альтернативний метод формулювання математичних моделей енергетичних систем на основі елементів теорії сингулярних систем з деякими показовими прикладами, що ілюструють здійсненність та ефективність цього підходу.

Ключові слова: *диференціально-алгебраїчні рівняння, сингулярні системи, моделювання динаміки енергетичних систем.*

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RESEARCH OF GEOMETRIC AND INFORMATION MODELS FOR AWNING STRUCTURES

The article analyzes membrane (awning) structures, which become relevant due to their cost-effectiveness and the creation of original forms. The characteristics of awning structures, the possibilities of molding, the use of various materials and combined options for combining an awning with other materials are considered. Due to their cost-effectiveness, tent structures are becoming increasingly popular today, because in modern socio-economic conditions there is a need for the rapid construction of low-cost buildings to overcome the shortage of mobile housing and structures for other purposes. In the conditions of restoration of the lost objects of buildings and structures, the use of tent coverings is important. Their development was held back for a long time due to the non-compliance of domestic tent materials with the high requirements for tent coverings of this type, namely: strength, durability, color diversity, light fastness, etc. The use of hinged structures allows you to create small architectural forms and mobile buildings that are not only quickly erected, but also easily transformed in accordance with a change in functionality. This allows you to create new types of objects, such as stadiums, airports, giant greenhouses, botanical gardens, warehouses, etc. Modern technologies combine the advantages of industrial construction methods with the individualization of form and open the way to the use of various awning structures. Membrane coatings, as one of the modern trends in the presentation of a new form of roofing, create new spatial characteristics of architectural objects. They form expanses freed from bulky internal structures. The freedom of space determines the flexibility and functionality of its use, a high degree of adaptation and, as a result, the durability of the

space and structure. Having a wide variety of forms, this type of coating has broad prospects for use along with other architectural and structural systems. To ensure such characteristics, the article proposes an information model of the proportionality of the elements of the architectural form, established on the basis of the information modularity of the relations of the elements for the volumetric structure.

Key words: *awning structure, simulation, mobile housing, information model, membrane construction, surface.*

Formulation of the problem. Due to their economy and the ability to create original forms, awning structures are becoming increasingly popular today [1, 2]. In the socio-economic conditions of modern Ukraine, complicated by the unstable situation in the east and south of the country and the activity of migration processes, the study of the mobile housing industry, including awning structures for temporary use is appropriate, especially given the lack of capital housing available to the public consumer.

In the modern period, there are a large number of interpretations of the classifications of mobile housing, as the use of mobile housing, its quantitative and qualitative components are different for different regions of the world [3]. For refugees whose forced migration is caused by military-political reasons and emergencies as a result of natural and man-made disasters. Express housing during necessary emergency relocations. A variety of summer and all-season prefabricated awning structures are less popular for servicemen (pneumatic ones are used less often). All-season mobile barracks of the modular container type, including those with the possibility of transformation, are used for long-term deployment of military personnel. Ukraine has the potential to use awning structures in the design of original objects, such as small architectural forms, prefabricated mobile buildings, which are easily transformed according to the change of functional purpose and have high aesthetic advantages.

Advanced technologies make it possible to combine the advantages of industrial methods with the individualization of form [4]. Analysis of the proportionality of the elements of the architectural form, established on the basis of the information modularity of the ratios of the elements of the dimensional structure, allows you to create an information model of modern awning structure.

Related works. The design of low-budget buildings is relevant at the moment. They demonstrate the possibilities of implementing modern economic construction solutions, and different forms of membrane structures allow you to create new objects with different spatial parameters. Membrane structures are a very modern type of building structures around the world [5]. They are based on the principle of fast and mobile assembly / disassembly of frame and awning structures. Membrane structures are not

only an effective accent of any architectural exhibition, but also a convenient tool for creating aesthetically pleasing compositions. When modeling the surface membrane, it is important that the system, which consists of a shell and a rigid frame is a system with distribution parameters [6]. The main problem of mathematical modeling is that with a small change in shape, significant changes in load can occur at individual points. Changing the parameters at one point in the system changes all other parameters.

As a rule, awning constructions are classified according to the following characteristics:

1. According to the degree of tightness of the space: open, closed.
2. In the presence / absence of the frame: frame (aluminum, steel, wood, concrete, composite, pneumatic frame), cable (system of supports and tension elements), frameless (air-filled).
3. By purpose of objects: hotels, shopping malls, exhibition centers, stages of entertainment facilities, congress halls, religious buildings, summer cinemas, cafes, playgrounds and dance floors, mobile homes for servicemen and refugees, etc.
4. By the nature of use: elements of the facade of buildings, architectural membrane canopies, entrance portals, architectural installations, sun protection facade systems, interior decoration, etc.
5. By degree of seasonality: summer, year-round.
6. By degree of mobility: stationary, transformed.

Membrane (awning) structures are structures consisting of two main components: a metal frame and a coating of fabric or film (Fig. 1).

Fig. 1. *Awning structure at the auto show in Czestochowa*

Metal frame awning structures open up unlimited design possibilities and allow to apply graphic images on their surface, which makes them very convenient for use in advertising and in creating festive interiors. Metal structures are building structures used as load-bearing in the frames of various buildings and engineering structures. Usually, such constructions from profile pipes are executed. The use of this material has no restrictions and allows you to create high-strength structures that are not prone to deformation. The membrane of the awning structure is under the action of tensile stress and does not carry any compression or bending stress. The stability of such surfaces is their anticlastic curvature, which allows the membrane not to lose its shape [7]. Designs of awnings, the basis of which is a metal frame, allow you to create buildings of different shapes, sizes and purposes (Fig. 2).

Fig. 2. *Awning structure of Oktoberfest in Munich*

The use of awning structures makes it possible to create new types of objects, such as giant greenhouse coverings, botanical gardens, mobile homes for servicemen, refugees, etc. The use of this type of structure allows the architect to create an optimal system-organized environment of any size — from small architectural forms to large-scale complexes.

The originality of the architectural image of awning objects is achieved due to the specific properties of the main element — mechanically stretched (stressed) shell. The stability of the geometry is ensured by the shape of the surface of negative Gaussian curvature.

The shape of this surface is determined by the geometry of the support circuit, the conditions of prestressing and attachment to the load-bearing structures of the coating on the circuit. Even a slight change in these conditions leads to the creation of a new surface shape with different values of surface area [8], internal volume and conditions of mechanical

work. This makes it possible to obtain a rich choice of forms, the architectural expressiveness of awning structures [7].

The membrane of the awning structure, the shape of which from the very beginning corresponds to the minimum surface [9, 10], that is, one that has already taken an equilibrium state, has the same tension at any point.

The process of constructing a membrane pattern begins with cutting the surface in the CAD system into its component parts [2]. Next, each of the parts of the surface is mapped to the plane using a certain method of flattening [11] and forms a flat figure.

The minimum surface [12], characterized by a nonzero Gaussian curvature, is non-expandable, which means that it cannot be flattened without distorting areas and angles. Stresses that cannot be compensated by elastic deformation of the material, lead to folds, sagging, rupture of the material [13]. The construction of the membrane pattern is a relevant subject of research [14], primarily because the shape of the boundary of each of the flattened parts determines the stress distribution along the membrane [15], and the service life of the entire awning structure.

Implementation of membrane construction projects. One of the characteristics of awning structures is the proportionality between the terms of depreciation of the structure and the physical aging of the material. The development of new types of durable materials and technologies with the simultaneous combination of metal, glass and awning coatings managed to achieve a new quality of buildings, elegance of form and variety of their coverage. This allowed to make adequate technological and economic changes in the modern dynamic life of society. The development of new types of durable materials has changed the attitude of customers and architects to such coatings. Nowadays, they are considered not only as technical objects that are used for some time and then dismantled, but are perceived as full-fledged structures of long-term operation.

In order to create an original image of the building and reduce its value in awning architecture, there are various combined options, as well as a combination of awning with other materials (glass, brick, concrete, etc.).

During the twentieth century there was a rapid development of new construction technologies using advanced materials and structures [3]. Among the materials used for awning coatings, the most common are: PVC (polyester coated with polyvinyl chloride), EPDM (ethylene-propylene diene copolymer), PTFE (fiberglass coated with polytetrafluoroethylene), ETFE (ethylene ether films).

PVC — fabrics and PTFE — films can be light-blocking and translucent. It is possible to use polymer nets for various purposes with a porosity of 14% to 60%. Various fillers are used in the manufacture of PVC fabric. With their help such properties of material as resistance to rotting and fire resistance are reached.

When overlapping large spans, awning shells are reinforced (stabilized) by cables (tension system). Implementation of membrane construction projects requires compliance with the correct sequence of works. At the first stage with the help of specialized software is a geometric modeling of the shape of the future shell. Then the loads and effects on the shell are determined, their analysis is performed. The variety of shapes makes it difficult to determine the initial geometry of the surface. To determine the final shape and calculate the stress-strain state of the membrane and elements of the flexible frame, the finite element method is used, which allows to obtain an exact solution in conditions of large displacements — geometric nonlinearity of structures. After analyzing the shape of the shell comes the stage of calculating the cut. It is carried out taking into account the properties of materials and their load-bearing capacity in each of the directions. The last (final) stage is verification calculations, which include a full cycle of studies of the behaviour of structures depending on various combinations of external influences, such as gusts of wind or increased pressure inside the shell for pneumatic structures. To ensure the conditions for further trouble-free operation of facilities, one of the most important stages of the calculation is the aerodynamic analysis of the membrane. The developed technique of carrying out numerical researches allows to receive the general laws of aerodynamic flow of a construction and its behaviour in air streams.

Consider the example of the material of a low-budget awning structure for servicemen and refugees Table 1.

Table 1

Analysis of the material of the proposed awning structure

Fabric composition:	**100% polyester with 100% polyurethane coating**
Surface density, g/m^2	130
Number of threads per unit length on the basis, not less than, threads/cm	270/10
Number of threads per unit length on the weft, not less than, threads/cm	220/10
Tensile load on the basis, not less than, H	1000
Breaking load on the weft, not less than, H	700
Resistance of painting to washing at a temperature of 40 Co, class, not less	4-5
Resistance of painting to friction, class, not less	4-5
Resistance of the fabric to moisture, not less	4-5
Resistance of the material to abrasion, not less	15000 cycles
Resistance to lubricants, not less	4
Water resistance, not less, mm	1500

The general practice of determining the spatial configuration of the awning structure membrane is the use of a numerical method of shape search [5]. The information obtained can be used to estimate the required ventilation of the internal volumes of the designed object.

The proportionality of the elements of the dimensional structure of the architectural form is characterized by their belonging to a single, common to them, proportional to a number of values. The affiliation of the elements of the dimensional structure of the architectural form to the common proportional series of values is established on the basis of the information modularity of the relations of the elements of the dimensional structure.

The amount of visual information contained in relation to two adjacent dimensional characteristics of the architectural form is the number of operations of elementary distinction of these dimensional characteristics and is determined by the Eq. (1):

$$u = k \log (ri / rj), \quad (1)$$

where k — is the coefficient that takes into account the difference sensitivity of the human visual system to the perception of differences (linear, angular, tonal, etc.) by sensitivity $C = 1 / 33$, $k = 76.56$; r_i and r_j — larger and smaller elements of the dimensional structure of the architectural form.

The relationship of two adjacent elements of the architectural form is called the information step (u). The strength of the proportional relationship of the two information steps in the information field Eq. (2):

$$Cp = 2\mu / (u_i + u_j) \quad (2)$$

where μ — information module of two information steps; at $u_i = u_j = \mu$ the force of proportional connection acquires the maximum value $Cp = 1$.

The information model of proportionality makes it possible to completely abandon the outdated methods of proportional analysis and harmonization of the dimensional structure of architectural objects, which are based on the search for traditional proportional relations.

Conclusions. High modern technologies make it possible to combine the advantages of industrial construction methods with the individualization of the form, opening the way to the use of awning structures. Membrane coatings, as one of the modern directions of representation of a new (nonlinear) shape of the roof, create new spatial characteristics of the architectural object. It is proposed to introduce a more expanded typology of mobile housing, which meets the conditions of the modern socio-economic structure, the development of migration processes and demographic transformations. Providing a wide variety of forms, this type of coating has broad prospects for use on a par with other architectural and structural systems.

The information model of proportionality reveals the physical nature and essence of proportionality and significantly expands the capabilities of researchers and designers.

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ДОСЛІДЖЕННЯ ГЕОМЕТРИЧНИХ ТА ІНФОРМАЦІЙНИХ МОДЕЛЕЙ ТЕНТОВИХ КОНСТРУКЦІЙ

У статті аналізуються мембранні (тентові) конструкції, які стають актуальними завдяки своїй економічності та можливості створення оригінальних форм. Розглянуто характеристики тентових конструкцій, можливості формування, застосування різних матеріалів та комбіновані варіанти поєднання тенту з іншими матеріалами. Завдяки своїй економічності, тентові конструкції набувають сьогодні все більшої популярності, тому що в сучасних соціально-економічних умовах виникає потреба у швидкому будівництві маловитратних будівель для подолання дефіциту мобільного житла та споруд іншого призначення. В умовах відновлення втрачених об'єктів будівель та споруд важливим є викори-

стання тентових покриттів. Їх розвиток довгий час стримувався через невідповідність вітчизняних тентових матеріалів високим вимогам, що висуваються до тентових покриттів подібного типу, а саме: міцність, довговічність, різноманітність кольору, світлостійкість та ін. Використання навісних конструкцій дозволяє створювати малі архітектурні форми і мобільні будівлі, що не тільки швидко зводяться, а й легко трансформуються відповідно до зміни функціонального призначення. Це дозволяє формувати нові типи об'єктів, наприклад, стадіони, аеропорти, гігантські оранжереї, ботанічні сади, склади і т.п.

Сучасні технології поєднують у собі переваги промислових методів будівництва з індивідуалізацією форми та відкривають шлях до застосування різних конструкцій тентів. Мембранні покриття, як один із сучасних напрямів уявлення нової форми покрівлі, створюють нові просторові характеристики архітектурних об'єктів. Вони утворюють простори, звільнені від громіздких внутрішніх структур. Свобода простору визначає гнучкість і багатофункціональність його використання, високий ступінь пристосування і в підсумку довговічність простору і споруди. Маючи велику різноманітність форм цей тип покриття має широкі перспективи використання нарівні з іншими архітектурно-конструктивними системами.

Для забезпечення таких характеристик запропоновано інформаційну модель пропорційності елементів архітектурної форми, які встановлюються на основі інформаційної модульності відносин елементів об'ємної структури.

Ключові слова: *тентова конструкція, моделювання, мобільне житло, інформаційна модель, мембранна конструкція, поверхня.*

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