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GEOMETRIC-COMPOSITIONAL AND COMBINATORIAL MODELS OF THE FORMATION OF SHELL ARCHITECTURAL SYSTEMS IN THE CONTEXT OF ORGANIZATIONAL AND TECHNOLOGICAL SUPPORT OF THE LIFE CYCLE OF MEDICAL BUILDINGS

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ABSTRACT

The article considers theoretical, methodological, and applied aspects of forming shell architectural systems in the design of medical buildings from the perspective of geometric-compositional and combinatorial approaches. The study aims to generalize modern scientific approaches to the formation of shell systems as integrated architectural and technological structures that determine the spatial organization, structural feasibility, and functional flexibility of medical buildings throughout their life cycle. Particular attention is paid to the role of shell geometry in the formation of the architectural structure of buildings and the possibilities of applying parametric and modular solutions in design practice. The study systematizes the main types of shell architectural systems, in particular cylindrical, spherical, double-curved shells (hyperbolic paraboloids), minimal and parametric surfaces, and summarizes the feasibility of their use in various functional areas of medical buildings. Typological tables have been compiled that reflect the geometric, structural, and planning and functional characteristics of shell systems in the context of their architectural application. It is shown that open geometric-compositional and combinatorial models play the role of a tool for forming variant planning and structural solutions, allowing the combination of typical geometric and structural modules depending on the functional and technological requirements of medical institutions. This approach provides the possibility of adapting the spatial structure of buildings without fundamentally changing their load-bearing systems. A qualitative relationship has been established between the geometry of shell systems and organizational and technological processes at the stages of design, construction, and operation of medical buildings. A summary of scientific and design solutions shows that the use of shell architectural systems contributes to increasing the spatial flexibility and architectural adaptability of buildings during their reconstruction and functional modernization. The results obtained can be used in the practice of architectural and BIM design of medical buildings, in the development of concepts for adaptive healthcare facilities, as well as in scientific and educational activities in architectural design.



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I. INTRODUCTION

The current stage of development of the healthcare system is characterized by profound transformations that encompass not only medical technologies but also architectural and construction approaches to the formation of the treatment environment. Medical buildings are increasingly seen as complex spatial and functional organisms capable of responding flexibly to changes in medical processes, regulatory requirements, and demographic and socio-economic conditions. In these conditions, it is particularly important to find architectural and structural solutions that ensure the long-term efficiency of a facility throughout its life cycle – from design and construction to operation, reconstruction, and possible repurposing. One of the promising areas in this context is the use of shell architectural systems that combine spatial rationality, structural efficiency, and high compositional potential.

The issues of shell structures and their geometric shaping are thoroughly covered in the works of foreign scientists [1], [2], who studied the patterns of spatial operation of shells, their typology, and structural features. A significant contribution to the development of the theory of shell systems has been made in studies devoted to the geometry of curved surfaces, parametric modeling, and compositional principles of architectural form creation. A separate area of scientific work concerns the application of combinatorial and modular approaches in building design, which allow the formation of variable spatial structures taking into account functional and technological requirements [3], [4]. At the same time, in a work [5] devoted to the architecture of medical buildings, the main focus is mainly on planning, engineering support, and sanitary and hygienic aspects, while the potential of shell systems is often considered fragmentarily.

An analysis of scientific sources [6–8] shows that the issue of the comprehensive combination of geometric-compositional and combinatorial models for the formation of shell architectural systems with the organizational and technological support of the life cycle of medical buildings remains insufficiently researched. In particular, approaches that allow assessing the influence of shell geometry not only on architectural, artistic, and structural characteristics, but also on the processes of design, construction, operation, and adaptation of buildings to changes in functional purpose require further study. It is these “blank spots” that necessitate a systematic study of shell architectural systems in the context of the life cycle of medical facilities. The aim of the study is to improve the efficiency of the formation and functioning of medical buildings through the use of geometric-compositional and combinatorial models of shell architectural systems.

II. LITERATURE REVIEW

The issue of forming shell architectural systems in modern construction has been actively developing over the past decades, which is due to the increasing complexity of architectural objects, the spread of digital design technologies, and the increasing requirements for energy efficiency and adaptability of buildings. Early research in this field [9–11] focused primarily on the structural and mechanical properties of shells, the principles of curved surfaces, and the minimization of material costs. In these works, shell systems were primarily considered as engineering structures with optimized load-bearing capacity. With the development of parametric and algorithmic design, the focus of research has shifted towards geometric and compositional analysis of shell forms and their architectural expressiveness. As noted by [12], [13], modern digital tools allow complex surfaces to be treated as controlled geometric systems in which form, structure, and construction technology are interrelated [12].

This approach is supported by [14], [15], who emphasize the transition from static form creation to process-oriented models, where geometry becomes the result of specified algorithmic and compositional rules. A separate area of scientific research is related to the application of combinatorial and modular models in the formation of architectural systems. In the works of [16–18], combinatorics is considered as a tool for generating a set of spatial variants based on a limited number of basic elements. The authors emphasize that such approaches contribute to the flexibility of architectural solutions and create the preconditions for adapting buildings to changes in their functional purpose. At the same time, in most studies, combinatorial models are analyzed outside the context of the full life cycle of a building. In the field of medical building architecture, scientific works focus mainly on planning, patient and staff flows, sanitary and hygienic requirements, and engineering support [19], [20].

Researchers emphasize that the quality of the architectural environment directly affects the effectiveness of the treatment process and the psychological state of users. At the same time, the issue of the geometric and compositional potential of shell systems in medical buildings is covered fragmentarily and, for the most part, without reference to the organizational and technological aspects of their implementation. Recent studies on building lifecycle management and digital modeling emphasize the importance of integrating architectural, structural, and technological solutions into a single information model [21], [22]. The authors note that the geometric complexity of shell systems can both increase the efficiency of building operation and create additional risks during construction and renovation if it is not coordinated with organizational and technological processes.

Summarizing scientific approaches, three main research paradigms can be identified:

1. Engineering and structural, focused on studying the strength and operation of shell systems [23], [24].
2. Geometric-compositional, aimed at studying the formation of shapes and parametric modeling of complex surfaces [25], [26].
3. Organizational and technological, which considers a building as an object of management throughout its life cycle [27], [28].

Thus, analysis of the literature shows that despite significant scientific achievements in the field of shell architectural systems, the issue of the complex combination of geometric-compositional and combinatorial models with organizational and technological support for the life cycle of medical buildings remains insufficiently studied. This is especially true for the domestic scientific tradition, which determines the relevance and scientific novelty of further research in this direction.

III. MATERIALS AND METHODS

The study is based on the analysis of scientific, regulatory, methodological, and analytical materials devoted to the formation of shell architectural systems, geometric modeling of complex spatial forms, and organizational and technological support for the life cycle of buildings, in particular those intended for medical use.

The information base of the study consisted of publications by domestic and foreign scientists in the field of architecture, construction engineering, and construction project management, as well as official materials from international professional organizations in the field of architecture and construction. To ensure scientific validity, only open and verified sources were used, including monographs, articles in professional publications, and recommendations from international architectural and construction institutions. The methodological approach of the study involved the use of systematic and comparative analysis methods to identify patterns in the formation of shell architectural systems and determine their impact on the spatial planning and technological solutions of medical buildings. Particular attention was paid to methods of geometric and compositional analysis, which made it possible to study the properties of curved surfaces, the principles of their combination, and their role in the formation of a coherent architectural structure.

To generalize the various solutions, the method of architectural combinatorics was used, which made it possible to systematize typical geometric modules and scenarios for their spatial combination. At the stage of generalizing the results, the method of structural and functional analysis was applied, with the help of which shell systems were considered as constituent elements of a holistic organizational and technological process of the life cycle of a medical building. This made it possible to trace the relationship between the geometry of the shells, construction technology, operational characteristics, and possibilities for further reconstruction. In addition, the analogy method was used to compare approaches to the formation of shell systems in medical buildings with practices tested in other types of public buildings. The study also relied on historical and logical analysis, which made it possible to trace the evolution of shell architectural systems – from classic engineering solutions to modern parametric and combinatorial models.

This made it possible to identify patterns in the transition from a predominantly structural interpretation of shells to their comprehensive consideration as architectural and technological systems. The analysis took into account current building codes and recommendations for the design of medical buildings, which made it possible to assess the compliance of shell solutions with modern regulatory requirements. Theoretical generalization and logical modeling methods were used to summarize the results and form reasonable conclusions. The emphasis was not on computational experiments, but on the systematization and interpretation of existing scientific and practical developments in order to identify promising areas of application for geometric-compositional and combinatorial models in the design and life cycle management of medical buildings. Thus, the chosen methodological structure ensures the comprehensive and interdisciplinary nature of the research and meets modern academic requirements for scientific publications in the field of architecture and construction.

IV. RESULTS

Modern scientific approaches to the formation of shell architectural systems are based on the integration of engineering-geometric, architectural-compositional, and digital modeling methods. The shell is considered as a spatial-functional system, the architectural expressiveness and structural efficiency of which are determined primarily by its geometry. This approach allows the shell to be interpreted not only as a structural element, but as an integrated architectural and technological system that influences the organization of functional processes in a building and the technological aspects of its construction. Within the geometric approach, central importance is given to the study of curved surfaces of varying curvature. Classical and modern works demonstrate that cylindrical, spherical, conical, hyperbolic paraboloids, and minimal surfaces provide different levels of load-bearing capacity and material intensity. The geometric parameters of the shell surface can be formalized through the parametric equation of the surface (1):

$$r(u, v) = \begin{bmatrix} x(u, v) \\ y(u, v) \\ z(u, v) \end{bmatrix} = \begin{bmatrix} u \\ v \\ f(u, v) \end{bmatrix}, (u, v) \in D, \quad (1)$$

Where $f(u, v)$ is the function of the height of the shell above the plane; D is the domain of the parameters. In particular, for a hyperbolic paraboloid, the function is defined as (2):

$$f(u, v) = au^2 - bv^2, \quad (2)$$

where a and b are the curvature coefficients along the respective axes. The use of such parametric models allows evaluating the geometric, structural, and operational characteristics of the shell, as well as optimizing materials and surface shape. At the same time, combinatorial principles of shape formation, based on the use of a limited set of geometric or structural modules to create complex spatial systems, have undergone significant development. Combinatorial approaches allow architectural expressiveness to be combined with the standardization of elements, which contributes to the improvement of the organizational and technological efficiency of construction and operation. A generalized description of the main types of shell systems and their use in medical buildings is presented in Table 1.

Table 1: Typology of shell systems and their architectural and technological characteristics.

Shell type	Main geometric parameters	Design features	Use in medical buildings
Cylindrical	Radius (R), length (L)	Simple frame, easy installation	Covering corridors, passageways
Spherical	Radius (R)	High load-bearing capacity, minimum material	Domes for halls, conference rooms
Hyperbolic paraboloid	Parameters (a, b)	Increased strength, modularity	Patios, atriums, multifunctional room coverings
Minimal surfaces	The shape is determined by energy optimization	Material optimization, complex curvatures	Architecturally expressive facades, covering of recreation areas

Source: Authors, (2026).

A summary of current scientific approaches demonstrates that the most promising are integrated form-building models that combine geometric-compositional and combinatorial principles in a single design process. This ensures an optimal balance between architectural expressiveness, structural expediency, and organizational and technological efficiency, which is crucial for improving the adaptability and functional flexibility of modern medical buildings. The systematization of geometric-compositional and combinatorial models of shell systems is a key step in the development of effective architectural solutions in medical buildings. Geometric-compositional models are formed on the basis of the patterns of spatial distribution of curvature, symmetry, and rhythm, which determine the architectural expressiveness and structural stability of the system. The main types of geometric-compositional models include:

1. Classic curved surfaces – cylindrical, conical, spherical; used to cover corridors, waiting rooms, and technical rooms.
2. Double-curved surfaces – hyperbolic paraboloids, minimal surfaces. They provide high load-bearing capacity with minimal use of materials and are optimal for atriums, patios, and large halls in medical centers.
3. Parametric surfaces – created using digital modeling tools (Rhino, Grasshopper, BIM), which allow the shape of the shell to be changed in accordance with the functional and technological requirements of the building.

Combinatorial models of shell systems are based on the use of typical geometric or structural modules that are combined in various configurations to form complex spaces. The main categories of combinatorial models include:

1. Geometric modular systems – a combination of standard curvature elements to form a complete shell. They ensure standardization and speed up installation.
2. Structural modular systems – the use of ready-made structural elements (frames, panels, nodes), which simplifies the technology of building construction and maintenance.
3. Spatial-functional modules – a combination of geometric and structural elements with functional blocks of medical premises (operating rooms, diagnostic areas, wards), which ensures flexibility in spatial planning.

Table 2 provides a systematic description of the main models of shell systems and their architectural, planning, and structural features in medical buildings.

Table 2: Main models of shell systems and their application in medical buildings.

Shell model	Geometric parameters	Type of modularity	Planning and functional purpose	Design features
Cylindrical	Radius, length	Geometric module	Covering corridors, technical areas	Simple frame, easy installation
Spherical	Radius	Geometric module	Domes for halls, conference rooms	High load-bearing capacity, material savings
Hyperbolic paraboloid	Parameters	Geometric-structural module	Atriums, patios, multifunctional halls	Strength, plasticity, modular assembly
Minimal surfaces	Form determined by optimization	Spatial-functional module	Facades, covering of recreation areas	Material optimization, complex curvatures
Parametric models	Variables	Combined module	Adaptive spaces with modification as needed	Precise shape, integration with BIM, digital parameter control

Source: Authors, (2026).

To ensure a comprehensive assessment of the feasibility of using shell architectural systems in medical buildings, it is advisable to supplement the geometric and compositional analysis with an integral efficiency criterion. This approach allows the shell to be considered not only as a geometric form or structural element, but as a multi-criteria architectural and technological system, the effectiveness of which is manifested at various stages of the building's life cycle.

For this purpose, an integral indicator of the effectiveness of the shell system (3) is proposed:

$$E = \omega_1 G + \omega_2 C + \omega_3 F + \omega_4 L, \quad (3)$$

Where: E – integral indicator of the efficiency of the shell architectural system; G – geometric efficiency of the shell, taking into account the rationality of curvature, spatial rigidity, and material intensity; C – structural efficiency, which characterizes the load-bearing capacity, manufacturability, and operational reliability of the structure; F – functional adaptability, reflecting the possibility of transforming space, changing the functional purpose of premises, and the flexibility of the planning structure; L – compliance with the requirements of the building's life cycle, including the stages of design, construction, operation, reconstruction, and modernization; ω_i – weight coefficients that determine the relative importance of each criterion depending on the type of medical building (hospital, diagnostic center, rehabilitation facility, etc.).

The introduction of an integrated efficiency criterion allows comparing different shell solutions not only in terms of geometric or structural indicators, but also taking into account functional and organizational-technological aspects. This creates a methodological basis for the informed selection of architectural solutions in the early stages of design and for assessing their feasibility throughout the life cycle of a medical building. An important addition to the integrated efficiency assessment is the formalization of a combinatorial approach to the formation of shell architectural systems. Within this approach, the shell is considered as a set of separate modules that can be combined in different configurations depending on functional and technological requirements. A generalized combinatorial model of a shell system can be presented as (4):

$$S = \bigcup_{i=1}^n M_i, \quad (4)$$

Where: S – shell architectural system; M_i – individual shell module; n – number of modules in the system. For a more detailed description, each module can be represented as an ordered set of parameters (5):

$$S = \{M_i | M_i = (G_i, C_i, F_i)\}, \quad (5)$$

Where: G_i – geometric parameters of the module (type of curvature, radii, spatial position); C_i – design characteristics (material, load-bearing structure, connection nodes); F_i – functional purpose of the module in the structure of the medical building. Such formalization of the combinatorial model allows describing the shell system as a flexible structure capable of phased development, local reconstruction, and adaptation to changes in functional purpose without radical intervention in the load-bearing system. The combination of an integral efficiency criterion with a combinatorial model for the formation of shell systems creates a comprehensive methodological basis for managing architectural, structural, and organizational and technological solutions throughout the life cycle of medical buildings. To illustrate the applied potential of the proposed geometric-compositional and combinatorial models, it is advisable to consider a conditional project of a multidisciplinary medical and diagnostic center, formed on the basis of generalized requirements for modern medical institutions. The facility is considered typical for large urban agglomerations and is characterized by a building area of approximately 22–25 thousand m², 3–5 floors, and a mixed functional structure (outpatient and diagnostic unit, inpatient unit, rehabilitation areas, public spaces).

Two options for the spatial and structural organization of the building were selected for analysis:

Option A (traditional) – a building with flat floors and a regular column grid, formed according to the principles of functional zoning without the use of shell systems. Spatial transformations are envisaged mainly through the redevelopment of internal partitions. Option B (shell) – a building using shell architectural systems, in particular hyperbolic paraboloids and parametric surfaces to cover atrium spaces, waiting areas, recreational and communication elements. The load-bearing structure is formed according to a combinatorial principle using modular geometric and structural elements integrated into the BIM environment. For comparative evaluation, the integral efficiency indicator of the shell architectural system E, proposed in formula (3), was used. The evaluation was carried out on a five-point scale with subsequent normalization of indicators in the range from 0 to 1. The weight coefficients ω_i were taken to be equal for both options in order to ensure the comparability of the results. The evaluation results are presented in Table 3.

Table 3: Comparative assessment of the effectiveness of architectural and structural solutions.

Criterion	Criterion content	Option A	Option B
G	Geometric efficiency (rationality of form, material intensity, spatial rigidity)	0	0.86
C	Structural efficiency (load-bearing capacity, ease of construction, reliability)	0.70	0.82
F	Functional adaptability (possibility of transformation, re-profiling)	0.55	0.9
L	Life cycle compliance (design, operation, reconstruction)	0.6	0.88
E	Integral efficiency indicator	0.62	0.87

Source: Authors, (2026).

The results show that the shell variant demonstrates significantly higher values of the integral efficiency indicator compared to the traditional design scheme. The greatest increase is observed in terms of functional adaptability and compliance with life cycle requirements, which is of fundamental importance for medical buildings given the dynamic nature of medical processes and technologies. In variant B, the shell system is considered as a set of M_i modules formed according to formulas (4) – (5). Each module includes geometric parameters (type of curvature, radii), structural characteristics (material, connection nodes), and functional purpose (atrium, passageway, recreation area). This approach allows the spatial structure of the building to be formed as an open system capable of phased development and local reconstruction.

Practical testing of the combinatorial model shows that the replacement or modification of individual modules (for example, the transformation of a waiting area into a diagnostic unit) is possible without interfering with the main load-bearing structure of the building. This reduces reconstruction costs, shortens the adaptation time of the facility, and increases operational reliability. The use of geometric-compositional and combinatorial models of shell systems has a positive effect on organizational and technological processes at all stages of the life cycle of a medical building. At the design stage, parametric shells allow for the optimization of spatial solutions, reduction of conflicts between engineering systems, and increased accuracy in forecasting material costs. At the construction stage, the use of standardized modules helps to reduce the duration of installation work and increase the manageability of the construction process.

In the operational phase, shell systems provide flexibility in the functional use of space and create the conditions for modernizing medical processes without radical reconstruction of the building. This is especially relevant for healthcare facilities that must operate continuously even during partial renovations or equipment upgrades. Thus, the example given confirms the practical feasibility of using geometric-compositional and combinatorial models of shell architectural systems in the design and operation of medical buildings and demonstrates their effectiveness from the point of view of organizational and technological support of the life cycle. The proposed approach enhances the scientific novelty of the research, as it provides a transition from descriptive analysis of shell geometry to formalized assessment of their effectiveness as complex architectural and technological systems. A summary of current research shows that combining geometric-compositional and combinatorial models allows for the simultaneous achievement of:

- architectural expressiveness;
- structural efficiency;
- planning flexibility;
- adaptability of medical buildings throughout their life cycle.

Geometric-compositional and combinatorial models of shell systems significantly influence the organizational and technological processes of designing, constructing, and operating medical buildings. The combination of parametric and modular approaches ensures high planning flexibility, standardization of structural elements, and optimization of technological operations during the construction of the facility. At the design stage, the use of geometric-compositional models ensures accurate determination of the parameters of the shell and its spatial characteristics, which allows for the integration of engineering systems, functional areas, and communication routes with minimal spatial conflicts. Parametric models enable digital modeling of configuration options, assessment of the load-bearing capacity of the shell, and prediction of material costs, which significantly increases the efficiency of design and engineering solutions.

During construction, combinatorial models allow the use of standardized modules and assemblies, which simplifies installation processes, reduces construction time, and lowers the likelihood of errors on the construction site. The use of geometric and compositional models in combination with BIM technologies ensures the integration of information about the structural, technological, and operational parameters of a building, which allows for the effective planning of logistics, material resources, and labor costs. In the operation of medical buildings, modular and parametric shells ensure high adaptability of premises to changes in functional purpose (for example, repurposing wards into operating or diagnostic areas) without the need for significant reconstruction of load-bearing structures. This reduces reconstruction and maintenance costs, increases the long-term efficiency of the facility, and its operational reliability.

Based on the analysis, the main practical directions for using the research results can be identified (Figure 1):

1. BIM design of medical buildings – integration of geometric-compositional and combinatorial models to optimize architectural form, spatial planning, and engineering support.
2. Standardization and modular construction – application of combinatorial modules to accelerate installation and reduce labor and material costs.
3. Adaptive functional planning – ensuring the flexibility of premises for re-profiling without reconstructing load-bearing structures.
4. Optimization of operational processes – forecasting resource costs, managing maintenance and modernization of facilities, taking into account the parameters of the shell.

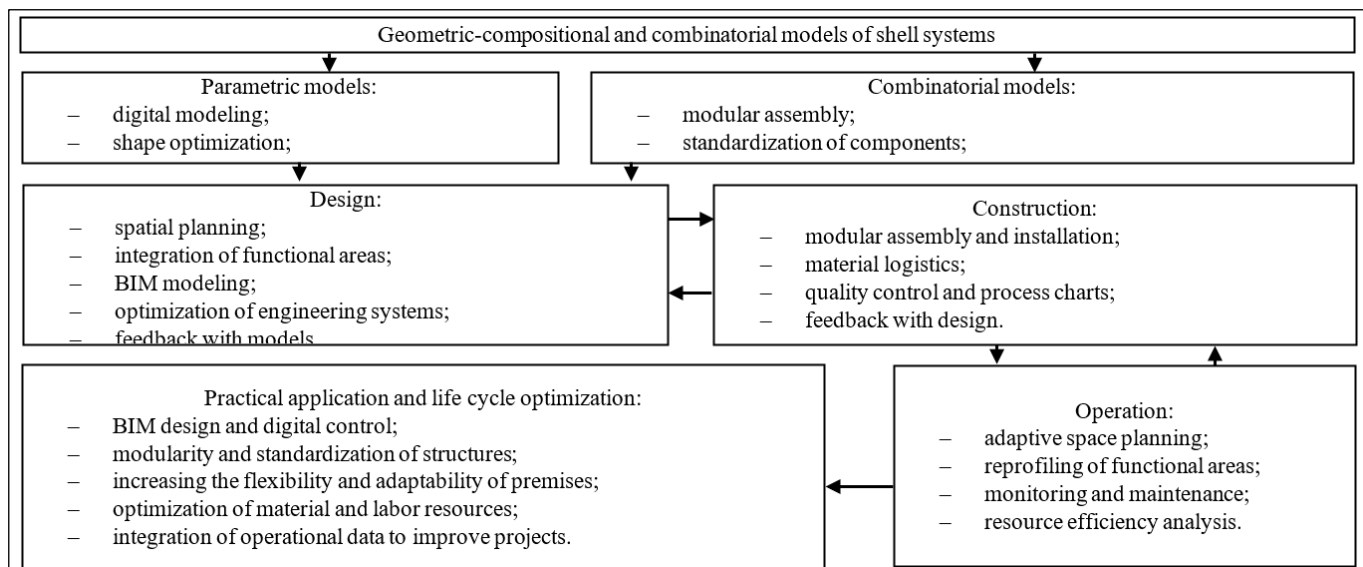


Figure 1: Comprehensive impact of geometric-compositional and combinatorial models on organizational and technological processes in medical buildings.

Source: Authors, (2026).

Figure 1 shows the logical connection between geometric-compositional and combinatorial models of shells and all the main stages of the organizational and technological cycle of medical buildings. It illustrates how the integration of such models ensures functional flexibility, structural reliability, and the efficiency of the building life cycle.

V. DISCUSSION

The results of the study show that geometric-compositional and combinatorial models for the formation of shell architectural systems are becoming particularly important in the context of changing requirements for medical buildings and the increasing role of life cycle management. An analysis of contemporary approaches confirms that shell systems based on rational geometry and parametric principles allow for high spatial efficiency, structural expediency, and architectural expressiveness. At the same time, their application in healthcare facilities goes beyond purely form-giving solutions and directly affects the organizational and technological processes of design, construction, and operation.

The question of the relationship between the architectural and artistic qualities of shell systems and their functional expediency in medical buildings remains controversial. On the one hand, proponents of geometrically complex shells emphasize their ability to form a holistic therapeutic environment, facilitate patient orientation, and create a psychologically comfortable space. On the other hand, critics of such solutions point to the increased complexity of design, the growing demands for precision in construction and installation work, and the potential risks of increased construction costs. The results obtained allow us to conclude that the use of combinatorial and modular principles can significantly reduce these risks through the standardization of elements and the optimization of technological processes.

The impact of combinatorial models on the adaptability of medical buildings requires separate discussion. In today's environment of rapid change in medical technologies and functional scenarios, it is precisely the possibility of transforming space that becomes a key criterion for the effectiveness of an architectural solution. Research shows that a combinatorial approach to the formation of shell systems creates the preconditions for the phased development of a building, local reconstruction, and re-profiling without radical intervention in the supporting structure. At the same time, the question of the limits of such adaptability remains open and requires further interdisciplinary research involving specialists in the field of medical management and engineering systems.

Another controversial issue is the digital support of shell architectural systems throughout the life cycle of medical buildings. The use of building information modeling creates conditions for the integration of geometric-compositional and combinatorial models into a single digital environment, ensuring the consistency of design, technological, and operational solutions. However, the practical implementation of this approach requires a high level of coordination between architects, engineers, and operational services, which is not always achieved in real projects. This highlights the need to develop methodological recommendations and standards for the application of shell systems in the BIM environment specifically for medical facilities.

An important aspect is the relationship between the versatility of shell architectural systems and the specifics of medical buildings. Unlike public or exhibition buildings, medical facilities have strictly regulated requirements for insulation, microclimate, sanitary and hygienic indicators, and the flow of staff and patients. The results confirm that the geometric and compositional models of shells must be adapted to these requirements and not mechanically borrowed from other building typologies. In this context, the combination of formal geometric optimization with functional and planning analysis is of particular importance.

Thus, the issue of using geometric-compositional and combinatorial models of shell systems in medical buildings is complex and covers architectural, technological, economic, and operational aspects. The results obtained allow us to consider shell architectural systems not only as a means of shaping, but also as a tool for improving the efficiency of the life cycle of medical buildings. Further research should be directed toward the development of integrated models that combine geometric optimization, combinatorial variability, and digital control of operational processes, ensuring the sustainable and adaptive development of medical architecture.

VI. CONCLUSIONS

The study confirmed that geometric-compositional and combinatorial models of shell architectural systems are an effective tool for improving the efficiency of the design and operation of medical buildings throughout their life cycle. In the current conditions of healthcare system transformation, such models allow medical facilities to be viewed not only as engineering and construction structures, but also as adaptive spatial and functional systems capable of responding to changes in medical technologies, regulatory requirements, and social needs. As a result of the analysis and generalization of scientific approaches, it has been established that the rational geometry of shells, combined with the compositional principles of form creation, ensures structural expediency, optimal load distribution, and spatial integrity of architectural solutions. At the same time, the use of combinatorial and modular models creates the preconditions for variability in planning structures, flexible organization of functional areas, and phased development of medical buildings without significant interference with the load-bearing system. Research into the impact of geometric-compositional and combinatorial models on organizational and technological processes has shown that their use contributes to the optimization of design solutions, reduction of construction time, and improvement of the manageability of operational processes.

Shell systems based on parametric and combinatorial principles facilitate the integration of digital design and operation technologies, in particular information modeling of buildings, which is an important factor in improving the long-term operational reliability of medical facilities. At the same time, it has been established that the effectiveness of using shell architectural systems in medical buildings largely depends on taking into account specialized sanitary-hygienic, technological, and functional-planning requirements. This necessitates a comprehensive approach that combines geometric optimization with an analysis of medical processes and scenarios for using space. Therefore, the results of the study allow us to conclude that geometric-compositional and combinatorial models of shell architectural systems should be considered as a strategic direction for the development of modern medical architecture. The practical significance of the work lies in the possibility of using the obtained generalizations and schemes in the design of new medical buildings, as well as in the processes of reconstruction and adaptation of existing facilities. Prospects for further research are related to the development of integrated methods for evaluating the effectiveness of shell systems at different stages of the life cycle of medical buildings and to the deepening of interdisciplinary interaction between architecture, engineering, and medical technologies.

VII. AUTHOR'S CONTRIBUTION

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