BUILDING CONSTRUCTIONS, BUILDINGS AND ENGINEERING STRUCTURES

СТРОИТЕЛЬНЫЕ КОНСТРУКЦИИ, ЗДАНИЯ И СООРУЖЕНИЯ

UDC 624.011.1

https://doi.org/10.23947/2949-1835-2026-5-1-32-39

Original Empirical Research

EDN: RUPNIO

Extended Wooden Panels for Flooring and Cladding of Buildings

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Abstract

Introduction. The development of the construction industry in Russia involves both emerging technologies and materials and traditional construction methods. One of the well-known tools in this country is wooden housing construction. Apartment buildings are being built from wooden CLT panels, glued timber, beams made of unidirectional veneer, etc. are commonly employed. Modern architecture seeks to create large open spaces for free planning. In wooden buildings, it is not always possible to organize such spaces due to a limited length of lumber being produced. Studies aimed at designing extended panels from wood are thus gaining momentum. The aim of this study is to develop new designs of wooden panels for cladding and flooring of buildings from standard lumber, plywood and oriented strand boards with spans exceeding the standard length of boards, to identify the limits in the load-bearing capacity of such panels, as well as to conduct their geometric calculation.

Materials and Methods. Two types of box-shaped panels made of wooden planks, plywood and/or oriented strand boards are considered. The load-bearing capacity of the suggested structures is estimated by means of both traditional methods of material strength and computer models.

Research Results. The design of extended panels is described differing from the known overseas analogues and is free from the inherent disadvantages of the latter. Geometric calculation of the suggested structures is performed. The rational size ratios of the sizes of boards that make up the panels are identified. Design limitations for individual elements of products are established. Computer models of the panels are designed and employed in order to identify the applicability limits of the suggested structures.

Discussion and Conclusion. As a result of the research, new designs of wooden panels for flooring and cladding of buildings with possible spans exceeding the standard length of lumber and made with no use of costly materials have been developed. The simplicity of the design makes it possible to organize manufacturing of products in small-size industries with complex and costly equipment involved. The panels can be employed for long open spaces in wooden buildings and structures for a broad range of purposes.

Keywords: panel, wood, lumber, plywood, flooring, cladding, long spans

For citation. Verzhbovsky GB Extended Wooden Panels for Flooring and Cladding of Buildings. *Modern Trends in Construction, Urban Territorial Planning.* 2026;5(1):32–39. https://doi.org/10.23947/2949-1835-2026-5-1-32-39

Оригинальное эмпирическое исследование

Протяженные деревянные панели перекрытий и покрытий зданий

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Аннотация

Введение. Развитие строительной отрасли России предполагает как появление новых технологий и материалов, так и использование традиционных методов строительства. Одним из хорошо известных методов в нашей стране является деревянное домостроение. В настоящее время возводятся многоквартирные дома из деревянных

CLT-панелей, широко используется клееная древесина, балки из однонаправленного шпона и т.п. Современная архитектура направлена на создание значительных открытых пространств для свободной планировки. В деревянных зданиях не всегда удается организовать подобные пространства из-за ограниченности длин выпускаемых пиломатериалов. В связи с этим актуальными становятся исследования, направленные на создание протяженных панелей из древесины. Целью настоящей работы является разработка новых конструкций деревянных панелей покрытий и перекрытий зданий из стандартных пиломатериалов, фанеры и ориентированностружечных плит с пролетами, превышающими стандартную длину досок, определение пределов несущей способности таких панелей, а также их геометрический расчет.

Материалы и методы. Рассмотрены два типа панелей коробчатого строения, выполненных из деревянных досок, фанеры и/или ориентированностружечных плит. Оценка несущей способности предлагаемых конструкций произведена как при помощи традиционных методов сопротивления материалов, так и на компьютерных моделях.

Результаты исследования. Описана конструкция протяженных панелей, отличающаяся от известных зарубежных аналогов и свободная от присущих последним недостатков. Выполнен геометрический расчет предлагаемых конструкций. Определены рациональные соотношения размеров досок, составляющих панели. Установлены конструктивные ограничения для отдельных элементов изделий. Созданы компьютерные модели панелей, при помощи которых установлены пределы применимости предлагаемых конструкций.

Обсуждение и заключение. В результате проведенных исследований разработаны новые конструкции деревянных панелей перекрытий и покрытий зданий с возможными пролетами, превышающими стандартную длину пиломатериалов и выполненные без использования дорогостоящих материалов. Простота конструкции позволяет организовать выпуск изделий на небольших производствах без сложного и дорогостоящего оборудования. Панели могут применяться для создания протяженных открытых пространств в деревянных зданиях и сооружениях различного назначения.

Ключевые слова: панель, древесина, пиломатериалы, фанера, перекрытие, покрытие, протяженные пролеты

Для цитирования. Вержбовский Г.Б. Протяженные деревянные панели перекрытий и покрытий зданий. *Современные тенденции в строительстве, градостроительстве и планировке территорий*. 2026;5(1):32–39. https://doi.org/10.23947/2949-1835-2026-5-1-32-39

Introduction. Extended open spaces have been embraced in modern civic architecture. For them, special structures of flooring and cladding – most frequently made of metal – are typically used. In wooden buildings, open spaces are commonly limited by the size of standard lumber and are not beyond six meters. In order to design large facilities, beams made of glued wood or products made of unidirectional veneer lumber (LVL) are to be employed with their spans depending on the cross-section sizes. The use of these beams increases the cost of a frame structure and considerably enhances the thickness of flooring and roofing. Extended box-shaped panels where the power bearing elements are "smeared" over the panel area are thus of interest.

One of the possible variants of such products are Kielsteg panels shown in Fig. 1 and allowing flooring of spaces up to 27 meters long [1]. It should be noted that in this country a similar design was patented as early as in 2010 [2].

These products have some design features that arguably reduce their effectiveness. As wood performs better in compression than in tension, it is advisable that a possibility of using boards of different thicknesses for upper and lower paneling is explored. Plywood ribs bent during the manufacture of panels experience prestressing, which must be considered in design. Finally, the edges converging at the same joint form hard-to-reach spaces inside the panel to accommodate effective insulation in them. It should be noted that laminated wood panels can have a highly diverse structure [3–5], and only two of the possible variants of such products are going to be considered.

Along with the flat coverings, the panels discussed can also be used in vaults. Wooden arches are one of the oldest and most interesting types of engineering structures in use. Initially, they emerged as a result of arched structures for overlapping sufficiently large spaces with no intermediate supports [6]. In ancient Rome, the Pantheon and the Colosseum came to be known as iconic structures using vaults. The structures were further developed in the Middle Ages when thin-walled cladding emerged that was capable of withstanding significant loads with a minimum thickness, e.g., the Notre Dame Cathedral in Paris. Modern architecture makes use of new approaches to designing vaulted structures, including use of composite materials, parametric design by means of a special software, etc.

It is obvious that for a comprehensive review of the suggested panels, it is necessary to address some issues with the main one being design of products and materials used to create them, as well as the geometric calculation of flat and vaulted panels.

a) *b)*

Fig. 1. Wooden floor panel by Kielsteg: *a* — cross section; *b* — an example of the use of panels [1]

It is also important to identify the method of assessing the stress-strain of the panels. Various approaches are employed to this end [7, 8]. However, the finite element method seems to be the most universal one allowing almost all the design features to be considered.

Use of renewable natural environmentally friendly materials in structures of buildings is becoming a modern trend in the construction industry. In the Russian Federation, more and more attention is being paid to wood use in construction, but the limited size of lumber makes it impossible to cover significant spans with no metal or massive glued structures. The creation of new products with lower material consumption compared to traditional structures is an urgent task [9], and their use in cladding of significant spans, including vaulted ones, opens up avenues for creating architecturally attractive objects.

The aim of the study is to evaluate a possibility of using the suggested panels as load-bearing structures of flooring and cladding, to identify their maximum spans and optimal ratios between the dimensions of the components of the product elements.

The tasks to be addressed to this end are as follows:

– geometric calculation of panels and obtaining analytical dependencies to identify the dimensions of all of the components of a product;

– assessment of the stress state of the forcibly curved edges of the middle layer of panels;

– designing parametric computer models of structures.

Materials and Methods. Two types of box-shaped panels with plank sheaths and ribs made of plywood or oriented strand boards (hereinafter referred to as OSB) are discussed. The panels consist of recurrent modules with the size shown in Fig. 2. The modules differ from each other in the shape of the edges. The first module has pre-curved edges, and the second has rectilinear ones. Each of the suggested options has its advantages and disadvantages. In the first case, chamfered boards are used, however, certain effort must be applied to pre-bend the ribs, which might require presses, and the ribs themselves will have lower safety margins due to prestressing. In case of rectilinear ribs, chamfering of the skin boards becomes necessary, but the ribs do not have prestressing.

The basic dimensions of the panels are their height H, the thicknesses of the skins and ribs t_1, t_2 and t, respectively, as well as the width of the lumber b. The remaining dimensions shown in Fig. 2 are identified using the basic ones.

Modules for vaulted cladding come in a larger number of sizes and are more challenging to manufacture (Fig. 3).

A numerical-analytical approach was employed for the stated aim of the study. At the same time, the geometric calculation of the panels is performed analytically, and the obtained dependencies are applied in the corresponding program. Computer models of the panels were created in the SolidWorks software package.

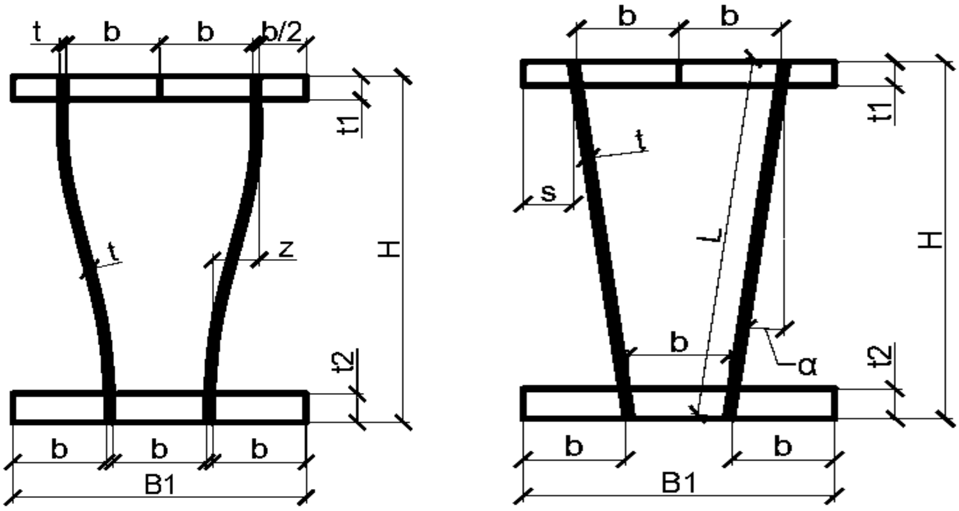


Fig. 2. Flat panel modules

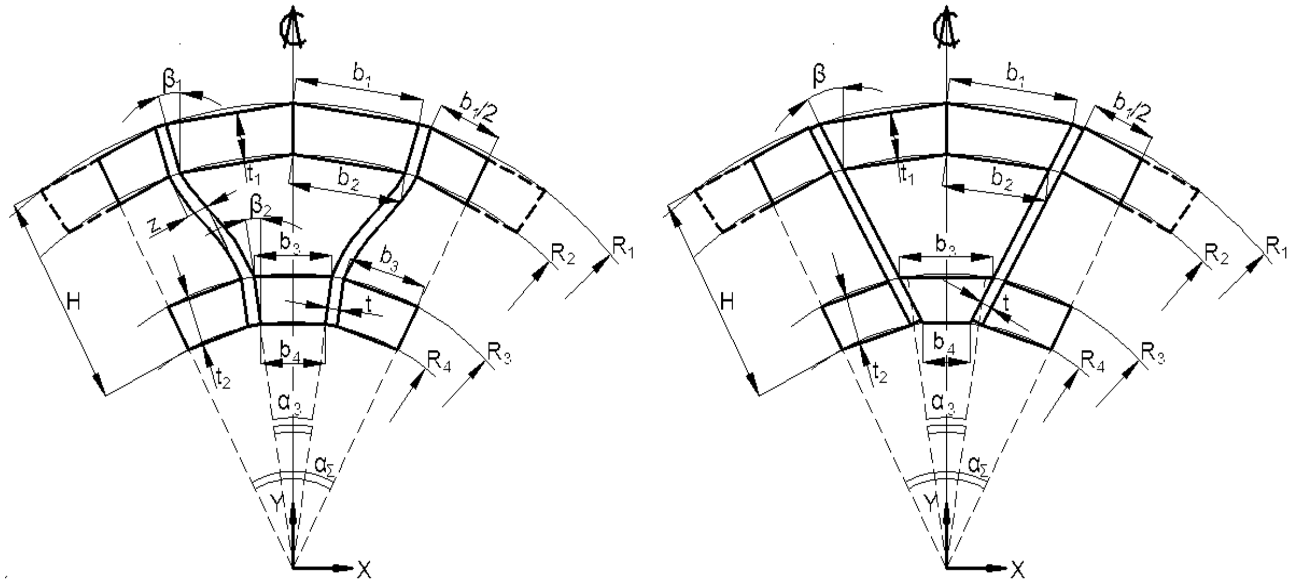
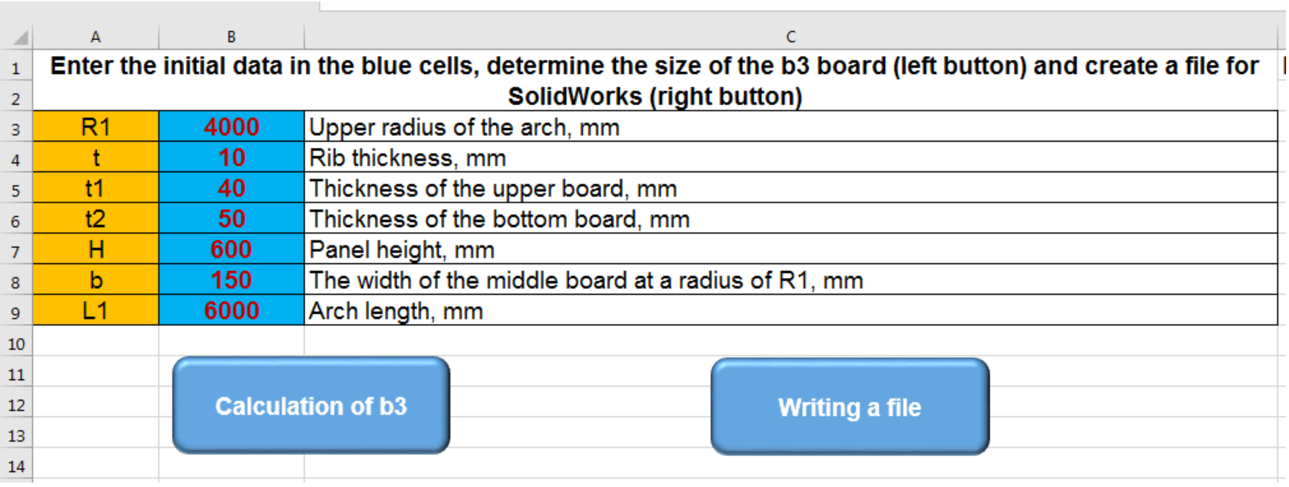


Fig. 3. Vault panel modules

Research Results. The first stage of the study was a geometric calculation of the panels. If in case of flat panels it turns out to be fairly simple, for the arch elements it is a rather laborious process due to a need to identify the central angles of the edges at radii R_1 and R_4, as well as the bevels of the cladding boards depending on the specified parameters. The problem had to be addressed using analytical geometry methods, and, e.g., to identify all the dimensions of the module of vaulted cladding with pre-curved edges, it was necessary to calculate more than fifty parameters.

The solution to the problem of geometric calculation of the vaulted panel is implemented in the Microsoft Excel software. Fig. 4 shows a workbook sheet for a module with curved edges where the width of the board b_3 is initially calculated so that the central corner of the lower skin is equal to the angle α_Σ (the designations are shown in Fig. 3), and a text file is then written with the data necessary for a generative code. A module with rectilinear edges is calculated in the same manner.

The curved edges of the panels are pre-bent during the panel manufacturing process as well as a plate under cylindrical bending. Obviously, to this end, some pressure must be applied to the rib that in this case can be identified using the methods of material resistance. A cantilever beam with a span equal to the length of the rib section between the board sheaths is considered whose free end a concentrated force and bending moment are applied to (Fig. 5).



	A	B	C
1	Enter the initial data in the blue cells, determine the size of the b3 board (left button) and create a file for		
2	SolidWorks (right button)		
3	R1	4000	Upper radius of the arch, mm
4	t	10	Rib thickness, mm
5	t1	40	Thickness of the upper board, mm
6	t2	50	Thickness of the bottom board, mm
7	H	600	Panel height, mm
8	b	150	The width of the middle board at a radius of R1, mm
9	L1	6000	Arch length, mm
10			
11			
12		Calculation of b3	Writing a file
13			
14			

Fig. 4. Program for geometric calculation of a vaulted panel module with curved edges

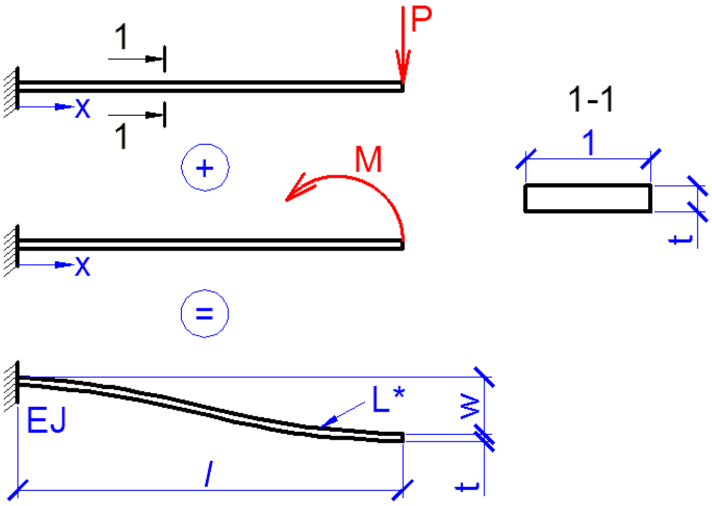


Fig. 5. Identifying the length of a work piece of the curved part of the rib

The ratio of these force factors is selected so that the specified deflection of the beam is ensured while the angle of rotation of its free end is zero. Obviously, in this case, the bending moment can be expressed in terms of a concentrated force, so the equation of the curved axis of the beam will have the form shown below. Given the fact that the stresses in the rib should not be beyond the calculated bending resistance, the values of the maximum deflection of the rib and the force creating it will be identified using the following expressions:

$$w(x)=\frac{Px^2}{Et^3}(3l-2x);\ w_{\max}=\frac{R_u l^2}{3Et};\ P=\frac{R_u t^2}{3l}.$$

Here R_u is the calculated bending resistance of the rib material with the remaining designations clear from Fig. 5.

In manufacturing panels, it is recommended that plywood or OSB sheets used as ribs are positioned so that the fiber direction of the outer layers is parallel to the thickness of a product.

The length of the work piece of the curved edge section is identified using an elliptical integral that takes the following form:

$$L^*=\int_0^l \sqrt{1+\left[\frac{Px}{2EJ}(l-x)\right]^2}\,dx.$$

As a result of a numerical experiment where the distance between the panel skins and the amount of preliminary bending of the rib varied, it was found that the length of the work piece of the curved section of the rib is slightly greater than the one between the skins and can be found using the formula

$$L^*=l+0{,}01w_{\max}^2.$$

All of the above actions were necessary in order to identify the stress-strain of the arches performed in the SolidWorks software package. This software tool provides a broad range of possibilities and can be used for modelling the behavior of structures made of new materials, accounting for the joint work of sheaths and a rib frame [10], as well as for comparing different design options [11]. E.g., the resulting three-dimensional model of an object in case of using global variables can change when the specified variables can change in an external text file, which is handy in numerical experiments.

In order to design a panel model in SolidWorks, it sufficed to form separate modules a so-called assembly was made from that included a required number of modules. Furthermore, in the Simulation software the object was automatically divided into solid-state volumetric finite elements, support anchorages and operating loads were specified followed by a static calculation.

As an example, Fig. 6 shows a module with curved edges and global variables from a Microsoft Excel text file.

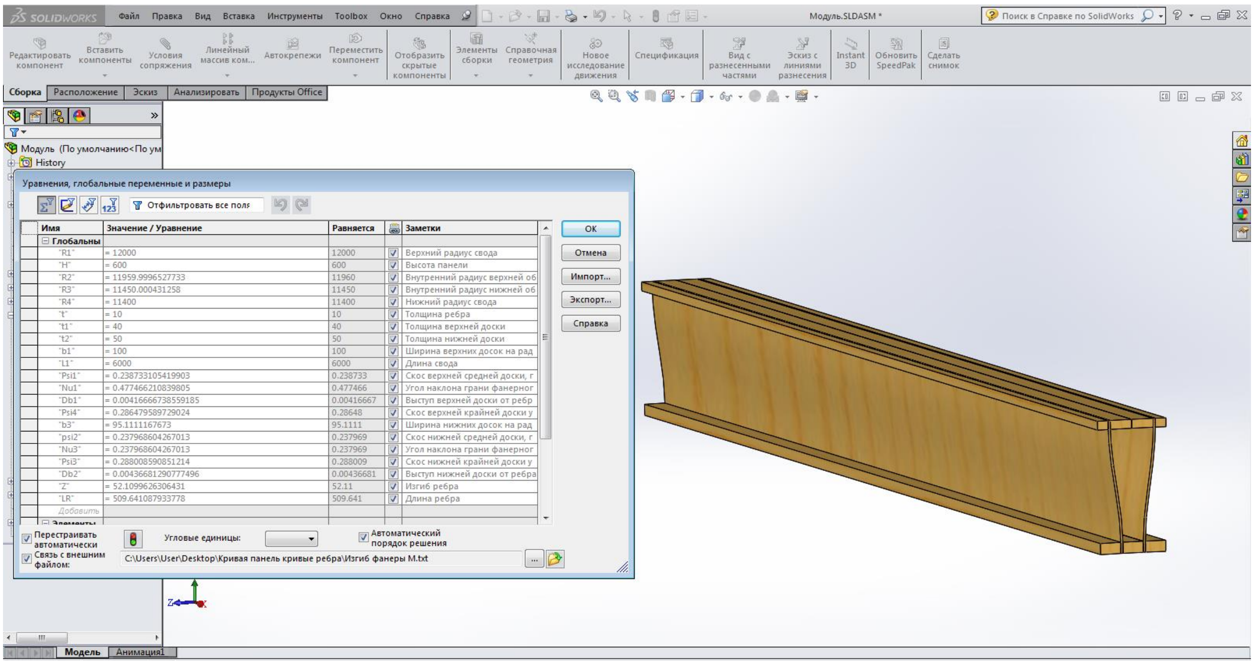
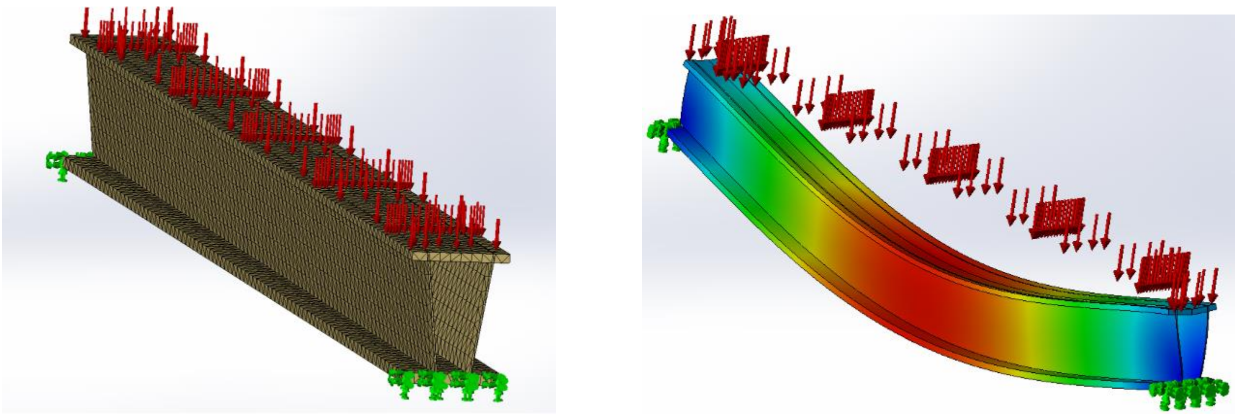


Fig. 6. Type 1 vault module model

In real-world design, it is more handy for engineers to use reference data that would provide rational dimensions of cladding elements depending on the geometric parameters of an object and natural and climatic area of construction. Obtaining such data is possible based on the results of a large numerical experiment where at least two hundred different module variants will have to be considered. The aim of the experiment is to identify the appropriate parameters of the cladding panels that could be written down in the form of simple formulas or tables, i.e., to design an engineering methodology for the above structures.

A possibility of designing such a technique is implicitly confirmed in [1] that examines Kielsteg panels, as well as the results of preliminary computer calculations for operational loads of individual modules (Fig. 7).



a) *b)*

Fig. 7. Computer simulation of Type 2 module: *a* — finite element model, *b* — deformed circuit

Discussion and Conclusion. As a result of the literature review, new types of cladding panels and floors made of wood, plywood and/or OSB have been set forth. Unlike the traditional glued plywood panels, the cladding of the suggested products is made of planks, and the middle layer is a system of ribs made of sheet materials. This solution enables a considerable increase in the span overlapped by the panels and therefore allows for extended open spaces in wooden buildings. The panels can be either flat or curved in a circular arc on the short sides making it possible for them to be employed in vaulted cladding.

As a result of the geometric calculation, the basic size ratios of the panels were identified and a software program was developed in order to obtain the specified characteristics of the vaulted products. Computer models of the panels have been compiled and preliminary calculations performed proving the applicability of the resulting structures as elements of building cladding with spans up to 15 meters. Large spans can also be blocked provided that a construction lift is designed.

Panels of the specified design are also applicable in flooring of buildings, however, in this case the spans will be slightly smaller. This is due to the higher load on flooring. Other types of similar panels are being considered, including those employing thin-walled steel curved profiles as a middle layer. Applications for inventions have been submitted for the products described in the study.

Further research directions involve analytical identification of a rational ratio of the thickness of the boards of the panels and design of an engineering methodology to calculate them with no use of complex computing systems.

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Conflict of interest statement: **the author does not have any conflict of interest.**

The author has read and approved the final version of manuscript.

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Конфликт интересов: **авторы заявляют об отсутствии конфликта интересов.**

Автор прочитал и одобрил окончательный вариант рукописи.

Received / Поступила в редакцию 03.12.2025
Reviewed / Поступила после рецензирования 21.12.2025
Accepted / Принята к публикации 10.01.2026