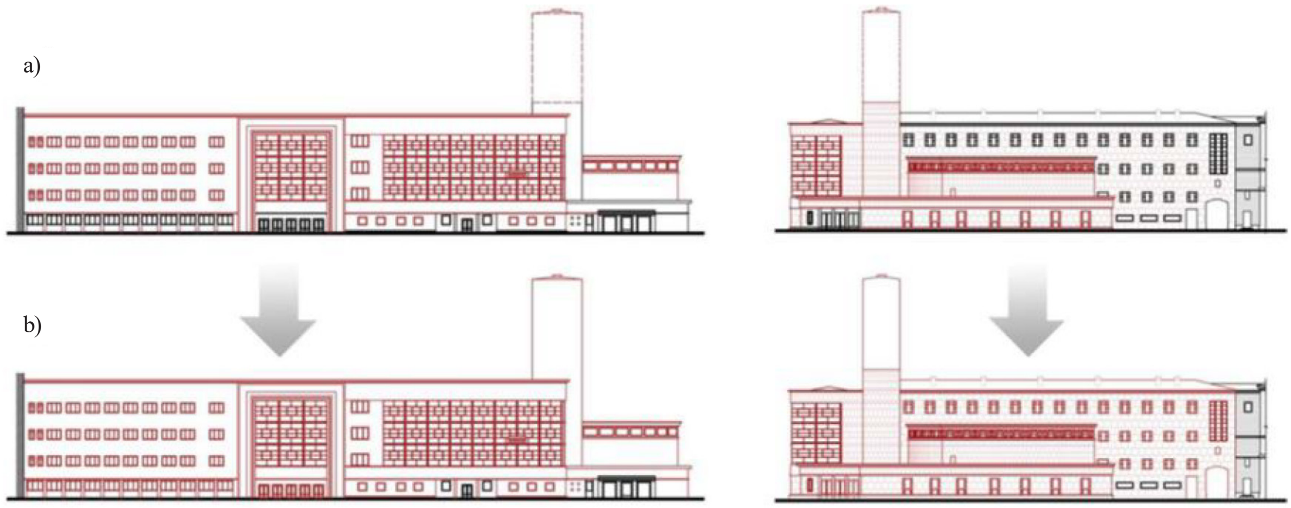

Fig. 4. Scheme of the Lensoviet Palace of Culture facades along Kamennoostrovsky (on the left) and Levashovsky (on the right) Avenues (Prospekts):
a — a graphic analysis of the existing object under protection;
b — a scheme of the proposed object to be protected

facilities that were not completed at the construction stage did not acquire any significant urban-planning role set in all the corresponding design drawings (e.g., the Lensoviet Palace of Culture). Thus, in some cases, it is required to consider designs that were not implemented as grounds for protection.

Paragraph 6 of the existing methodology to establish grounds for cultural heritage facility protection, approved by the Ministry of Culture of the Russian Federation on January 13, 2016, regulates specifics of their establishment and approval but does not give any recommendations on the nature, scope, and composition of the relevant document.

It is necessary to introduce the following mandatory sections and subsections into the existing structure of the object to be protected:

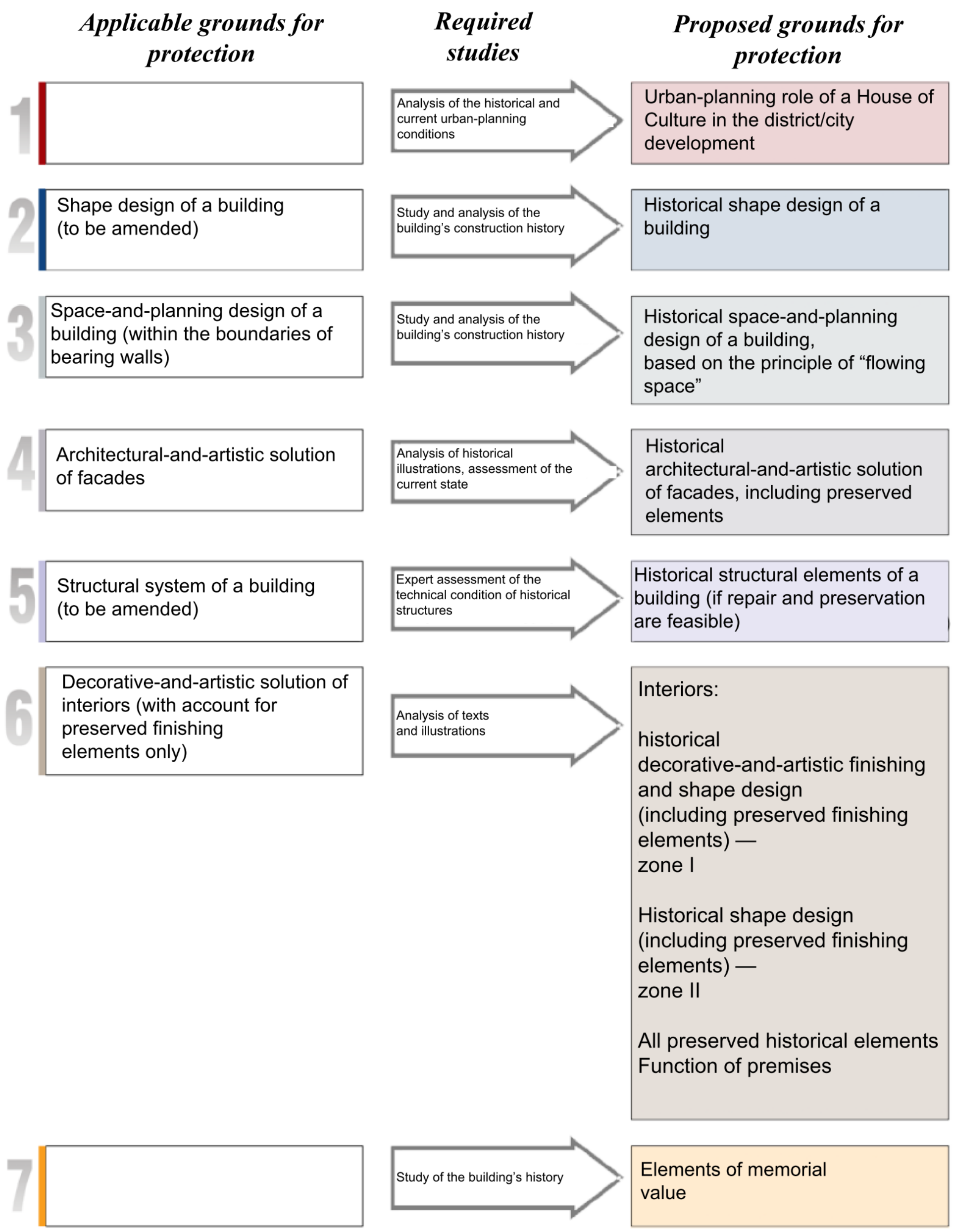

Fig. 5. Scheme for clarifying grounds for the protection of Houses and Palaces of Culture designed in the style of constructivism, with proposed amendments

– the urban-planning role of Houses and Palaces of Culture;

– the elements of memorial value;

– the principle of defining specially protected zones, introduced in the "Decorative-and-Artistic Solution of Interiors" section, which will ensure a more holistic, comprehensive approach to the preservation of facilities;

– the function of some premises is proposed to be included in the list of grounds for protection.

The "Shape Design of a Building", "Space-and-Planning Design of a Building", "Architectural-and-Artistic Solution of Facades", and "Structural System of a Building" sections require amendments and clarifications.

The results of the study can be recommended for use by architects when developing restoration and reconstruction designs for Houses and Palaces of Culture in Saint Petersburg and other cities, experts and art historians when establishing or updating the grounds for the protection of cultural heritage facilities of the avant-garde period, as well as faculty of universities when training bachelors, masters, and PhD students.

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ОСОБЕННОСТИ ВЫЯВЛЕНИЯ ЦЕННОСТНЫХ ХАРАКТЕРИСТИК ДОМОВ И ДВОРЦОВ КУЛЬТУРЫ ЛЕНИНГРАДА АРХИТЕКТУРЫ КОНСТРУКТИВИЗМА

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Аннотация
Статья является результатом многолетнего всестороннего изучения Домов и Дворцов культуры Ленинграда 1920-30-х годов XX века, закрепляет и уточняет ранее выполненные авторами промежуточные исследования и выводы. Результатом статьи является уточненная методика составления предметов охраны для особого типа зданий – конструктивистских Домов и Дворцов культуры на градостроительном и объектном уровнях. **Материалы и методы:** Изучение архивных и опубликованных научных, библиографических и иконографических источников по теме исследования; анализ генеральных планов Петрограда-Ленинграда; натурное обследование; камеральная обработка выполненных исследований с составлением подробных графических моделей. **Результаты:** Выявлены все запроектированные, частично возведенные и осуществленные объекты особой функции – Дом и Дворец культуры на территории Ленинграда в 1920-30-х годах, прослеживаются предпосылки их создания на градостроительном уровне в системе застройки Ленинграда тех лет, приводится их классификация по основным градостроительным, архитектурно-художественным и общекультурным особенностям, выявляются примеры наиболее сформировавшихся построек такого типа. На примере выявленных объектов предлагаются методические подходы к выявлению ценностных характеристик конструктивистских Домов и Дворцов культуры, уточняющие существующую структуру предметов охраны, составленных для таких объектов. Исследование показало, что некоторые важнейшие архитектурно-художественные и градостроительные особенности Домов и Дворцов культуры в настоящее время весьма уязвимы. **Выводы:** Предложенная методика выявления (уточнения) ценностных характеристик (предметов охраны) для таких объектов обеспечит более целостный, всеобъемлющий подход к сохранению уникальных архитектурно-художественных, объемно-планировочных и градостроительных особенностей объектов культурного наследия эпохи авангарда.

Ключевые слова
Предмет охраны, объект культурного наследия, конструктивизм, Дворец культуры, Дом культуры, советская архитектура, реставрация, приспособление.

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RESTRUCTURING ARCHITECTURAL EDUCATION POST COVID-19: PROFESSIONAL PRACTICE AND CONSTRUCTION INDUSTRY EXPECTATIONS

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Abstract

Introduction: It is clear that there is a gap between academic knowledge and professional practice in the field of architecture. Based on feedback from the industry, recent graduates lack the required skills, technical knowledge, and professional competencies. To keep pace with the rapidly changing technological scenario, the entire curriculum and syllabus of undergraduate (UG) level architectural education in India need restructuring and revision with reference to the contents to be taught and technical skills to be gained. In the past few years, student enrollment in UG-level architecture programs in India has declined, whereas demand projected experiences an upward movement. **Purpose of the study:** We aimed to restructure architectural education post COVID-19 pandemic with reference to professional practice and market expectations. For that purpose, we needed to review various aspects of higher education, the current scenario, and graduate attributes and reformulate those in terms of architectural education. It has become imperative to strengthen architectural education, especially post COVID-19 crisis. Prospective future professionals should be trained to meet the construction industry expectations while continuing their independent lifelong learning to ensure their global acceptability. **Methods:** The study methodology involves a market survey to analyze the current situation and determine construction industry expectations for recent graduates of architecture programs. The survey covered representatives of academia and construction industry professionals. **Results and Discussion:** The findings show that there is potential for restructuring the architectural education curriculum to both suit the educational purpose and meet the industry expectations. Its restructuring with a fresh approach will help architecture students learn more thoroughly how to become professionals ready to work in the Indian market as well as accept the global challenges presented by changing technology. The outcome of this study is presented in the form of a simple model curriculum, which can be adopted by institutions imparting architectural education.

Keywords

Architectural education, curriculum design, post COVID-19 education, architects, market-ready professionals, construction industry expectations, B. Arch. model curriculum.

Introduction

The challenges experienced by higher education institutions (HEIs) imparting architectural education before COVID-19 have not gone away. Moreover, due to the pandemic, other issues (like admissions and retention of faculty members) have arisen. However, by utilizing digital tools and methods, academicians have proven that the sector can adapt to changing circumstances at a fast pace. Greater openness toward online learning and collaboration has not only helped institutions mitigate the challenges but also made it possible to do well and set new higher education directions in this digital era with higher confidence.

It is clear that there is a gap between academic knowledge and professional practice in the field of architecture. The entire curriculum and syllabus of architectural education in India need restructuring and revision with reference to the contents to be taught, especially post COVID-19 crisis. Long before the COVID-19 pandemic, many institutions imparting architectural education in India were already struggling with economic, competitive, and regulatory challenges. Enrollment was dropping, and the threat to the existence of institutions became very real. These days, institutions can analyze their strengths, weaknesses, opportunities, and challenges in order to respond to the unprecedented situation.

Architectural education in India traditionally focuses on training students to become market-ready professionals equipped with necessary technical knowledge and skills. However, feedback from the industry on graduates' fundamental knowledge and skills is far from satisfactory. Academicians recognize the need to revise and strengthen the architecture curriculum by incorporating courses in new emerging areas while bringing them in line with changing market demands. This study involves the revision of the curriculum of a five-year full-time B. Arch. program. The purpose of the study is twofold: a) to explore the gap between academic knowledge and professional practice in the field of architecture, and b) to propose a model curriculum for an architecture program. In the course of the study, we conducted a survey approaching a number of professionals, academicians, and students related to the construction industry. The survey was our primary source of data. The findings show that there is clear potential for meaningful changes in architectural education, aimed at training students to become market-ready professionals able to accept global challenges.

Architectural design has been in a period of rapid change for the last few decades, but architectural education and, more specifically, faculty members have not been able to keep up with those transformations. Some institutions and individuals focus on design as a "process", and some focus on design as a "product". As a result, design students remain in a state of dilemma and continue to learn methods and techniques that have now become obsolete. Design students of the future must learn design during their formative years, studying both the abstract and practical. This approach challenges the traditional faculty system, in which educators who have repeated the same tired exercises for years may find themselves teaching something that it is without an audience, and as a result, they may well find themselves without a role to play. But a revamped approach would create competent designers for industry, government, and the non-profit sector, where design thinking and detailed, knowledgeable designs are fundamental to addressing the complex and dynamic qualities of our world (Ozkaynak and Ust, 2012).

The Council of Architecture in India issues enrollment numbers regarding students admitted by architectural institutions to ensure that only eligible students are admitted as per the sanctioned intake approved by the Council. Data on enrollment numbers for 2015–2019 are presented in Table 1 (Council of Architecture, 2021).

Table 1. Sanctioned intake approved by the Council of Architecture for the past five years

Academic year	Enrolled students	Number of colleges applied for enrollment
2015	19,241	395
2016	18,702	396
2017	14,677	382
2018	16,576	390
2019	8182	225

Some of the major causes behind the decline in the number of enrollments are as follows:

(i.) The duration of programs (five years) is one year more than that of other UG-level engineering programs.

(ii.) Levels of scholarship for interns/trainees and salary for recent graduates are much lower than levels of initial salary packages for engineering graduates.

(iii.) Recession/correction in the real estate market.

There is a widely divergent figure for the ratio of architects to inhabitants in various countries, and broadly, it appears to be based on the position of the country on the growth curve of development. An approximate estimate in 2014 at the Venice Architecture Biennale showed the number of architects in 36 countries. There is one architect per 414 inhabitants in Italy, one for every 1300 in the USA, and one for every 1880 in the United Kingdom. The lowest ratio is for China, which shows there is one architect per 40,000 inhabitants (Council of Architecture, 2020b).

Keeping this information in mind, the Council of Architecture felt that a pragmatic figure of 1:9000 could be the approximate target in India for the next few years, possibly up to one decade, i.e., up to the year 2030. With this target, India is expected to have about 150,000 architects for a population of 1,320,000,000. As of 2018, there were 84,775 architects registered with the Council of Architecture.

In order to bridge the rapidly increasing gap between the number of required architects and the number of those admitted to B. Arch. programs in the country, we need to review the architectural education scenario and restructure it to mitigate the challenges.

Need for Restructuring Architectural Education Post COVID-19

The global pandemic has caused many challenges for the education sector, yet it has also provided higher education institutions with an opportunity to show that they can adapt rapidly. In many ways, however, the past year has distracted from fundamental challenges the education sector faced before the crisis, including the shift toward the platform economy and more collaborative, rather than transactional, ways of working. Universities must catch up with the skills needed to thrive in a networked economy. Rather than providing a "stamp on the forehead" for young undergraduates, universities need to focus much more on lifelong learning and reskilling (PA Consulting, 2021). In view of the availability of ample learning opportunities online and the many ways to access and share knowledge using digital platforms, institutions should ponder how they can strengthen their existence, avoiding the label of a channel partner to award degrees.

This is the right time for deep reflection on the architectural curriculum, particularly as we struggle against the denial of scientific knowledge and actively fight misinformation. The UNESCO calls on all educational stakeholders to prioritize scientific literacy to ensure a curriculum with strong humanistic objectives that explores the relationship between fact and knowledge and is capable of leading students to understand and situate themselves in a complex world (UNESCO, 2020). Curricula should be increasingly integrated and based on themes and problems that allow us to learn to live in peace with our common humanity and our common planet.

The change from objective-based pedagogy to competency-based approaches appears to be no more than a change in the language rather than a change in the way the education system is structured or designed, as many countries are still organizing their education systems based on technological objective-based pedagogy (Martín-Alonso et al., 2021). Zhao and Watterston (2021) identified three big changes that education should make post COVID: a curriculum that is developmental, personalized, and evolving; pedagogy that is student-centered, inquiry-based, authentic, and purposeful; and delivery of instruction that capitalizes on the strengths of both synchronous and asynchronous learning.

India's education during the COVID-19 pandemic has been standing still and will continue to be in a state of confusion until this pandemic stands as a major threat to human lives. During this state of confusion and chaos, it's not only the classroom teaching that will be affected, but also numerous factors like organizational routines, employment rates/placement rates at various educational institutions, and other factors. At present, the two Golden A's of education, namely availability and accessibility, are being disrupted. Nearly all the Indian educational institutions are going to experience the negative impact of COVID-19 and a few revolutionary policies will be required to stabilize this system and the country at large (Dhanalakshmi et al., 2021).

It is incumbent upon all educators to use this crisis-driven opportunity to push for significant shifts in almost every aspect of education: what, how, where, who, and when. In other words, education, from curriculum to pedagogy, from teacher to learner, from learning to assessment, and from location to time, can and should be radically transformed (Zhao and Watterston, 2021).

Liberalization, privatization, and globalization of education have deteriorated remarkably due to limited mobility and limitedly confined exchange programs of academic activities among the countries during the COVID-19 lockdown. Third-world countries are facing policy paralysis in handling the sudden shifting scenario of educational planning, management, and organization during this pandemic with their fractured technical infrastructure, academic incompetency, and lack of resources. Everyone must learn to live and survive in the present crisis as it is only the beginning. In the long run, no one can afford the negligence toward digital transformation in HEIs. Few steps should be taken in the wake of this pandemic to develop a curriculum that reflects the perceptible change in the content knowledge and learning experience of students as well as enables them to think critically (Mishra et al., 2020).

Institutions must place greater focus on their purpose. The economic viability of institutions remains challenged due to a decline in enrollments. The universities must also embrace openness by sharing resources and collaborating with competitors, building "ecosystems rather than sets of transactions". This could mean working with online education platforms or fostering collaborations with international providers. "There will be a need for more work-related content and continuing education, and universities need to find that symbiosis if they are to diversify and make a living" (PA Consulting, 2021).

Ultimately, this will require a reassessment of business models and how universities generate value. Arizona State University, for example, has launched a research and innovation facility with Starbucks to design more sustainable ways to run its stores and hone employees' decision-making skills. The university's president, Michael Crow, describes this approach as creating "knowledge enterprises, not cost centers". It's a trend that will see institutions reflect market demands, offering short courses, bespoke corporate learning, and stackable awards. Through partnerships and an openness to collaboration, universities can create "borderless higher education", ensuring they thrive for decades to come (PA Consulting, 2021). A few progressive universities in the UK are already investigating alternative norms, market strategies, and working practices. They are re-framing and expanding their relationships with learners, businesses, local communities, and each other — often using technologies common to other sectors.

Knowledge alone is not a key factor for success for an engineering student. A skill set is another factor required for sustaining in today's industrial work environment. Industries keep complaining to educational institutions about the low skill levels or lack of skill sets observed in engineering graduates across the country (Kulkarni et al., 2020). In this paper, we emphasize the need for restructuring architectural education while adapting to industry-oriented curriculum design.

Researchers, curriculum designers, education officers, and educational institutions work together to transform the education system during the closures. Educational institutions should design curriculums, prepare learning strategies and techniques for post-COVID-19, and transform the education system itself (Tadesse and Muluye, 2020). With the rapid development of computer applications in the architectural profession, the need to find a framework to integrate computer applications into the architectural curriculum has increased. Hence, it became mandatory to examine the computer integration impact on architectural schools and, at the same time, explore the architecture profession's needs in order to help find an efficient framework for architectural education (Soliman et al., 2019).

There is a scarcity of research discussing the integration of fundamental, interpersonal, cognitive, problem-solving, and continuous improvement skills in architectural education. Therefore, Khodeir and Nessim (2020) were mainly concerned with analyzing the typical curriculum in the present scenario of architectural education, which is considered one of the root causes of the gap between architectural education and the changes in the job market. Various missing skills, which can be referred to as "employability skills", include, but are not limited to: problem-solving, creativity, communication, ethics, and accountability.

Approach and Policies of Restructuring the Architectural Education Curriculum

An architect is expected to possess abilities that include creativity, conceptualization, visualization, interdisciplinary knowledge, management skills, team spirit, and much more in order to make a worthwhile contribution to the profession. Such knowledge and skills are to be developed during five years of education and training. Academicians and professionals in architecture deliberate and decide the contents of courses and modules/topics to be taught in a particular course. At times, several topics and contents are eliminated from the syllabus and new contents are introduced in order to bridge the gaps. This is often done on the basis of best judgment by academicians and experts following their individual perceptions and prejudices. However, there is no scale or tool to judge the usefulness and impact of a particular topic/subject in measurable terms before taking such decisions. It is required to develop such a tool to evaluate and quantify usefulness and impact in order to facilitate the decision-making process while modifying the curriculum.

The word "curriculum" began as a Latin word, which means "a race" or "the course of a race" (which in turn derives from the verb *currere,* meaning "to run/to proceed").

Several researchers suggested various models for evaluating a curriculum. Prof. Pillai (2016) discussed types of curriculum, approaches to curriculum evaluation, and various models suggested by other scholars.

Olarinoye (Adirika, 2017) illustrated a narrow viewpoint of the curriculum by defining it as "a blueprint consisting of subject themes, topics, performance or behavioral activities, content or subject matter, and students' activities". According to Taba, the chief functions of curriculum objectives are:

- Guiding the process of decision-making on what to cover, what to emphasize, what content to select, and which learning experiences to stress.
- Setting the scope and the limits of what is to be taught and learned.
- Helping with the selection of areas of knowledge in various discipline objectives.
- Serving as a guide for the evaluation of achievements.

Since the subject of restructuring architectural education is broad and comprehensive in nature, the scope of this study is confined to developing a tool to measure the impact of a particular topic or subject in quantifiable terms (for UG-level architectural education).

There is a challenge in incorporating new content into the existing curriculum, either as a module in available courses or as a new course. Most of the time, the existing curriculum is already at the upper limit in terms of the number of courses and credits. Since total contact periods per week remain constant in institutions, it is not advisable to increase those to avoid an undue burden on students and faculty members. Additionally, there are new technologies and applications that are desirable to be included in an existing curriculum but present bigger challenges for academicians when they try to include them in the existing curriculum (Rodriguez, 2020).

Learning is categorized into knowledge, skills, and attitudes as per Bloom's Taxonomy. These learning outcomes are attained by designing various courses for students. All courses are designed with measurable course outcomes. Courses can have sub-outcomes for detailed tasks designed for the students. All course outcomes can be mapped to knowledge (Cognitive domain), skills (Psychomotor domain), and attitudes (Affective domain). The courses and their outcomes are designed to attain program outcomes. Engineering education is made up of various formats of courses like lectures, seminars, workshops, tutorials, laboratory studies, elective courses, self-learning courses, projects, discussions, personality development courses, soft skills courses, social science courses, extra-curricular activities, and sports activities. The outcomes of these courses focus on the knowledge, skills, and attitudes required for employability (Johnson and Ramadas, 2020).

All courses in architectural education should be designed with a specific measurable outcome(s) in view of industry expectations for recent graduates of architecture programs. Courses should be judiciously designed so that all the program outcomes are addressed. To address all the program outcomes, courses of various categories like lectures, tutorials, elective courses, laboratory studies, seminars, workshops, self-learning courses, projects, discussions, personality development courses, soft skills courses, social science courses, extra-curricular and co-curricular activities, and physical education are introduced.

Given the 21st-century requirements, quality higher education must aim to develop good, thoughtful, well-rounded, and creative individuals. It must enable an individual to study one or more specialized areas of interest at a deep level, and also develop character, ethical and constitutional values, intellectual curiosity, scientific temper, creativity, spirit of service, and 21st-century capabilities across a range of disciplines, including sciences, social sciences, arts, humanities, languages, as well as professional, technical, and vocational subjects. A quality higher education must enable personal accomplishment and enlightenment, constructive public engagement, and a productive contribution to society. It must prepare students for more meaningful and satisfying lives and work roles and enable economic independence (Ministry of Human Resource Development. Government of India, 2020).

In the National Education Policy (Ministry of Human Resource Development. Government of India, 2020), some of the major problems currently faced by the higher education system in India include:

a.) a severely fragmented higher educational ecosystem;
b.) less emphasis on the development of cognitive skills and learning outcomes;
c.) a rigid separation of disciplines, with early specialization and streaming of students into narrow areas of study;
d.) limited access particularly in socio-economically disadvantaged areas, with few HEIs that teach in local languages;
e.) limited teacher and institutional autonomy;
f.) inadequate mechanisms for merit-based career management and progression of faculty and institutional leaders;
g.) lesser emphasis on research at most universities and colleges, and lack of competitive peer-reviewed research funding across disciplines;
h.) suboptimal governance and leadership of HEIs;
i.) an ineffective regulatory system; and
j.) large affiliating universities resulting in low standards of undergraduate education.

This policy envisions a complete overhaul and re-energizing of the higher education system to overcome these challenges and thereby deliver high-quality higher education, with equity and inclusion. The policy's vision includes the following key changes to the current system:

a.) moving toward a higher educational system consisting of large, multidisciplinary universities and colleges, with at least one in or near every district, and with more HEIs across India that offer medium of instruction or programs in local/Indian languages;
b.) moving toward a more multidisciplinary undergraduate education;
c.) moving toward faculty and institutional autonomy;
d.) revamping curriculum, pedagogy, assessment, and student support for enhanced student experiences;
e.) reaffirming the integrity of faculty and institutional leadership positions through merit appointments and career progression based on teaching, research, and service;
f.) establishment of a National Research Foundation to fund outstanding peer-reviewed research and to actively seed research in universities and colleges;
g.) governance of HEIs by highly qualified independent boards having academic and administrative autonomy;
h.) "light but tight" regulation by a single regulator for higher education;
i.) increased access, equity, and inclusion through a range of measures, including greater opportunities for outstanding public education; scholarships by private/philanthropic universities for disadvantaged and underprivileged students; online education, and Open Distance Learning (ODL); and all infrastructure and learning materials accessible and available to learners with disabilities.

This vision of higher education will require, in particular, a new conceptual perception/understanding for what constitutes a higher education institution (HEI), i.e., a university or a college. A university will mean a multidisciplinary institution of higher learning that offers undergraduate and graduate programs, with high-quality teaching, research, and community engagement. The definition of the university will thus allow a spectrum of institutions that range from those that place equal emphasis on teaching and research, i.e., Research-intensive Universities, to those that place greater emphasis on teaching but still conduct significant research, i.e., Teaching-intensive Universities. Meanwhile, an Autonomous degree-granting College (AC) will refer to a large multidisciplinary institution of higher learning that grants undergraduate degrees and is primarily focused on undergraduate teaching, though it would not be restricted to that and it need not be restricted to that, and it would generally be smaller than a typical university.

Institutions will have the option to run Open Distance Learning (ODL) and online programs, provided they are accredited to do so, in order to enhance their offerings, improve access, increase GER (Gross Enrollment Ratio), and provide opportunities for lifelong learning. All ODL programs and their components leading to any diploma or degree will be of standards and quality equivalent to the highest quality programs run by the HEIs on their campuses. Top institutions accredited for ODL will be encouraged and supported to develop high-quality online courses. Such quality online courses will be suitably integrated into the curricula of HEIs, and a blended mode will be preferred.

Various models of curriculum development were proposed by various curriculum theorists and authors:

a.) Ralph Tyler's model (1949)
b.) Wheeler's cyclic model (1971)
c.) Nicholls and Nicholls (1972)
d.) Giles
e.) Walker's model (1972)
f.) Hilda Taba's model (1962)

The intent of all these models is to serve educational purposes through the formulation of a curriculum. While these models have the same intent, they still pursue or approach education from different premises (Adirika, 2017). Tyler's model is objective, Taba's is interactive, Wheeler's is cyclical, and Walker's is naturalistic or descriptive. The models reveal both similarities and differences. All the curriculum models have components of process, planning, implementation, and evaluation. They all have "beginning" and "ending" points.

After analyzing the mentioned models, Adirika (2017) concluded the following: the curriculum development process is a continuous one. It is not a one-time affair, because the curriculum serves a dynamic society. It cannot effectively help society meet its needs if it does not move with society. This is why it is continuously reviewed to ensure that it contains those elements that can help achieve the educational goals of society.

The COVID-19 situation is unprecedented, and, hence, there is no bias with regard to any of the mentioned models, and an independent, fresh approach was adopted. For the purpose of the study, we relied on data collected through a market survey. The survey was conducted in July 2021 on a sample of professionals, faculty members, researchers, and students in order to investigate the architectural education scenario and industry expectations for recent graduates of architecture programs. The study was carried out to bridge the gap between architectural education and professional practice.

Hence, we suggest revisiting and revising architectural education and curriculum by optimizing the course contents and weighing academic contact hours, while removing contents that are not of prime importance, and incorporating courses in view of a futuristic vision.

The professional practice of architecture requires considerable training in the use of CAAD techniques. There is a need to explore ways of improving the use of CAAD among undergraduate students. It is useful to evaluate and re-evaluate the education process to ensure that it goes in a parallel way with the practice field and to be informed of up-to-date computer applications (Soliman et al., 2019).

Methodology

We prepared a survey questionnaire aimed at identifying industry expectations for recent graduates. The sample size was 300 intended participants, whereas the rate of response was 115%. We selected participants based on purposeful sampling. The target group included practicing architects, academicians, researchers, and students with varying years of experience in India. Among the respondents, 49.2% were professionals, 31.7% were faculty members, and the rest were researchers, students, and employers. The respondents were given the option to record their suggestions, in addition to marking check boxes and choosing multiple-choice options. The outcome of this study is presented after analyzing various aspects like the type of courses and their importance (in quantified terms) as well as contact hours assigned for various courses, during the typical duration of a five-year full-time B. Arch. program in line with the Minimum Standards of Architectural Education 2020 recommended by the Council of Architecture (Council of Architecture, 2020a).

Survey Analysis

A wider look at the curricula of more than 30 Indian institutions indicates that an average of 75 courses are offered in UG-level programs, which is higher than in leading international institutions, where 45 to 60 courses are offered in the equivalent programs. Some academicians and professionals believe that these programs should be more exhaustive and include more courses. However, students feel exhausted with the number of courses. We think that an increase in their number reduces learning outcomes due to overburden.

Question 1: Which type of work is assigned to recent graduates (B. Arch.) during internship / professional training? (Please select/check minimum three, maximum five boxes).

Aspect: Task	Responses (%)
Concept development / architectural design	43.6
Preparation of architectural drawings (2D)	89.7
Preparation of architectural drawings (3D)	75.6
Estimation (BoQ) and costing	20.3

Building construction and site supervision	35.8
Interaction with clients	17.2
Preparation of reports and PPT presentations	65.3
Some other suggestions received	
Assistance to senior architects	0.6
Model making	0.6
Documentation of old projects	0.3
Research	0.3
Data/sample collection	0.3
Printing and documentation	0.6

Question 2: Which of the following skills a recent graduate (B. Arch.) must possess? (Please select/check minimum five, maximum seven boxes, which you think are most important).

Aspect: Skills	Responses (%)
Creativity and concept development	86.1
Visualization and 3D modeling	76.9
Preparation of error-free architectural drawings (presentation drawings and detailed drawings) using CAD/BIM tools	78.9
Estimation (BoQ) and costing	42.5
General management and administration	17.5
Project execution, building construction and supervision	36.4
Fundamental knowledge of building sciences (acoustics, climatology, and lighting)	68.9
Fundamental knowledge of building services (water supply, sanitation, HVAC, electrical, fire fighting)	73.9
Structural design of buildings	23.1
History of architecture	22.2
Environmental impact assessment and planning	33.6
Humanities and social sciences	17.8
Some other suggestions received	
Ability to unlearn the irrelevant	0.3
Knowledge of building bylaws and approval procedure	0.6
Business development and funding	0.6
Communication/writing skills	0.6
Professional behavior and ethics	0.3
Presentation drawings	0.6

Question 3: B. Arch. curricula should be overhauled since Institutions are teaching too much and some of the syllabus units/contents are not utilized by recent graduates (B. Arch.) in their work. Do you agree?

Aspect: Rating scale	Responses (%)
Strongly agree	23.1
Agree	26.4
Cannot comment on this	14.4
The B. Arch. curriculum in the majority of institutions is OK	24.4
Disagree	10.8
Some other suggestions received	
The B. Arch. curriculum will always need to be overhauled. It should have only fundamental units and the rest needs to be revised annually since the rate of urbanization is increasing with changes in technology. I think this is the right time to create a new curriculum system since the principles of urbanization and technological development of the 1960s are not followed anymore.	0.3
As an institution, we mostly focus on design subjects and electives, and other skill development subjects are mostly neglected by both students and institutions. This leads to half-baked knowledge because design skills alone are not enough in the field.	0.3
Some institutions teach all the content but they do not emphasize important topics. They should teach accordingly with account for the future and the professional field.	0.3
Architecture is a very strong mixture of arts, science, engineering, and social studies. A young architect must have an understanding of all these.	0.3
To be relevant to the modern world, the curriculum needs to be reviewed rather than overhauled.	0.3
The curriculum should be relevant to market demands and the latest construction trends.	0.3
What is really necessary is not curriculum revision but recruitment of good teachers (not necessarily good researchers/academicians). Whatever the curriculum, teachers can teach only what they know.	0.3
An upgrade is needed in line with the current scenario and demands of the professional industry.	0.3

Results and Discussion

The architectural profession can be seen as a developing and multidisciplinary career. It is one of the major professions that affect the development of a country. Architectural education is somehow special. Unlike other disciplines, architectural courses are usually hands-on in which students are confronted with projects and assignments, which simulate real projects. In addition, architecture is one of the most influential professions in our society as it involves all aspects that affect the way in which our built environment is designed, constructed, and used, thus affecting the user experience. It has however often been assumed that the universities do not produce graduates with the appropriate employability skills. Architectural firms are dissatisfied with the quality of the graduates and still note that they have to re-train fresh graduates to make them fit for their jobs before starting their practice. In addition, employers usually seek other skills apart from the technical skills gained during undergraduate studies (Khodeir and Nessim, 2020).

Higher education needs to prepare engineers of the future with the skills and know-how, which they will need to manage rapid change, uncertainty, and complexity. The key here is the ability to tailor engineering solutions to the local social, economic, political, cultural, and environmental context and to understand the impact of local action on the wider world. Although there is a global dimension within all subject areas, engineering and technology have unique importance in addressing global challenges, delivering environmental sustainability, international poverty reduction, and economic growth. India also has the potential to be a global technology leader. The Indian industry is competing globally in software and even in areas such as automobiles, chemicals, and engineering equipment (Parashar and Parashar, 2012).

As a result, giving the knowledge to the student on time, referring the student to research and gaining the habit of doing research, providing integration between theoretical and practical courses, and using theoretical knowledge in the practical application of design will promote a certain amount of creativity (Khodeir and Nessim, 2020).

The main benefit of elective courses in higher education is the flexibility achieved because these courses allow students to study subjects that satisfy their interests, abilities, and career determination. Elective courses help students develop their talent and nurture their individuality (Ghonim and Eweda, 2018). Elective courses also help them choose among wider available options in view of their interests and aspirations. Besides, students can study at their own pace by using MOOC (Massive Open Online Courses) platforms. This model will save time and cost of education for institutions since the majority of courses offered by online platforms have a nominal examination and certification fee, which is much lower in comparison to the classroom teaching costs. Pursuing elective courses with the use of online MOOC platforms will also develop the habit of self-study and strengthen lifelong learning abilities. It is likely that more students will be moving toward competency-based learning, which has an emphasis on developing unique skills and abilities. Learning has to be based on strengths and passions and become personalized.

Based on the market survey and policy/guidelines provided by Indian statutory bodies, the following recommendations can be made:

a.) Recent graduates (B. Arch.) should get jobs on the basis of their skills in preparing error-free architectural drawings (2D and 3D), and this is the fundamental expectation for recent graduates.

b.) Developing competencies in preparing error-free architectural drawings (2D and 3D) is more important than developing proficiency in architectural design and concept development. However, both are major core courses in the curriculum.

c.) Students must achieve proficiency in visualization and 3D modeling using computer applications.

d.) Knowledge of local and national building bylaws (as per the National Building Code of India) is a must.

e.) Knowledge of building materials and construction techniques is necessary.

f.) Building structures (analysis and design) courses can be revised since, in the current curriculum, significant contact hours are assigned to these courses, but students' learning outcomes are not satisfactory. The content of the syllabus and pedagogy of these courses require transformation.

g.) History of architecture courses are worthwhile but not so significant in the curriculum. The content and pedagogy of these courses require revision.

h.) Understanding building services is more important than understanding building sciences.

i.) Courses in environmental studies, together with environmental impact assessment and planning, must be given due weightage in the curriculum.

j.) More flexibility should be given to students to choose elective courses in view of their interests and aspirations.

k.) Online learning must be encouraged. Elective courses must be pursued with the use of MOOC platforms in order to develop the habit of self-study and lifelong learning. Some theory-based courses may also be pursued using online resources.

l.) The total number of courses offered in a semester may be restricted to six, with total credit limits in the range of 26 to 30, where the basic requirement for degree awarding is earning 270 credits. The definition of credit may vary among institutions since the weightage of contact hours vs. credits varies for lectures, workshops, and practical sessions.

m.) Flexibility should be considered for the inclusion of theme-based courses or courses in line with the specialization of the institution or in view of regional demands.

n.) Practical training of six calendar months (120 work days) must be considered to achieve the purpose.

o.) A thesis/project must be carried out independently by each student in the tenth semester with critical evaluation using checklists.

We consider 15 weeks of teaching in a semester of 18 weeks, where 3 weeks are reserved for examinations. As per the recommendations of Indian statutory bodies (Council of Architecture, 2020a), 30 contact hours per week are considered. Hence, the total contact hours are equal to 450 contact hours in a semester and 4500 contact hours during the entire duration of a five-year full-time B. Arch. program. The major challenge for academicians is to utilize those 4500 academic contact hours in a meaningful manner in view of the importance of various courses for prospective professionals.

Based on our understanding of architectural education, feedback from the industry market survey, suggestions from the respondents, and guidelines under the new education policy approved by the Government of India, we suggest a broad distribution of academic contact hours for various courses for a model curriculum of UG-level architectural education.

No.	Course Category	Suggested Courses/Modules/Units	Suggested Contact Hours	Suggested Credits
1	Architectural design	Can be distributed across min 6 to max 8 semesters Design aspects Theory of design Monofunctional units Multifunctional units Module-based units Campus planning High-rise buildings Mixed-use development Computational design	750	50
2	Architectural drawings	Can be distributed across the initial 6 semesters Freehand sketching Scaled drawings Orthographic projections Isometric drawings 3D visualization and sciography 2D architectural drawings 3D architectural drawings Rendering and presentation drawings Building Information Modeling Detailed (GFC) drawings	450	30
3	Basic design and visual arts	First semester	60	4
4	Building materials and construction technology	Can be distributed across the initial 6 semesters	450	30
5	Building sciences	Acoustics Climatology Lighting Can be taught in 2 or 3 semesters separately	150	10
6	Building services	Fire and life safety Water supply and sanitation HVAC services Electrical services Elevators and escalators Can be taught in 3 or 4 semesters separately	300	20

No.	Course Category	Suggested Courses/Modules/Units	Suggested Contact Hours	Suggested Credits
7	Building structures	Analysis and design courses can be planned in the initial 6 semesters	240	16
8	Environmental impact assessment and planning	Environment and ecology EIA and EMP Can be planned in 2 semesters separately	120	8
9	History of architecture	Can be planned in the initial 2 semesters	120	8
10	Principles of management and financial planning	Can be planned in the seventh semester	60	4
11	Professional practice	Can be planned in the seventh or eighth semester	60	4
12	Practical training / internship	Can be planned in the seventh or eighth semester	450	15
13	Estimation (BoQ) and costing	Cane be planned in the fifth or sixth semester	60	4
14	Thesis/Project	Can be planned in the tenth semester	450	15
15	Workshop practice	Can be planned in the first or second semester	60	4
16	Business communication	Can be planned in the seventh or eighth semester	60	4
17	Humanities, etc. as per the institution's specializations and/or mandated by statutory bodies	Human value and ethics Participation in social responsibility programs Health and fitness related activities Can be planned across the duration of the program	360	24
	ELECTIVE COURSES			
18	These shall be professional and/or any interdisciplinary courses, which should be mandatorily pursued with the use of MOOC platforms like SWAYAM/NPTEL/ATAL in order to develop the habit of self-study and lifelong learning. Students may choose courses based on their interests and aspirations.		300	20
		TOTAL	**4500**	**270**

It has been widely acknowledged that to thrive in a future globalized world, traditionally valued skills and knowledge will become less important and a new set of capabilities will become more dominant and essential. For humans to thrive in the age of smart machines, it is essential that they do not compete with machines. Instead, they need to be more human. Education must be seen as a pathway to attaining lifelong learning, satisfaction, happiness, wellbeing, opportunity and contribution to humanity. A new curriculum that responds to these needs must be simple, minimal, and easy to implement. It must help prospective professionals develop new competencies for the new era. The curriculum needs to focus more on developing students' capabilities instead of focusing only on the one-way transfer of content and knowledge.

Conclusions

The development of a student is like the growth of a plant. In this process, the curriculum and syllabus serve as the "seed". If the seed is defective, we cannot expect a healthy plant. It is imperative that curricula be formulated and refined from time to time. Besides, they shall be simple and easy to understand and implement. A well-designed curriculum facilitates faculty members to achieve educational goals without missing any content. Ambiguous curriculum and syllabus may lead to confusion among all process participants: students, faculty members, and examiners. Well-designed curriculum and syllabus are the key to maintaining similar information and understanding at all points. Though the curriculum is an ever-evolving entity, an attempt was made to suggest a simple model curriculum for UG-level architectural education, which can be adopted by institutions in the current scenario with further refinement in line with their vision and mission.

The COVID-19 crisis has forced us to review our educational model, which has been necessary for a long time. Education will undoubtedly go through major changes in this decade as the combined result of multiple major forces, including COVID-19 and the technological advancements of online learning. These changes include curricular changes that determine what is imperative to be learned by students and what is minimum to be offered by institutions to meet educational goals. We need to make sure that students have an educational experience that is relevant to the present time and globally accepted. With that in mind, we proposed a model curriculum for UG-level of architectural education in line with the expectations of the industry. The new or updated education model will indeed determine how and what the future generation of architecture students will be taught. In our efforts to bring about a change, let us try and fight for a new and better world.

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OTTOMAN ARCHITECTURE

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Abstract

Introduction: Throughout the years, numerous factors have contributed to the formation of city identity, urban fabric, and architecture. These factors include inspirations from various civilizations and religious influences. Architecture is also determined by such physical constraints as climate, geography, and the availability of specific materials. This article in particular addresses Turkey, a vast country with significant culture, and its architecture shaped by the strong identity of the nation. **Methods:** The article explores the influence of diverse aspects and intangible factors on Turkish residential and sacral architecture. For that purpose, the history of the Ottoman Empire is analyzed, and the evolution of the Turkish Hayat house is examined, which is the basis of various housing styles in Turkey. **Results and discussion:** Political will and ambition as well as the glorification of victories in battles were the key elements behind many landmarked mosques. As for the Hayat house, it is closely associated with the lifestyle of the Turks who founded the Ottoman Empire.

Keywords

Byzantine architecture, Ottoman architecture, Mimar Sinan, monumental mosques.

Introduction

The location of Turkey became a key factor shaping the Ottoman architecture since Turkey is situated between Europe and Asia, thus combining two cultures. It serves as a bridge between two conflicting religions: Christianity in the west and Islam in the southern regions. After the fall of Rome, Christianity spread to Constantinople (currently Istanbul). Constantinople stood as the seat of a new evolving empire for 1100 years till 1455. The areas to the east of Constantinople included many weak provinces, and that was the state of affairs till the arrival of the Seljuks and the establishment of the Seljuk Empire that lasted from 1037 to 1194. Hence, in the 11th – 15th centuries, the Turkish religious architecture was profoundly influenced by the surrounding cultures, in particular, those of the Byzantine Empire, Seljuk Empire, and various Islamic nations, and gradually formed its new identity by borrowing various components from them.

In his book, Al Abidin (2005) suggested studying the history of Turkey to gain a clear vision for the development of Turkish architecture. According to some historical resources, the history of the Ottomans dates back to the small Kayi tribe, which in the 13th century fled from the Mongol invasion and migrated in search of land to inhabit. The Seljuk leader was impressed with their bravery and granted the Kayi clan lands at the northeast border with the Byzantine Empire. That way they could fight against the Christians from the west. At the time, the Kayis were led by Ertuğrul. When he died, his son Osman, the future founder of the Ottoman Empire, became the leader of the clan. The successors of Osman expanded the Ottoman Empire west and south. For instance, in 1326, Orhan, one of his sons, took the lead and enlarged his province by conquering Bursa. Orhan's son, Murad I, conquered Adrianople, renamed it Edirne, and announced it the capital of the Ottoman Empire. Later, after Murad I was assassinated, his son Bayezid expanded the empire southeast. Mehmed the Conqueror, the grand-grandson of Bayezid, conquered the Christian city of Constantinople and made it the new capital, replacing Edirne. He brought an end to the Byzantine Empire. The fall of Constantinople dealt a massive blow to Christendom, as the Muslim Ottoman armies thereafter were left unchecked to advance into Europe. In 1453, after the fall of Constantinople, Hagia Sophia, the largest Christian church of the Byzantine Empire, was converted into a mosque. Hagia Sophia served as inspiration for Ottoman architecture. Its multi-domed roofing with a central spherical dome was adopted by the Ottomans in their mosques. Another element of early Ottoman architecture is the Byzantine technique of alternating courses of brick and stone. This technique replaced the ashlar facing of the Seljuk period in central and western Anatolia.

During the early era of the Ottoman Empire, resources were mainly used to defend or extend its boundaries. Therefore, churches were converted into mosques so that some building materials could be reused. According to the Turkish historian

Fig. 1. Portal to the of Ottoman Mosques and Seljuk stoneworkers (https://www.merhabahaber.com/ince-minare-yeniden-insaa-edilmeli-mi-1657595h.htm)

Doğan Kuban (2010), the Sultan took 50–90% of state revenues for personal use, leaving to city councils only 10%. Thus, in the early period of Ottoman expansion, architecture was undeveloped and was under the influence of Seljuk traditions. For instance, in Turkistan and the Islamic states of Anatolia (currently east of Turkey), the premises constructed by the locals were heavily influenced by Seljuk architecture, imitating its major features, which can be seen in ornamental stone buildings of elegantly simple design, harmonious proportions, and elaborate decoration around doorways. During the Seljuk period, not the dome but distinct portals and gates were the key elements of Ottoman mosques (Fig. 1). After the fall of the Seljuk Empire followed by the fall of the Ilkhanate, Mehmed the Conqueror turned to Anatolia to unite Anatolian beyliks under his rule. The monumental approach of the time can be seen in the building of Yakutia madrasa. *"From the reign of Murad I onwards, the Ottomans, having gained wealth and power as a result of the conquest in Balkans, now turned to a new monumental style based on their 14th-century experience and potentials"* (Kuban, 2010).

These monumental components manifested in the addition of twin minarets in front of the building (Fig. 2). *"Here a synthesis non-existent in the 13th century is created by the combination of a twin-minaret façade with a roofed madrasa. The 14th century witnessed in Eastern Anatolia the erection of an imposing monument reminiscent of the traditions of the proceeding century"* (Kuban, 2010).

Nonetheless, the influence of Christian architecture on local traditions was evident in the stonework of Yakutia madrasa.

In Europe, it was the religious authority that played a key role in constructing and subsidizing monumental architecture, while in Turkey, the willpower of sultans was the crucial factor behind the construction of spectacular monumental buildings. After the 14th century, the Ottomans gained more

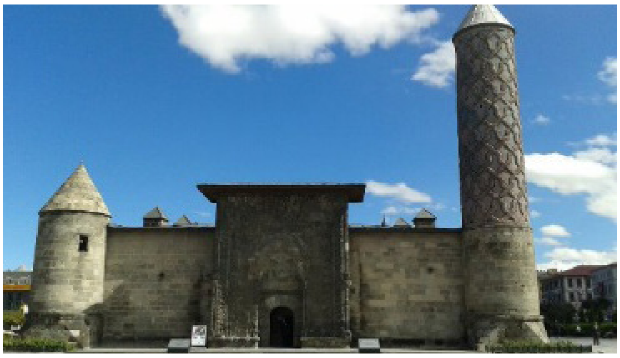
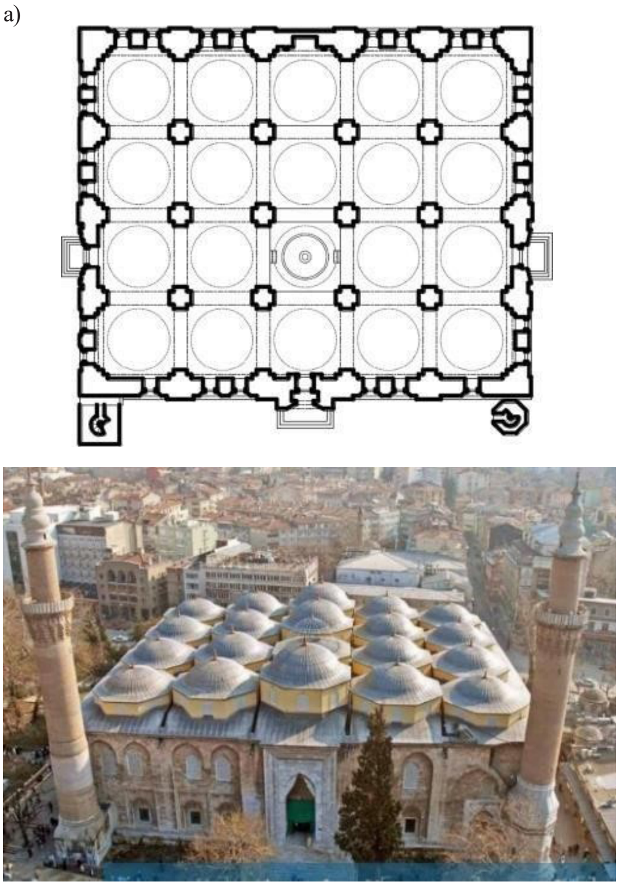


Fig. 2. Monumental portal to the Madrasa

a)



b)

Fig. 3a. Multiple-dome arrangement of the mosque (https://seyyahalemi.com/bursa-ulu-camii/)
Fig. 3b. A fountain in the middle of the prayer hall (https://acoustima.com/acoustic-solution-for-mosques/)

power and extended the boundaries of the Ottoman Empire. That is why they needed to construct monumental buildings reflecting the triumph of their achievements. Monumental mosques were erected in the main cities of political significance: Manisa, Bursa, Amasya, Edirne, and Constantinople. Thus, the core of imperial administration formed in those provinces, and high-ranked buildings, including palaces, conducting cultural, social, and commercial activities, appeared there. In the following section, we will consider several case studies to assess the development of the Ottoman style in sacral architecture. We will also study the history of Turkey and some other aspects to identify the main inspirations shaping Ottoman mosques.

Case Studies

1.1. Ulu Mosque, Bursa, 1396, Bayezid I

Political power surpassed all other factors, including religious and economic influences, in shaping the identity of architecture in the Ottoman Empire. Bursa was a key city in the political fabric of the Ottoman Empire, thus many state institutions were established there. During the Ottoman era, Bursa became a capital. Many monumental buildings were constructed in the city. New types of buildings appeared: baths, covered markets, courts, schools, and zawiyas (centers with various functions, such as being a place of worship, school, monastery, and/or mausoleum). Bursa was one of the most important cities in the Byzantine Empire. It was closely connected to the Western culture and remained virtually unchanged after the fall of the Byzantine Empire.

The growth of the city during the Ottoman era was determined by the desire of the Sultan. He instructed the construction of many zawiyas, public baths, and the great Ulu Mosque. The mosque in Bursa is one of the first mosques in Turkey. It manifests a shift in Ottoman architecture since the central dome was replaced by multiple smaller domes stretching over the prayer hall (Fig. 3a). Ordered by Sultan Bayezid I, the mosque was built in 1396 to commemorate his great victory at the Battle of Nicopolis. It is a major monument of early Ottoman architecture and one of the most important mosques in the city. The mosque has a rectangular shape and is crowned by twenty hemispherical domes replacing the central dome, which was a distinct feature of Byzantine architecture. The domes in the central row of the Ulu Mosque are higher than the rest, thus emphasizing the fountain located underneath (Fig. 3b). However, the Seljuk influence is quite evident: it manifests in the simple design, elaborate main gates, brick-built minarets, and stone structures. It should be noted that all those features were common in the first period of the Ottoman Empire.

1.2. Bayezid Mosque, 1501, Istanbul, Bayezid II

In the 14^{th}–15^{th} centuries, the mosque design gradually developed. The central dome over the prayer hall now was supported by a semi-dome instead of multiple columns. Before this new concept, numerous columns in prayer halls divided the internal space, separating the rows of those praying and interfering with the line of sight. The new concept provided a single spacious prayer hall. Bayezid II ordered to build a new mosque in his honor. It is known that Khair Al Deen was the architect who implemented this new approach of arranging single prayer halls for a better relationship between those praying and a person giving Friday speeches. The layout was changed from a rectangle to a cross. The cross layout reflects the influence of Byzantine Christian architecture, but this feature is undesirable in Islamic architecture. Nevertheless, the two asymmetrical wings in the west and east were considered new distinct elements. The roof over the east wing comprised four small domes with a large central dome, while the west wing included two additional domes, thus making the building a non-uniform multi-unit mosque (Fig. 4).

Kuban thought that this mosque was a great inspiration for many Ottoman architects, where the courtyard marked a turning point to the new approach in Ottoman architecture (Fig. 5). The central dome supported by two semi-domes over the prayer hall was inspired by the Byzantine architecture of Hagia

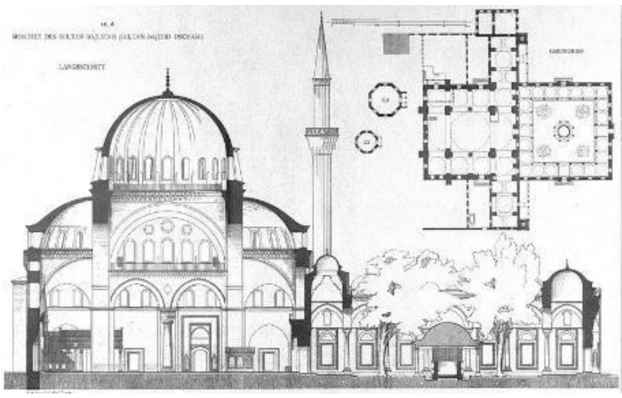


Fig. 4. Semi-domes of the mosque

Fig. 5. Roofing of the mosque

Sophia. The layout of this mosque and, in particular, its roofing was further developed in the Süleymaniye Mosque by the architect Mimar Sinan.

1.3. Üç Şerefeli Mosque, 1447, Edirne, Murad II

Edirne was one of the first cities where numerous churches were converted into mosques. The Üç Şerefeli Mosque was commissioned by Sultan Murad II and built in 1447 as a symbol referring to Edirne as the capital of the Ottoman state. In its design, the monumental approach was employed, which manifested in the following: 1. a single central dome supported by four lower domes emphasizing the central one, 2. emphasis on the prayer hall with the central dome centered around it, 3. taller minarets with three balconies next to the prayer hall. The mosque has a rectangular shape in plan. Here the influence of Byzantine architecture is less evident since the central dome dominates over the small ones and there are no semi-domes. The Üç Şerefeli Mosque features a new element — an open courtyard (Fig. 6) surrounded by open arcades. It also includes two types of minarets at the corners. The taller pair of minarets highlights the prayer hall (Figs. 6 and 7). The layout of the mosque represents an intermediate stage between the Seljuk Turkish style and the truly Ottoman style, which will later reach its pinnacle in Istanbul.

1.4. Şehzade Mosque, 1544, and Süleymaniye Mosque, 1557 (architect: Mimar Sinan)

The architect Mimar Sinan was a member of Sultan Selim's military campaigns and fought in many Ottoman battles in Europe, Asia, and Africa. He played an important role in shaping Ottoman architecture. During the battles, he advised on the construction of bridges within a shorter period of time, thus helping the army to advance and conquer cities. During his military career in the army of Sultan Selim and his son Suleiman, including the occupation of European cities, Sinan had the opportunity to study architectural monuments. He also was in charge of converting churches into mosques. The desire to design monumental mosques commemorating Ottoman emperors led Sinan to develop a different approach to iconic architecture (in particular, in his later career), which was employed in the Şehzade Mosque built to honor Suleyman's beloved son Şehzade Mehmed who died of smallpox at the age of 21. When designing the Şehzade Mosque, Sinan was inspired by Hagia Sophia but managed to come up with a unique approach to the construction of a larger central dome: 1. by supporting the pendentives of the central dome with four piers located at the corners of the dome; 2. by arranging semi-domes north, east, west, and south of the central dome so that the massive buttressed walls could take the load (Fig. 8). The four piers were topped with elegant small domes, and the massive buttressed walls were wisely concealed (Fig. 9). The dome dimensions varied in order to break the monotony and emphasize the central dome, forming a triangle (Fig. 10). A triangle emphasizing the vertical was an essential feature of the Ottoman style, employed in the Süleymaniye Mosque with a two-story gallery topped with domes and a pitched roof to break the monotony of similar-sized domes. The Süleymaniye Mosque is one of the most important historical landmarks in Istanbul, designed by Sinan and erected on the orders of Sultan Suleiman on one of the seven

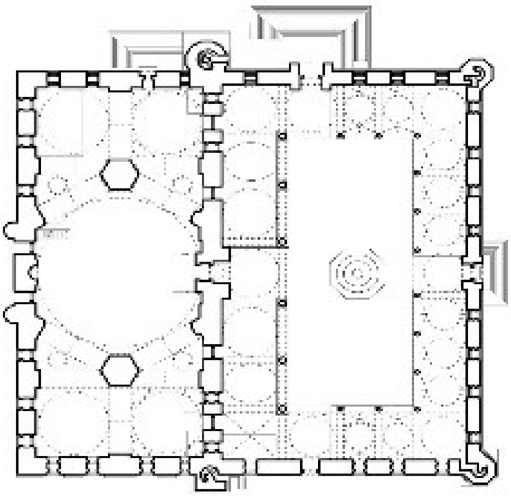


Fig. 6. Plan of the open courtyard

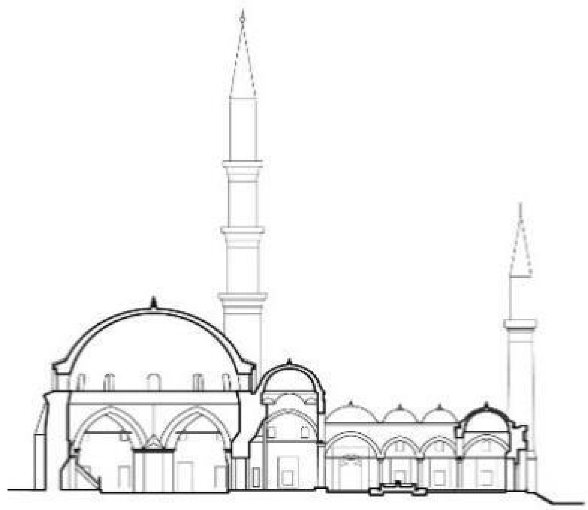


Fig. 7. Vertical of the building, emphasized by various components (https://cengizselcuk.com/edirne/)

hills of the city, which asserted Suleiman's historical significance. Sinan replaced two semi-domes north and south of the central one with five domes. They include two small domes alternating with three larger ones to break the monotony. Meanwhile, twin semi-domes remain on the east and west sides.

The Süleymaniye Mosque is the second largest mosque in Istanbul. It features both Islamic and Byzantine structural elements. The central dome is supported by semi-domes and four pillars, similar to those in the Şehzade Mosque.

The four minarets of the Süleymaniye Mosque refer to Suleiman's being the fourth sultan who took the throne after the conquest of Constantinople, while the ten balconies on the minarets refer to Suleiman's being the tenth Ottoman sultan (Figs. 11 and 12). The design of the Süleymaniye Mosque also plays on Suleiman's self-conscious representation of himself as a "second Solomon". It references the Dome of the Rock, which was built on the site of the Temple of Solomon, as well as Justinian's boast upon the completion of Hagia Sophia. The Süleymaniye Mosque, similar in magnificence to the preceding structures, asserts Suleiman's historical importance. The structure is nevertheless smaller in size than Hagia Sophia.

1.5. Selimiye Mosque, 1569, Edirne, Selim II

The mosque was commissioned by Sultan Selim II and designed by the great Ottoman architect Mimar Sinan. It stands at the center of a complex comprising a hospital, an Islamic school, a library, baths, and shops. For its location, Sinan chose Edirne's highest point so that it could be visible from every corner of the city. In his design, Sinan attempted to stand up to the rumors spread by Christian engineers who claimed that Muslims could not build a mosque larger than Hagia Sophia.

He employed a new approach by placing an octagonal supporting system created through eight pillars incised in a square shell of walls, and that allowed him to surpass the size of Hagia Sophia's central dome. The building represents political power as well as the development of economic and cultural functions. In fact, Sinan succeeded in creating a larger dome, but his design was inspired by Hagia Sophia: many elements were borrowed from Hagia Sophia, including the octagonal piers and the central spherical dome, small semi-domes around the central dome (Fig. 13), multiple-dome gradient in height (a creative approach forming a triangle), and

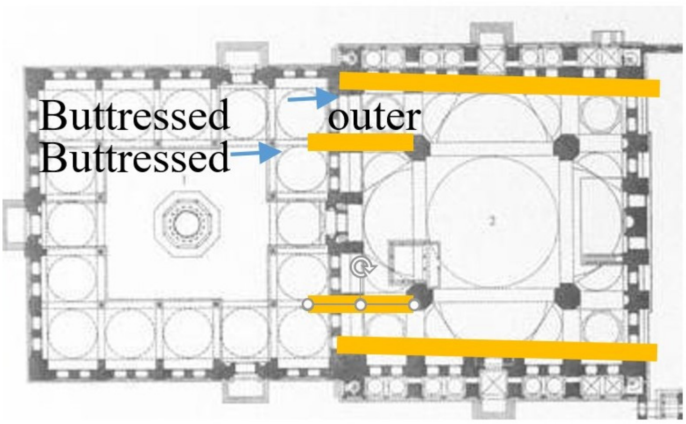


Fig. 8. Şehzade Mosque (on the top) (https://worldplaces.org/turkey/MGeKzcpENz97uCUlB2Rvlw-ehzade-camii.html)
Plan of the Şehzade Mosque with four semi-domes (from below)

Fig. 9. Domed towers of the Şehzade Mosque (http://gezgindergi.com/sehzade-camii/)

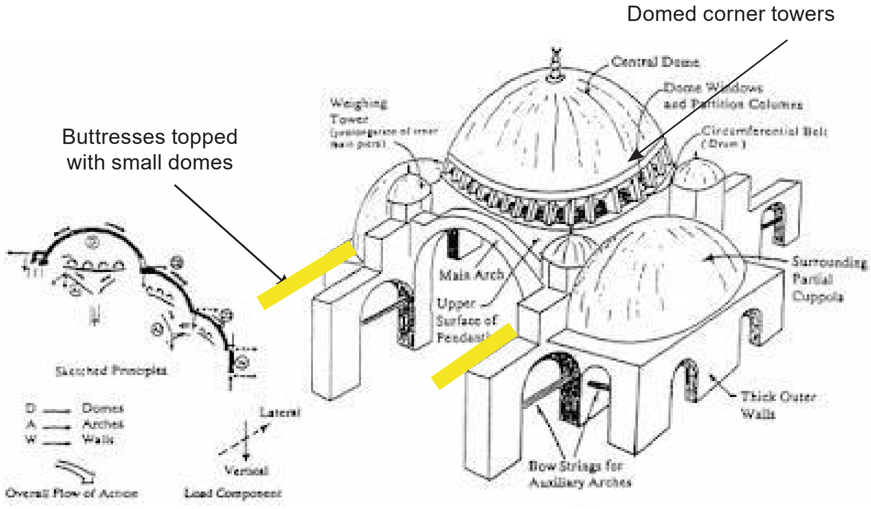


Fig. 10. Roofing system of the Şehzade Mosque

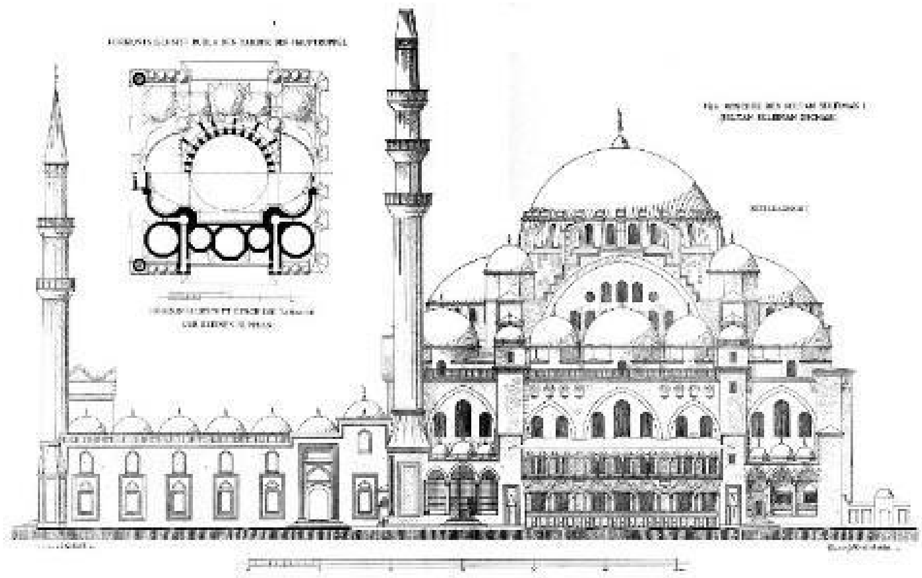


Fig. 11. Semi-domes around the central dome of the Süleymaniye Mosque (https://designarchitects.art/ottoman-empire-architecture-and-art/)

Fig. 12. Roofing of the Süleymaniye Mosque (https://www.manevihayat.com/konu/suleymaniye-cami-resmi.7641/)

Fig. 13. Hagia Sophia

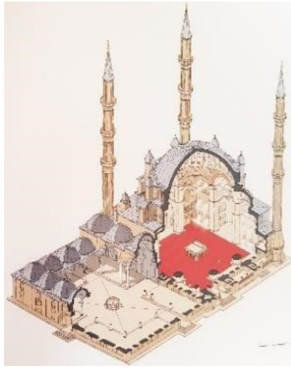


Fig. 15. Four minarets of the Selimiye Mosque

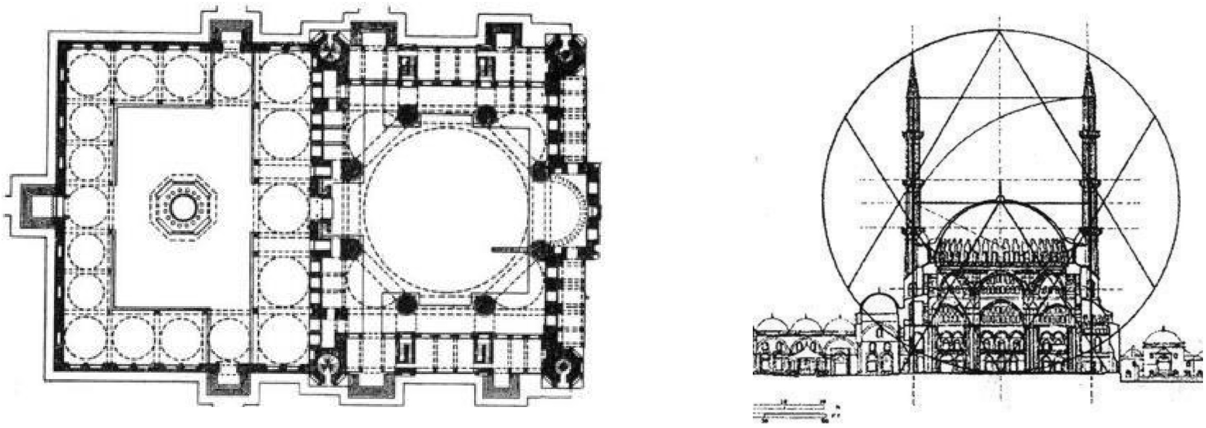


Fig. 14. Plan of the Selimiye Mosque, top view (on the left). Octagonal supporting system of the Selimiye Mosque and a triangle formed (on the right)

a preference for high land. When the construction of the Selimiye Mosque was finished, Sinan was 84 years old. He managed to overcome the need for four giant semi-domes around the one in the middle by replacing the square walls below the dome with an octagonal system on eight pillars (Fig. 14).

The result was a massive spacious inner dome and enhanced visibility in the prayer hall. The monumentalism and symbolism were highlighted by the use of the following six layers:

1. The first (base) layer is the arcade around the open courtyard.

2. The second layer is the passage from the prayer hall to the backyard.

3. The third and fourth layers connect the roofing with the vertical supports and accommodate the domed corner towers and buttresses. In these layers, the roofing is an alteration between the pitched roof, towers, and small semi-domes.

4. The fifth layer is the central dominant dome with eight pillars.

5. The sixth layer is represented by four minarets around the prayer hall (Fig. 15).

They emphasize the vertical of the structure, forming a triangle.

Hayat house

2.1. Background

The Hayat house design emerged thanks to the Turkomans who were nomads migrating from Central Asia or Western China. They converted to Islam during their migrations and around the 11th century settled in the Anatolian basin where they lived on agriculture, cattle breeding, and weaving. The Hayat house consists of many components, where the main one is an eyvan, a space leading to two rooms on each side (an open gallery). At later stages, the gallery evolved into many configurations (Fig. 16). The ground level was raised a little to form a half-basement that could be used as a stable or a store room.

The Halil Agha house in Mudanya (Bursa Province) is modeled after the Hayat house. It has a wooden colonnade with two-tier galleries and multiple openings on the front facade, while the side face is blind and does not have any openings. The Turkomans used open areas to move between the premises in a Hayat house since they originally lived in tents. This way is still used in the Balkans and Anatolian regions. When the nomads settled and stopped migrating, they adapted their customs to the new environment. Tents turned into rooms, and the Hayat house emerged.

Since they lived on agriculture and cattle breeding, the Turkomans designed the layout to suit their way of living. The open galleries of the Hayat house ensure contact with the surroundings and make it possible to supervise farming activities. Therefore, the possibility to move through open spaces is quite a logical solution.

2.2. Lack of privacy

However, such a layout resulted in a lack of privacy for women. Thus, since the Hayat house did not meet Islamic rules, open galleries were inadvisable.

In Islam, the configuration and components of a house must protect women's privacy and ensure they lead a secluded life. That led to the transformation of open galleries into inner courtyards with semi-open spaces. Furthermore, separate zones were allocated for men and women. Actually, such segregation was common in palaces and houses of wealthy owners. A middle-class house consists of multiple-purpose spaces. For instance, during the day, a living room is a place to welcome guests, but in the evening, it is mainly used by family members.

The idea of allocating separate zones for men and women became quite popular in the 18th and 19th centuries, as Muslims believed that houses are for family, and, since men are usually out during the day, they normally belong to women. In agricultural communities, women participate a lot in outdoor activities, while in urban environments, they spend most of their time at home. Thus, privacy is very important in urban residential areas. As a result, particular measures are taken to protect privacy: high walls, concealed openings, latticed and stained-glass windows, enclosed spaces, and separate zones for men and women. The living room on the first floor and other spaces project over the street, so the inhabitants can see what is outside without being seen. The Murat House in Bursa (Fig. 17) serves as an example of minor adjustments to the Hayat house, aimed to protect privacy. All rooms open into the gallery (hayat) but face the inner courtyard. The side walls extend to the ceiling, reflecting the continuity of blind openings, which was common for the 18th- and 19th-century houses.

The shape of the Hayat house evolved over time as can be seen in the Beyoglu house (Kula, Manisa Province). It is a typical version of the Hayat house, with all the rooms leading to the gallery (Fig. 18). The building has wooden colonnades. The upper level projects over the lower one, and the two rooms and the gallery extend further.

The Hayat house features additional extended spaces — a brilliant new element creating a three-dimensional effect. A similar approach was taken in the Cakiraga mansion in Birgi (Izmir Province), built at the end of the 18th century. The building was mostly rooted in antiquity, reflecting cultural relations with early nomadic peoples.

The Cakiraga mansion has a U-shaped layout and extends toward the courtyard. However, it is still determined by the original layout of the Hayat house, which consists of two rooms flanked by the eyvan (Fig. 19). In the Cakiraga mansion, the eyvans are at the end of the gallery, leading to additional rooms, forming a U-shape, and facing the garden. The areas projecting from the gallery extend the layout into the courtyard. This extended space forms new covered areas overlooking the garden, which can be used for socializing, family gatherings, and interaction with the private surroundings. Eyvans together with the rooms next to them, opening into the gallery, can be considered quite a new feature of Turkish houses.

In the case of the Cakiraga mansion (Fig. 20), the open layout of the Hayat house was transformed into a semi-open layout, which will further develop later. *"The Cakiraga mansion in Birgi represents a particular stage in the development of the Hayat house when the rural character of the house remained intact and its most highly developed characteristics were displayed"* (Kuban, 2010).

2.3.. Influence of Christian architecture on the Hayat house layout

In the 18th century, Turkish houses were affected by European culture. That resulted in the transformation of the Hayat house layout and its transition to the shape of a cross. This layout featuring double access is quite common in the dense urban fabric, where gardens and courtyards have minimum dimensions (Fig. 21).

For instance, the influence of Western architecture on the Sipahi house in Izmir is quite

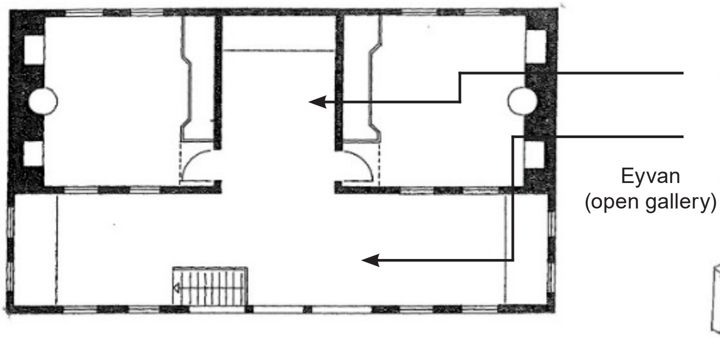


Fig. 16. Halil Agha house in Mudanya (Bursa Province), a typical Hayat layout

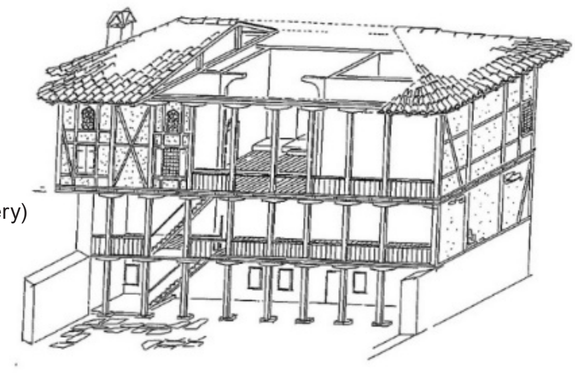


Fig. 17. Murat house, the blind wall without any openings

evident (Fig. 22). According to Kuban (2010), the house looks like a church with the layout in the shape of a cross, an opening in the middle, and four rooms at the corners, located symmetrically. He argued that the house design was affected by European influences and was characterized by symmetry and center-aligned halls (Kuban, 2010).

The axial arrangement is actually a version of the Hayat house layout without an open gallery, which usually opens into the surroundings, with the four eyvans transformed into enclosed spaces. In fact, the four eyvans with the rooms at the corners form a cross-like shape, thus reflecting the influence of Christian architecture. In densely populated areas in Central Anatolia, Balkan regions, and Istanbul, the mentioned center-aligned layout was transformed into a central sofa space going along the entire length of the house, with rooms on one or both sides of the sofa space (Fig. 23). At the ends of the rectangular sofa space, enclosed zones with windows are located, which ensure the visual connection with the outdoor landscape.

After World War I, massive destructions affected Constantinople (both the city center and other vast areas). According to many Turkish authors, the Hayat House and its altered version were already widely spread in the city and its early districts.

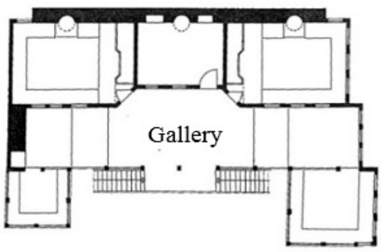
At the end of the 19th century, new luxurious waterfront houses emerged in the city, with the modified Hayat house layout where the premises were clustered around multiple horizontal and vertical axes. For instance, the Koceoglu palace built in the 18th century follows such an approach, where the components of the Hayat house are clustered around the vertical axis (Fig. 24).

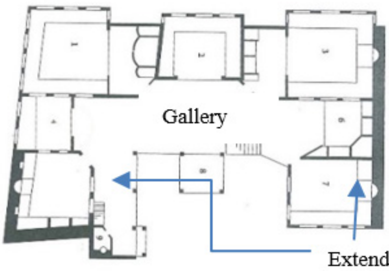
Furthermore, new elements were added such as columns in the middle of the main sofa space. The house was also divided into male and female sections, with corridors connecting them.

In the Koceoglu palace, the lower cluster of units is the female section. It consists of multiple private rooms and baths (hammams). This section is center-aligned and is further away from the entrance, while the upper male section is connected to the entrance. The layout of the Koceoglu palace was further developed in the Yasinci palace built at the end of the 18th century.

Fig. 25 shows rounded staircases and sofa spaces of the Yasinci palace. The palace also has male and female sections (men are not allowed in the female section). This layout is symmetrical along the vertical axis. The female (haramlek) section differs from the male (salamlik) section in some places, but this is less evident in the lower strata of society. The living room was used by men and women in turns (during the day and night).

The Saffet Pasha palace in Istanbul was built in the late 19th century. Here the idea of male and female separation is also evident. The male and female sections are located on the opposite sides of the space in the middle. Fig. 26 shows its layout in the shape of a cross, which is a modification of the Hayat house layout, symmetrical along the horizontal axis. According to Kuban (2010), in this layout, the core of the Hayat house with the sofa space in the middle is located on two sides of the





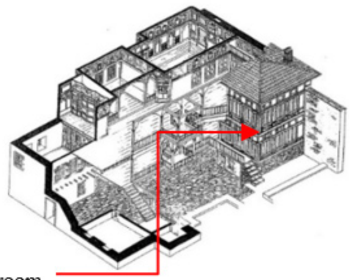


Fig. 18. (on the left). U-shaped Beyoglu house. Fig. 19. (in the middle). Cakiraga mansion.
Fig. 20. (on the right). U-shaped Hayat house, semi-open layout

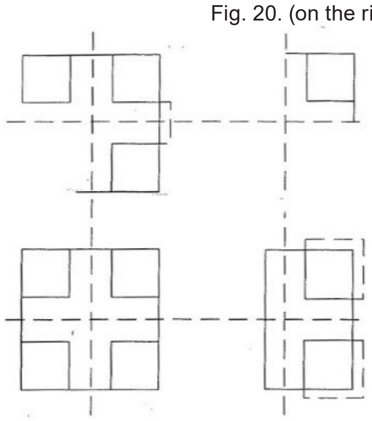


Fig. 21. Layout in the shape of a cross.

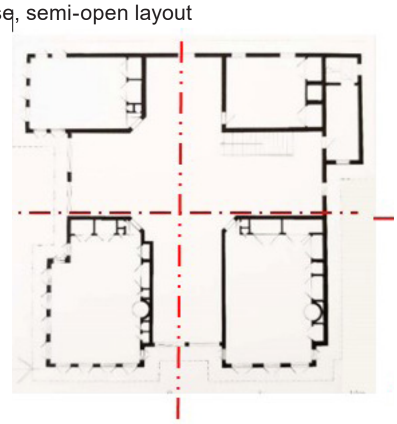


Fig. 22. Sipahi house with the layout in the shape of a cross

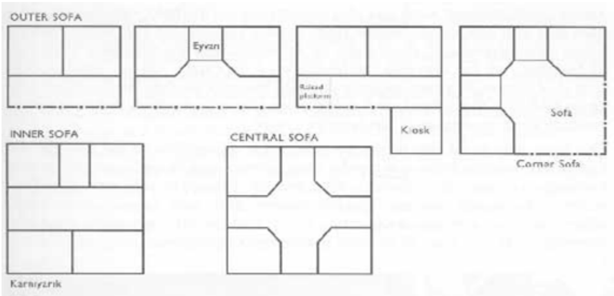


Fig. 23. Modification of the Hayat house layout

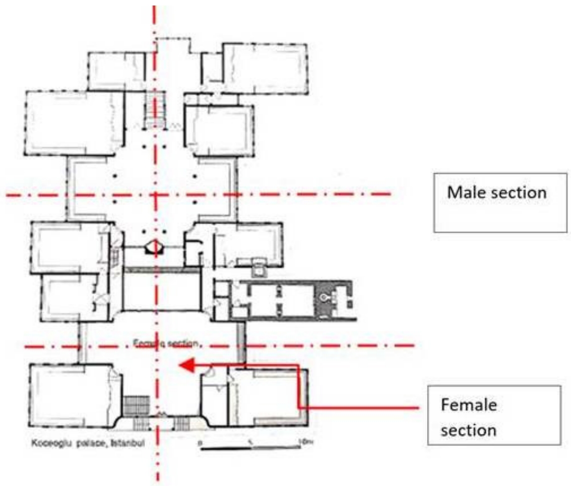


Fig. 24. Koceoglu palace

axis. Thus, the central space takes the shape of a cross (sometimes — an ellipse, much less often — a circle). The mansion is elevated from the ground, and the entrance has several steps, reflecting the influence of European architecture.

The layouts considered earlier were mostly used in large residential houses of wealthy people and merchants who conducted commercial activities at home, where privacy was a key factor.

All these case studies show that various layouts were actually based on the original Hayat house layout, where the basic components were altered, rearranged, or enclosed under religious, social, and cultural influences. The premises could be arranged along the horizontal or vertical axes. The sophisticated combination of premises in the Hayat house layout is reflected in the structure of buildings and is evident in the drawings of the Koceoglu palace or Saffet Pasha palace with stone as foundation material, sloped roofing, and walls with mudbrick between the timber frames.

The influence of the Turkomans is evident in many palaces and residential buildings. For instance, the ceiling of a living room may have a dome in the middle, imitating the shape of tents used by the Turkomans (Fig. 27). The use of the identical seating arrangement resulted in the development of a divan chamber (a room for male guests, or a spacious living room). The leaders of the tribe usually met people in huge tents, where legal cases were heard and other issues such as the needs of the tribe or future prospects were discussed (Fig. 28). Later, this was reflected in affluent residential buildings and palaces, with the divan space developed into a reception area.

In grander residential buildings and palaces, the divan space used as a reception area was a place where the Sultan would meet administrators and visitors. Later this resulted in a need to separate male and female sections to ensure privacy.

Conclusion

Prior to the establishment of the Ottoman Empire, architecture was heavily influenced by Seljuk, Islamic, and Byzantine approaches. After its foundation in the 13th century, Sultan Osman and his descendants conquered various provinces within and outside the borders of modern Turkey. The Ottoman Empire was named after Sultan Osman. Various Ottoman leaders occupied parts of Asia, Europe, and Africa, and those achievements forced them to create colossal buildings. For Ottoman Sultans who claimed to be leaders of Islamic nations, mosques were a symbol of political power rather than places of worship.

Political power (or will) was a key factor behind most monumental buildings in the Ottoman Empire. In fact, based on the research, it is possible to conclude that such intangible factors as architect Sinan's immense knowledge and willingness to challenge Christian engineering resulted in spectacular mosques. Due to the lack of funds in the early Ottoman era, churches were converted into mosques. At later stages, the accomplishments and triumph of the Ottoman army prompted Sinan to design monumental mosques surpassing Byzantine structures.

Byzantines were the first to use semi-domes around the central dome and arrange domes of different sizes near the main one, and Sinan embraced that method. Most of his proposals were heavily influenced by Byzantine and Greek architecture. Nevertheless, he made changes in the drum of domes, thus significantly improving the roofing framework in the Selimiye and Süleymaniye mosques. The connection between the dome and the supporting vertical wall is crucial, and Sinan ingeniously ensured a smooth transition between domes of different sizes.

Despite the use of rows of windows to soften strong lines, the buttressed side walls and the massive square space under the central dome of Hagia Sophia remained rigid. Sinan covered the massive walls by extending the domes along the side walls, forming a curved outline around the center of the mosque. In fact, the results of the

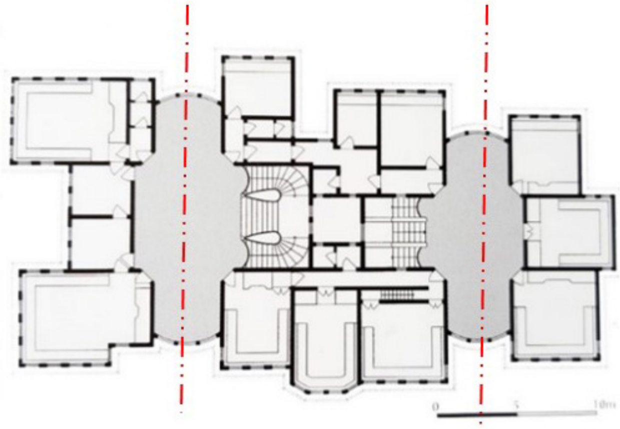


Fig. 25. Yasinci palace

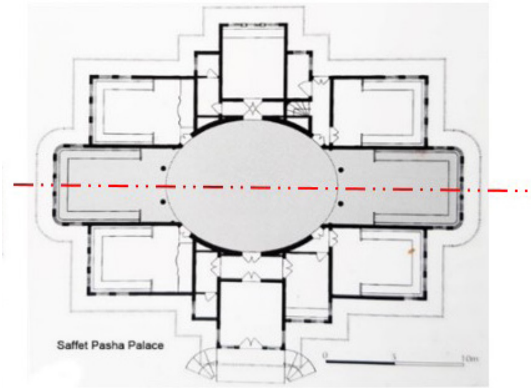


Fig. 26. Saffet Pasha palace. Male and female sections on the opposite sides of the sofa space in the middle

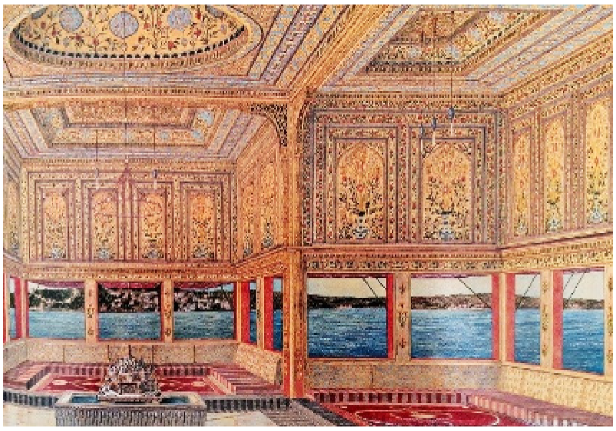


Fig. 27. Inner dome in a living room

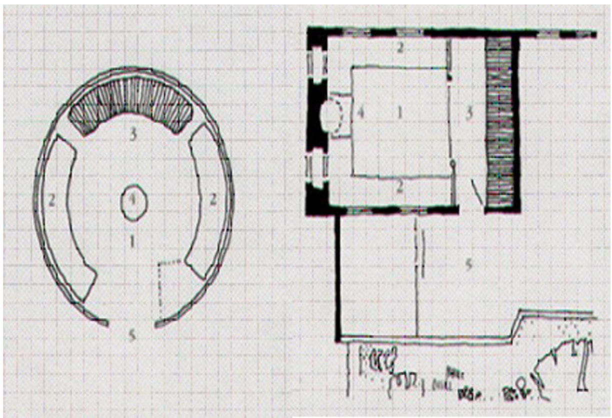


Fig. 28. Seating arrangement in a tent developed into the divan reception area

research show that Sinan and Ottoman sultans (or their remarkable success in expanding the empire's territory) were key factors in shaping the features of Turkish architecture and creating iconic buildings that combined Islamic and Christian architecture.

Osman, the founder of the Ottoman Empire, descended from the same tribe (Turkomans) that designed the layout of the Hayat house to suit their way of living. In both types of architecture, residential and sacral, the influence of the clan is very evident. Turkish iconic sacral architecture reflects the accomplishments and triumphs of the tribe, whereas the Hayat house components formed based on the needs of the Turkomans and their rural lifestyle. Residential buildings, such as the Hayat house, were intended to emphasize the close relationship with the surroundings.

The culture of the Turkomans is as rich as their architectural heritage, and the Hayat house became a key component of Ottoman architecture by reflecting those.

Traditional houses are just as important in Turkish culture as monumental buildings. In particular, they were built in agricultural settings, with the Hayat house emphasizing the close relationship with nature. According to several Turkish authors, the culture of the Turkomans is evident in strong ties with the surroundings. The open gallery of the Hayat house overlooking the countryside can serve as an example of that approach. During the Islamic period, a need for privacy became apparent, and the layout of the Hayat house was altered to ensure privacy. Now the gallery would overlook a private courtyard. With the development of that idea, the layout was later divided into male and female sections. The sophisticated combination of Hayat premises in Istanbul palaces of the 18th and 19th centuries followed Islamic rules while gradually incorporating elements of Western culture through the layout in the shape of a cross. Later, the Hayat house evolved in response to changing social and cultural needs, but its main components remained at the heart of various configurations. As a result, based on the centuries-old experience of ancient civilizations, Turks were able to handle those demands while also improving the elements and the concept of the Hayat house, which shaped a distinct Turkish style.

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ASSESSING THE PERFORMANCE OF UNITS FOR THE SYNTHESIS OF OLIGODYNAMIC SOLUTIONS FOR WATER TREATMENT

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Abstract

Introduction: Fresh water suitable for water supply has been depleted due to production activities. Thus, closed water supply cycles are required at civil infrastructure facilities. The quality of water must meet the requirements on its use for various purposes. It is common knowledge that water is essential in providing adequate health and sanitary conditions for the public. Therefore, issues of water treatment remain in the focus of researchers. Water disinfection is one of the mandatory methods used in water purification and treatment. Currently, chlorination is still the main technology for water disinfection. However, it is responsible for toxic, carcinogenic, and other types of negative effects on the human body. In this paper, we consider the use of oligodynamic solutions as a new, rapidly-developing direction in water treatment. In the course of our study, we addressed a method of swimming pool water disinfection using units of oligodynamic synthesis and examined the results of treated water quality analyses. **Methods**: The study was based on the statistical analysis of water quality indicators in pools with water treated with silver and copper ions. The analysis made it possible to determine the hygienic safety and reliability of products. To assess hygienic safety and reliability, we analyzed the composition and properties of the product (oligodynamic solution) as well as the composition and concentration of impurities in pool water and determined if the disinfecting properties of water are preserved and proper levels of copper and silver ions (not exceeding MAC) in pool water are maintained. **Results:** The paper provides a rationale for procedures to analyze and determine the safety and reliability of small-scale units producing disinfection solutions to ensure optimal swimming conditions in swimming pools. **Discussion:** The obtained results indicate that it is expedient to apply oligodynamic water treatment to ensure the hygienic safety and reliability of swimming pools. The technology suggested fully meets the requirements of sanitary regulations on water quality.

Keywords

Water quality indicators, oligodynamic solutions, oligodynamic synthesis units, hygienic safety and reliability.

Introduction

Our health and longevity depend on our lifestyle. That is why a healthy lifestyle is gaining more and more followers and is promoted at the state level. These circumstances determine trends in the construction and reconstruction of such health and leisure facilities as gyms, stadiums, swimming pools, etc. In their design, particular attention should be paid to the choice of water treatment method and technology. The choice of water purification technology and water purification systems depends on the sanitary and hygienic requirements on swimming pool water, the size of the pumping and filtering unit, the volume of the pool basin, the quality of feed water, technical and economic indicators, and other parameters.

Traditional methods of water disinfection with chlorine and its derivatives have particular negative effects, e.g., sensitizing and carcinogenic effects. Besides, such water may irritate the mucous membranes of the eyes and the respiratory tract and pose a toxic hazard in emergencies (overdose). The chemical transformation of substances contained in the water is of particular relevance since it results in the formation of organic halogen compounds dangerous to human health (Carter and Joll, 2017; Firuzi et al., 2020; Liu et al., 2020; Wyczarska-Kokot et al., 2020; Zhang et al., 2022). In new regulatory documents, significant changes have affected chlorine and chlorination by-products. Unfortunately, these changes are due to the disappointing statistics of mass poisoning in swimming pools. In the prior regulatory document, combined chlorine was not even included in the sanitary inspection program and was mentioned only when referring to the unit on standby. The maximum allowable concentration of residual chlorine has been reduced by 10 times and is equal to 0.2 mg/l (Sanitary Rules SP 2.1.3678-20 (Chief Public Health Officer of the Russian Federation (2020))). The maximum allowable concentration of chloroform has been changed as well, from 0.1 to 0.06 mg/l (Sanitary Rules and Regulations SanPiN 1.2.3685-21 (Chief Public Health Officer of the Russian Federation (2021))).

These new regulations are aimed at improving the safety of swimming pool water (both microbiological and toxicological) due to the use of chlorine-containing agents. Measures taken to gain a more comprehensive understanding of the water safety issue and risk management associated with the use of chlorine comply with the global trends creating a comfortable and safe environment. New regulations require all process participants to make informed decisions during swimming pool design and construction and ensure strict compliance with the maintenance mode during swimming pool operation.

Considering the above, it is required to turn attention to alternative methods of water disinfection to improve hygienic reliability and reduce the number of emergencies in swimming pools, caused by the negative effects of agents used in water disinfection.

In recent decades, new methods of industrial water disinfection by enriching it with metal ions were found. Among those methods, silver and copper electrolysis became the most popular. Those new technologies significantly improved the procedure of pool water treatment and provided particular advantages in terms of hygiene. For instance, silver-copper (oligodynamic) solutions form insoluble compounds with amines and carbamides — substances released by humans into water. The resulting solid sediments can be easily removed from the basin. Proper technological conditions aimed at maintaining the sub-threshold concentrations of these ions in the basin at a constant level can ensure a long-term disinfection effect, and that — in contrast to chlorine and oxidants — is without any chloramines, chloroforms, peroxides, and other derivative compounds prone to chemical transformations and causing negative effects for humans.

The method of water disinfection with silver and copper ions as well as the ions of other metals in the form of oligodynamic solutions (Adelshin and Leonteva, 2011; Allen et al., 2021; Karataev, 2009; Krasovsky et al., 2021) is based on the fact that very low concentrations (below the MAC level) of the positive ions of metals and other substances with high electric potential have an adverse effect on microorganisms. Pure silver and copper ions, which are not bound in salts and with other substances, have the ability to disinfect water. Their bactericidal effect manifests in the amounts significantly lower than the adverse effect and/or the sensation threshold (in terms of turbidity, odor, and water color index). What silver and copper ions have in common in their adverse effect on biological objects is their influence on the concentration of SH groups.

Oligodynamic solutions are aqueous solutions with antimicrobial characteristics due to low concentrations of the ions of mercury, silver, copper, iron, lead, zinc, bismuth, gold, aluminum, and other metals (Voznaya, 1967). This characteristic depends on the availability of the cations of metals with high electric potential (Ag++, Hg++, C++) as well as some non-metallic ions that can inactivate enzymes whose active groups are located on the surface of microbiological substrates (bacteria, cells).

During water treatment with oligodynamic solutions, water is enriched with silver and copper ions to sub-threshold values (bactericidal concentrations), which brings its composition closer to the natural one. The concentration of other constituents depends on feed drinking (tap) water.

The advantages of the method involving the use of oligodynamic solutions (as compared with water chlorination and other methods of water disinfection) should be evaluated not only by economic indicators but also by physicochemical and biological characteristics. It is those characteristics that ensure a hygienic advantage.

To collect and analyze data when evaluating water treatment method effectiveness, we considered AE-1 units for the synthesis of oligodynamic solutions, by AQUA-EFFECT Research and Innovation Enterprise (Units for the synthesis of oligodynamic solutions. Specifications TU 361469-001-30917173-2015 (AQUA-EFFECT Research and Innovation Enterprise (2015a))). Their operation is based on electrolysis using silver and copper electrodes. Water is treated automatically depending on the mode set. The following metals with an oligodynamic effect are used: silver in accordance with the requirements of State Standard GOST 25474-2015; copper in accordance with the requirements of State Standard GOST 767-2020. The unit provides the following rate of metal ion formation: silver — up to 3 g/h; copper — up to 2 g/h. The rated water consumption per unit is 1–5 m^3/h. The equipment is powered by a single-phase general-purpose network.

Based on the established procedure of water treatment, the water flow in the AE-1 unit is divided into two unequal parts. A small part of water (about 20 l/min) goes to an electrolysis reactor, where it is enriched with metal ions. Then it is transferred back to the main flow and goes to the filters.

Despite the apparent advantages of water enrichment with silver and copper, scientific and technical sources contain no objective research data on the safety and reliability assurance necessary to provide required water quality indicators. The Rospotrebnadzor (Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing) has not yet established requirements on swimming pools using methods of oligodynamic water treatment.

Materials and methods

We aimed to evaluate the efficiency of AE-1 units for the synthesis of oligodynamic solutions, used for swimming pool water disinfection. The efficiency, hygienic safety and reliability of AE1 units for oligodynamic synthesis and their products correspond to the ability of equipment in pools to maintain constant sanitary characteristics of water in the basin during the entire operation period in terms of microbiological, organoleptic as well as sanitary and chemical indicators.

To reach the goal, we analyzed studies performed by accredited laboratories for the following six facilities (Izhevsk, Lesnaya Nov, Mitino, Sportivny Park, Chuvashia, and Raduga). In total, we processed 445 laboratory water analysis reports, including 154 sanitary and bacteriological analysis reports, 148 organoleptic indicator analysis reports, and 143 silver and copper ion chemical concentration analysis reports.

Water quality indicators were analyzed in accordance with the requirements of the following regulatory documents: State Standard GOST R 51232-98 (Technical Committee for Standardization, 1998), Sanitary Rules SP 1.1.1058-01 (Chief Public Health Officer of the Russian Federation, 2001) and SP 2.1.3678-20 (Chief Public Health Officer of the Russian Federation, 2020), and Sanitary Rules and Regulations SanPiN 1.2.3685-21 (Chief Public Health Officer of the Russian Federation, 2021).

To evaluate the hygienic reliability of the units, hygienic and technical information blocks were formed. The hygienic information block includes data on the comparison of the laboratory analysis results with hygienic standards. The technical information block includes technical parameters characterizing the performance of the units.

The initial data (properties of water treated, used as dependent variables) were as follows:

- microbiological: total coliforms per 100 ml, etc.
- organoleptic: turbidity, color, odor.
- sanitary and chemical: silver (Ag) and copper (Cu) ion concentration.

The results of laboratory analyses according to Sanitary Rules SP 2.1.3678-20, Sanitary Rules and Regulations SanPiN 1.2.3685-21, and State Standard GOST R 51232-98 shall not exceed regulatory values. Any case when such regulatory values are exceeded can and should be considered an emergency (especially in terms of microbiological indicators), which gives “code red” to hygienic reliability.

Table 1 shows some regulatory values for water quality in swimming pools during water treatment using AE-1 units.

Table 1. Hygienic regulatory values for water quality

Indicator (dependent variables)	Regulatory value	Regulatory document
1. Sanitary water indicators		
1.1. Total coliforms per 100 ml of water	NMT 1	Sanitary Rules SP 2.1.3678-20
1.2. Thermotolerant coliforms per 100 ml of water	0	
1.3. Coliphages per 100 ml of water	0	
1.4. Staphylococcus aureus per 100 ml of water	0	
1.5. Enteric pathogens	0	
1.6. Pseudomonas aeruginosa per 100 ml of water	0	
1.7. Giardia intestinalis cysts per 50 l of water	0	
1.8. Eggs and larvae of helminths per 50 l of water	0	
2. Organoleptic water indicators		
2.1. Turbidity, mg/l	NMT 2.0	
2.2. Water color index, color degrees	NMT 20	
2.3. Odor, points	NMT 3	
3. Metal ions		Sanitary Rules and Regulations SanPiN 1.2.3685-21
3.1. Silver, mg/l	NMT 0.05	
3.2. Copper, mg/l	NMT 1.0	

External influences on the quality of treated water were determined by particular technical characteristics (used as dependent variables):

- Unit service life (days)
- Pool volume, m^3
- Water consumption, m^3/h
- Circulation flow, m^3
- Water change, m^3/h
- Pool attendance (people/day)
- Average swimming time per swimmer (person/hour)
- Electrode replacement time
- Number and diameter of filters

Based on the statistical analysis of the laboratory studies on water quality in six pools over five years, it was established that the following three criteria of the hygienic safety and reliability of AE-1 units shall be distinguished: microbiological, organoleptic, and ionic.

At the first stage of work, the size of a random sample was determined based on the data on nine pools for 230 months of their operation. The calculations were performed by the standard formula for the size of a random sample with three types of error (5%, 10%, and 15%), confidence level: 95%.

Results and discussion

The system used to evaluate the hygienic safety and reliability of synthesis products (pool water) and AE-1 units is based on microbiological, organoleptic, and ionic criteria.

The microbiological criterion is a qualitative indicator of the reliability of products and operating AE-1 units; there shall be no positive results in the detection of pathogenic and conditionally indicative microflora as well as the detection of surface contamination with the eggs of certain helminths. The criterion also determines the epidemiological significance of water treated.

The study of a random sample of 154 microbiological analysis reports for six pools over five years did not reveal a single positive result.

Table 2 lists the basic sanitary indicators of pool water (**microbiological studies**), determined by the applicable regulations (Sanitary Rules SP 2.1.3678-20, Sanitary Rules and Regulations SanPiN 1.2.3685-21). We performed laboratory water quality control by these criteria.

Table 2. Basic indicators of microbiological water safety in pools

Indicator (dependent variables)	Regulatory value
1. Total coliforms per 100 ml of water	0
2. Thermotolerant coliforms per 100 ml of water	0
3. Coliphages per 100 ml of water	0
4. Staphylococcus aureus per 100 ml of water	0
5. Enteric pathogens	0
6. Pseudomonas aeruginosa per 100 ml of water	0
7. Giardia intestinalis cysts per 50 l of water	0
8. Eggs and larvae of helminths per 50 l of water	0

All the microbiological analysis reports drawn up over five years show only negative results. Other methods of water disinfection cannot ensure such a result since there is always a possibility of microbial contamination (Cherkasova, 2007; Karataev, 2009; Krasovsky et al., 2020, 2021; Tul'skaya, 2012). That can be explained by the equipment configuration and the specifics of the process. If bacteriological studies show no positive results, therefore, no statistical analysis can be conducted for the system used to evaluate the hygienic reliability of AE-1 units. Thus, to develop the system, we will consider an alternative: "positive results—no positive results". That can be explained by the specific duration of the bactericidal effect of silver ions and the fact that, in terms of composition, oligodynamic solutions bring water close to the category of drinking water while maintaining disinfection properties. The analysis of data makes it possible to define the microbiological criterion of the safety and reliability of AE-1 units as "a qualitative indicator indicating the absence of harmful microflora in pool water" during the guaranteed service life (5 years (Sanitary Rules SP 2.1.3678-20)). The criterion is aimed at diagnosing the potential danger of infection transmission (taking epidemic control measures). Thus, the first criterion of the hygienic safety and reliability of AE-1 units is no positive results of microbiological studies. In case any indicative microorganisms are detected in water of pools equipped with AE-1 units, that should be considered an emergency requiring immediate response: from a detailed inspection of the units to water draining and disinfection of the basin and other.

The existing system for the hygienic evaluation of microbiological indicators of pool water in view of using electrolysis technologies for water treatment needs to be improved: the list of indicative microorganisms as well as methods of sampling for sanitary and bacteriological studies shall be defined more accurately (to the point of automating the identification of prioritized microorganisms).

The **hygienic evaluation of organoleptic characteristics** of water refers to turbidity, water color index, odor and other impurities. This evaluation is subjective since the ability to distinguish and evaluate odors depends on various external causes (air motion, other microclimatic conditions, etc.).

Table 3 and Fig. 1 show the summary indicators of descriptive statistics for the organoleptic factor. The sets of data cover an interval of 468 days and include the results of analyses performed with the use of new spectrophotometers.

Table 3. Statistics for organoleptic water characteristics

Indicator name	Interval (days)	Turbidity (mg/l)	Water color index (color degrees)	Odor (points)
1	*2*	*3*	*4*	*5*
Regulatory value =		NMT ≥ 2.0	NMT ≥ 20	NMT ≥ 3
Mean =	467.8	0.511	2.446	0.568
Error of the mean (set of data) =	75.5	0.132	0.260	0.130
Variance =	*193,377.5*	*0.592*	*2.302*	*0.577*
Standard deviation =	*439.8*	*0.769*	*1.517*	*0.759*
Mode No. =	9	0.1	2.4	0
Median =	378	0.325	2.2	0
Maximum =	1454	1.7	7.3	2
Minimum =	1	0.1	0.3	0
Amplitude =	*1453*	*1.6*	*7*	*2*

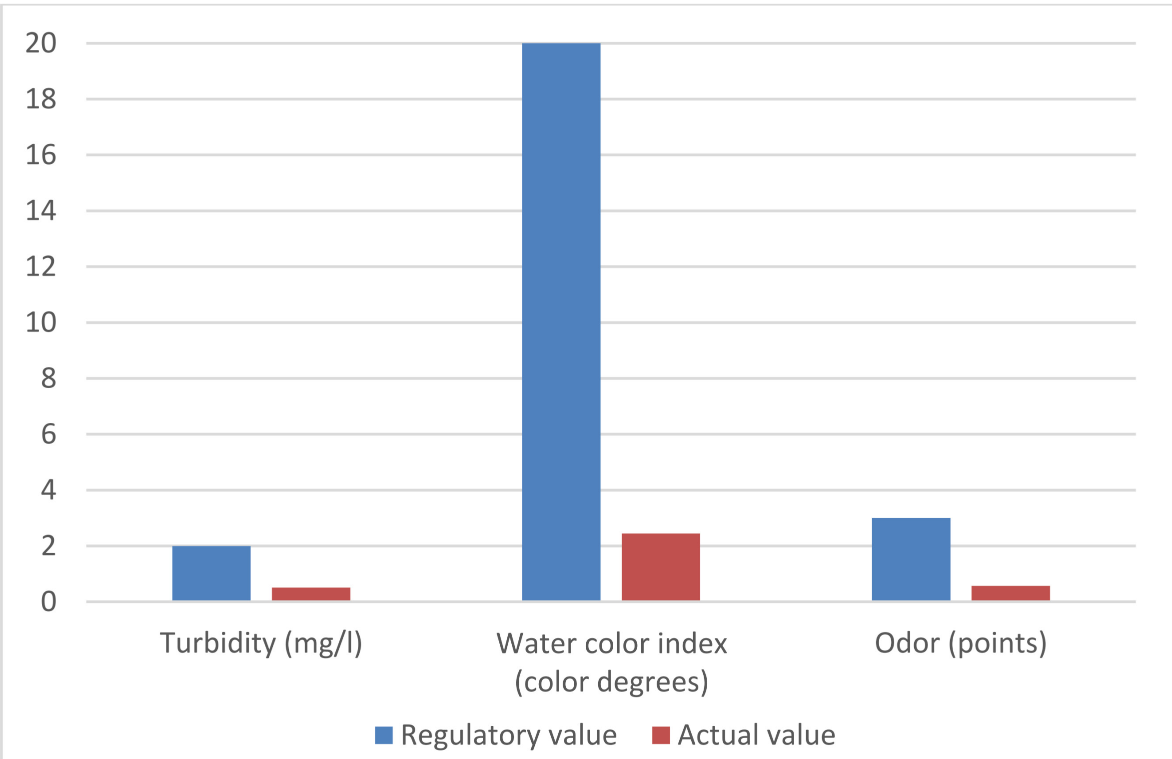

Fig. 1. Summary indicators of descriptive statistics for the organoleptic factor

The mean values of turbidity, water color index, and odor do not exceed the regulatory values. The monotonicity of the series also manifests in scattering indicators, shifts in the median as well as in modal values, showing the most frequently encountered number in a set of values analyzed.

Based on Table 3, we established the relationship between changes in the organoleptic water characteristics and service life.

The calculations showed the following:

- the relationship between turbidity and the service life of AE-1 units is inverse (the longer the service life, the less turbidity) and weak: Rxy = –0.287 units (correlation) and Dt = 8.2% (explained variance). (Rxy is the correlation coefficient showing relationships between the variables analyzed, Dt is the correlation coefficient characterizing the value of "linkage" between the variables in percent (Aivazyan et al., 1989; Förster and Rönz, 1983).
- the relationship between the water color index and the service life of AE-1 units is inverse (the longer the service life, the lower the water color index), not significant (almost no relationship): Rxy = –0.041 units (correlation) and Dt = 0.2% (explained variance).

The described algorithm to evaluate relationships between organoleptic indicators and service life can be used to measure the hygienic reliability of AE-1 units in other cases.

When the regulatory values indicated are exceeded, this means that, based on subjective evaluation, water is not suitable for swimming or may point to water disinfection procedure violation or AE-1 unit malfunctions. In this case, it is required to perform a detailed inspection of the units and a search for causes behind the overall and specific (microbial) contamination of the pool.

Organoleptic water indicators are semi-quantitative (mainly subjective) and, therefore, cannot always be used in statistical studies. Oligodynamic water disinfection requires the improvement of methods used to determine corresponding indicators and minimization of subjectivity as far as the procedure and analysis results are concerned.

Over five years, the pools studied did not show any signs of substandard water quality in the basin (elevated turbidity and water color index, odor).

The third reliability criterion, the **ionic** criterion, is the most complex one. Its distinctive feature is that there are no directions regarding the frequency of control over silver and copper concentrations in water in the applicable sanitary regulations. Besides, the residual amounts of these substances in the analyzed laboratory control materials never exceed the specified MACs (they are always 15–20% lower).

The disinfection characteristics (the **ionic quality criterion**) of AE-1 units are determined by the technology of obtaining and using silver and copper ions. This disinfection procedure is a new special technology. It might be that silver and copper concentrations in water will serve as the most relevant sign of safety and reliability.

The procedure implies water enrichment with silver and copper ions. When bactericidal ions enter the water, most of them bind to the microflora, and the rest of them remain in the solution. The latter can persist in water for a long time and should be classified as those "in the form of residual (background) concentrations".

Table 4 shows statistics of changes in silver and copper concentrations in the collected water samples, where the total number of sampling days is equal to 68,740.

According to the analysis of the reports, the mean background concentrations do not exceed the MAC levels (Sanitary Rules and Regulations SanPiN 1.2.3685-21):

- silver: 0.024 ± 0.03 mg/l with a regulatory value of NMT 0.05 mg/l;
- copper: 0.221 ± 0.014 mg/l with a regulatory value of NMT 1.0 mg/l.

Therefore, the most frequent modal values are as follows: for the first series of 647 days, silver — 0.011 mg/l and copper — 0.22 mg/l. The amplitude of the series in absolute values is as follows: silver — 0.22 mg/l, copper — 0.92 mg/l (at the MAC levels of NMT 0.05 and 1.0 mg/l, respectively).

Based on the studied set of analyses, the most significant mean residual (background) concentrations are as follows (mg/l):

- silver — 0.0005 (minimum), 0.024 (mean), 0.224 (maximum);
- copper — 0.001 (minimum), 0.221 (mean), 0.92 (maximum).

The relevance of the ionic criterion is determined by the following:

- silver and copper ions are responsible for the main function of oligodynamic solutions, which is disinfection (bactericidal effect);
- the persistence and/or the residual amount of ions ensure the antimicrobial characteristics of water;
- ion concentration control means the evaluation of the antimicrobial characteristics of water in the pool basin and, therefore, requires monitoring.

However, despite the comprehensive statistical data, Table 4 does not give a full picture for the hygienic evaluation of variations in ion concentrations. Therefore, we will try to analyze relationships between the obtained concentration series and the number of unit operation days (sampling days) as well as the corresponding relationships for silver and copper concentrations. In fact, we need to resolve the following question: Is there a relationship

Table 4. Statistics of changes in residual concentrations of silver and copper by sampling days

Indicator name	Sampling days	Silver ions	Copper ions
Total operation days	68,740	2.593	24.035
Mean (background concentration)	630.6	0.024	0.221
Error of the mean	*33.8*	*0.003*	*0.014*
Variance	*124,441.0*	*0.001*	*0.022*
Standard deviation	*352.8*	*0.035*	*0.147*
Mode No. =	220	0.009	0.17
Median =	647	0.011	0.22
Maximum	1464	0.224	0.92
Minimum	1	0.0005	0.001
Amplitude	1463	0.2235	0.919

between the service life (equipment wear) and silver and copper concentrations in solutions?

The calculations of the sampling days / ion concentration correlation coefficients (a sample with n = 143) showed the following: silver ions — Rxy = –0.103 units (Dt = 1%), copper ions — Rxy = –0.109 units (Dt = 1%).

The obtained values indicate that there is almost no correlation between the service life and concentrations. Despite the problematic relationship with this indicator, an inverse correlation is observed: the greater the consumption of silver, the lower the consumption of copper (and vice versa). This circumstance requires further research.

In 143 samples of water from pools equipped with AE-1 units, the MAC levels were not exceeded. The dynamics of changes in residual (background) ion concentrations in the case under consideration may be the result of periodic procedures performed during electrode replacement. No rigid correlations between ion concentrations and the service life were established in the analyzed statistical material. Besides, considering the similarity of dynamics with regard to organoleptic indicators and metal concentrations, we can assume that they depend on the load, i.e., the number of visitors per day (sampling day). This circumstance can serve as a reference point when determining the sampling term. However, given the results of studies on metal concentrations and organoleptic evaluations, it is possible to recommend sampling for residual ion concentrations at a frequency of once per month (approval from local Rospotrebnadzor (Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing) authorities is mandatory).

The analysis of ion concentration dynamics makes it possible to select silver and copper ion concentrations as the third criterion of the hygienic reliability of equipment. The obtained statistics for the mean metal concentrations can be used as a temporary hygienic reference point.

The obtained mean metal concentrations in the samples analyzed (Table 4) can serve as temporary reference regulatory values, which can be used to evaluate the hygienic safety and reliability of the products of AE-1 units for the synthesis of oligodynamic solutions.

The method used to calculate the **composite index** for the relationships in the set of “regulatory value – actual value” pairs with different dimensions has such an advantage as the possibility to take into account both cases when regulatory values are exceeded and cases when sub-threshold values are observed (Aivazyan et al., 1989; Förster and Rönz, 1983).

This characteristic is determined by the reduction of arrays of heterogeneous information in relation to the corresponding standards in a weighted Euclidean space. For instance, the “regulatory value – actual value” pairs are measured in dB, lx, mg/l, etc. Using a computational procedure, they can be combined into a single numerical estimate showing how an entire set of indicators differs from the regulatory values: ≥ 1.0 — the array includes cases when regulatory values are exceeded ≤ 1.0 — sub-threshold values prevail in the array (Aivazyan et al., 1989; Gnedenko et al., 1965).

In **Table 5**, along with the absolute mean (background) values of turbidity and water color index (line 2), composite estimates are shown (line 3). It can be seen that the composite indices of turbidity and water color index and the total index (0.490 ± 0.1, 0.137 ± 0.04, and 0.344 ± 0.02) are less than 1.0 relative units.

Therefore, the regulatory values of turbidity and water color index are not exceeded, and no such cases are expected. If relevant data are available, the same calculations can be performed for other organoleptic characteristics.

As for odor, the composite index was not calculated due to the highly monotonous series, all the more so as no cases when regulatory values are exceeded were observed.

Table 6 presents the actual and composite estimates for the concentration of residual ions in water. It can be seen that regulatory values in terms of the mean values and composite estimates were not exceeded (0.917 ± 0.014 for silver and 0.137 ± 0.04 for copper, respectively).

The total composite estimates for all four reliability characteristics (two organoleptic and two ionic) are shown in **Table 7.** The total composite estimate calculated for a sample of 594 reports is equal to 0.904 units, which indicates that there were no cases when regulatory values were exceeded in the analyzed set of 594 “regulatory value – actual value” pairs.

The method used to obtain composite estimates confirms the conclusions previously made, indicating no cases when regulatory values were exceeded in terms of organoleptic and ionic criteria. The values of the composite indices show that such cases cannot be possibly observed.

Conclusions

The paper addressed procedures to analyze and determine the safety and reliability of small-scale units producing disinfection solutions to ensure optimal swimming conditions in swimming pools.

We studied AE-1 units for the synthesis of oligodynamic solutions, used for water disinfection in swimming pools of any type. Their operation is based on silver and copper electrolysis, since the ions of these metals have a bactericidal effect. As compared with other units (UV, ozone, and other oxidation systems) and methods of water treatment (chlorination), the units under consideration have a number of advantages: for instance, they form solid copper-coagulated compounds (that can be easily removed from water) with amines introduced into the pool basin by swimmers; there are no chemical transformations of disinfection agents as in the case of chlorination, etc.

We performed the statistical analysis of five-year laboratory studies on the water in six pools equipped with synthesis units, which showed that the criteria of hygienic reliability are as follows:

- microbiological criterion (qualitative), which requires that there shall be no positive results in the detection of indicative microflora during the entire period of operation;
- organoleptic criterion (turbidity, water color index, and odor), which requires that

Table 5. Composite estimates for hygienic characteristics of organoleptic indicators

Indicator	Turbidity	Water color index	Total index
1	*2*	*3*	*4*
Regulatory value	NMT ≥ 2.0 mg/l	NMT ≥ 20 color degrees	X
Absolute value	0.404 ± 0.1	2.4 ± 0.02	X
Composite index	0.490 ± 0.1	0.137 ± 0.04	0.344 ± 0.02

Table 6. Composite estimates for background silver and copper concentrations

Indicator	Concentration	
	Silver	Copper
1	*2*	*3*
Maximum allowable concentration, mg/l	0.05	1.0
Absolute value	0.21 ± 0.01	0.73 ± 0.01
Composite index	0.92 ± 0.01	0.14 ± 0.04

Table 7. Total composite estimates for background indicators of organoleptic characteristics and mean silver and copper concentrations

Indicator name	Turbidity	Water color index	Silver	Copper	Total
1	*2*	*3*	*4*	*5*	*6*
Absolute value	0.4 ± 0.1	2.4 ± 0.02	0.21 ± 0.01	0.73 ± 0.01	X
Composite index	0.5 ± 0.1	0.14 ± 0.04	0.92 ± 0.01	0.14 ± 0.04	0.904

regulatory values shall not be exceeded during the entire life cycle of the facility;
- sanitary and chemical (ionic) criterion, which requires that silver and copper concentrations shall not exceed the MAC levels during the entire period of AE-1 unit operation.

The hygienic safety of the units is determined by zero cases when regulatory values are exceeded. For instance, the analysis of 143 reports over five years showed the following mean concentrations (Table 6, at the following MAC levels: silver — NMT ≥ 0.05 mg/l in terms of the sanitary and toxic index, copper — NMT ≥ 1.0 mg/l in terms of the organoleptic index):

• silver — 0.0005 (minimum), 0.024 (mean), 0.224 (maximum);

• copper — 0.001 (minimum), 0.221 (mean), 0.92 (maximum).

The indicated mean ion concentrations based on the statistics of laboratory analyses can be considered temporary reference points that can be used for water quality control in the pool basin.

The results of the statistical analysis of laboratory control indicators in a random sample of reports with the use of six AE-1 units for the synthesis of oligodynamic solutions over five years and calculations of ion intake from pool water indicate their sufficient efficiency as well as hygienic safety and reliability in terms of requirements of Articles 18, 19, and 24 of Federal Law No. 52-FZ dated March 30, 1999 (State Duma of the Russian Federation, 1999).

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ОЦЕНКА ЭФФЕКТИВНОСТИ УСТАНОВОК СИНТЕЗА ОЛИГОДИНАМИЧЕСКИХ РАСТВОРОВ В ТЕХНОЛОГИИ ВОДОПОДГОТОВКИ

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Аннотация
Сокращение пригодной для целей водоснабжения пресной воды, связанное в первую очередь с производственной деятельностью, обуславливает необходимость использования замкнутых циклов водообеспечения объектов гражданской инфраструктуры. При этом качество воды должно соответствовать требованиям к её использованию для различных целей. Общеизвестна роль воды в обеспечении здоровья населения и создании санитарных условий его жизнедеятельности. Поэтому вопросам исследования методов водоподготовки уделяется большое внимание. Процесс обеззараживания воды относится к обязательным методам, применяемым в очистке и водоподготовке. Основной применяемой технологией для обеззараживания воды продолжает оставаться хлорирование несмотря на то, что является причиной токсического, канцерогенного и других видов негативного воздействия на организм человека. Использование олигодинамических растворов – одно из новых и активно развивающихся направлений в системах водоподготовки. В статье рассмотрен метод обеззараживания воды плавательных бассейнов с использованием установок олигодинамического синтеза, а также проведено исследование результатов анализа показателей качества обработанной воды. **Методы:** Исследования базируются на методах статистического анализа показателей качества воды бассейнов с обработкой ионами серебра и меди, который позволяет охарактеризовать гигиеническую безопасность и надежность продукции для здоровья пользователей. Гигиеническая надёжность и безопасность оценивается составом и свойствами производимого продукта (олигодинамический раствор), составом и содержанием примесей в воде в бассейне, сохранением обеззараживающих свойств воды и исключением ситуаций повышенных уровней ионов меди и серебра (превышение ПДК) в воде бассейна. **Результаты:** В работе обоснованы методические приёмы анализа и прогноза соответствующей надёжности и безопасности малогабаритных установок, производящих дезинфицирующие растворы для обеспечения оптимальных условий занятий плаванием пользователей бассейнов. **Обсуждение:** Полученные результаты обосновывают целесообразность использования олигодинамической обработки воды для обеспечения гигиенической надежности и безопасности плавательных бассейнов. Предлагаемая технология полностью обеспечивает требования санитарных регламентов по качеству воды.

Ключевые слова
Показатели качества воды, олигодинамические растворы, установки олигодинамического синтеза, гигиеническая безопасность и надежность.

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MODELING NON-STATIONARY TEMPERATURE FIELDS WHEN CONSTRUCTING MASS CAST-IN-SITU REINFORCED-CONCRETE FOUNDATION SLABS

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Abstract

Introduction: Due to hydration heating and heat exchange with the environment during hardening, mass cast-in-situ reinforced-concrete structures exhibit non-uniform heating, which can result in early cracking and make the structures unsuitable for further use. One of the main risk factors for early cracking is the temperature difference between the center and the surface of the structure. **Purpose of the study:** We aimed to study how such factors as the ratio of dimensions, heat transfer conditions on the surfaces, concrete recipe, pauses during concreting and their duration affect the maximum temperature difference between the center and the surface of the structure. **Methods:** In the course of the study, we applied finite element modeling in one-dimensional and three-dimensional cases using the software in the MATLAB environment that we developed earlier. **Results:** We established that the most significant risk factors for early cracking are heat exchange conditions on the top surface, structural thickness, and the heat release rate of concrete. Verification and validation of the model were performed based on experimental data and by comparing it with a numerical solution in the ANSYS software.

Keywords

Mass reinforced-concrete structures, foundation slab, cracking, temperature field, finite element method, internal heat sources.

Introduction

The issue of cracking in hardening reinforced-concrete structures has been existing as long as reinforced concrete itself. It was first encountered at the beginning of the 20th century during dam concreting (Javanmardi and Léger, 2005; Van Breugel, 1998).

Due to non-uniform temperature distribution throughout the volume as well as concrete shrinkage deformations, an internal stress field may form in mass cast-in-situ structures, exceeding the strength characteristics of concrete at the stage of its structure formation. That may result in early cracking followed by crack development, thus not only negatively affecting the performance of the structure but bringing its operation into question (Castilho et al., 2018; Chuc et al., 2018; Korotchenko et al., 2016).

One of the main risk factors for early cracking is the temperature difference between the center and the surface of the structure (Klemczak and Knoppik-Wróbel, 2011). Table 1 shows the allowable temperature difference between the center and the surface of the structure *ΔT* and the allowable temperature gradient *ΔT/Δh* (based on the use of some available sources).

Table 1. Allowable temperature parameters during the construction of mass cast-in-situ reinforced-concrete structures

Reference	Indicator	Value
Rahimi and Noorzaei, 2011	ΔT	< 20°C
TCXDVN 305:2004	$\Delta T/\Delta h$	< 50°C/m
Bofang, 2014	ΔT	19…16°C[1]
CIRIA C600	ΔT	$\Delta T < \frac{3.7\varepsilon}{\alpha}$ [2]
R NOSTROY 2.6.17-2016	ΔT	9…16°C[3]

Notes: 1 — at a block length of 31–40 m and a height/length ratio of less than 0.1; 2 — where ε is the ultimate tensile strain of concrete, α is the coefficient of thermal expansion of concrete; 3 — depending on the ultimate strength of concrete and reinforcement ratio.

The temperature origin of cracks in cast-in-situ structures at the stage of construction was first pointed out by the Soviet scientist V. S. Lukyanov in the 1930s. At the time, it was impossible to obtain a direct solution to the problem of calculating temperature fields by integrating differential equations, and he designed a device to predict temperature conditions based on the hydraulic analogy (Lukyanov, 1935).

With modern computing systems, we can easily obtain a direct solution to the differential equation for thermal conductivity, including in a three-dimensional case. Numerous works addressed the calculation of temperature fields at the stage of manufacturing mass cast-in-situ structures. For instance, Kuriakose et al. (2016) solved the problem of calculating the temperature field, considering the relationship between the thermal conductivity coefficient of concrete and the degree of hydration. Nguyen and Luu (2019) proposed a method to reduce the temperature difference between the center and the surface of the structure by surface insulation. They carried out modeling using the Midas Civil software. Xu et al. (2019) performed finite element modeling of cracking prevention in concrete using water cooling in the ABAQUS environment. This problem was also considered by Nguyen et al. (2019) as well as Tasri and Susilawati (2019). Klemczak et al. (2017) studied the influence of concrete composition on the thermophysical properties of concrete and the risk of early cracking using finite element analysis. A similar problem was solved by Van Lam et al. (2018). Xie et al. (2020) proposed an interval finite element method to calculate temperature fields. Using this method, it is possible to perform analysis under the influence of multiple uncertainties, e.g., environmental temperature, material properties, pouring and pipe cooling technology. Havlásek et al. (2017) proposed a weakly-coupled thermo-mechanical model for early-age concrete with an affinity-based hydration model for the thermal part, taking into account concrete mix design, cement type, and thermal boundary conditions. Abeka et al. (2017) performed experimental and numerical investigations of thermal effects on mass concrete structures in the tropics.

Długosz et al. (2017) presented evolutionary computation procedures to identify thermophysical properties in hardening mass cast-in-situ reinforced-concrete structures Fairbairn et al. (2004) used genetic algorithms for the optimization of mass cast-in-situ structures. Kuryłowicz-Cudowska (2019) addressed the modeling of temperature fields in cast-in-situ reinforced-concrete bridge decks. When studying the temperature fields of mass cast-in-situ structures, Zhang et al. (2020) introduced the temperature influence factor for the heat release rate.

In all the papers mentioned above, during temperature field modeling, it was assumed that the structure is made in one step. In real practice, concreting can take considerable time and may involve pauses. Besides, there are several other factors affecting non-uniform temperature distribution through the thickness of the structure. They affect the likelihood of early cracking to different extents. We aimed to study how such factors as the ratio of dimensions, heat transfer conditions on the surfaces, concrete recipe, pauses during concreting and their duration affect the maximum temperature difference between the center and the surface of the structure.

Methods

It is known that in the case of structures made of isotropic materials, the non-stationary problem of thermal conductivity with account for internal heat sources reduces to the following differential equation (Semenov, 2019):

$$\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+Q=\rho c\frac{\partial T}{\partial t}, \quad (1)$$

where λ — the coefficient of thermal conductivity, T — temperature, Q — heat release rate, ρ — material density, c — specific heat capacity, t — time.

When modeling heat release in foundation slabs, we will consider boundary conditions of two types. If there is convective heat exchange with the environment on any surface of the foundation, then the boundary conditions can be written in the following form:

$$\lambda\frac{\partial T}{\partial n}+h\left(T-T_\infty\right)=0, \quad (2)$$

where n — the normal to the surface, h — the heat transfer coefficient, T_∞— the environmental temperature.

The foundation is modeled together with the soil mass. For soil points at a sufficient distance from the foundation, the temperature can be considered set as follows:

$$T_g\left(t\right)=f\left(t\right). \quad (3)$$

Foundation heating from solar radiation is disregarded. To solve the non-stationary problem of thermal conductivity, we developed a program based on the finite element method in the MATLAB environment. When temperature fields are calculated with the use of the finite element method, the solution to Eq. (1) with boundary conditions (2), (3) reduces to finding the minimum of the following functional (Segerlind, 1984):

$$\chi=\int_V\frac{1}{2}\left[\begin{array}{c}\lambda\left(\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2+\left(\frac{\partial T}{\partial z}\right)^2\right)- \\ 2\left(Q-\rho c\frac{\partial T}{\partial t}\right)T\end{array}\right]dV+ \quad (4)$$

$$\frac{1}{2}\int_S h\left(T^2-2TT_\infty+T_\infty^2\right)dS,$$

where V — the volume of the body, S — the area of the surface with convective heat exchange on it.

During calculations, we used finite elements in the form of parallelepipeds. When the temperature is approximated within an element:

$$T(x,y,z)=[N]\{T\}, \quad (5)$$

where [N] — the shape function matrix, {**T**} — the vector of nodal temperature values, then after minimizing functional (4), the problem reduces to the following system of differential equations:

$$[C]\frac{\partial\{T\}}{\partial t}+[K]\{T\}+\{F\}=0, \quad (6)$$

where [C] — the damping matrix, [K] — the thermal conductivity matrix, {**F**} — the load vector.

For each finite element, the matrices [C], [K], {**F**} can be represented by integrals:

$$\left[C^{(e)}\right]=\int_V \rho c[N]^T[N]dV, \left[K^{(e)}\right]= \int_V [B]^T[D][B]dV+\int_S h[N]^T[N]dS, \quad (7)$$
$$\left[F^{(e)}\right]=-\int_V Q[N]^T dV-\int_S hT_\infty[N]^T dS.$$

where [B] — the shape function gradient matrix, $[D]=\begin{bmatrix}\lambda & 0 & 0\\ 0 & \lambda & 0\\ 0 & 0 & \lambda\end{bmatrix}$ in the case of isotropic material.

There are various difference schemes to solve systems of the form (6). With the simplest approximation of the time derivative:

$$\frac{\partial\{T\}}{\partial t}=\frac{\{T_i\}-\{T_{i-1}\}}{\Delta t}, \quad (8)$$

at the ith step, the system of differential equations (6) reduces to the following system of linear algebraic equations:

$$\left([K]+\frac{[C]}{\Delta t}\right)\{T_i\}=\frac{[C]}{\Delta t}\{T_{i-1}\}-\{F\}. \quad (9)$$

In this study, foundation slabs rectangular in plan were considered. Due to symmetry, only a quarter of the structure was modeled. Fig. 1 shows its analytical model.

On the top surface of the foundation (yellow), boundary conditions (2) with the heat transfer coefficient h_1 are accepted. On the side surfaces of the foundation covered with the formwork (green), boundary conditions (2) with the heat transfer coefficient h_2 are accepted. On the top surface of the soil (orange), boundary conditions (2) with the heat transfer coefficient h_3 are accepted. On the side surfaces of the soil (blue) and on its bottom surface, the temperature is considered to be set.

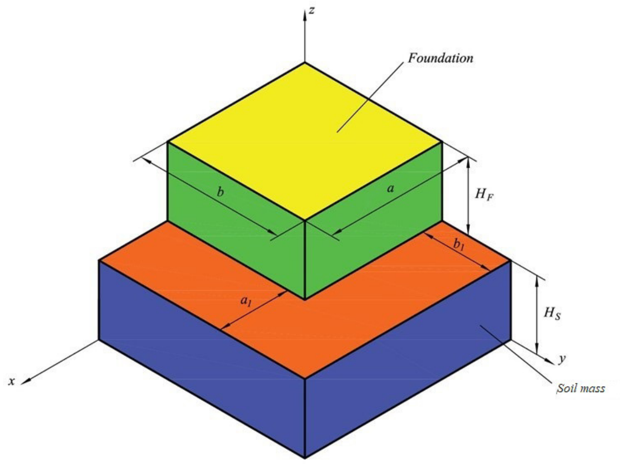

Fig. 1. Analytical model

In mass cast-in-situ foundations of constant thickness, at points at a sufficient distance from the edges, temperature distribution does not depend on the *x* and *y* coordinates, i.e., instead of a three-dimensional thermal conductivity problem, a one-dimensional problem can be solved with the use of the following equation:

$$\lambda\frac{\partial^2 T}{\partial z^2}+Q=\rho c\frac{\partial T}{\partial t}. \quad (10)$$

The use of a one-dimensional model instead of a three-dimensional one significantly saves computing time when conducting parametric studies on the influence of various variables responsible for heat exchange. The possibility of using a one-dimensional formulation instead of a three-dimensional one will be discussed in the next section.

We measured the rate of heat release Q during hardening for five concrete compositions, which differed in cement hydration heat values. Fig. 2 presents corresponding $Q(t)$ graphs.

Results

To validate the model, we first performed tests based on experimental data. Let us present the results of the analysis for a mass structure, involving in-situ temperature measurements and finite element modeling in the program that we developed earlier. Table 2 shows those calculated characteristics.

Table 2. Characteristics of the structure under consideration

Dimensions, m	Temperature, °C			Heat transfer coefficient, W/(m²·°C)		
	concrete mix during laying	air	soil	h_1	h_2	h_3
28.7 × 4 × 2	15	8...13	8	4.5	2	25

The thermophysical properties of concrete: λ = 2.67 W/(m·°C), ρ = 2500 kg/m³, c = 1000 J/(kg·°C). The thermophysical properties of the soil mass: λ = 1.5 W/(m·°C), ρ = 1600 kg/m³, c = 1875 J/(kg·°C). The composition of concrete corresponds to curve 2 in Fig. 2.

Fig. 3 shows data on temperature changes in the center and on the top surface of the structure at x = 0 and y = 0, obtained as a result of in-situ measurements (dashed lines) and modeling with the use of the finite element method (solid lines).

The experimental results are in good agreement with the numerical calculations. The deviation of the results is probably due to the fact that the thermophysical properties of concrete were taken constant in time and their dependence on the degree of cement hydration was not considered. It should also be noted that the results of the analysis with the use of the three-dimensional and one-dimensional models for the center of the structure differ insignificantly.

Our objective was to establish ratios between the dimensions of the structure in plan and its height, at which conditions on the side surfaces do not affect the maximum temperature difference through the thickness of the structure. It is possible

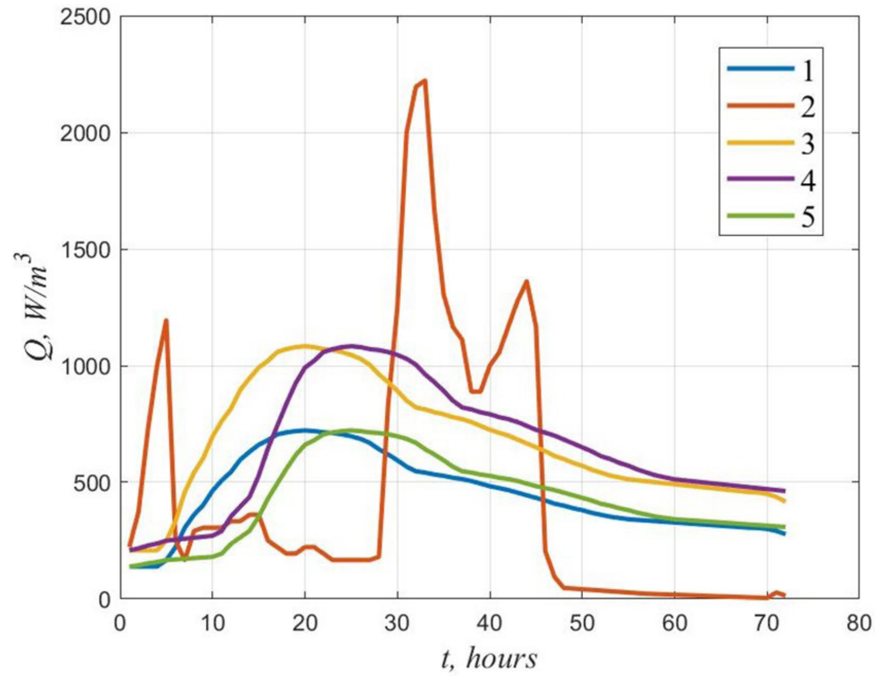

Fig. 2. Rate of heat release $Q(t)$ for various concrete compositions

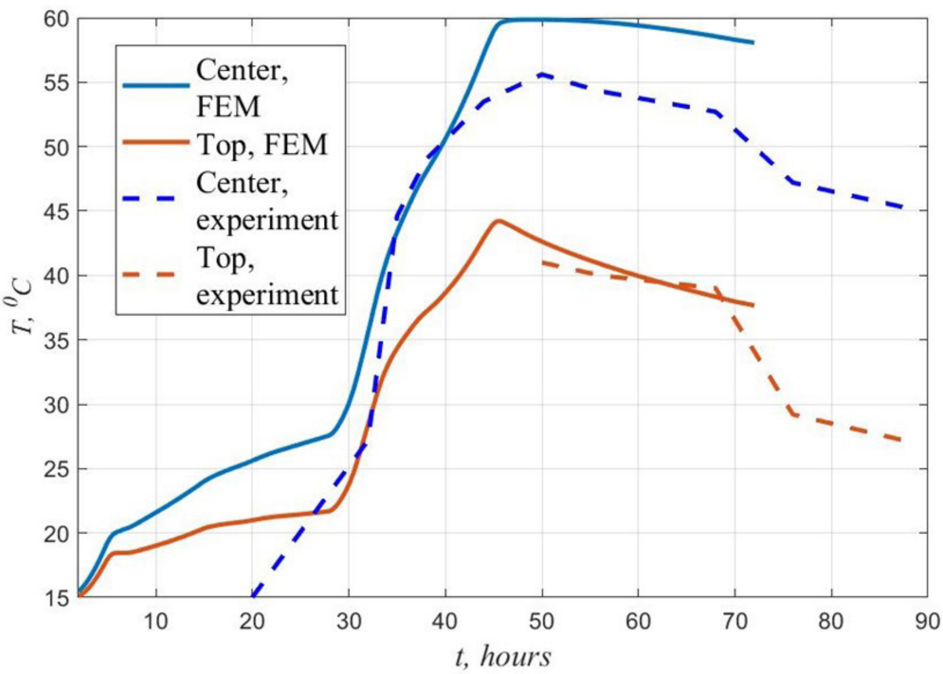

Fig. 3. Temperature vs. concrete hardening time

to use a one-dimensional model instead of a three-dimensional one for calculations. The parametric study was carried out based on the same initial data as in Table 2, except for the dimensions and the heat transfer coefficient h_2 on the side surfaces. The thickness of the structure was assumed to be constant (H_F = 2 m). For simplicity, it was taken that $a = b$, and the ratio a/H_F varied. For the coefficient h_2, the calculations were performed at the following two values: h_2 = 2 W/(m²×°C), which corresponds to the insulated formwork, and h_2 = 25 W/(m²×°C), which corresponds to the exposed surface left for drying.

Fig. 4 presents the maximum temperature difference ΔT between the center and the top surface of the structure vs. time curves. The graphs show that already at a/H_F = 1.5, the influence of conditions on the side surfaces becomes insignificant, and the one-dimensional model makes it possible to obtain acceptable results. A similar analysis was carried out at smaller foundation thicknesses: H_F= 1 m and H_F= 0.7 m. The corresponding graphs are shown in Figs. 5 and 6. At H_F= 1 m, a one-dimensional model can be used if $a/H_F \geq 3$, and at H_F= 0.7 m, a one-dimensional model can be used if $a/H_F \geq 4$.

Next, we studied the heat exchange conditions on the top surface of the foundation. The parametric study was carried out based on the same initial data as in Table 2, except for the coefficient h_1, which varied. Fig. 7 presents changes in the maximum temperature difference between the center and the top surface of the structure in time at various h_1 values. It shows that with an increase in the heat transfer coefficient, the maximum temperature difference increases as well. A similar pattern was observed under other environmental conditions as well as other foundation dimensions. Thus, to reduce the difference between the center and the top surface of the structure, it is reasonable to reduce heat transfer on the top surface.

We also analyzed the influence of concrete composition on the maximum temperature difference between the center and the surface of the structure. The calculations were carried out based on the same initial data as in Table 2 for concrete compositions 1–5 in Fig. 2. Fig. 8 presents changes in the maximum temperature difference between the center and the surface of the structure in time. It shows that the use of concretes with low hydration heat (compositions 1, 2, 5) is an effective way to reduce the ΔT value.

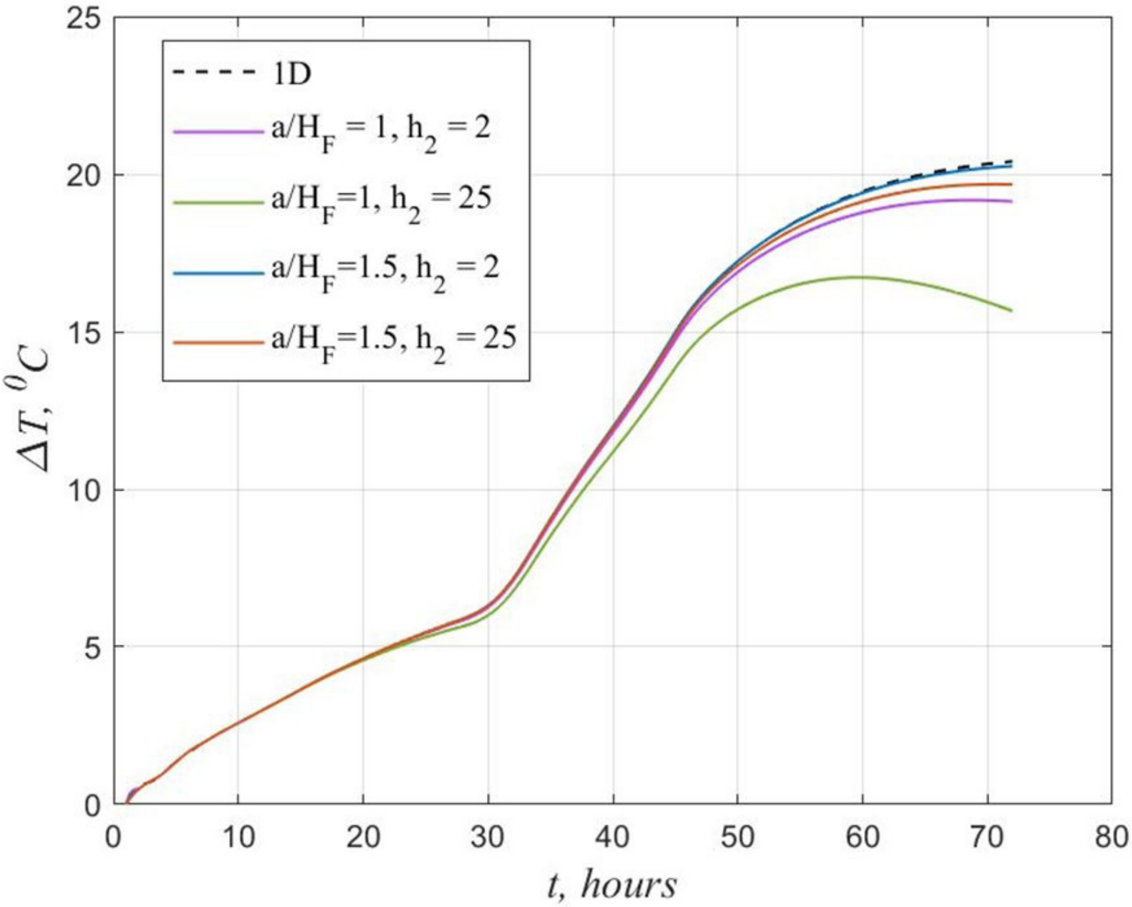

Fig. 4. Relationship between the temperature difference (between the center and the top surface of the structure) and the ratio of the foundation dimensions and conditions on the side surfaces at H_F= 2 m

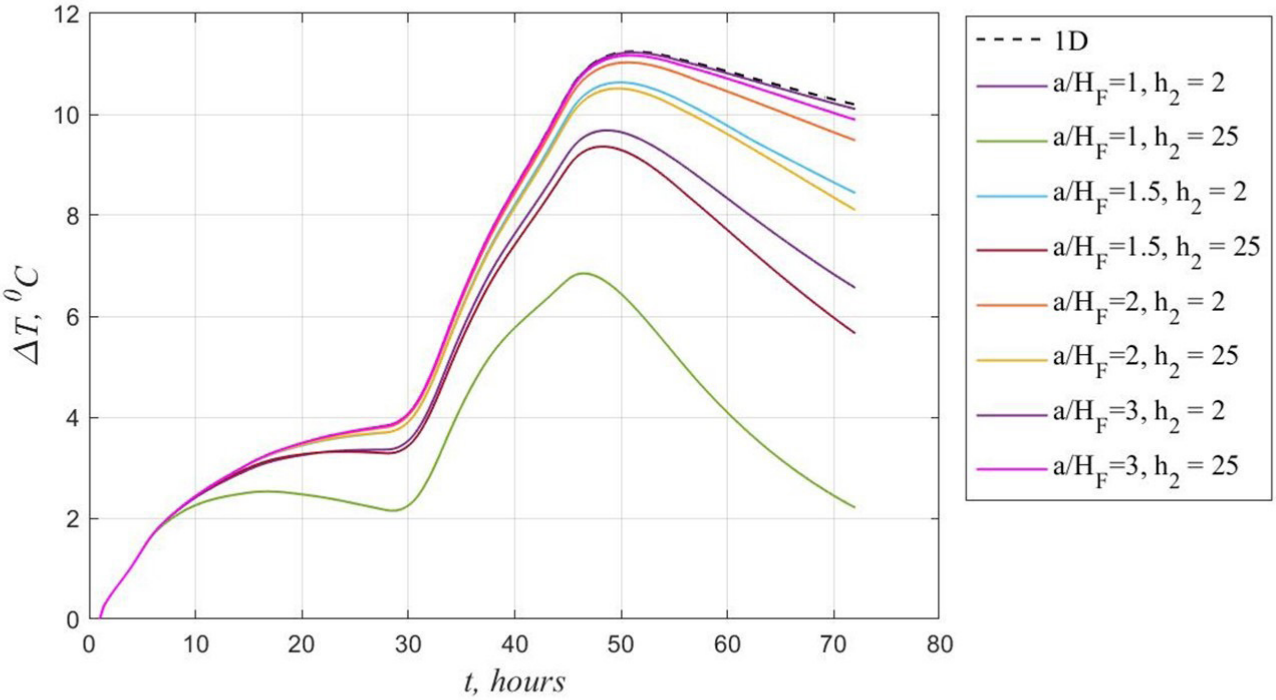

Fig. 5. Relationship between the temperature difference (between the center and the top surface of the structure) and the ratio of the foundation dimensions and conditions on the side surfaces at H_F= 1 m

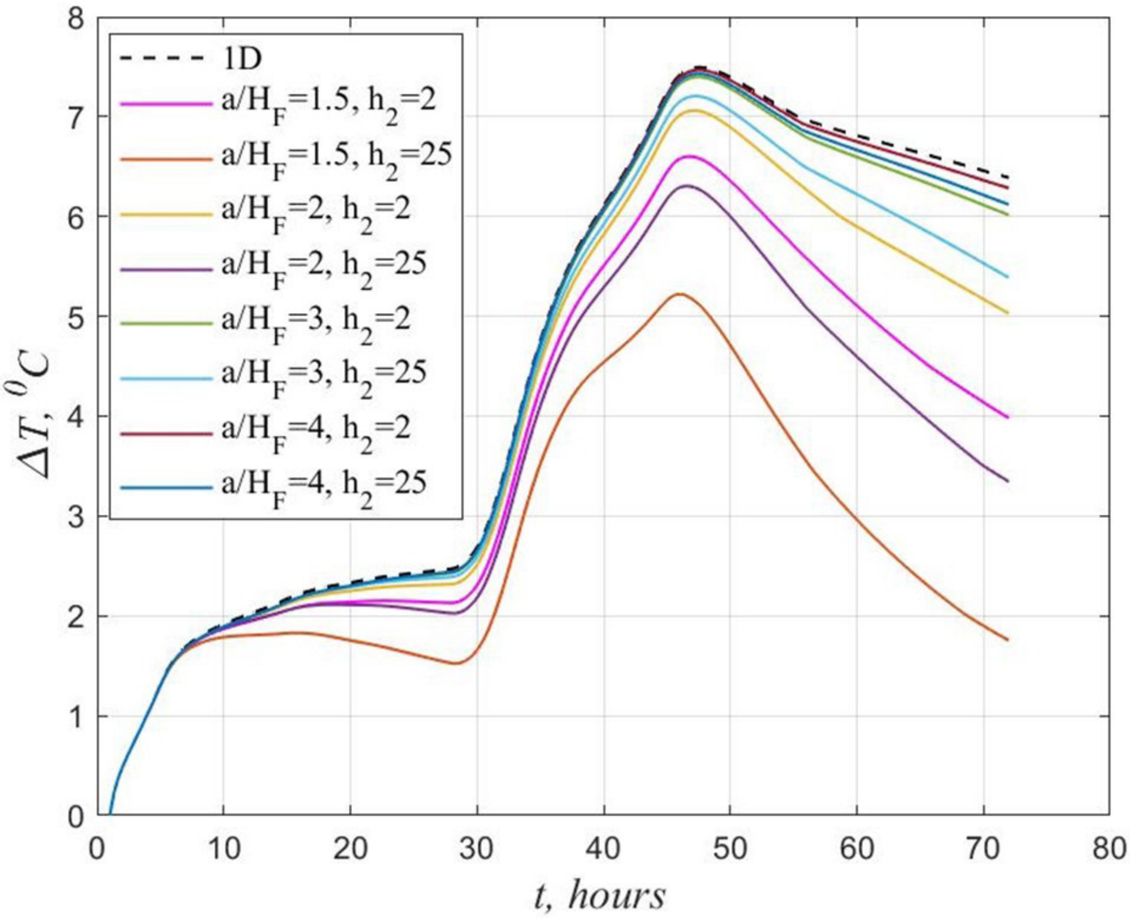

Fig. 6. Relationship between the temperature difference (between the center and the top surface of the structure) and the ratio of the foundation dimensions and conditions on the side surfaces at H_F= 0.7 m

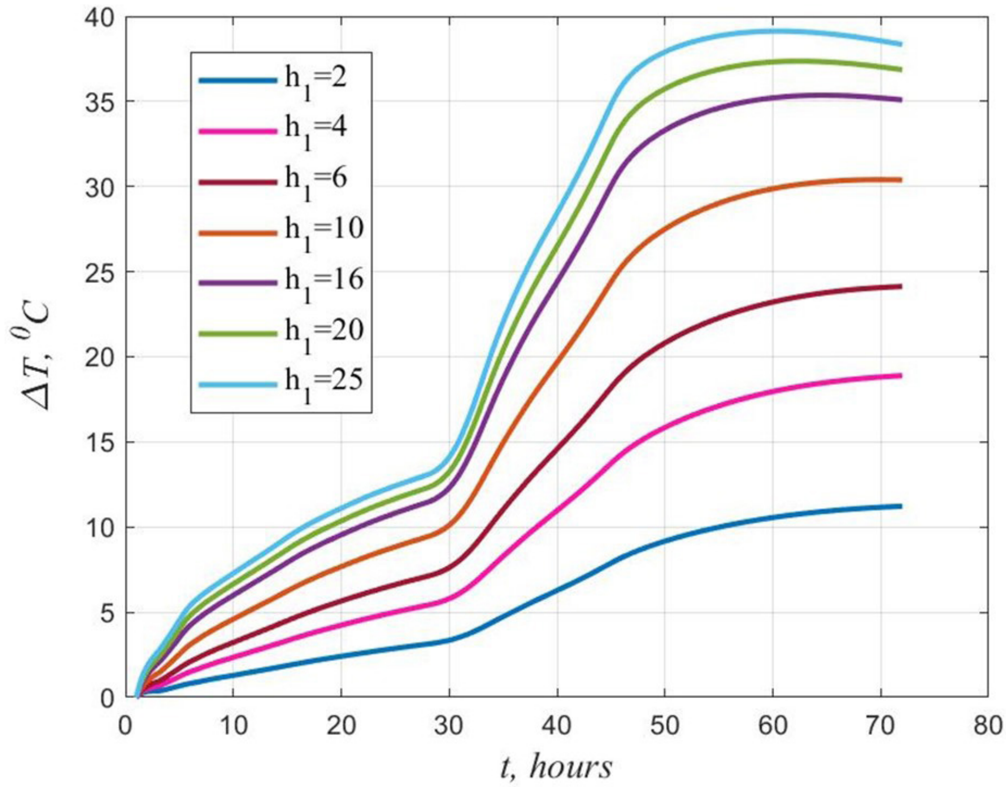

Fig. 7. Relationship between the temperature difference and the heat transfer coefficient on the top surface

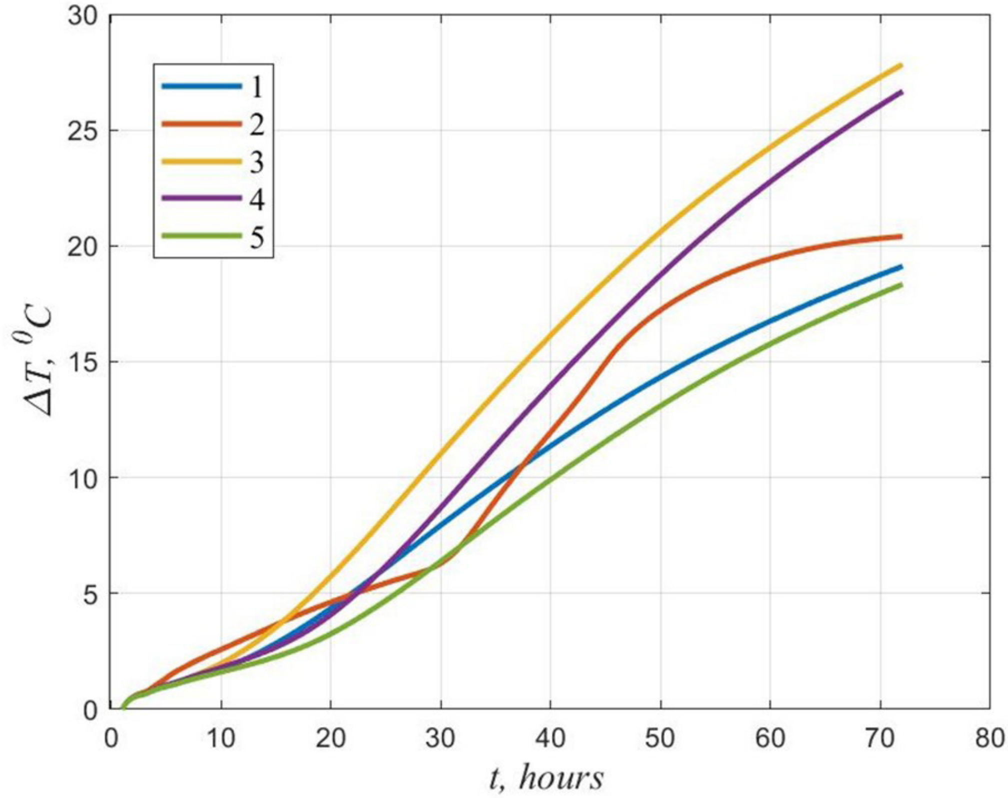

Fig. 8. Relationship between the maximum temperature difference and concrete composition

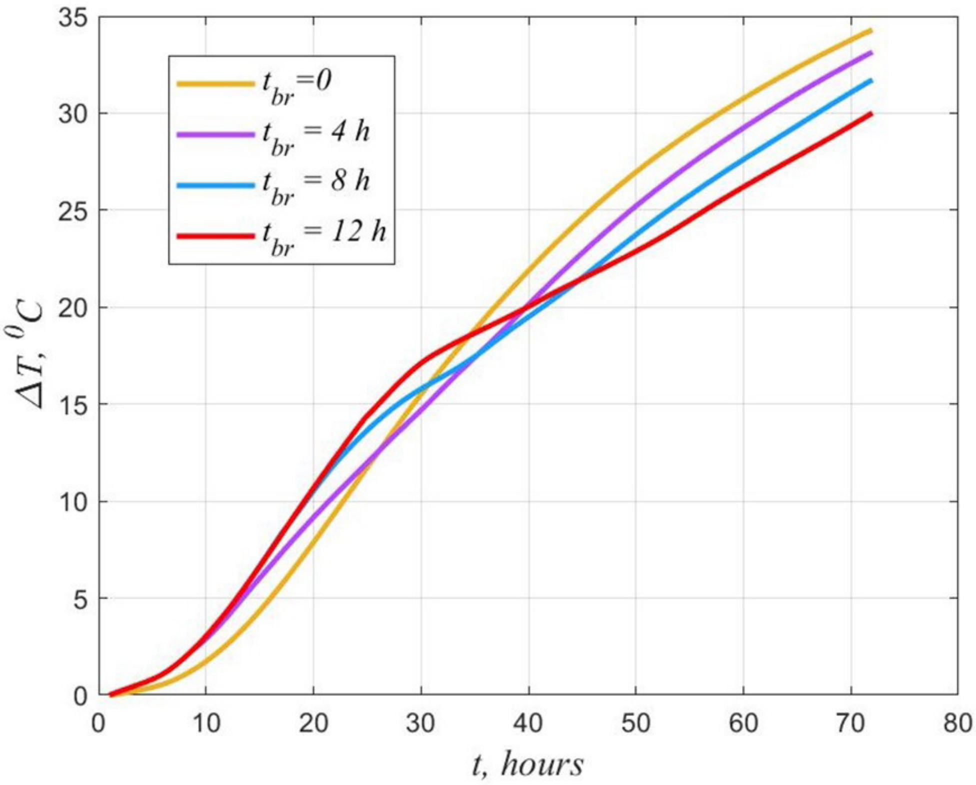

Fig. 9. Changes in the difference between the maximum temperature and the temperature of the top surface in time at different values of t_{br}.

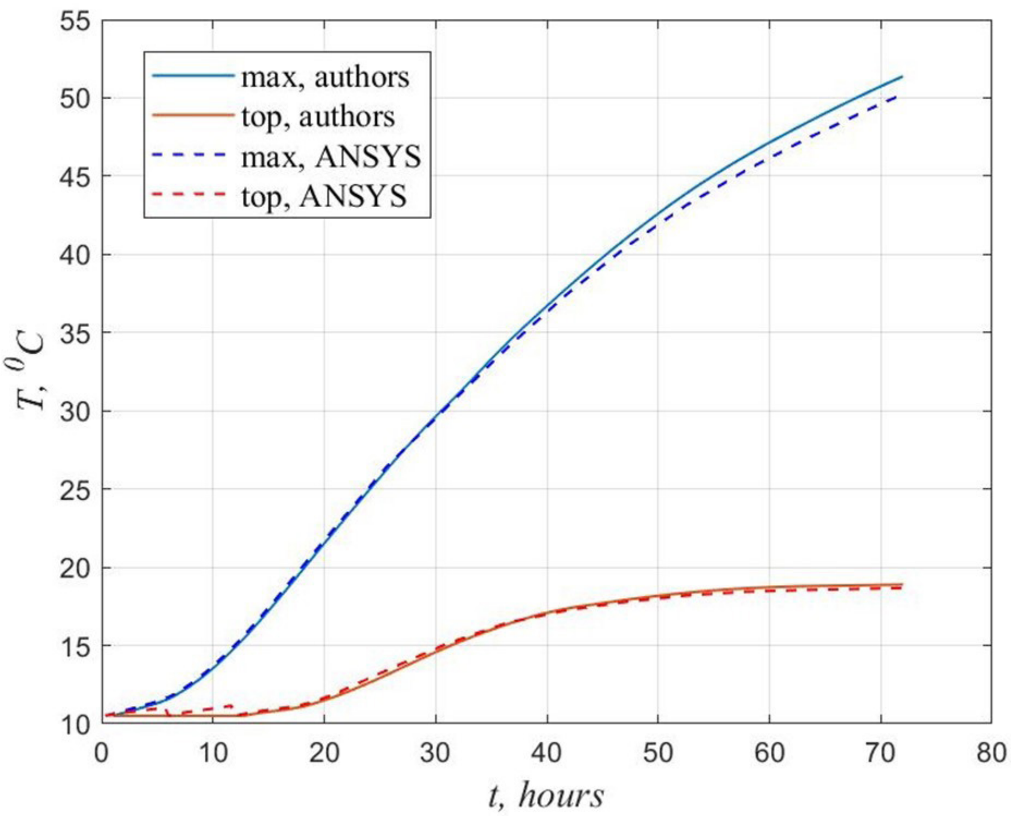

Fig. 10. Comparison of the solution with the results in the ANSYS software

The calculations described above assumed that the structures are made in one step, i.e., stages of construction were not considered. In the program that we developed earlier, this circumstance can be easily considered by adding new finite elements in concreting. This option is also available in the ANSYS software and is called “Element Birth and Death”.

Let us provide an example for the analysis of a foundation slab with dimensions of 10 × 10 × 2 m. The structure is concreted in three layers with a thickness of 0.667 m. The pauses (breaks) in concreting in layers t_{br} varied from 0 to 12 hours. For simplicity, the soil temperature, the initial temperature of the concrete mix, and the environmental temperature were taken constant and equal to 10.5°C. The coefficient of heat transfer between the environment and the top surface h_1 = 25 W/(m²×°C). The composition of concrete corresponds to composition 1 in Fig. 2.

Fig. 9 presents changes in the maximum temperature difference at different t_{br} values. It shows that pauses (breaks) in concreting in layers make it possible to reduce the maximum temperature difference but not so significantly. It is more efficient to use concretes characterized by low heat release and control heat exchange conditions on the top surface.

To ensure the validity of the results, we compared the solution with the ANSYS software results at 6-hour pauses (breaks) in concreting in layers. Fig. 10 shows a comparison of the maximum temperatures in the foundation and the temperatures on the top surface, obtained using the program that we developed earlier and ANSYS. Fig. 11 shows the temperature distribution obtained with the use of ANSYS at t = 72 h. The discrepancy between the results is insignificant.

Discussion

Based on the parametric studies, we established that the most significant factors affecting the temperature difference between the center and the surface of the structure of mass foundation slabs are heat exchange conditions on the top surface, structural thickness, and the heat release rate. The need for heat insulation of the top surface immediately after concreting is finished was previously addressed by Korotchenko et al. (2016), Nguyen and Luu (2019), and others.

The results of numerical modeling at different ratios between the thickness of the foundation slab H_F and its dimensions in plan a show that, already at $a/H_F>=4$, the temperature distribution through the thickness in the middle part of the foundation, when the problem is solved in a three-dimensional formulation, coincides with the distribution from the solution of a one-dimensional problem. For instance, a structure with dimensions of 2.8 × 2.8 × 0.7 m will have the same risk of early cracking as a structure with dimensions of 28 × 28 × 0.7 m. Besides, the use of a one-dimensional formulation significantly saves computing time when selecting the optimal construction conditions.

The calculation of temperature fields with account for the layer-by-layer concreting with pauses (breaks) showed that such pauses in concreting in layers make it possible to reduce the temperature difference between the center and the surface of the structure but not so significantly. Meanwhile, these pauses should have a sufficient duration.

In the examples considered, the thermophysical

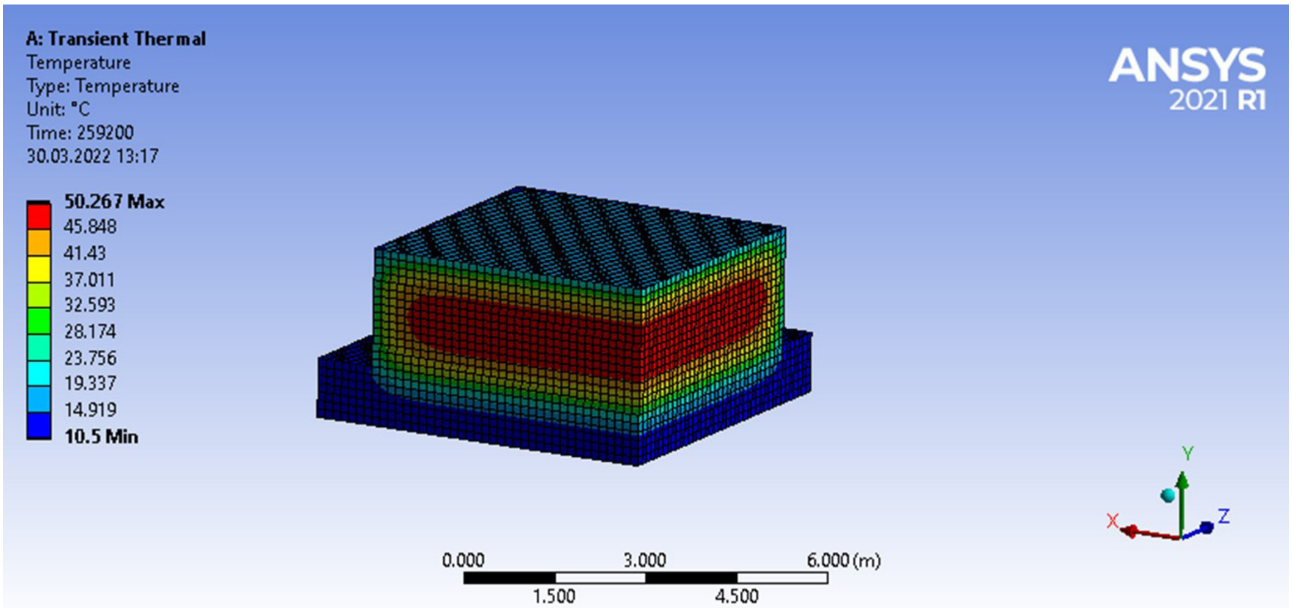

Fig. 11. Temperature distribution in the ANSYS software at t = 72 h

properties of concrete were taken constant in time. In the program that we developed earlier, the thermal conductivity coefficient and heat capacity of concrete vs. time relationships can be easily considered (in contrast to the existing software (ANSYS, Abaqus, etc.)), but reliable experimental data are required.

It should be noted that the conclusions above were drawn from the perspective of minimizing the temperature difference between the center and the surface of the structure, which allows us to estimate thermal stresses arising in the structure only indirectly. To obtain a complete picture of the risk of early cracking, it is necessary to perform a stress-strain state analysis based on the obtained temperature fields. In this case, such factors as changes in the mechanical characteristics of concrete in time, creep and chemical shrinkage as well as the reinforcement ratio should be considered. Besides, during stress-strain state analysis, it is also required to apply the analysis of the influence of construction stages, which we performed when calculating the temperature fields. This will be the focus of our further research.

Conclusions

In the course of the study, we developed a mathematical model to calculate temperature fields that arise during the manufacturing of mass cast-in-situ foundation slabs. The novelty of the proposed model is that it takes into account the influence of construction stages on the resulting temperature fields. We applied finite element modeling in one-dimensional and three-dimensional cases using the software that we developed earlier. Verification and validation of the model were performed based on experimental data and by comparing it with a numerical solution in the ANSYS software. It was shown that the discrepancy between the solution obtained and experimental data as well as the results of the numerical analysis in the ANSYS environment does not exceed 5%. We also performed a parametric study to determine how such factors as the ratio of dimensions, heat transfer conditions on the surfaces, concrete recipe, pauses during concreting and their duration affect the maximum temperature difference between the center and the surface of the structure. As a result, we established that the most significant risk factors for early cracking are heat exchange conditions on the top surface, structural thickness, and the heat release rate.

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МОДЕЛИРОВАНИЕ НЕСТАЦИОНАРНЫХ ТЕМПЕРАТУРНЫХ ПОЛЕЙ ПРИ ВОЗВЕДЕНИИ МАССИВНЫХ МОНОЛИТНЫХ ЖЕЛЕЗОБЕТОННЫХ ФУНДАМЕНТНЫХ ПЛИТ

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Аннотация

Для массивных монолитных железобетонных конструкций за счет внутреннего тепловыделения бетона и теплообмена с окружающей средой при твердении происходит неравномерный нагрев, что может привести к раннему трещинообразованию и невозможности дальнейшей эксплуатации конструкций. Одним из основных факторов, предопределяющих риск раннего трещинообразования, является перепад температур между центром и поверхностью конструкции. **Целью работы** является анализ влияния на величину максимального перепада температур между серединой и поверхностью конструкции таких факторов, как соотношение габаритов конструкции, условия теплопередачи на поверхностях, рецептура бетона, наличие и величина технологических перерывов. **Использованы следующие методы**: Конечно-элементное моделирование в трехмерной и одномерной постановке с использованием разработанного авторами программного обеспечения в среде MATLAB. **В результате** установлено, что факторами, в большей степени влияющими на риск раннего трещинообразования, являются условия теплообмена на верхней поверхности, толщина конструкции и плотность внутреннего тепловыделения бетона. Верификация и валидация модели выполнена на экспериментальных данных, а также путем сравнения с численным решением в программном комплексе ANSYS.

Ключевые слова

Массивные железобетонные конструкции, фундаментная плита, трещинообразование, температурное поле, метод конечных элементов, внутренние источники тепловыделения.

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SAFETY REQUIREMENTS FOR SNOW LOAD ON UNIQUE TRANSPORT INFRASTRUCTURE FACILITIES

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Abstract
Introduction: Wind-induced snow drift is the main reason behind the non-uniform snow load on a snow-covered area. As known, snow load poses a serious hazard to the roofing of buildings and structures. According to the applicable regulatory documents, snow loads for non-standard roofs must be determined based on the results of model tests in wind tunnels. **Purpose of the study:** We aimed to study snow load on a unique transport infrastructure facility — the world's first cross-border cable car connecting Blagoveshchensk in Russia to Heihe in China. **Methods:** We performed model tests to study snow accumulation and drifting with the use of a unique research setup — the Large Gradient Wind Tunnel, courtesy of the National Research Moscow State University of Civil Engineering. **Results:** Based on climate analysis and tests under different wind attack angles, we obtained distribution patterns for snow deposits on the roofing of the unique transport infrastructure facility under consideration and derived the values of the coefficient μ (the coefficient of transition from the weight of the snow cover on the ground to the snow load on roofing).

Keywords
Snow deposits, snow drifting, transport safety, physical modeling, wind tunnels.

Introduction

The world's first cross-border cable car connecting Blagoveshchensk in Russia to Heihe in China was designed to run across the Amur River, which marks the border between eastern Russia and China (Fig. 1).

Snow load poses a serious hazard to the roofing of residential, public, and industrial buildings (Churin and Gribach, 2016). As winter sets in, various regions of the Russian Federation report accidents involving roofing collapse due to snow load.

Thus, in northern regions with a long cold season, prone to heavy snowfall, structural engineers need accurate estimates for snow load redistribution on the roofs of unique buildings and structures under the action of wind.

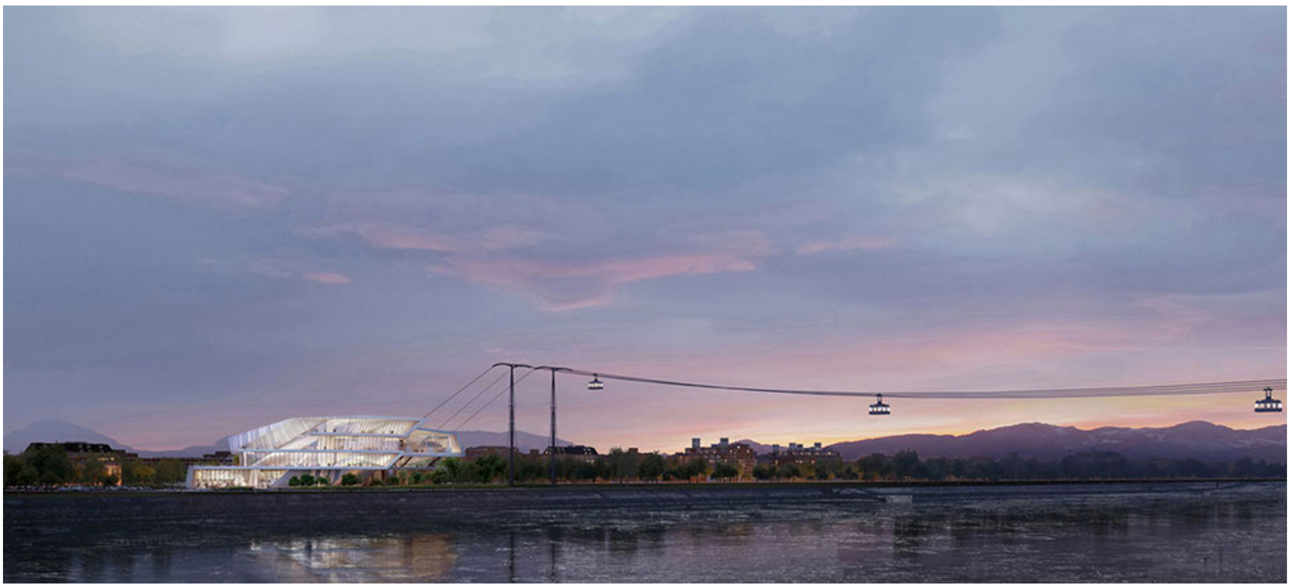

Fig 1. Design of the unique cable car connecting Blagoveshchensk in Russia to Heihe in China

The patterns of snow deposition given in Appendix B to the Regulations SP 20.13330.2016 (and other standards, e.g., Eurocodes) (American Society of Civil Engineers, 2005) cover only a limited number of the most common types of profiled sheeting for roofing. The cable car terminal under consideration falls into the category of unique construction facilities, and according to cl. 10.4 of the Regulations SP 20.13330.2016 "Loads and Actions", the patterns of snow load distribution on roofing and the values of the coefficient μ must be set forth in the special recommendations based on the results of model tests in wind tunnels or data published in technical literature.

In this paper, we adopt patterns of snow load distribution based on the results of model tests in a wind tunnel.

Methods

To perform model tests, a model of the facility under consideration was designed and manufactured (Fig. 2). Considering the dimensions of the test section, we chose the maximum possible scale of the model with account for blockage conditions. The model was mounted on an automatic turntable in the test section of the wind tunnel.

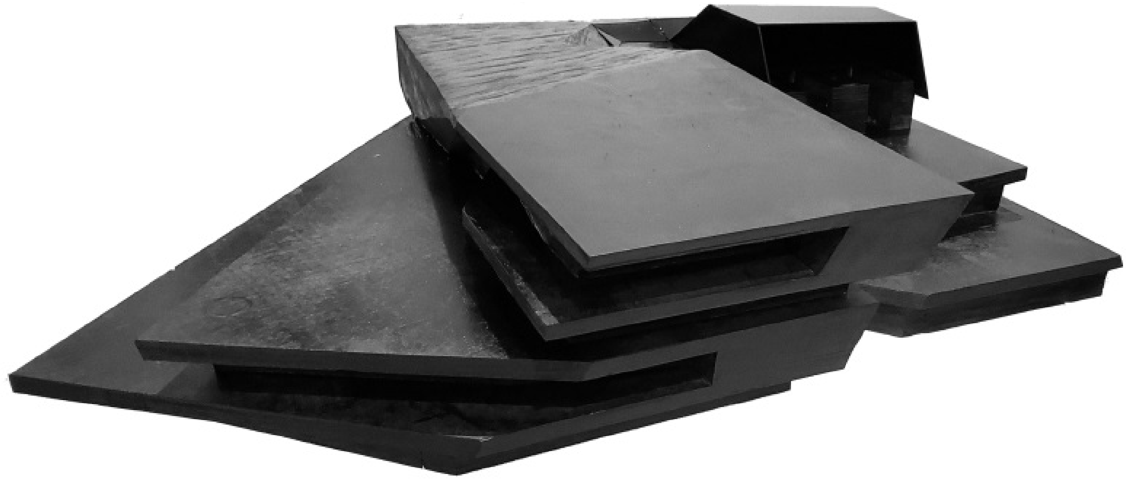

Fig. 2. Model of the facility under consideration

Fig. 3. Characteristic areas of snow deposits, wind angles: 0° (N) and 45° (NW)

Wind-induced snow drift is the main reason behind the non-uniform snow load on a snow-covered area (O'Rourke et al., 2004, 2005; Thiis and O'Rourke, 2012). Snow drifting results in areas with masses of snow carried away and areas of snow accumulation (so-called snow bags). Their location is mainly related to the roofing (profiled sheeting) configuration and wind direction (Li et al., 2022).

During snow load formation, non-uniform snow deposits as well as snow blowing and falling off the roofs can be observed (even in the case of single-span buildings) (Jiang et al., 2020). These phenomena are taken into account in the standards of most countries by the coefficients μ (the coefficient of transition from the weight of the snow cover on the ground to the snow load on roofing), which mainly depend on the inclinations of roofs and level variations.

We performed model tests with the use of a unique research setup — the Large Gradient Wind Tunnel, courtesy of the National Research Moscow State University of Civil Engineering.

The characteristic wind speeds at which snow drifting was analyzed were in the range of 3.4–8 m/s.

To simulate snow, it is recommended to use wood powder with a particle size of 50–250 μm and moisture content of 3.5–4%, drifting from a smooth painted surface at a wind speed of 3.4 m/s (Poddaeva, 2021).

As a result of long-term exposure of the model covered with a thin layer of wood powder to the air flow at a speed of 6–7 m/s, a pattern of characteristic snow deposits was generated.

The shapes of snow bags are analyzed to decompose the roof surface into primitive elements, and then the snow load is determined for those elements.

When the model is blown from different directions, snow is subject to the impact of wind in accordance with the wind rose in the particular region. During the tests, the turntable made a full circle in increments of 45°. Below we present photos of snow drifting under different wind directions. Based on these photos, it is possible to obtain data on the snow drifting type as well as directions and volumes of snow transported for each type of snow drifting.

Results

The photos of snow distribution patterns are given below (Figs. 3–5).

The transition from qualitative patterns to quantitative values of the shape coefficient μ is carried out for the most unfavorable loading configurations. These configurations are chosen based on both the analysis of test results and climatic data. A detailed methodology for the analysis of experimental studies is given in a paper by Lebedeva et al. (2020). The results of climate analysis performed in the construction area show that the characteristic wind directions in winter are as follows: from the east (model setting angle: 270°), from the north-east (model setting angle: 315°), and from the south-east (model setting angle: 225°).

Fig. 4. Characteristic areas of snow deposits, wind angles: 0° (N) and 270° (E)

Fig. 5. Characteristic areas of snow deposits, wind angles 315° (NE) and 225° (SE)

Based on the results of the wind tunnel tests, we calculated potential volumes of snow drifting with account for the roofing shape and drew up diagrams of snow deposits on the roofing of the facility under consideration for those directions (Fig. 6).

Discussion

During the study, we performed physical modeling of snow drifting and accumulation on the roofing of a unique transport infrastructure facility — the Blagoveshchensk–Heihe cross-border cable car terminal. We designed and manufactured a physical model of the facility under consideration, presented a methodology for snow drifting and accumulation modeling in wind tunnels, took photos of the characteristic areas of snow deposits under different angles, and based on the results, drew up diagrams of snow deposits on the roofing of the facility under consideration for different wind directions. Based on the results obtained, we also derived the maximum value of the coefficient μ (the coefficient of transition from the weight of the snow cover on the ground to the snow load on roofing).

Funding

This study was funded by the Ministry of Science and Higher Education of the Russian Federation (project: theoretical and experimental design of new composite materials to ensure safety during the operation of buildings and structures under conditions of technogenic and biogenic threats #FSWG-2020-0007).

All tests were carried out with the use of equipment of the Head Regional Shared Research Facilities and the Large Gradient Wind Tunnel, courtesy of the National Research Moscow State University of Civil Engineering.

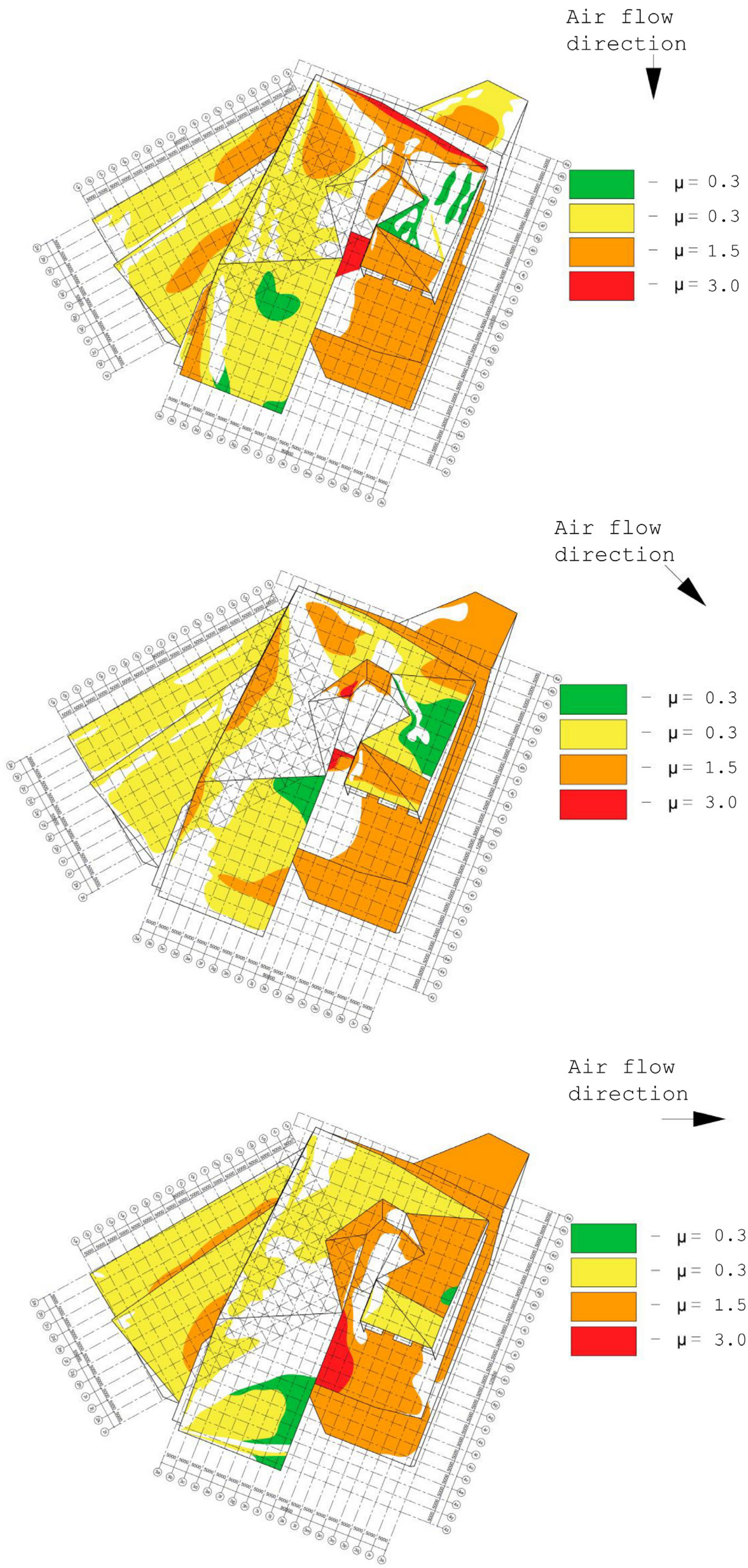

Fig. 6. Diagrams of snow deposits on the roofing of the facility under consideration for different wind directions

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СНЕГОВАЯ БЕЗОПАСНОСТЬ УНИКАЛЬНЫХ ОБЪЕКТОВ ТРАНСПОРТНОЙ ИНФРАСТРУКТУРЫ

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Аннотация

Перенос снега под влиянием ветра является основным фактором, вследствие которого уровень снеговой нагрузки неодинаков по площади покрытия. Снеговая нагрузка представляет серьезную опасность для кровельных покрытий зданий и сооружений. Согласно действующим нормативным документам снеговые нагрузки на кровли нетиповых форм необходимо назначать по результатам модельных испытаний в аэродинамических трубах. **Целью данного исследования** является изучение влияния снеговых воздействий на уникальный объект транспортной инфраструктуры – первую в мире трансграничную канатную дорогу Благовещенск–Хэйхэ, которая соединит Россию и Китай. Были использованы **следующие методы**: проведение серии модельных испытаний для изучения процессов снегообразования и снегопереноса с использованием уникальной научной установки – Большой Градиентной аэродинамической трубы. По **результатам** климатического анализа и проведенных испытаний для различных углов атаки ветра получены схемы распределения снеговых отложений на поверхности кровли уникального объекта транспортной инфраструктуры, получения значения коэффициента μ (коэффициент перехода от веса снегового покрова на поверхности земли к снеговой нагрузке на покрытие).

Ключевые слова

Снегоотложение, снегоперенос, транспортная безопасность, физическое моделирование, аэродинамические трубы.

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STRUCTURAL CHARACTERISTICS AND PERFORMANCE OF CONCRETE WITH A COMPOSITE MODIFYING ADDITIVE

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Abstract

Introduction: The paper addresses the effect of a composite modifying mineral additive based on waste — tailings from the Balkhash Mining and Processing Plant — and microsilica on the structural characteristics and performance of heavy concrete. **Purpose of the study:** We aimed to select optimal B25 and B35 concrete mixes based on the MV-D20 modified binder with the composite additive in its composition and evaluate the characteristics of concrete. **Methods:** In the course of the study, standard methods were used to design concrete mixes and test the characteristics of concrete. Proportioning was performed in accordance with State Standard GOST 27006-86 "Concretes. Rules for Mix Proportioning". The physical and mechanical properties of heavy concrete were determined in accordance with State Standard GOST 10180-2012 "Concretes. Methods for Strength Determination Using Reference Specimens". The strength of concrete was assessed in accordance with State Standard GOST 18105-2018 "Concretes. Rules for Control and Assessment of Strength". **Results:** It was established that in terms of the rate of strength gain, the designed heavy concrete mixes are fast-curing. In the initial curing period of 7 days, B25 and B35 concretes gain 90.1 and 85.4% of the required standard strength, respectively. The average values of water absorption in B25 and B35 concretes are 4.20 and 3.46%, respectively. In terms of water tightness, concrete mixes have W10 and W12 grades. The application of the MV-D20 modified binder with the composite additive consisting of tailings and microsilica instead of standard sulfate-resistant Portland cement will reduce the relative deformation of B35 concrete in an aggressive environment by 12%.

Keywords

Composite mineral additive, sulfate-resistant Portland cement, tailings, microsilica, strength, fast-curing concrete, water absorption, water tightness.

Introduction

Modern building materials science offers a lot of theoretical insights and case studies on the use of finely-dispersed active mineral additives. Their application in the production of concrete and reinforced concrete makes it possible (Guvalov et al., 2017; Lothenbach and Winnefeld, 2006; Ngo et al., 2020a; Slavcheva et al., 2020; Zvezdov and Mikhailov, 2001):

- to reduce concrete mix disintegration in transportation and improve its workability;
- to improve the structural characteristics and performance of heavy concrete;
- to increase compression strength;
- to increase significantly the durability of concrete and reinforced-concrete structures.

However, the use of waste from mining and processing plants in the Republic of Kazakhstan as mineral additives to cement binders has not been sufficiently studied.

Studies (Zhilkibaeva and Estemesova, 2020; Zhilkibayeva, 2021) show that the activation of waste — tailings from the Balkhash Mining and Processing Plant — with microsilica increases significantly the chemical activity of the additive to cement and, thus, determines the strength characteristics of concrete.

Previously, the following optimal composite mineral additive was chosen: 60% tailings from the Balkhash Mining and Processing Plant + 40% microsilica. It was established that with a microsilica content higher than 40%, the water demand of the mix increases. The pozzolanic activity of the composite additive consisting of 60% tailings from the Balkhash Mining and Processing Plant + 40% microsilica is 48 mg/g. Thus, when microsilica is introduced into tailings, the pozzolanic activity of the composite additive doubles (Zhakipbekov et al., 2021a, 2021b; Zhilkibaeva and Estemesova, 2020; Zhilkibayeva, 2021).

Microsilica is a critical component in the production of high-performance concrete. It has a unique ability to positively affect the properties of concrete, improving its qualitative characteristics: reducing water absorption and increasing strength, frost resistance, chemical resistance, sulfate resistance, wear resistance, etc. (Kaprielov et al., 1992).

Microsilica also affects the structure of concrete at the nanoscale and, according to available data, increases its compression strength (Batrakov et al., 1989). An increase in strength is attributable to pore filling with small microsilica particles and the formation of additional C-S-H bonds during the pozzolanic reaction of microsilica and $Ca(OH)_2$ (Zhang et al., 2016). Besides, microsilica reduces the shrinkage and water permeability of concrete and increases its wear resistance and grip on steel (Nesvetayev, 2006).

Those scientific principles and practical recommendations on the maximum cement content and its rational reduction that were set forth in some papers and monographs cannot be applied to the technology of high-strength concrete curing under normal conditions since there are other problems that need to be solved (Lothenbach et al., 2008; Singh et al., 2017; Yestemessova et al., 2020; Zhakipbekov et al., 2021a, 2021b; Zhilkibayeva et al., 2021):

- ensuring fast strength gain in the initial curing periods and high required strength of concrete;
- choosing aggregates having good compatibility with superplasticizers to ensure maximum rheological effect;
- obtaining higher dispersion in the aggregate (as compared to that in cement) to ensure high reactivity with cement hydration products and the formation of additional crystallization centers;
- ensuring low porosity and high density of concrete.

Materials and Methods

To make heavy concrete, a modified binder was used based on sulfate-resistant Portland cement CEM I 42.5N SS (ordinary curing) by CaspiCement LLP (Mangystau Region) with a composite additive. In terms of its physical and mechanical properties as well as mineral and chemical composition, sulfate-resistant Portland cement meets the requirements of GOST 22266-2013 “Sulfate-Resistant Cements. Specifications”.

Tailings from the Balkhash Mining and Processing Plant of the following composition were used as a composite mineral additive to the binder based on sulfate-resistant Portland cement in the amount of 12% of the cement mass:

Tailings from the Balkhash Mining and Processing Plant	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	S_{tot}
	74.40	1.25	0.25	1.97	1.10	-	10.36

To activate waste (tailings from the Balkhash Mining and Processing Plant), microsilica in the amount of 8% of the cement mass was used. Thus, an MV-D20 modified binder with a composite additive was obtained (Zhakipbekov et al., 2020).

Sand from the Beineu deposit (Mangystau Region) and crushed stone of 5–10 and 10–20 mm size by Koktas-Aktobe JSC were used as fine and coarse aggregates.

In terms of its grain composition, strength (crushability), the content of lamellar (flaky) and needle-shaped grains, and the content of dust-like and clay particles, crushed stone of 5–10 and 10–20 mm size by Koktas-Aktobe JSC meets the requirements of State Standard GOST 8267-93 “Crushed Stone and Gravel of Solid Rocks for Construction Works. Specifications”. The fineness modulus of sand from the Beineu deposit is 2.75 and sand is classified as coarse, grade I. Sand from the Beineu deposit meets the requirements of State Standard GOST 8736-2014 “Sand for Construction Works. Specifications”.

To ensure targeted control over the rheological behavior of cement systems so as to obtain concrete with specified structural characteristics and performance, such functional additives as MasterAir 200 (air-entraining admixture) and MasterGlenium 305 superplasticizer were used in the amounts as per the manufacturers’ recommendations.

Proportioning was performed in accordance with State Standard GOST 27006-86 “Concretes. Rules for Mix Proportioning”.

The physical and mechanical properties of heavy concrete were determined in accordance with:

- State Standard GOST 10180-2012 “Concretes. Methods for Strength Determination Using Reference Specimens”;
- State Standard GOST 18105-2018 “Concretes. Rules for Control and Assessment of Strength”.

The compression strength of test specimens was determined with the use of a C23CO2 CONTROLS automatic compression tester.

An accelerated procedure to determine the water tightness of B35 concrete with the modifying additive by its air permeability was carried out in accordance with State Standard GOST 12730.5-84 “Concretes. Methods for Determination of Water Tightness”. For that purpose, an Agama-2RM device was used.

Water absorption tests were performed to determine concrete resistance to the penetration of aggressive salts according to paragraph 5.5, item 41, CIV-CU-850-TCO specification. The test procedure was as follows:

- cores with a diameter of 100 mm and a length of 150 mm were cut out of 10 test specimens (test cubes) with a portable SOLGA SDR 450 diamond drill rig;
- the core samples were weighed to determine their wet mass;
- to determine the moisture-free mass, the core samples were placed in a drying oven. They were continuously dried at a temperature of 105°C for 72 hours;
- the samples were cooled in the drying oven for 24 hours and weighed to determine the moisture-free mass;
- the samples were saturated with water for 30 minutes;
- the surface of the samples was dried, and the samples were weighed to determine the mass of absorbed water.

Differential thermal analysis was carried out with a Q-1500D derivatograph in the temperature range of 25–1500°C in the air flow. The rate of temperature increase was 7.5°/min. Based on the results of thermal transformation and differential mass loss, the amount of $Ca(OH)_2$ was determined.

Sulfate resistance was determined in accordance with State Standard GOST R 56687-2015 “Protection of Concrete and Reinforced-Concrete Constructions from Corrosion. Test Method of Sulfate Resistance of Concrete”. The standard takes into account the main regulations of ASTM C 452-06 “Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate”.

Results and Discussion

When the strength properties of B35 concrete with the composite additive with MasterGlenium 305 superplasticizer were determined, it was established that at a constant W/C ratio, in the first 24 hours, the rate of strength gain slows down a bit as compared to concrete based on a non-modified binder. By day 3, the rate of retardation is reduced. After seven days of curing, an increase in the rate of strength gain can be observed. The physical and mechanical properties of B25 and B35 heavy concretes based on the MV-D20 modified binder are given in Table 1.

Table 1. Physical and mechanical properties of B25 and B35 heavy concretes based on the MV-D20 modified binder with the composite additive

Concrete grade	Concrete density, kg/m³	Porosity, %	Compression strength, MPa (at a particular age of curing, days)			
			7	28	90	360
B25	2360	4.5	25.0	31.0	32.0	32.5
B35	2440	4.4	32.0	43.0	43.5	44.0

When the strength of B35 heavy concrete with the composite modifying additive was assessed in accordance with State Standard GOST 18105-2018 “Concretes. Rules for Control and Assessment of Strength”, it was established that the average strength of the designed concrete composition is 40.75 MPa. The standard deviation of strength in a batch is 1.35 MPa, and the current coefficient of strength variation in a batch is 3.5%. The required strength of B35 concrete with the composite modifying additive is 37.45 MPa, and the required strength of B25 concrete is 27.75 MPa.

Among the important indicators that determine the quality of binders, the following can be mentioned: activity and the kinetics of strength gain with an increase in the curing period or when using concrete and reinforced-concrete products.

Fig. 1. presents the kinetics of strength gain in B25 and B35 heavy concretes based on the MV-D20 modified binder with the composite additive. It shows that after one day of curing, B25 and B35 concretes gain 56.7 and 55.3% of the required strength, respectively.

The designed B25 and B35 concrete mixes based on the MV-D20 modified binder with the composite additive gain the required standard strength after 28 days of curing. In the initial curing period of 7 days, they gain 90.1 and 85.4% of the required standard strength, respectively.

Based on the obtained results, it is possible to divide the mechanism of hydration and curing (with regard to heavy concrete based on the MV-D20 modified binder with the composite additive) into the following two stages:

- the stage of intense hydration (4.5 hours of concrete mix preparation – 7 days of curing). At this stage, clinker minerals are hydrated, the pozzolanic activation of the mineral additive takes place, and stable hydrates are formed;

- the stage of slow hydration (7 days – one year). At this stage, pozzolanic reactions prevail.

Thus, in terms of the rate of strength gain, the designed mixes of heavy concretes based on the MV-D20 modified binder with the composite additive consisting of tailings and microsilica are fast-curing.

To determine if it is possible to use B35 heavy concrete with the composite additive for the construction of facilities to be operated in moderately and highly aggressive environments, water absorption, water tightness, and sulfate resistance

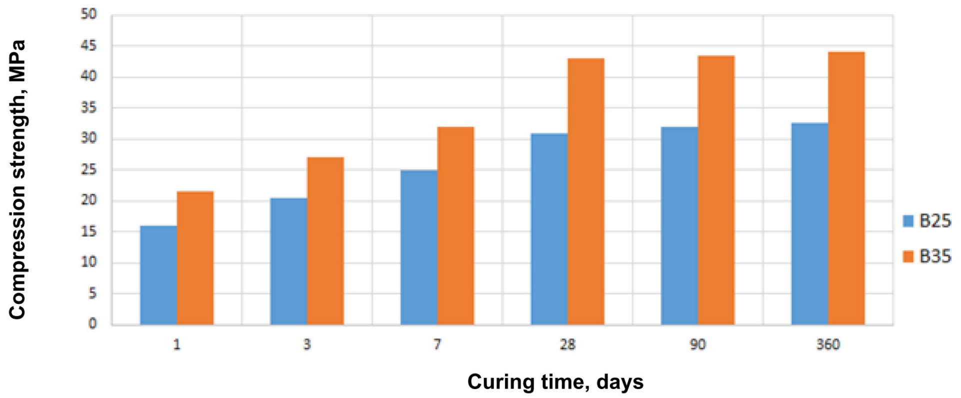

Fig. 1. Kinetics of strength gain in heavy concrete based on the MV-D20 modified binder with the composite additive

were also studied.

The high specific surface area (up to 1500 m^2/kg) in combination with the amorphized structure of microsilica particles and silicon carbide elements ensure high reactivity (Batrakov et al., 1989; Zhang et al., 2016).

Table 2 presents data on the effect of the composite additive consisting of 60% tailings + 40% microsilica on the amount of formed $Ca(OH)_2$ in C_3S stone.

Table 2. Effect of the composite mineral additive on the amount of $Ca(OH)_2$ in C_3S stone

Additive, %	Amount of Ca(OH)2, % (at a particular age of curing, days)				
	3	7	28	180	360
Without additive	12.0	14.0	20.5	22.5	24.5
60% tailings from the Balkhash Mining and Processing Plant + 40% microsilica	11.5	12.0	14.5	15.0	15.5

The experimental data (Table 2) show that after 28 days of curing, the composite mineral additive reduces the amount of Portlandite by 6.0%. With an increase in the curing period with regard to C3S stone with the composite modifying additive up to 360 days, the $Ca(OH)_2$ content is reduced by 9.0%.

In their paper, Tang et al. (2017) showed that when introduced into the composition of a modifying additive, due to their high pozzolanic activity, microsilica and fly ash from the Vung Ang thermal power plant reduce the amount of Portlandite in cement stone at the age of 28 days of normal curing by 1.27–3.29% as compared to the reference composition, which does not contradict our data.

There is an opinion (Bazhenov, 2002; Lothenbach et al., 2008; Singh et al., 2017; Tang et al., 2017; Yestemessova et al., 2020; Zhakipbekov et al., 2021a, 2021b; Zhilkibayeva et al., 2021) that a decrease in the amount of $Ca(OH)_2$ in cement stone increases the corrosion resistance of concrete in aggressive environments.

Table 3. Results of water absorption tests for B25 and B35 heavy concretes based on the MV-D20 modified binder with the composite additive

Core sample No.	Mass of the sample, g			Mass of water absorbed	
	before drying	after drying	after saturation with water for 30 minutes	g	%
Heavy concrete (B25)					
1	2560	2430	2490	60	4.44
2	2550	2440	2490	50	3.69
3	2540	2420	2480	60	4.46
Average value					4.20
Heavy concrete (B35)					
1	2520	2410	2450	40	2.99
2	2520	2430	2480	50	3.70
3	2520	2430	2480	50	3.70
Average value					3.46

a

b

c

d

Fig. 2. Testing of the core samples to determine water absorption in B25 and B35 concretes:
a — a portable SOLGA SDR 450 diamond drill rig; b — marking of the core samples; c — drying of the samples to determine the moisture-free mass (in a SNOL 58/350 laboratory low-temperature electric drying oven); g — weighing of the core samples after drying to determine the moisture-free mass (MWP-3000H laboratory balance, verification certificate No. VG-000000401 dated May 02, 2019)

Table 3 presents the results of water absorption tests for B25 and B35 heavy concretes based on the MV-D20 modified binder with the composite additive (Fig. 2).

Since the core samples had a length different from 75 mm, an adjustment coefficient was used to standardize the volume of the samples according to the requirements of State Standards GOST 12730.0 – GOST 12730.4-78 and GOST 12730.5-84. The adjustment coefficient K_a is 1.8.

The results of water absorption tests (Table 2) showed that water absorption in B25 concrete based on the MV-D20 modified binder with the composite additive consisting of tailings and microsilica is in the range of 3.69–4.46%. The average value of water absorption in B25 concrete is 4.20%. Water absorption in B35 heavy concrete is 2.99–3.70%. The average value of water absorption in B35 concrete is 3.46%.

The results of water tightness tests (Table 4) showed that the actual value of B25 concrete resistance to air penetration is in the range of 18.4–19.0 s/cm^3. In terms of water tightness, the B25 concrete grade is W10. As for B35 concrete with the composite additive, in terms of water tightness, it has grade W12. The actual value of its resistance to air penetration is in the range of 24.4–26.6 s/cm^3.

Studies of sulfate resistance in cement concrete performed by Moskvin et al. (1980) showed that the main structural characteristics and performance of heavy concretes based on Portland cement depend on its compression strength, density, and the number and nature of pores.

Kreis and Nigol (1969) determined that there is a direct relationship between the water absorption coefficient and corrosion resistance of samples produced based on shale ash, lime, and Portland cement. In their opinion, the greater the water content in the concrete mixture, the less its resistance to salt corrosion.

Studies addressing the properties of heavy silicate material showed that sulfate resistance depends not on density but on the internal structure of autoclaved concrete (Rooni, 1972). According to Ngo et al. (2020b), the resistance of heavy concrete in aggressive environments depends mainly on the morphology of cement hydrates, and density is less essential.

Table 4. Water tightness of B25 and B35 of heavy concretes based on the MV-D20 modified binder with the composite additive

Core sample No.	Concrete resistance to air penetration in accordance with the applicable regulatory document, s/cm^3	Actual value	Water tightness grade, W
Heavy concrete (B25)			
1	13.8–19.6	18.4	10
2	13.8–19.6	18.6	10
3	13.8–19.6	19.0	10
Heavy concrete (B35)			
4	19.7–29.0	25.2	12
5	19.7–29.0	24.4	12
6	19.7–29.0	26.6	12

Table 5. Sulfate resistance of B25 and B35 heavy concretes based on the MV-D20 modified binder with the composite additive

Relative deformation, % (in a month)											
1	2	3	4	5	6	7	8	9	10	11	12
B35 heavy concrete based on cement CEM I 42.5N CC (ordinary curing) (without additive)											
0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.08	0.09	0.097
B25 heavy concrete based on MV-D20											
0.01	0.02	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.08	0.085	0.095
B35 heavy concrete based on MV-D20											
0.01	0.01	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.085

The sulfate resistance of the heavy concrete specimens was determined in accordance with State Standard GOST R 56687-2015 "Protection of Concrete and Reinforced-Concrete Constructions from Corrosion. Test Method of Sulfate Resistance of Concrete". Table 5 presents the results of sulfate resistance tests involving B25 and B35 heavy concretes based on the MV-D20 modified binder with the composite additive

The relative deformation of B35 concrete based on sulfate-resistant Portland cement CEM I 42.5N SS (ordinary curing) by CaspiCement LLP at the age of 12 months during the tests is 0.097%. Concrete is classified as concrete of group III (sulfate-resistant) (Table 5). The application of the MV-D20 modified binder with the composite mineral additive instead of standard sulfate-resistant Portland cement CEM I 42.5N SS (ordinary curing) by CaspiCement LLP reduces the relative deformation of B35 concrete by 12%.

Conclusions

The experiments proved that the obtained B25 and B35 concretes based on the designed MV-D20 modified binder with the composite additive can be classified as concretes of group III (sulfate resistant) since the relative deformation of the samples at the age of 12 months is lower than the standard index of 0.1%.

It was established that the sulfate resistance of concrete can be improved by introducing into cement a composite mineral additive of optimal composition, consisting of tailings from the Balkhash Mining and Processing Plant, activated with microsilica.

The composite modifying additive of optimal composition, consisting of 60% tailings + 40% microsilica by mass is capable of binding $Ca(OH)_2$ into insoluble compounds, thus reducing the leaching rate of CaO. Besides, the composite mineral additive reduces the water absorption and increases the water tightness of concrete, and also reduces the relative deformation of B35 concrete by 12%.

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СТРОИТЕЛЬНО-ЭКСПЛУАТАЦИОННЫЕ ХАРАКТЕРИСТИКИ БЕТОНА С КОМПЛЕКСНОЙ МОДИФИЦИРУЮЩЕЙ ДОБАВКОЙ

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Аннотация

Рассмотрено влияние комплексной модифицирующей минеральной добавки на основе отходов – хвостов обогащения Балхашского горно-обогатительного комбината с микрокремнеземом на строительно-эксплуатационные свойства тяжёлого бетона. **Целью работы** был подбор оптимальных составов бетонов класса В 25 и В 35 на основе полученного модифицированного вяжущего МВ-Д20 с комплексной добавкой в его составе и оценка характеристик бетонов. **Методы:** Проектирование составов и испытания характеристик бетона проводили **стандартными методами.** Подбор состава бетона выполнен согласно ГОСТ 27006-86 «Бетоны. Правила подбора состава». Физико-механические свойства тяжёлого бетона определяли по ГОСТ 10180-2012 «Бетоны. Методы определения прочности по контрольным образцам». Оценку прочности проводили по ГОСТ 18105-2018 «Бетоны. Правила контроля и оценки прочности». **Результаты:** Установлено, что разработанные составы тяжелых бетонов по скорости набора прочности относятся к быстротвердеющим. Бетоны в начальном сроке твердения 7 суток набирают 90,1 и 85,4 %, соответственно, требуемой нормативной прочности. Средние значения показателя водопоглощения бетонов класса В 25 и В 35, соответственно, составляют 4,20 и 3,46 %. Марки бетонов по водонепроницаемости соответствуют W10 и W12. Применение полученного модифицированного вяжущего МВ-Д20 с комплексной добавкой на основе отходов хвостов обогащения и микрокремнезема в его составе взамен базового сульфатостойкого портландцемента позволяет снизить относительную деформацию бетона класса В 35 в агрессивной среде на 12%.

Ключевые слова

Комплексная минеральная добавка, сульфатостойкий портландцемент, отходы – хвосты обогащения, микрокремнезем, прочность, быстротвердеющий бетон, водопоглощение, водонепроницаемость.

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EXPERIMENTAL STUDIES OF NODAL JOINTS OF WOODEN ELEMENTS IN TRUSSES AND GEODESIC DOMES

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Abstract

Introduction: In this paper, we consider LVL (laminated veneer lumber with unidirectional veneer) as an element of plane trusses and geodesic domes, acting as the bearing structure of roofs, and study destruction of LVL joints, which is necessary to improve designs of wooden roofs under consideration. **Methods:** Our studies were based on structural mechanics and wood science. In the course of the study, we used analytical, experimental, and statistical methods to process the results of tests. **Results:** Based on the experimental studies performed, we suggest a method to determine the design bearing capacity of treenails per edge joint (conventional shear) for joints of LVL elements with wood laminate (DSP-V, wood laminate where veneer fibers in the adjacent layers are mutually perpendicular) plates. **Discussion:** We obtained new values of the coefficient taking into account the compliance of connections for nodes and joints in LVL composite elements, which make it possible to quickly determine the required cross-sections of bearing rod elements in plane trusses.

Keywords

Construction, wooden roofs, LVL, new nodal joints, laboratory tests, elements of plane trusses, geodesic dome, joints of wooden elements, bearing capacity, treenail.

Introduction

In modern construction, buildings and structures with wooden frames in the roof are less common than buildings and structures with reinforced-concrete and metal elements in the roof. Besides, in most cases, roofs have limited spans, which, in turn, limit the scope of application of wooden frames. Lumber produced out of logs has always been the basic element of structures, and that reduces the efficiency of wood utilization in construction. We suggest replacing lumber produced out of logs with LVL (Zhivotov, 2009a). In this paper, LVL means laminated veneer lumber with unidirectional veneer. LVL has more uniform dimensions and strength properties than regular lumber. This is important in the construction of large-span wooden roofs consisting of arches, frames, and trusses, as well as geodesic domes assembled from LVL members, which are often used not only in construction but also in the reconstruction of buildings in the historical part of Saint Petersburg (Golovina, 2020; Yudina, 2019; Yudina and Tilinin, 2019; Yudina et al., 2019, 2020).

In terms of the construction of wooden roofs with the use of trusses and domes made of LVL, we performed strength tests of new types of LVL joints in plane trusses and geodesic domes in a laboratory environment. We also analyzed the results of previous studies addressing joints of wooden elements.

Methods

The study was based on the science behind wood utilization as a structural material produced as a result of sawing tree trunks (Chernykh et al., 2020, 2022). In the course of the study, we used analytical, experimental, and statistical methods to process the results of the strength tests involving new types of LVL joints in plane trusses and geodesic domes, performed in a laboratory environment.

LVL is made of high-density veneer, where all soft wood layers have fibers in longitudinal direction (Chernykh et al., 2020; Zhivotov, 2009b).

LVL joints in a truss are performed with the use of plates, nails, treenails, and studs (Fig. 1).

First, we conducted experiments to determine the coefficient taking into account the compliance of connections (K_c) for wood laminate (DSP-V, wood laminate where veneer fibers in the adjacent layers are mutually perpendicular) and steel plates.

In the case of many connections in nodes with plates, the coefficient taking into account the compliance of connections (K_c) for wood laminate (DSP-V) plates is used. The viscosity of LVL and wood laminate (DSP-V) joints is determined by viscous mortise bearing resistance.

The pull-out resistance of connections in the joints of truss members with double-sided plates is analyzed with account for the characteristics of the plate:

n — the number of holes in the plate;
b — the width of the plate;
t — the thickness of the plate.

The tensile stresses in the plate are as follows:

$$\sigma_N = \frac{N}{2*A} = \frac{N}{2*(b-d)*t}. \quad (1)$$

The bending moment in the plate at the number of connections n = 3 is as follows:

$$M_{BEND} = \frac{N*5}{2} = \frac{N*t}{4*n}. \quad (2)$$

The bending stress in the plate is as follows:

$$\sigma_M = \frac{M}{W_{PLATE}} = \frac{6N}{4*n*b*t}. \quad (3)$$

The total stress in the plate is as follows:

$$\sigma_{TOT} = \frac{\sigma_N}{R_p} + \frac{\sigma_M}{R_l} \le 1 \quad \text{or}$$

$$\sigma_{TOT} = \sigma_N + \sigma_M \frac{R^{PLATE}}{R^{PLATE}_l} \le R_P \quad (4)$$

$$\sigma_{TOT} = \frac{\sigma_N^{PLATE}}{R_P^{PLATE}} * (1 + \frac{3*R_P^{PLATE}}{n*R_l^{PLATE}}) = \frac{N}{2(b-d_c)*t*R_P^{PLATE}} * (1 + \frac{3*R_P^{PLATE}}{n*R_l^{PLATE}}) = \frac{N}{2(b-d_c)t*R_P^{PLATE}*m_0*K_C},$$

where $K_C = \frac{1}{(1+\frac{3*R_P^{PLATE}}{n*R_l^{PLATE}})}$

m_0 — the coefficient taking into account the stress concentration effect. In the case of wood laminate (DSP-V), m_0 = 0.9; in the case of steel, it is neglected.

$\frac{R_P^{PLATE}}{R_l^{PLATE}}$ increases the role of the effect of wood material features and takes into account the influence of loading and properties of the material on long-term behavior.

The limit state of the plates can be checked as follows:

$$\frac{\sigma_P^{PLATE}}{K_C * R_P^{PLATE}} \le 1. \quad (5)$$

Based on the equation above, it is possible to determine the coefficient taking into account the compliance of connections (K_c) for wood laminate (DSP-V) plates (Table 1).

Below, we provide values of the coefficient taking into account the compliance of connections (K_c) for steel plates: high-strength plates with yield point σ_y > 38.0 kN/cm^2 (Table 2) and regular plates with yield point σ_y < 38.0 kN/cm^2 (Table 3).

The data in Tables 1, 2 and 3 are recommended to be introduced in regulatory standards addressing the design of wooden plane trusses.

Nodal joints were tested with the use of hydraulic and mechanical drives according to a diagram below (Fig. 2).

We aimed to study the effect of the connection type on the bearing capacity of the joint.

During the tests, the following types of connections were considered:

- type 1 — with Casco S9 Super adhesive (by AkzoNobel) over the entire plate, S = 10 cm^2. Arrangement of the connecting elements: LVL — across the fibers (horizontal), wood laminate (DSP-V) — along the fibers (vertical);
- type 2 — with lag screws (d = 1.2 cm). Arrangement of the connecting elements: LVL — across the fibers (horizontal), wood laminate (DSP-V) — along the fibers (vertical);
- type 3 — with adhesive + lag screws (d = 1.2 cm). Arrangement of the connecting

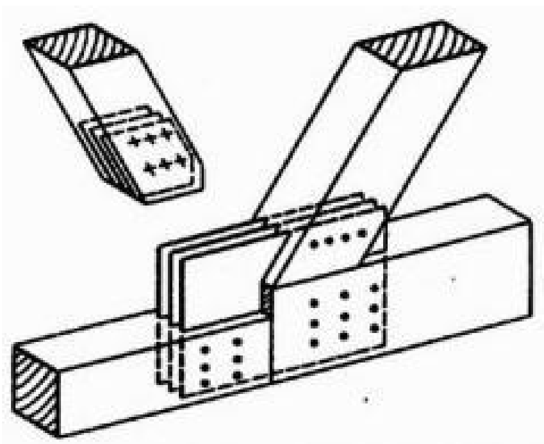


Fig. 1. Truss node with a nailed joint of elements using plates

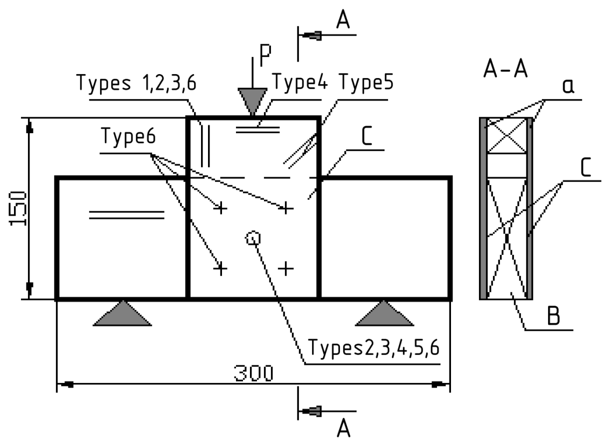


Fig. 2. Diagram of connections at an angle of 90°:
a — wood laminate (DSP-V); b — LVL;
c — adhesive; = fiber direction

Table 1. Values of the coefficient taking into account the compliance of connections for wood laminate (DSP-V) plates

n	1	2	3	4	6	8	10	20
K_c	0.498	0.665	0.749	0.799	0.856	0.888	0.908	0.952

Table 2. Values of the coefficient taking into account the compliance of connections for high-strength steel plates

n	1	2	3	4	6	8	10	20
K_c	0.268	0.423	0.524	0.595	0.688	0.746	0.786	0, 880

Table 3. Values of the coefficient taking into account the compliance of connections for regular steel plates

n	1	2	3	4	6	8	10	20
K_c	0.259	0.412	0.512	0.583	0.677	0.737	0.778	0.875

elements: LVL — across the fibers (horizontal), wood laminate (DSP-V) — along the fibers (vertical);

- type 4 — with adhesive + lag screws (d = 1.2 cm). Arrangement of the connecting elements: LVL — across the fibers (horizontal), wood laminate (DSP-V) — across the fibers (vertical);
- type 5 — with adhesive + lag screws (d = 1.2 cm). Arrangement of the connecting elements: LVL — across the fibers (horizontal), wood laminate (DSP-V) — at an angle of 45° to the fibers (vertical);
- type 6 — with adhesive + lag screws (d = 1.2 cm) + 4 self-tapping screws (d = 0.38 cm). Arrangement of the connecting elements: LVL — across the fibers (horizontal), wood laminate (DSP-V) — along the fibers (vertical).

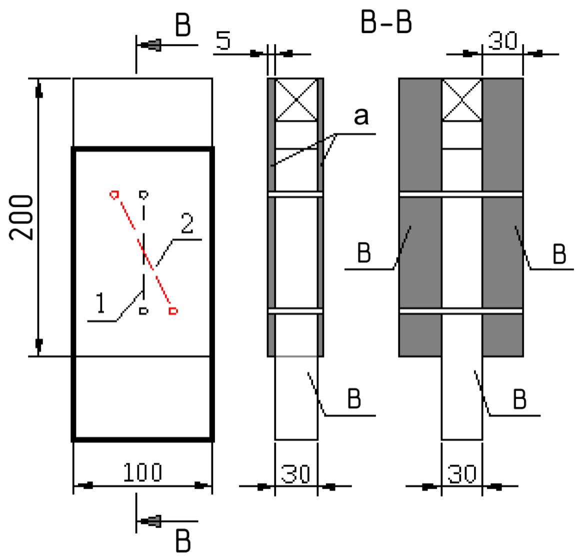


Fig. 3. Diagram of connections along the fibers: a — wood laminate (DSP-V); b — LVL. 1 — the bolts are lined up, 2 — the bolts are in a staggered order

The constructed diagrams imply the following:

1. When types 1, 2, and 3 are compared, the breaking load is as follows:
   - with adhesive: 701 kgf
   - with lag screws (d = 1.2 cm): 1396 kgf
   - with adhesive + lag screws (d = 1.2 cm): 1882 kgf
2. When types 3, 4, and 5 are compared, the breaking load, depending on fiber direction in the plate elements, is as follows:

Type 3. Plates made of wood laminate (DSP-V) with fiber direction along the load axis: 1882 kgf (adhesive + lag screws (d = 1.2 cm)).

Type 4. Plates made of wood laminate (DSP-V) with fiber direction across the load axis: 1687 kgf (adhesive + lag screws (d = 1.2 cm)).

Type 5. Plates made of wood laminate (DSP-V) with fiber direction at an angle of 45° to the load axis: 1528 kgf (adhesive + lag screws (d = 1.2 cm)).

Based on the study conducted, we can assume that fiber direction in wood laminate (DSP-V) elements affects the bearing capacity of the joint and matches the strength properties of the material.

The behavior of elements in treenail joints was analyzed according to a diagram below (Fig. 3).

We aimed to study the effect of connection arrangement on the bearing capacity of the joint for bolts with d = 0.6 cm. For each spacing value, five samples were studied.

We analyzed the behavior of a prestressed treenail by tightening nuts with washers on both sides. The purpose was to study the theoretical prerequisites for an increase in the strength of the joint with prestressing — thrust (Fig. 4). This might be possible due to the reduction of temperature and moisture deformations in LVL.

To avoid torsion of the elements, the samples were made double-shear and symmetrical. The treenails (bolts with d = 0.6 cm of steel 8.8) were set at different spacing *S1* along the fibers. The distance from the vertical axis of the treenail to the edge was more than 3*d* and was equal to 50 mm. Before the tests, dial gauges with a division value of 0.01 mm and a stroke of 10 mm were installed on top of the samples to measure deformations. The load increment was taken equal to 0.1 Pmax.

The bearing capacity of a treenail joint was determined as follows:

Symmetrical joints, bearing resistance in the elements in the middle T^m_b. (6)

Symmetrical joints, bearing resistance in the elements on the edges T^e_b. (7)

Symmetrical joints, bending of a treenail made of steel C38/23 T_{bend}. (8)

Based on the shear condition

$$T_{sh} = R^{av}_{sh} * F_{sh}. \quad (9)$$

$$R^{av}_{sh} = \frac{R_{sh}}{1+\beta\frac{l_{sh}}{e}}. \quad (10)$$

T^m_b (LVL) = 0.5 * c * d * $R_{b,\ LVL}/R_{b,\ wood}$ = 0.5 * 3.0 * 0.6 * 2.3/1.4 = 1.48 kN

T^e_b (LVL) = 0.8 * a * d * $R_{b,\ LVL}/R_{b,\ wood}$ = 0.8 * 3.0 * 0.6 * 2.3/1.4 = 2.37 kN

T_{bend} (Table 4) $2.7d^2$ = 0.972 kN

Table 4. Bearing capacity in treenail bending at an angle α

α	0°	30°	45°	60°	90°
T_{bend}	$2.7d^2$	$1.8d^2$	$1.7d^2$	$1.6d^2$	$1.4d^2$

$T_{sh} = R^{av}_{sh} * F_{sh}$ = 0.189 * 3.0 * 2.4 = 1.36 kN

$R^{av}_{sh\ (LVL)} = R_{sh\ (LVL)}/(1 + \beta * (l_{sh}/e))$ = 0.24 / (1 + 0.25((4 * 0.6)/(0.25(3.0 + 3.0 + 3.0))) = 0.189 kN

The safety factor *(Ksafe)* was determined as follows:

$$K_{safe} = \frac{_{max} * m_{dur}}{T_b}. \quad (11)$$

Thus, the estimated bearing capacity of the entire joint was 4 * 97.2 = 389 kgf. The load increment was taken equal to 150 kgf.

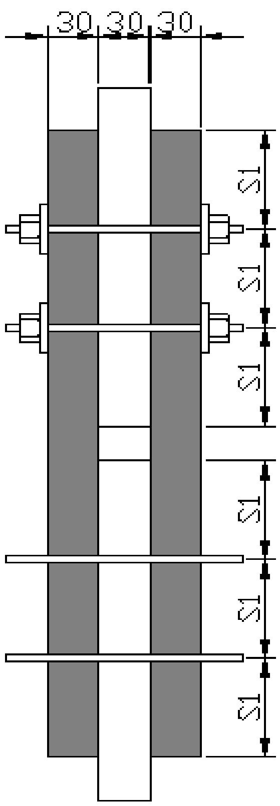


Fig. 4. Diagram of connection arrangement

The tests were carried out using an IM-50 hydraulic press with residual deformation measured. The rate of load increase/decrease was constant throughout the test. During the tests, visual observation was performed and the corresponding test log was filled. After destruction, the fracture pattern was analyzed and photos were taken (Fig. 5). As a result, a deformation vs. load diagram was constructed (Fig. 6).

The measurement results were entered in the test report for LVL (thickness t = 30 mm).

The data obtained were transformed into a diagram showing the relationship between the bearing capacity of a joint and the arrangement of connections (Fig. 7).

The tests showed that in the case of restraint, the LVL joint strength increases by 15%. However, the suggestion to include this theory in regulatory standards will require long-term tests and analysis of the state of nodes in structures operated after several seasons (autumn, spring). This is due to the effect of moisture on the strength properties of LVL.

To study how the connection diameter affects the bearing capacity of the joint, we performed tests using treenails of different diameters. Fig. 8 shows a sample loading pattern.

The tests were carried out using an IM-50 hydraulic press. During the tests, visual observation was performed and the corresponding test log was filled.

The bearing capacity of a treenail joint was determined by Eqs. 6, 7, 8, 9, and 10.

The measurement results were entered in the test report for LVL (thickness t = 30 mm).

The data obtained were transformed into a diagram (Fig. 9).

Since we considered a combined roof consisting of plane trusses and a dome, then in addition to tests for lumber joints in plane trusses, we also performed strength tests involving a new nodal joint of an LVL geodesic dome.

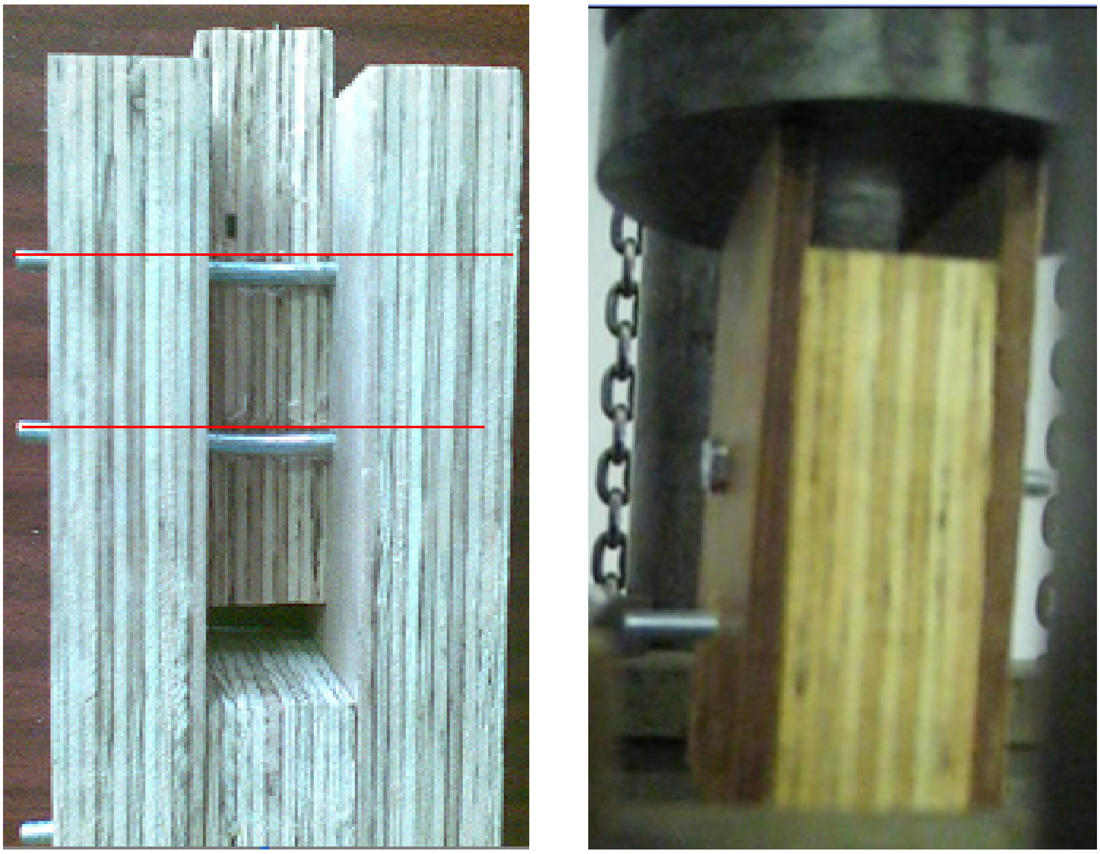


Fig. 5. A sample destroyed

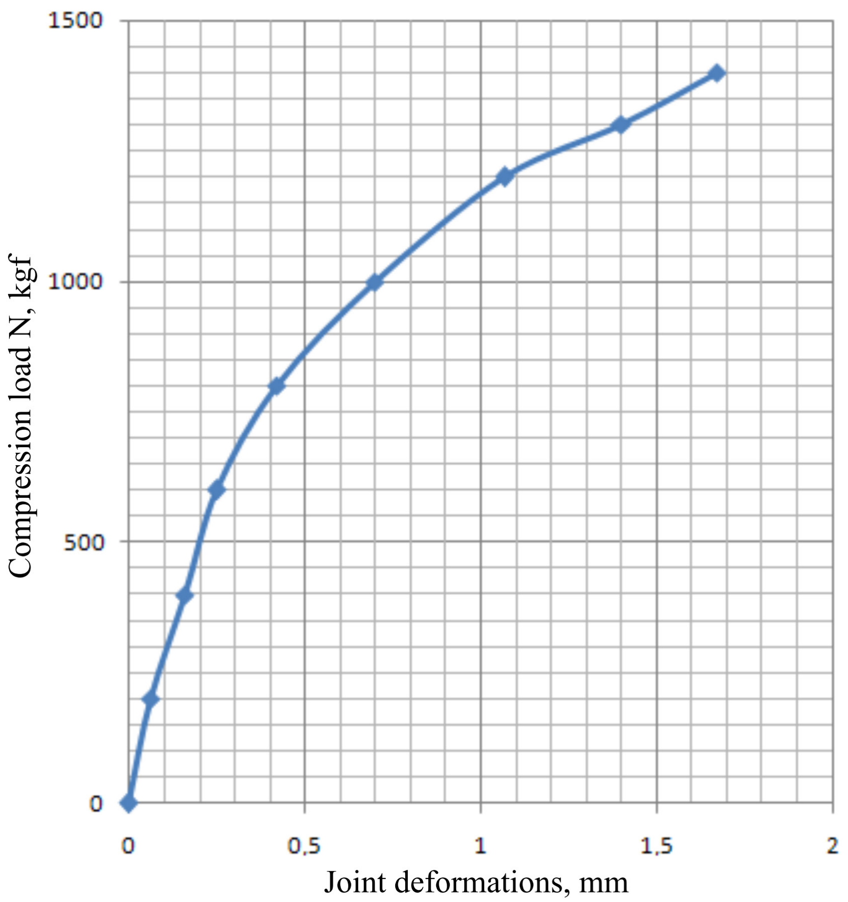


Fig. 6. Deformation vs. load diagram

We considered new patented fiberglass nodal joints (Bushin et al., 2017) tested in a laboratory environment. The node elements were made of TOTAL GF-30 (N) plastic and assembled into a single node, which then was tested under the maximum load of 8.56 kN with an Instron 5998 tensile strength tester (Figs. 10–12).

Fig. 12 shows a destroyed sample, whose elements were made using additive manufacturing techniques.

Results

Based on the studies performed, we suggested a method to determine the design bearing capacity of treenails per edge joint (conventional shear) for joints of LVL elements with wood laminate (DSPV) plates, considering the coefficient taking into account the compliance of connections (K_c) for wood laminate (DSP-V) plates. The results are presented by diagrams showing the relationship between the bearing capacity of the joint and the arrangement of connections as well as the relationship of the breaking load P_{max} and the safety factor K_{safe} with the connection diameter.

These tests of new nodes of geodesic domes are pilot and require further research.

Discussion

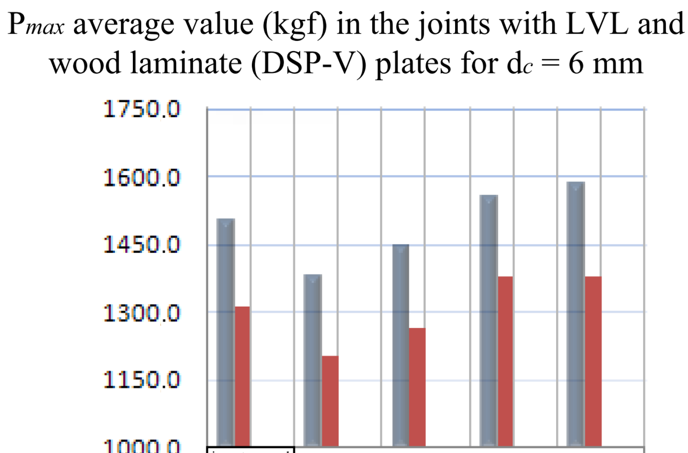
The obtained positive results of testing nodal joints in plane trusses and spatial structures in the form of LVL geodesic domes can be used in the design of wooden roofs in the form of a dome with a diameter of 24 m, resting on the elevated edge of single-slope trusses with a length of 24 m, thus forming a building round in plan with a roof having a diameter of 72 m.

In this paper, equations to determine joints of LVL elements with wood laminate (DSP-V) and LVL plates were proposed.

We established patterns showing the influence of the breaking load P_{max} on the type and diameter of connections as well as method of their arrangement in the joints of LVL elements.

A new design of nodes was proposed. The static tests involving real structures confirmed the effectiveness of the proposed solution for wood laminate (DSP-V) plates under the influence of various aggressive environments.

Further research should include preliminary studies aimed to develop software for the design of nodal joints in trusses with the use of standard elements to reduce material consumption and cut costs. It should also include experimental studies of the new nodal joint of geodesic domes.



	in a staggered order	lined up			
	4d	4d	5d	6d	7d
Pi, kgf (with nuts)	1501.8	1377.8	1446.7	1553.3	1583.3
Pii, kgf (without nuts)	1312.7	1204.3	1263.3	1380.0	1380.0
k=Pi/Pii	1.14	1.14	1.15	1.13	1.15
ratio, %		9%	5%	7%	2%

Fig. 7. Diagram showing the relationship between the bearing capacity of a joint and the arrangement of connections

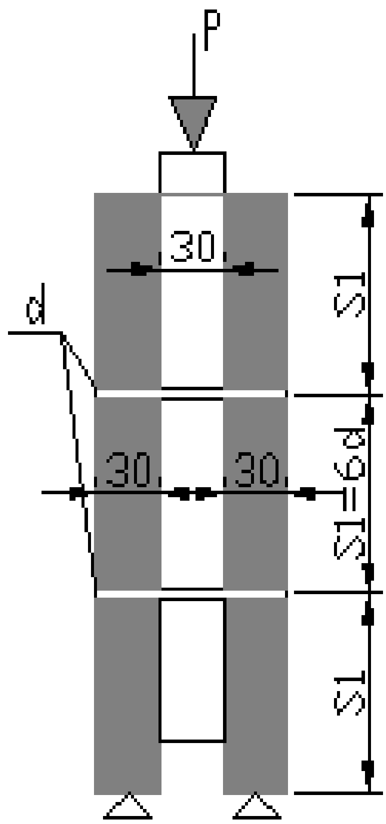


Fig. 8. Sample loading diagram

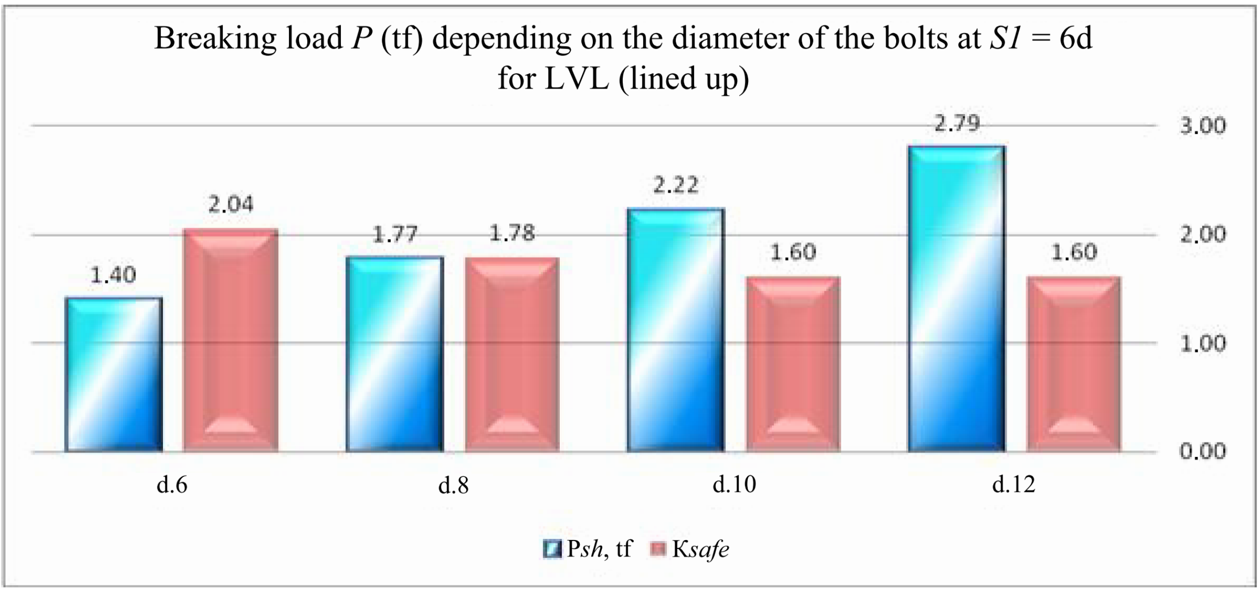


Fig. 9. Breaking load P_{max} and safety factor K_{safe} vs. connection diameter

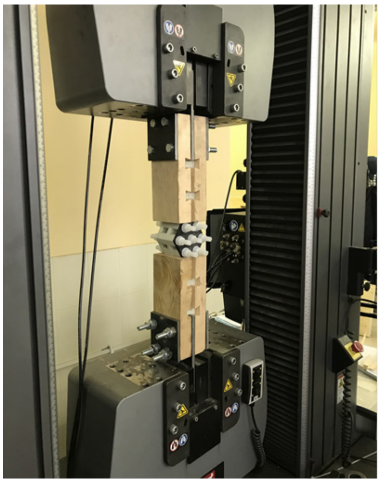


Fig. 10. A sample gripped in an Instron 5998 tensile strength tester

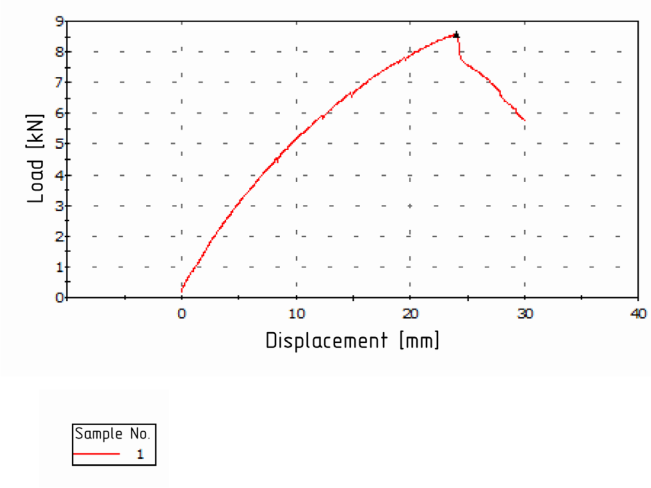


Fig. 11. Displacements vs. applied load

Fig. 12. Node after the tensile test

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ УЗЛОВЫХ СОЕДИНЕНИЙ ДЕРЕВЯННЫХ ЭЛЕМЕНТОВ СТРОИТЕЛЬНЫХ ФЕРМ И ГЕОДЕЗИЧЕСКИХ КУПОЛОВ

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Аннотация

Рассмотрен деревянный клееный брус в качестве элемента плоских ферм и геодезических куполов, выполняющего функцию несущих конструкций покрытий зданий, а также проведено исследование разрушения узлов сопряжения клееного бруса, необходимое для совершенствования проектных решений рассматриваемых деревянных покрытий. В работе использовали клееный брус из однонаправленного шпона (LVL - Laminated Veneer Lumber). **Методы:** Исследования базируются на теоретических положениях строительной механики и древесиноведении. В исследовании использован аналитический, экспериментальный методы и статистический метод обработки результатов испытаний. **Результаты:** На основании экспериментальных исследований предложена методика определения расчетной несущей способности нагелей на один шов сплачивания (условный срез) для соединений элементов из LVL с фасонками из ДСП-В. **Обсуждение:** Получены новые значения коэффициентов учета податливости связей в узлах и соединениях в составных элементах из LVL, которые позволяют оперативно подобрать сечения несущих стержневых элементов плоских балочных ферм.

Ключевые слова

Строительство, деревянные покрытия зданий, клееный брус, новые узловые соединения, лабораторные испытания, элементы плоских ферм, геодезический купол, сопряжения деревянных элементов, несущая способность, нагель.

Guide for Authors
for submitting a manuscript for publication in the «Architecture and Engineering»

The journal is an electronic media and accepts the manuscripts via the online submission. Please register on the website of the journal **http://aej.spbgasu.ru/**, log in and press "Submit article" button or send it via email **aejeditorialoffice@gmail.com.**

Please ensure that the submitted work has neither been previously published nor has been currently submitted for publication in another journal.

Main topics of the journal:

1. Architecture
2. Civil Engineering
3. Geotechnical Engineering and Engineering Geology
4. Urban Planning
5. Technique and Technology of Land Transport in Construction

Title page

The title page should include:

The title of the article in bold (max. 90 characters with spaces, only conventional abbreviations should be used); The name(s) of the author(s); Author's(s') affiliation(s); The name of the corresponding author.

Abstract and keywords

Please provide an abstract of 100 to 250 words. The abstract should not contain any undefined abbreviations or unspecified references. Use the IMRAD structure in the abstract (introduction, methods, results, discussion).

Please provide 4 to 6 keywords which can be used for indexing purposes. The keywords should be mentioned in order of relevance.

Main text

It should have the following structure:

1) Introduction,
2) Scope, Objectives and Methodology (with subparagraphs),
3) Results and Discussion (may also include subparagraphs, but should not repeat the previous section or numerical data already presented),
4) Conclusions,
5) Acknowledgements (the section is not obligatory, but should be included in case of participation of people, grants, funds, etc. in preparation of the article. The names of funding organizations should be written in full).

General comments on formatting:

- Subtitles should be printed in Bold,
- Use MathType for equations,
- Tables should be inserted in separate paragraphs. The consecutive number and title of the table should be placed before it in separate paragraphs. The references to the tables should be placed in parentheses (Table 1),
- Use "Top and Bottom" wrapping for figures. Figure captions should be placed in the main text after the image. Figures should be referred to as (Fig. 1) in the text.

References

The journal uses Harvard (author, date) style for references:
- The recent research (Kent and Park, 1990)...
- V. Zhukov (1999) stated that…

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Do not use footnotes or endnotes as a substitute for a proper reference list. All references must be listed in full at the end of the paper in alphabetical order, irrespective of where they are cited in the text. Reference made to sources published in languages other than English or Russian should contain English translation of the original title together with a note of the used language.

Peer Review Process

Articles submitted to the journal undergo a double blind peer-review procedure, which means that the reviewer is not informed about the identity of the author of the article, and the author is not given information about the reviewer.
On average, the review process takes from one to five months.