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# Modern Trends in Construction, Urban and Territorial Planning

Building Constructions, Buildings and Engineering Structures
Footings and Foundations, Subsurface Structures
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Technology and Organization of Construction
Structural Mechanics
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# Современные тенденции в строительстве, градостроительстве и планировке территорий

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Журнал создан в целях информирования читательской аудитории о новейших достижениях, тенденциях и перспективах в области строительства, архитектуры, градостроительства и смежных научных направлений. Издание является платформой для научно-образовательного сотрудничества российских и иностранных исследователей, вовлеченных в строительную сферу.

**Журнал включен в перечень рецензируемых научных изданий, в котором должны быть опубликованы основные научные результаты диссертаций на соискание ученой степени кандидата наук, на соискание ученой степени доктора наук (Перечень ВАК) по следующим научным специальностям:**

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2.1.2 – Основания и фундаменты, подземные сооружения (технические науки)
2.1.5 – Строительные материалы и изделия (технические науки)
2.1.7 – Технология и организация строительства (технические науки)
2.1.9 – Строительная механика (технические науки)
2.1.13 – Градостроительство, планировка сельских населенных пунктов (технические науки)
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# CONTENTS

# СОДЕРЖАНИЕ

# BUILDING CONSTRUCTIONS, BUILDINGS AND ENGINEERING STRUCTURES

# СТРОИТЕЛЬНЫЕ КОНСТРУКЦИИ, ЗДАНИЯ И СООРУЖЕНИЯ





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## Determination and Analysis of Flexure $\Delta_{flexure}$ and Shear $\Delta_{shear}$ Displacements of Reinforced Concrete Walls of Civil Buildings

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***Abstract***

***Introduction.*** To date, there have been extensive experimental data made available in both domestic and foreign scientific literature on the study of displacements and deformations of reinforced concrete walls under the combined action of horizontal load *Q* and vertical load *N*. However, there are not enough comprehensive works systematizing the obtained data to be used as an empirical basis for designing more accurate deformation models and engineering calculation methods for walls, allowing differentiated assessment of flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements. This article aims to look into this issue.

***Materials and Methods.*** The object of the study is reinforced concrete walls of buildings and structures under the combined action of horizontal load *Q* and vertical load *N*. The subject of the study are the displacements and deformations of the walls. Materials include scientific articles on the topic by foreign authors. The methods being used are formal logic (analysis, synthesis, induction, deduction), graphical methods for constructing deformation schemes, and analytical methods of nonlinear structural mechanics.

***Research Results.*** For wall aspect ratios $1.5 < H/B < 2.0$, flexure $\Delta_{flexure}$ displacements dominate in the total displacement structure $\Delta$, while horizontal sliding displacements $\Delta_{slid}$ amount to about 1% of $\Delta$ and can be neglected. The share of flexure $\Delta_{flexure}$ is approximately 98% of $\Delta$ at the initial loading stages. As horizontal load *Q* increases, the contribution of $\Delta_{flexure}$ gradually decreases: to 90% at the moment of crack formation, to 85% at the yielding of vertical reinforcement, and to 80% at the failure stage (when compressed concrete spalls).

For wall aspect ratios $1.0 < H/B < 1.5$, shear displacement $\Delta_{shear}$ has a significant influence on the total displacement $\Delta$: its share at the initial loading stages is about 22%, while determining a protective concrete layer — 46%, and reaches 64% at failure.

Using the graphs of relative displacements of walls with aspect ratios $1.5 < H/B < 2.0$, it was found that at the failure stage, the shares of flexure and shear displacements are 88% and 12% of the total, respectively. Similar graphs obtained for walls with aspect ratios $1.0 < H/B < 1.5$ confirmed that $\Delta_{shear}$ significantly affects the total displacement $\Delta$. The share of $\Delta_{shear}$ at initial loading is about 22%, while determining a protective concrete layer — 46%, and reaches 64% at failure.

***Discussion and Conclusion.*** The "*X*-diagonals" method implemented in a planar calculation scheme allows for highly accurate separation of components caused by flexure and shear deformations from the total displacements. Thanks to this the scheme is a promising tool for further experimental and theoretical studies. We assume that the height of the wall segment where the diagonals are designed should be arbitrary — $H_i$ making this method more universal.

In addition to the planar calculation scheme, a rod (beam) scheme can also be used. The rod calculation scheme of the wall, with known patterns of stiffness parameter changes in the rod end sections (at the locations of plastic hinge formation), is convenient for engineering calculations of frame buildings and structures based on the finite element method in diverse computational complexes.

**Keywords:** reinforced concrete, monolithic walls, experimental data, wall strength, flexure displacements, shear displacements, total displacements, flexure deformation, shear deformation, total deformation

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*Оригинальное эмпирическое исследование*

# Оценка и анализ перемещений от изгиба $\Delta_{flexure}$ и сдвига $\Delta_{shear}$ железобетонных стен гражданских зданий

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**Аннотация**

***Введение.*** К настоящему времени в отечественной и зарубежной научной литературе накоплен обширный экспериментальный материал по исследованию перемещений и деформаций железобетонных стен при совместном действии горизонтальной *Q* и вертикальной *N* нагрузок. Однако отсутствуют обобщающие работы, систематизирующие полученные данные с целью их использования в качестве эмпирического базиса для построения более точных деформационных моделей и инженерных методик расчёта стен, позволяющих дифференцированно оценивать перемещения изгиба $\Delta_{flexure}$ и сдвига $\Delta_{shear}$. Данная статья направлена на решение этой проблемы.

***Материалы и методы***. Объект исследований — железобетонные стены зданий и сооружений при совместном действии горизонтальной *Q* и вертикальной *N* нагрузок. Предмет исследований — перемещения и деформации стен. Материалы — научные статьи зарубежных авторов, посвящённые исследуемому вопросу. Методы — формальная логика (анализ, синтез, индукция, дедукция), графический метод построения схем деформирования, аналитические методы нелинейной строительной механики.

***Результаты исследования.*** При соотношении сторон стены $1{,}5 < H/B < 2{,}0$ преобладают изгибные перемещения $\Delta_{flexure}$ в структуре общих перемещений Δ, а перемещения горизонтального скольжения $\Delta_{slid}$ составляют порядка 1 % от Δ, и ими можно пренебречь. Доля перемещений от изгиба $\Delta_{flexure}$ составляет приблизительно 98 % от Δ на начальных этапах. С увеличением горизонтальной нагрузки *Q* вклад перемещений $\Delta_{flexure}$ постепенно снижается: до 90 % — в момент появления трещин, до 85 % — при текучести вертикальной арматуры и до 80 % — в стадии разрушения (при выкрашивании сжатого бетона).

При соотношении сторон стены $1{,}0 < H/B < 1{,}5$ перемещение $\Delta_{shear}$ оказывает значительное влияние на общее перемещение Δ: доля $\Delta_{shear}$ на начальных этапах нагружения составляет около 22 %, в момент отслоения защитного слоя бетона — 46 %, и достигает 64 % в момент разрушения.

По графикам относительных перемещений стены при соотношении сторон $1{,}5 < H/B < 2{,}0$ нами выявлено, что в стадии разрушения доля перемещений при изгибе и сдвиге составляет соответственно 88 % и 12 % от общих. Аналогичные графики получены для стен с соотношением сторон $1{,}0 < H/B < 1{,}5$ и установлено, что перемещение $\Delta_{shear}$ оказывает значительное влияние на общее перемещение Δ. Доля $\Delta_{shear}$ на начальных этапах нагружения составляет около 22 %, в момент отслоения защитного слоя бетона — 46 % и достигает 64 % в момент разрушения.

***Обсуждение и заключение***. Метод «*X*-диагоналей», реализованный в плоской расчётной схеме, позволяет с высокой точностью выделить из общих перемещений составляющие, вызванные деформациями изгиба и сдвига. Благодаря этому преимуществу, данная схема является перспективным инструментом для дальнейших экспериментальных и теоретических исследований. Причём, на наш взгляд, высота фрагмента стены, в границах которого строятся диагонали, должна быть произвольной — $H_i$, что позволит сделать данный метод более универсальным.

Помимо плоской расчётной схемы возможно использование и стержневой. Стержневую расчётную схему стены при известных закономерностях об изменениях жесткостных параметров стержня на концевых участках (в местах образования пластических шарниров) удобно применять в инженерных расчётах каркасных зданий и сооружений на основе метода конечных элементов в том или ином вычислительном комплексе.

**Ключевые слова:** железобетон, монолитные стены, экспериментальные данные, прочность стены, перемещения при изгибе, перемещения при сдвиге, общие перемещения, деформация при изгибе, деформация при сдвиге, общая деформация

**Благодарности.** Авторы выражают благодарность редакции и рецензентам за внимательное отношение к статье и указанные замечания, которые позволили повысить ее качество.

**Для цитирования.** Радайкин О.В., Хнычева Н.В. Оценка и анализ перемещений от изгиба $\Delta_{flexure}$ и сдвига $\Delta_{shear}$ железобетонных стен гражданских зданий. *Современные тенденции в строительстве, градостроительстве и планировке территорий*. 2025;4(3):7–17. https://doi.org/10.23947/2949–1835-2025-4-3-7-17

**Introduction.** Reinforced concrete walls are among the most common types of building structures. They typically combine load-bearing and enclosing functions, experience vertical and horizontal loads, and thereby operate under conditions of complex stress-strain states. An accurate assessment of the deformations occurring during the process is key to their precise mechanical calculation and further safe operation. This paper looks into the movements and deformations of walls.

Before moving on with the study description, let us get clear on the terminology:

– movement is a change in the coordinates of a point of a solid body (in our casea reinforced concrete wall) in space under the action of loads (external forces) denoted by the Greek letter $\Delta_{index}$ with its lower index showing the nature of the influence of deformations of the solid body, such as flexure, shear, sliding, etc.;

– deformation is a change in the size and shape of a solid body under the action of a load, i.e., it is the mutual displacement of points of a solid body relative to each other in space. Linear relative deformations — ε, shear angles — γ, angles of rotation of sections of the solid body relative to its axes — φ, and the curvature of the axes themselves — χ (*note:* they are commonly denoted as 1/ρ in literature).

The total displacement of any point of a reinforced concrete wall due to loads acting in its plane can be broken down into the following components:

$$\Delta = \Delta_{flexure} + \Delta_{shear} + \Delta_{slid} + \Delta_{BR}, \quad (1)$$

where $\Delta_{flexure}$ — displacements caused by the influence of pure flexure deformations; $\Delta_{shear}$ — displacements caused by the influence of pure shear deformations in the plane of the wall; $\Delta_{slid}$ — displacements caused by the influence of sliding-shear deformations at the bottom or the top of the wall; $\Delta_{BR}$ — displacements caused by the influence of the rotation of the bottom or top of the wall relative to the foundation or floor.

Having studied the scientific and technical literature analyzed below, we have identified the following problem: there are no comprehensive studies systematizing the experimental data (accumulated considerably over the past few decades) on the deformation of reinforced concrete walls under the combined action of horizontal, *Q*, and vertical, *N*, loads. This serves as an obstacle both for improving the existing methods and techniques for the differentiated calculation of flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements of reinforced concrete walls, as well as for coming up with fundamentally new approaches. The current studying is aimed at addressing this obstacle.

The movements caused by loads acting out of the plane of the wall are beyond the scope of the research.

**Materials and Methods.** Prevously in [1], we described the general mechanisms of deformation and failure of walls under the combined influence of the load ratio *N/Q* and the height-to-width ratio of the wall — *H/B*. It was found that the ratio *H/B* qualitatively predetermines the wall failure mechanism, i.e., it impacts the pattern of appearance and development of cracks from a microscopic size to major ones, along the trajectory of which the wall structure is divided into separate parts. The load ratio *N/Q* is responsible for the quantitative values of the parameters of implementing this mechanism. At small values of *H/B*, the share of shear displacements $\Delta_{shear}$ predominates in the resulting displacements of the wall Δ, while the resistance to horizontal load *Qu* is at its maximum. In this case, the failure is more brittle in its nature. As the ratio *H/B* increases, so does the share of the flexure displacements $\Delta_{flexure}$, while the shear displacements $\Delta_{shear}$ decrease; so does $Q_u$, and plastic deformations are more intense.

The mechanisms of deformation and failure of walls under load described in [1] enable one to design deformed schemes with the overlay of internal force schemes balancing external loads. These deformed schemes allow us to calculate the total displacements of the wall Δ at its characteristic sections, and most importantly, to isolate the components caused by the influence of flexure and shear deformations — $\Delta_{flexure}$ and $\Delta_{shear}$ respectively — from the total displacements. Some variants of such schemes by different authors are considered below, along with their analysis regarding the correspondence of each to a relevant study of wall structures and their convenience as a tool for analyzing the stress-strain state of walls.

**Research Results**. One of such schemes is found in [2, 3]. Given some necessary additions made for a more complete 9nderstanding, it is shown in Fig. 1.

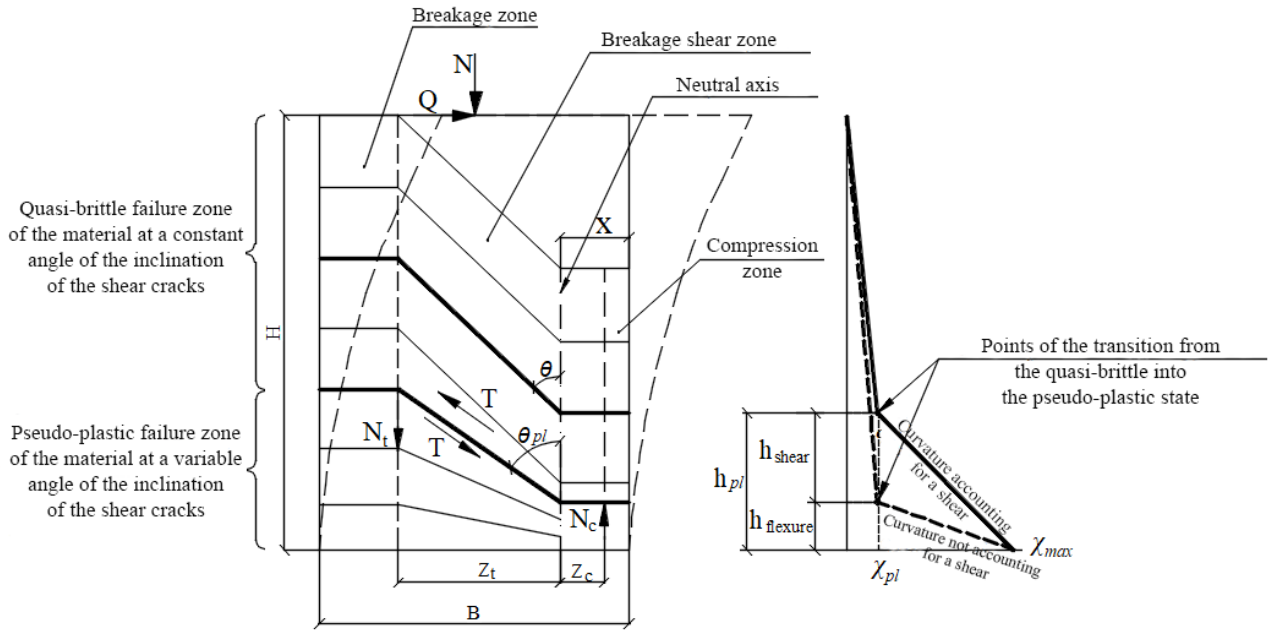



Fig. 1. Calculation scheme of deformation of a reinforced concrete wall (left) under the combined action of vertical $N$ and horizontal $Q$ loads and the graph of curvature distribution along its height (right) [2]

The scheme is a rectangular plate with a clamped lower edge, while all of the other three edges are free from constraints. A vertical load $N$ and a horizontal load $Q$ are applied from above. A pattern of fan-shaped cracks is drawn on the plate whose nature was revealed during the experiment. Along the trajectory of one of the cracks, a calculated section is drawn, i.e., the first thick line from the bottom. It intersects on the left with the stretched zone of the wall, or the detachment zone, where the detachment mechanism of crack formation dominates; in the center is the zone of combined shear and detachment where two mechanisms of crack formation overlap, i.e., transverse detachment and longitudinal shear; on the right is the compression zone of the wall. The stable development of cracks occurs largely due to the dissipation of accumulated energy from elastic-plastic deformation of pure flexure causing displacements $\Delta_{flexure}$, while shear or sliding deformations causing displacements $\Delta_{shear}$ and $\Delta_{slid}$ result in spontaneous cracking and almost instantaneous brittle failure in the local zone.

On the right in Fig. 1 are the theoretical curvature diagrams of the neutral axis of the wall. The solid line corresponds to the total curvature defined by the combined consideration of flexure and shear deformations, while the dashed line corresponds only to flexure with no shear. Each diagram consists of two straight lines with different slopes: in the lower part of the wall, the angle is softer, accordingly, the curvature changes more intensively in the height than at the top. The point of inflection between these sections corresponds to the transition from a quasi-brittle failure mechanism at the top of the wall to a pseudo-plastic failure mechanism at the bottom of the wall. Along the broken line of the cross-section of the wall, a system of internal forces is applied: $N_c$ — the resultant compressive stresses in the concrete; $N_t$ — the resultant tensile stresses in the concrete; $T$ — the resultant shear stresses along the edges of the inclined crack. Fig. 1 also denotes $h_{flexure}$, $h_{pl}$ — the height of the pseudoplastic failure zone at the bottom of the wall, respectively, assuming that there are only pure flexure deformations, and while accounting for a combination of flexure and shear deformations; $\chi_{pl}$ — the curvature corresponding to the height $h_{pl}$; $\chi_{max}$ — the maximum curvature; $x$ — the height of the compressed zone; $z_c$ — the arm of the resultant $N_c$ relative to the neutral axis; $z_t$ — the arm of the resultant $N_t$ also relative to the neutral axis; $\theta$, $\theta_{pl}$ — the angle of inclination of the cracks forming according to the pull-shear mechanism, respectively, in the upper zone of the wall (above the point of transition from quasi-brittle failure to pseudoplastic) and in the lower zone (below this point), with $\theta$ — const and $\theta_{pl}$ — *var*.

It should be noted that the resultant tensile stresses $N_t$ in the calculated section is located above the resultant compressive stresses $N_c$ precisely due to the influence of shear deformations. In pure flexure these forces would be at the same horizontal level.

The angle of inclination of the cracks $\theta_{pl}$ at the transition point is given by the formula:

$$\theta_{pl} = arctg\left(\frac{z_t}{h_{shear}}\right). \qquad (2)$$

where $h_{shear} = h_{pl} - h_{flexure}$.

According to the experiment [2], the value of $\theta_{pl}$ ranges from 55° to 65°.

In Fig. 2, the curvature diagrams of the neutral axis of the wall are shown [2]: two theoretical ones — the first under the assumption of deformations only due to flexure (1), the second — accounting for both flexure and shear (2), as well as the experimental diagram (3) described (approximated) by the previous two theoretical diagrams.

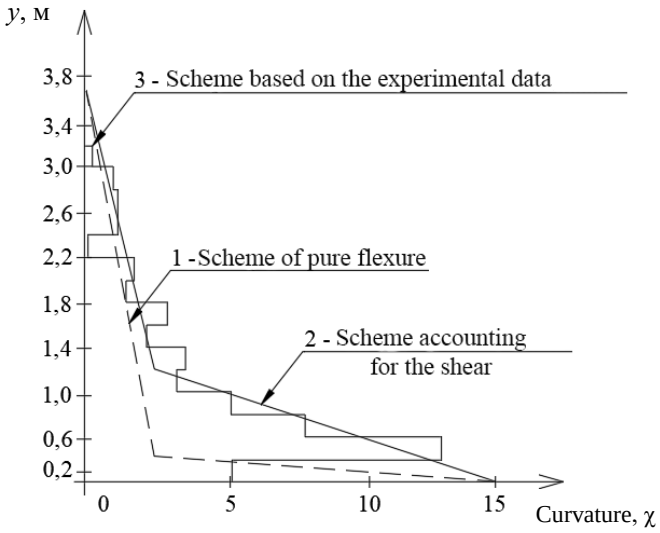
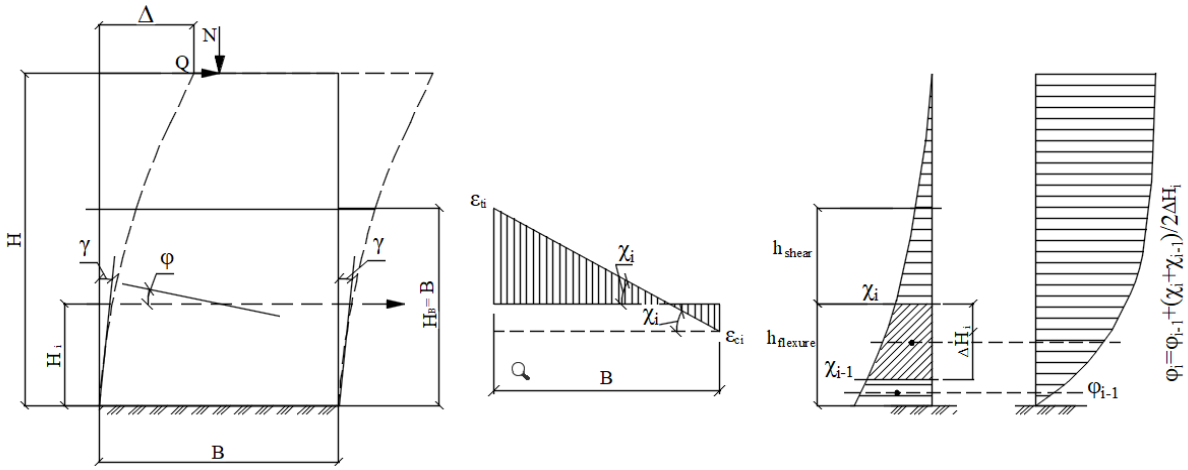



Fig. 2. Curvature distribution schemes along the wall height [2]

The maximum difference between diagrams 1 and 2 was 31%, which is significant.

In order to calculate the components of deformations and displacements caused by flexure and shear separately, some general clarifications will be introduced into the calculation scheme (Fig. 1) and moved to the scheme (Fig. 3) [4]:




*a)* *b)* *c)* *d)*

Fig. 3. Calculation schemes for determining shear angles, γ, longitudinal relative deformations, ε, curvatures, χ, and rotation angles, φ, while deforming a wall: *a* — scheme of wall deformation; *b* — diagram of the distribution of longitudinal deformations ε in an arbitrary i-th section of the wall drawn at a height $H_i$ from the base; *c* — diagram of the distribution of curvature along the height of the wall; *d* — diagram of the distribution of rotation angles [4]

In order to assess the bending deformations, let us look at the curvature diagram in Fig. 3B described by some continuous and differentiable function $\chi = \chi(y)$. Let *i* be the ordinal number of an arbitrary cross-section of the wall located at a height $H_i$ from its bottom. In this section, the diagram of relative deformations ε of the wall is shown in Fig. 3A whose extreme values are related to the curvature known from the strength of materials formula:

$$\chi_i = \frac{|\varepsilon_{ti}| + |\varepsilon_{ci}|}{B}, \quad (3)$$

where $\varepsilon_{ti}$ and $\varepsilon_{ci}$ — deformations of tension and compression on the side faces of the wall width *B*.

The average value of the curvature on a wall section with a height of $\Delta H_i$ enclosed between two close sections *i* and *i*–1 is $(\chi_i + \chi_{i-1})/2$. Then the angle of rotation of the wall cross-section at the level of the center of gravity of the section $\Delta H_i$ (Fig. 3*d*) is given by the formula:

$$\varphi_i = \int_0^{H_i} \chi(y)dy = \frac{\varphi_{i-1} + (\chi_i + \chi_{i-1})}{2\Delta H_i}. \quad (4)$$

The desired displacements in an arbitrary *i*-th section are given by the formulas:

$$\Delta_{flexure,i} = \varphi_i H_i, \quad (5)$$

$$\Delta_{shear,i} = \gamma_i H_i, \quad (6)$$

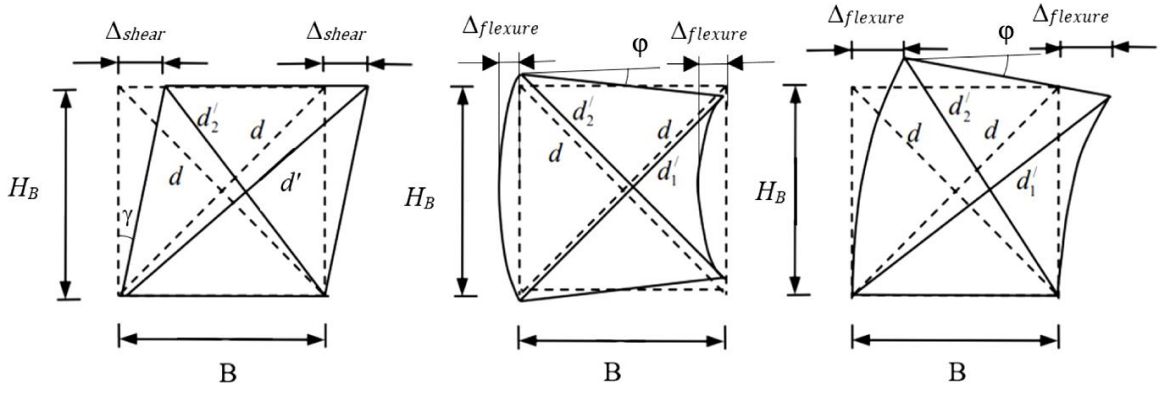
where $\gamma_i$ — the angle of displacement of the wall face at a height from the base (Fig. 3 *a*).

Determining the relative deformations $\varepsilon_{ti}$ and $\varepsilon_{ci}$ of the vertical wall faces during the experiment appears to be not challenging. To this end, the methods such as strain gauges, holographic interferometry, etc. can be used. It is thus fairly simple to estimate the movements of pure flexure $\Delta_{flexure}$ with formulas (3)-(5). However, the pure shear disp $\Delta_{shear}$ are more challenging [5].

In [4, 6-8], the computational method of "*X*-diagonals" is set forth in order to estimate these displacements (Fig. 4). To this end, the authors selected a square fragment of the wall with a width *B* and a height $H_b = B$. But we believe that the height of the fragment can be arbitrary, i.e., $H_i$, which will make this method more universal.

The desired displacement of the shift $\Delta_{shear}$ is estimated by changing the lengths of the diagonals of the selected square before *(d)* and after deformation ($d_1'$, $d_2'$) (Fig. 4 *a*):

$$\Delta_{shear} = \gamma H_B = \left(\frac{d}{2B}\right)(d_1' - d)d - (d_2' - d)H_B. \quad (7)$$




*a*) *b*) *c*)

Fig. 4. Geometric schemes of wall deformation for determining flexure $\Delta flexure$ and shear $\Delta shear$: a — scheme of pure flexure; b — scheme of pure flexure with a constant curvature along the height; c — scheme of pure flexure with a variable curvature along the height [4, 7]

Formula (7) is accurate only if the curvature of the deformed wall faces is constant in height (Fig. 4*b*). This is possible in some small (infinitesimal) area, in other cases it results in noticeable errors. The estimate of the shear displacement $\Delta_{shear}$ in this case turns out to be overestimated as it also contains flexure displacements $\Delta_{flexure}$ (Fig. 4 *c*).

In order to clarify formula (7), let us consider the wall deformation scheme in Fig. 5 accounting for vertical displacements.

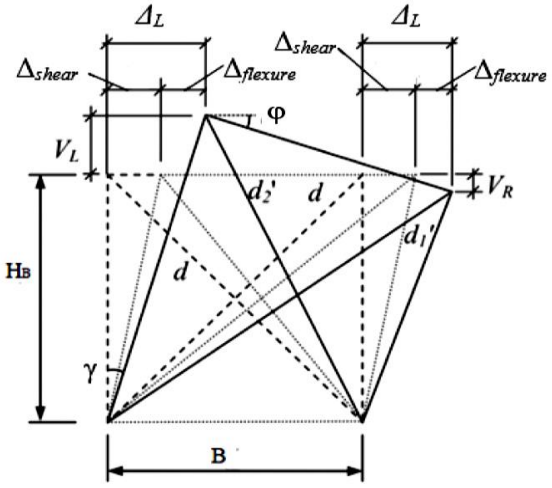



Fig. 5. Flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements accounting for vertical displacements $V_L$ and $V_R$ [4, 7]

The flexure displacements and the angle of rotation of the horizontal section of the wall φ are equal to:

$$\Delta_{flexure} = \alpha\varphi H_B, \tag{8}$$

$$\varphi = \frac{V_L - V_R}{L}, \tag{9}$$

where $V_L$ and $V_R$ — vertical displacements of the upper face of the wall on the left and right sides, respectively; α — coefficient accounting for a change in the curvature along the height of the wall given by the formula (for a graphical interpretation of the coefficient, see Fig. 6):

$$\alpha = \frac{\int_0^H \varphi(y)dy}{\varphi H}. \tag{10}$$

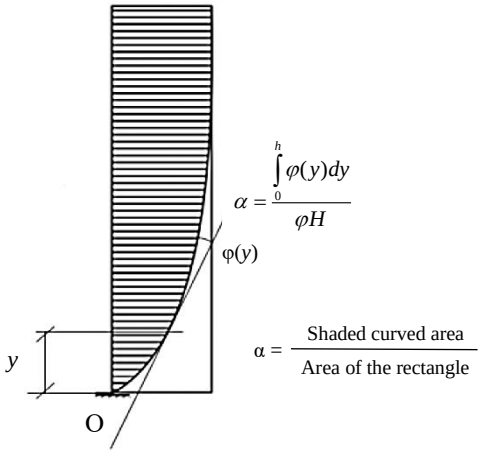



Fig. 6. Scheme of the distribution of the angles of rotation of the curved wall face after deformation for determining the coefficient α [4, 7]

This coefficient ranges within $0.5 < \alpha < 1.0$ and averages $\alpha \approx 0.62$. The values of α close to the boundaries of the interval (0.5; 1.0) are an idealized abstraction which can be used in theoretical models for simplification, but they are not implemented in practice. The essence of the coefficient is that the greater α, the more flexible the wall structure is, i.e., the lower its flexure stiffness is. Conversely, the lower the α, the higher the bending resistance of the wall structure is, i.e., the higher its flexure stiffness is.

The specified shear displacements are equal to:

$$\Delta_{shear} = \left(\frac{d}{2B}\right)\left[(d_1' - d) - (d_2' - d)\right] - \left[\Delta_{flexure} + \left(\frac{H_B}{2B}\right)(V_R - V_L)\right] \tag{11}$$

or

$$\Delta_{shear} = \left(\frac{d}{2B}\right)\left[(d_1' - d) - (d_2' - d)\right] - (\alpha - 0{,}5)\varphi H. \tag{12}$$

Hence in order to obtain the contribution of flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements to the total displacements, it is necessary to determine the coefficient α accounting for a change in the curvature over the height of the wall. Moreover, at $\alpha = 0.5$, formula (12) is reduced to (7), i.e., in this case, the gradient of the flexure curvature no longer impacts the shear.

The experimental results [4, 7] showed that before cracks are formed, the curvature of the walls has an almost constant height distribution, respectively, the coefficient $\alpha \approx 0.5$. As cracks appear, the plot of the curvature distribution becomes triangular, and the coefficient α increases to about 0.67. As the load further increases, so does α and tends to 1.0 at the moment of failure, which is accompanied first by the shutdown of the vertical reinforcement and then by the discoloration of the compressed concrete.

It was also found that as the wall aspect ratio *H*/*B* increases, the value of α decreases.

[9] provides a core model for calculating the wall accounting for the compliance of the supporting nodes *A* and *B* (Fig. 7) under the combined action of longitudinal *N* and transverse *Q* forces. Initially, the scheme was used to calculate columns, but in this case it is used to model reinforced concrete walls with an aspect ratio of $1.5 < H/B < 2.0$ in order to obtain flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements separately.

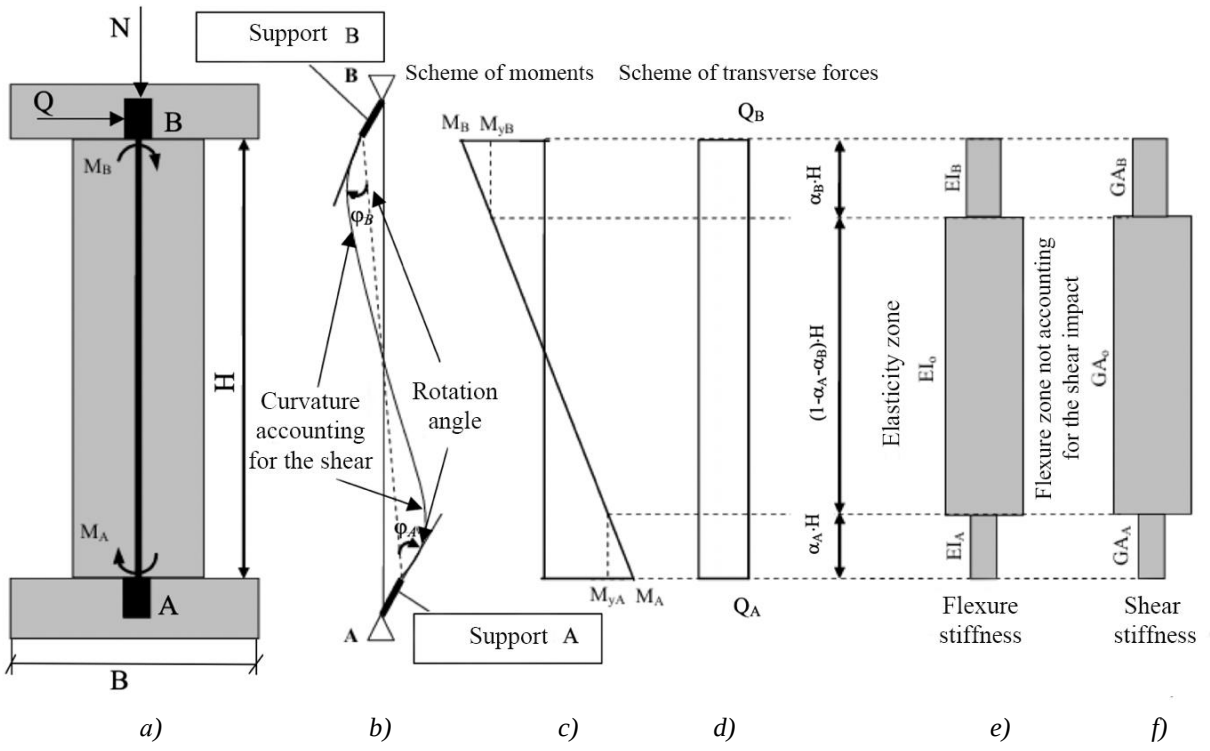



Fig. 7. Core design scheme for deforming a reinforced concrete wall under the combined action of vertical *N* and horizontal *Q* loads: *a* — core model for calculating the wall; *b* — scheme for bending the longitudinal axis of the rod during deformation; *c* — plot of moments; *d* — plot of transverse forces; *e* — scheme for modeling wall flexure; *f* — scheme for modeling walls accounting for the interaction of shear and flexure [9]

The scheme consists of a rod pinched in the upper and lower parts at points *A* and *B* (Fig. 7*a*). The rod deformation scheme is shown in Fig. 7*b*. In Fig. 7*c* in and Fig. 7*d* are the schemes of moments and transverse forces, respectively.

In order to determine the curvature of the longitudinal axis of the flexure rod $\chi_{flexure}$ caused by flexure, the distribution of bending stiffness *EI* over the height of the wall is shown in Fig. 7*d*. In order to determine the curvature of the axis of the $\chi_{shear}$ rod caused by shear, the distribution of shear stiffness *GA* over the height of the wall is shown in Fig. 7*e*. At the ends of the rod, for one and the other stiffness, it is assumed that the physical nonlinearity of reinforced concrete is accounted for (the stiffness of $EI_A$ and $EI_B$, $GA_A$ and $GA_B$ in Figs). In the middle part of the rod, the stiffness is assumed as for an elastic body (stiffness $EI_0$, $GA_0$). At the same time, a constant value is assumed for each of the three stiffness sections.

The lengths of the end sections of the rod within which physical nonlinearity is accounted for, are determined by multiplying the height of the wall *H* by the empirical coefficients $\alpha_A$ and $\alpha_B$. The points separating the end sections from the middle are plastic hinges.

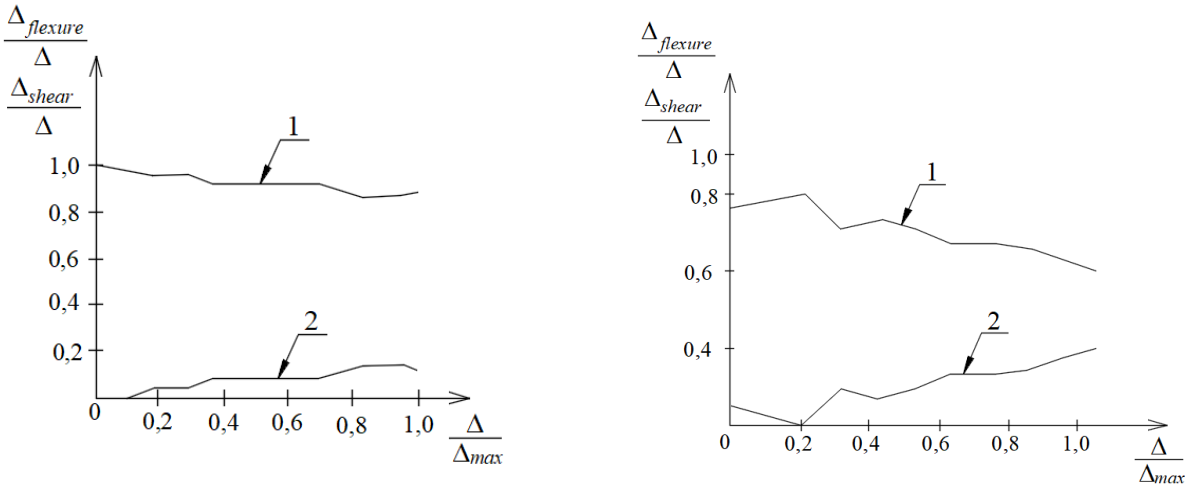
The shear displacements $\Delta_{shear}$ acquire noticeable values at the end sections of the rod, they practically do not appear in the middle part and the movements $\Delta_{flexure_c}$ caused by flexure dominate.

The total displacement of the wall $\Delta$ in the area of the plastic hinge is equal to:

$$\Delta = \Delta_{shear} + \Delta_{flexure} \tag{13}$$

The studies [6–7, 10–12] consider examine pure flexure $\Delta_{flexure}$ and shear displacements $\Delta_{shear}$ as part of the total displacement $\Delta$ with a wall aspect ratio of $1.5 < H/B < 2.0$. It is shown that flexure displacements $\Delta_{flexure}$ dominate in such walls, and sliding displacements $\Delta_{slid}$ are on the order of 1% of $\Delta$ and can be ignored. The proportion of movements from bending is approximately 98% of the total movement of the reinforced concrete wall at the initial stages. As the horizontal load *Q* increased, the contribution of movements from bending $\Delta_{flexure}$ gradually decreased to 90% at the moment of cracking; 85% — during the fluidity of vertical reinforcement; 80% — at the stage of failure (while painting compressed concrete).

According to the results of processing experiments [6, 7], graphs of relative wall movements with an aspect ratio of $1.5 < H/B < 2.0$ were obtained as shown in Fig. 8 *a*. It can be seen that at the failurre stage, the proportion of flexure and shear displacements is 88% and 12% of the total, respectively.



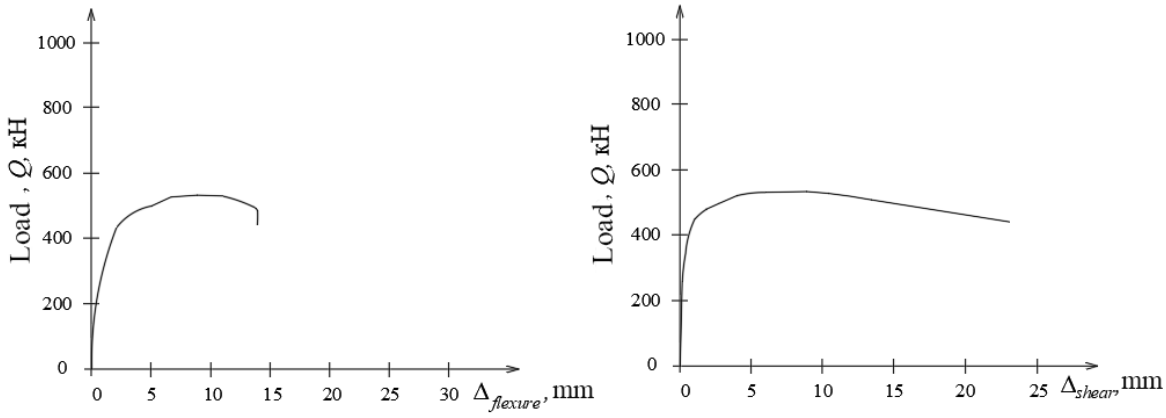

*a*) *b*)

Fig. 8. Graphs of relative wall displacements with the aspect ratio: *a* — 1,5 < *H*/*B* < 2,0; *b* — 1,0 < *H*/*B* < 1,5 (1 — curve of relative flexure displacements $\Delta_{flexure}/\Delta_{max}$; 2 — curve of relative shear displacements $\Delta_{shear}/\Delta_{max}$; $\Delta_{max}$ — maximum wall displacements)

We obtained similar graphs after processing the data [6] (Fig. 8*b*) for walls with an aspect ratio of 1.0 < *H*/*B* < 1.5. It has been found that the shear displacement $\Delta_{shear}$ has a significant impact on the overall movement of Δ. The proportion of $\Delta_{shear}$ at the initial stages of loading is about 22%, at the moment of detachment of the protective layer of concrete — 46% and reaches 64% at the moment of failure.

In an experiment [6] it was shown that at the initial stages of loading, slight displacements $\Delta_{flexure}$ are observed in the samples (Fig. 9*a*). As the first crack appears, the bending stiffness of the wall decreases sharply leading to a significant increase in the displacements $\Delta_{flexure}$.

Fig. 9*b* shows that as the first inclined crack appears, the displacements $\Delta_{shear}$ start having a more significant effect on the total wall displacements Δ, despite the fact that the shear strength of the walls is more than 2 times higher than the horizontal load *Q*.




*a*) *b*)

Fig. 9. Graphs of the dependence of the flexure $\Delta_{flexure}$ (*a*) and shear $\Delta_{shear}$ (*b*) displacements of the wall on the applied horizontal load *Q* [6]

**Discussion and Conclusion.** The mechanisms of deformation and failure of walls under load identified in the experiments conducted by a wide range of foreign authors enabled us to design appropriate deformation schemes with the superposition of internal forces balancing external loads. This made it possible to obtain mathematical formulas for determining the total displacements of the wall Δ in its characteristic sections, as well as dependencies that allow the components caused by the influence of flexure and shear deformations $\Delta_{flexure}$ and $\Delta_{shear}$ to be isolated from the total displacements.

The scheme in Fig. 1 enables us to determine the desired displacement of shear $\Delta_{shear}$ and flexure $\Delta_{flexure}$ under the combined action of vertical, *N*, and horizontal, *Q*, loads. Theoretical diagrams of the curvature of the neutral axis of the wall are provided where a solid line corresponds to the total curvature determined by accounting for a combination of flexure and shear deformations, and a dotted line corresponds only when flexure without shear is accounted for. It is found that the maximum difference between the pure bending and shear-adjusted plots is 31% indicating that the calculation of

walls using the model of an uncenterically compressed rod without accounting for shear displacements will have a significant error.

The scheme in Fig. 3 enables us to calculate the components of deformations and displacements caused by bending and shear separately, but with some generalizing refinements. Pure flexure displacements $\Delta_{flexure}$ are determined by means of fairly simple formulas, but pure shear displacements $\Delta_{shear}$ are challenging. In order to estimate these displacements, the computational method of "*X*-diagonals" is set forth. However, in order to obtain the contribution of flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements to the total displacements, it is necessary to perform arithmetically complex operations to find the coefficient α accounting for a change in the curvature along the height of the wall.

Initially the scheme in Fig. 7 was used for calculating columns, but in this case it is used for modeling reinforced concrete walls with an aspect ratio of $1.5 < H/B < 2.0$ in order to obtain flexure $\Delta_{flexure}$ and shear $\Delta_{shear}$ displacements. In order to implement this scheme in a computing complex, it is required that conduct large-scale experimental and theoretical studies are performed on more complex (more precise) wall models.

As a result of the theoretical study, it was found that the scheme shown in Fig. 1 provides a more precise description of the wall structure and can be used as a practical tool in order to analyze its stress-strain state under the combined action of vertical force *N* and horizontal force *Q*.

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**NV Khnycheva:** data collection, analysis and interpretation, manuscript preparation.

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**Н.В. Хнычева:** сбор данных, их анализ и интерпретация, оформление.

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# BUILDING CONSTRUCTIONS, BUILDINGS AND ENGINEERING STRUCTURES

# СТРОИТЕЛЬНЫЕ КОНСТРУКЦИИ, ЗДАНИЯ И СООРУЖЕНИЯ





*Original Empirical Research*

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## Energy-Absorbing Gusset of Steel Frame Bonds

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**Abstract**

***Introduction.*** This study looks at the urgent problem of ensuring the seismic resistance of buildings and structures in areas with increased seismic activity. The aim of the study is a comprehensive analysis of existing methods of protection against seismic impacts and the development of innovative design solutions in order to increase the stability of buildings. The study is relevant due to the growing need to protect the population and infrastructure in seismically active regions around the globe.

***Materials and Methods.*** Two major approaches to increasing seismic resistance were considered: the traditional method of increasing structural cross-sections and a special method of reducing load by means of changing the dynamic scheme of the structure. Special attention is paid to the development and analysis of the operation of the fastening unit of the frame using a curved thin-walled plate. Modern methods of mathematical modeling and computer analysis were employed.

***Research Results.*** Architectural, planning and constructive solutions for increasing the earthquake resistance of buildings were analyzed. The principles of designing earthquake-resistant buildings to minimize earthquake damage were formulated. The plastic properties of steel as an effective method of absorbing seismic energy were studied. Energy-absorbing devices are classified into five main types: rod-type, annular, tubular, beam-type and shear-type. The design features of energy absorbers, their advantages and disadvantages were thoroughly investigated.

***Discussion and Conclusion.*** A finite element analysis of the stress-strain state of the fastening unit was conducted by means of the Stark ES software package. The results of the analysis enabled us to evaluate the efficiency of the suggested constructive solution. The practical importance of the study lies in the possibility of applying the developed solutions in the design and construction of earthquake-resistant buildings in areas of increased seismic activity. The suggested methods and designs make it possible to increase the stability of buildings, reduce metal consumption, and easy to replace elements if needed. The developed solutions can be scaled for use in different types of building structures and climatic conditions.

**Keywords:** seismic resistance, energy absorbers, seismic impact, design solutions, building design, active seismic protection, seismic isolation systems, damping, vibration absorbers, seismic resistance of buildings, design solutions

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*Оригинальное эмпирическое исследование*

## Энергопоглощающие фасонки связей стального каркаса

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**Аннотация**

***Введение.*** Настоящая работа посвящена актуальной проблеме обеспечения сейсмостойкости зданий и сооружений в зонах с повышенной сейсмической активностью. Целью исследования является комплексный анализ существующих методов защиты от сейсмических воздействий и разработка инновационных конструктивных решений

для повышения устойчивости зданий. Актуальность исследования обусловлена растущей необходимостью защиты населения и инфраструктуры в сейсмически активных регионах мира.

***Материалы и методы.*** В ходе исследования рассмотрены два основных подхода к повышению сейсмостойкости: традиционный метод увеличения сечений конструкций и специальный метод снижения нагрузки через изменение динамической схемы работы сооружения. Особое внимание уделено разработке и анализу работы узла крепления связи каркаса с использованием фасонки из гнутой тонкостенной пластины. Для проведения исследования применялись современные методы математического моделирования и компьютерного анализа.

***Результаты исследования.*** Выполнен анализ архитектурно-планировочных и конструктивных решений, направленных на повышение сейсмостойкости зданий. Сформулированы принципы проектирования сейсмостойких зданий, обеспечивающих минимизацию ущерба от землетрясений. Проведено исследование пластических свойств стали как эффективного способа поглощения сейсмической энергии. Представлена классификация энергопоглощающих устройств по пяти основным типам: стержневые, кольцевые, трубчатые, балочного типа и работающие на сдвиг. Детально изучены конструктивные особенности энергопоглотителей, их преимущества и недостатки.

***Обсуждение и заключение.*** Проведен конечно-элементный анализ напряженно-деформированного состояния узла крепления с использованием программного комплекса Stark ES. Результаты анализа позволили оценить эффективность предложенного конструктивного решения. Практическая значимость исследования заключается в возможности применения разработанных решений при проектировании и строительстве сейсмостойких зданий в зонах повышенной сейсмической активности. Предложенные методы и конструкции позволяют повысить устойчивость зданий, снизить металлоемкость и обеспечить простоту замены элементов при необходимости. Разработанные решения могут быть масштабированы для применения в различных типах строительных конструкций и климатических условиях.

**Ключевые слова:** сейсмостойкость, энергопоглотители, сейсмическое воздействие, конструктивные решения, проектирование зданий, активная сейсмозащита, системы сейсмоизоляции, демпфирование, гасители колебаний, конструктивные решения

**Для цитирования.** Котенко М.П., Скачков С.В. Энергопоглощающие фасонки связей стального каркаса. *Современные тенденции в строительстве, градостроительстве и планировке территорий*. 2025;4(3):18–24. https://doi.org/10.23947/2949-1835-2025-4-3-18-24

**Introduction.** Earthquakes are among the most destructive natural phenomena causing massive damage to buildings and structures, particularly in areas with increased seismic activity. Ensuring the earthquake resistance of buildings is a key task facing modern architecture and engineering in order to protect human life and health, as well as to preserve material assets.

With earthquakes occurring frequently, it is critical to develop and implement innovative design solutions to minimize damage and ensure the safety of buildings. One of the urgent issues is designing constructive methods in order to increase the overall earthquake resistance of buildings and their individual elements.

The main aim of the research is a comprehensive study of existing methods of protecting buildings from seismic effects, as well as the development and calculation of an effective attachment point for the building frame.

The study looks at two major approaches to improving earthquake resistance:

– a traditional method involving increasing the cross-sections of structures;

– a special method for reducing the load by changing the dynamic scheme of the structure.

Special attention is paid to architectural, planning and structural solutions that make it possible to increase the earthquake resistance of buildings. Different types of energy absorbers are also studied that efficiently absorb the energy of seismic vibrations preventing the destruction of load-bearing structures.

The analysis of typical earthquake damage enables ways and methods for increasing the earthquake resistance of a building to be formulated:

- reduction of inertial loads during seismic action due to the use of lightweight and efficient building materials;
- uniform and symmetrical distribution of stiffness and mass relative to building axes;
- location of butt joints outside the areas of greatest effort;
- ensuring the plastic operation of structures to absorb the energy of seismic impacts.

The study also examines modern active seismic protection systems, including seismic insulation, adaptive systems, damping and vibration dampers.

Special attention is paid to the development and analysis of the attachment point of the frame using a curved thin-walled plate. This solution makes it possible to effectively transfer forces from seismic impacts and ensure high earthquake resistance of the building.

Hence this study seeks to develop innovative design solutions increasing the reliability of buildings and structures, to create conditions for reducing possible damage including that to load-bearing structures.

Considering the typical earthquake damage, buildings and structures in regions with seismic activity of 8, 9, and 10 points should be designed so that the impact of seismic force is kept to a minimum. The aim of the study is to investigate the existing options for protecting buildings from seismic effects, as well as to calculate a possible attachment point for the building frame.

**Materials and Methods.** There are two ways to increase seismic resistance: traditional one— by increasing the cross-sections of structures and a special one — by reducing the load by means of changing the dynamic scheme of the structure [1].

The major ways of increasing the earthquake resistance of buildings are architectural planning and design solutions[1], as well as a range of energy-absorbers.

Based on the results of an engineering analysis of the effects of earthquakes, the following principles of earthquake-resistant buildings design were obtained [2]:

– reduction of seismic forces due to the use of lighter and more efficient building materials, thereby reducing the mass of structures;

– optimization of bending stiffness, the location of nodal masses equally distant, including symmetrically, in the most dangerous directions of seismic load;

– positioning / butt joints outside the area of greatest effort;

– ensuring the plastic operation of structures.

The standards for the design of steel structures allow the use of plastic properties. These properties can also be used for reducing the energy transferred to structures during seismic action. Such special elements are called energy absorbers. At the same time, additional design solutions to, e.g., increase rigidity, strength, and stability will not be required. If the yield point is exceeded, the energy absorbers can be replaced with no loss of structural performance [3, 4].

There are a few major types of energy absorbers in the literature. These include rods or plates used in frame systems characterized by low energy consumption; rings or pipes — as a rule — typically installed in connections to transfer stretching and compression forces through braces, bolted joints are used; beams are used instead of diagonal connections, energy absorption is provided due to the bending or torsional rigidity of the element; structures providing shift are characterized by a relatively high specific energy consumption.

In order to eliminate stress concentrations, structural elements should not include sudden changes in cross-sections for increasing cyclic strength and durability [5].

The issue of developing active seismic protection systems is relevant. The basic principles of such systems are the overall self-isolation of buildings or individual elements adaptive systems with variable characteristics, dampers and vibration dampers are used for [6].

**Research Results.** The simplest and most effective example of such an energy absorber can be a shape made of a bent thin-walled plate installed in the junction of the bond with the column with an offset relative to the axis of the bond. At the same time, the shape enables a transfer the forces from the seismic impact within the elastic operation of the material. Fig. 1 shows a diagram of the attachment point of the frame bond, Fig. 2 shows section 1–1.

[1] SP 14.13330.2014 Construction in Seismic Areas. Updated Edition of SNiP II-7-81*. Moscow: Standartinform; 2018. 114 p.

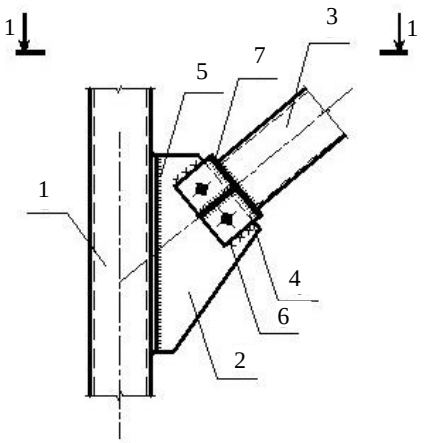


Fig. 1. Diagram of the attachment point of the frame bond

1–1

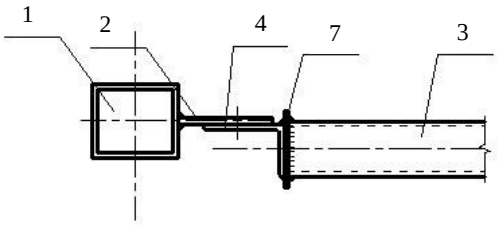


Fig. 2. Section 1–1

1. A coupling element 3 is attached to the column of the frame 1 having a shape 2. Fastening of the coupling element 2 to the column 1 is provided using factory welds 5. Fastening of the coupling element 4 of the bond 3 to the shape 2 is provided using bolts and mounting welding 6. Fastening of the coupling element 4 is provided through the plug 7 of the coupling element 3 from a closed bent-welded the profile.

2. Forces from the coupling element 3 to the column 1 are transferred through the shape 4 attached with an offset relative to the axis of the coupling 3. The node operates as follows: the shape 4 perceives the forces from the coupling element 3, while elastically deforming, due to ductility reduces the internal forces transmitted to the column 1. The operation in the elastic area does not lead to residual deformations and ensures sufficient reliability of the attachment point of the bond with the column.

3. While exposed to a horizontal seismic load, there are elastic deformations in the profile 4 at the junctions of the bond 3 with the column 1, due to which a significant part of the vibrations is absorbed increasing the seismic stability of the building.

4. A finite element analysis of the stress-strain of the shape under a compressive force has been performed via the Stark ES software package. The main stresses and deformations in the element are identified. The calculation scheme is shown in Fig. 3, the voltage distribution is shown in Fig. 4. The essence of the finite element method is that the calculated structure is divided into a number of small but finite elements, which, depending on the type of structure and the nature of its deformation, might have different shapes. An example of calculation using this method is discussed in [7], where the research model is a freely supported single-span beam made of a thin-walled profile with a channel section. Isotropic plates with a thickness of 1.2 mm are used as the finite elements.

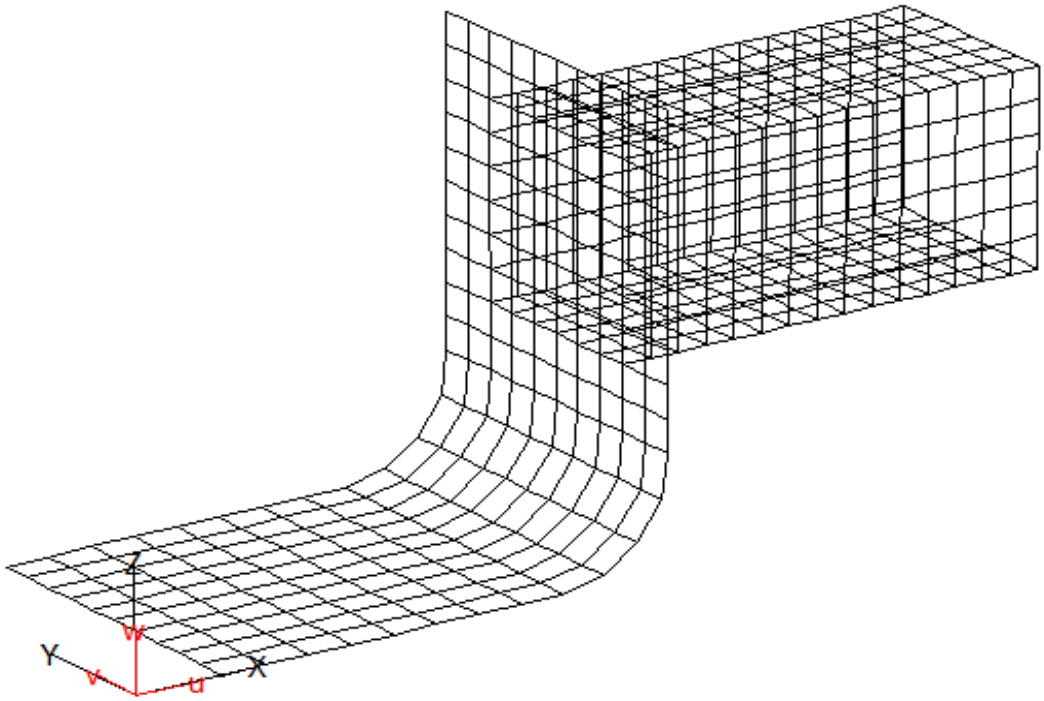


Fig. 3. Calculation scheme

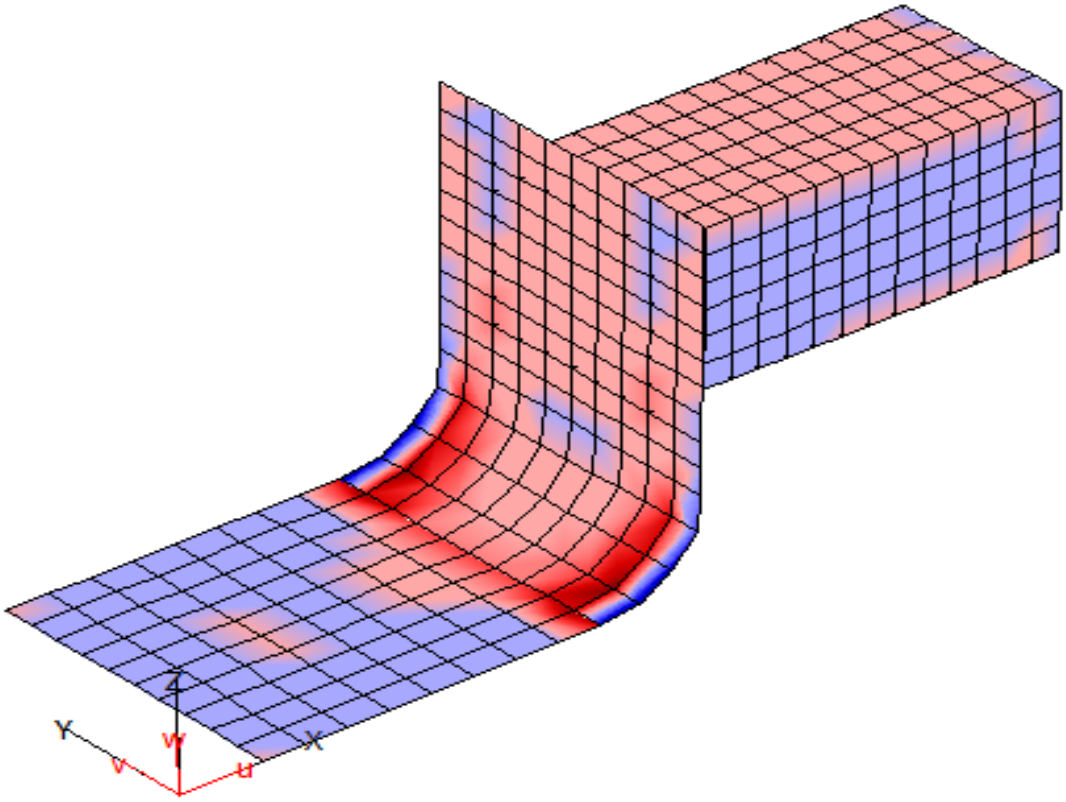


Fig. 4. Main stresses in the gusset

5. The frame structure is easy to manufacture, reduces metal consumption, provides high seismic stability, and is easily replaced with a new one allowing quick complete restoration of the bearing capacity of the frame.

**Discussion and Conclusion.** As a result of the study, innovative design solutions have been set forth in order to increase the earthquake resistance of buildings. These include the use of energy-absorbing shapes made of bent thin-walled plates in the attachment points of the frame bonds.

The application of the suggested constructive solutions allows one:

– to reduce the metal consumption of structures;
– to ensure easy replacement of elements if needed;
– to scale the solutions for different types of building structures and climatic conditions.

Therefore the resulting solutions are a critical contribution to the development of earthquake-resistant construction and can be successfully applied in a wide range of regions experiencing an increased seismic activity.

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***Claimed contributorship:***

**SV Skachkov:** study of existing options for protecting buildings from seismic effects, study of various energy sinks and active seismic protection systems, as well as the development of constructive solutions to improve the earthquake resistance of buildings.

**MP Kotenko:** development of the content and concept of the manuscript, substantiation of the conclusions.

***Conflict of interest statement:*** **the authors do not have any conflict of interest.**

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**С.В. Скачков:** исследование существующих вариантов защиты зданий от сейсмического воздействия, изучение различных энергопоглотителей и систем активной сейсмозащиты, а также разработка конструктивных решений для повышения сейсмостойкости зданий.

**М.П. Котенко:** разработка содержания статьи, концепция статьи, обоснование выводов.

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

***Все авторы прочитали и одобрили окончательный вариант рукописи.***

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# BUILDING MATERIALS AND PRODUCTS
# СТРОИТЕЛЬНЫЕ МАТЕРИАЛЫ И ИЗДЕЛИЯ





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*Original Empirical Research*

## Kinetics of Heat Release of Mechanically Activated Cement-Sand Composition

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**Abstract**

***Introduction.*** Mechanical activation of the dry components of cement composites is utilized in order to increase the initial strength, improve the rheological characteristics of the mixture, as well as to reduce the setting time by increasing the reactivity of the binder. Heat release kinetics of components of cement composites modified by means of mechanical activation methods has been insufficiently investigated and studying its changes is an urgent task. In order to describe heat release kinetics, well-known equations are used relating a degree of hydration and a relative heat release. The aim of this study is to examine heat emission of a mechanically activated cement-sand composition as well as to identify parameters of equations describing heat release kinetics.

***Materials and Methods.*** The investigated mechanically activated composition consists of cement and sand with a weight ratio of 1:2.14, with a specific surface area of 3690.8 $cm^2/g$. Using an isothermal calorimeter, a calorimetric analysis of a mechanically activated cement-sand composition, as well as non-activated cement, was conducted, and heat flux data were obtained.

***Research Results.*** The cement in the composition of the mechanically activated composition was found to be moderately thermal in terms of heat release, with heat release values of 247 J/g and 281 J/g at the age of 3 and 7 days, respectively. During preliminary mechanical activation of the cement-sand composition, the time of the induction period and that to reach 50% of the maximum heat release of cement are reduced by 1.34 and 1.76–1.79 times, respectively.

***Discussion and Conclusion.*** In the course of the study, the heat release kinetics of a mechanically activated cement-sand composition is described. A decrease in the induction period of the hydration process during mechanical activation of cement has been identified confirming the efficiency of mechanical activation of initial dry concrete components. The results can be practically applied in plants for producing dry building mixtures and concretes while introducing the technology of mechanical activation of concrete composite components.

**Keywords:** cement, hydration reaction, reaction rate, mechanical activation, cement-sand composition, heat release kinetics

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*Оригинальное эмпирическое исследование*

## Кинетика тепловыделения механоактивированной цементно-песчаной композиции

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**Аннотация**

***Введение.*** Механическая активация сухих компонентов цементных композитов используется для повышения начальной прочности, улучшения реологических характеристик смеси, сокращения сроков схватывания за счет повышения реакционной способности вяжущего. Кинетика тепловыделения компонентов цементных композитов, модифицированных методами механической активации, на данный момент мало изучена, и исследование ее

изменения является актуальной задачей. Для описания кинетики тепловыделения используются известные уравнения, связывающие степень гидратации и относительное тепловыделение. Целью данной работы является исследование процесса тепловыделения механоактивированной цементно-песчаной композиции с определением параметров уравнений, описывающих кинетику тепловыделения.

***Материалы и методы***. Исследуемая механоактивированная композиция состоит из цемента и песка с отношением по массе 1:2,14, удельная поверхность — 3690,8 см$^2$/г. С помощью изотермического калориметра проведен калориметрический анализ механоактивированной цементно-песчаной композиции, а также неактивированного цемента, получены данные тепловых потоков.

***Результаты исследования*.** Определено, что цемент в составе механоактивированной композиции по показателям тепловыделения относится к умереннотермичным со значениями тепловыделения в возрасте 3 и 7 суток 247 Дж/г и 281 Дж/г соответственно. При предварительной механической активации цементно-песчаной композиции сокращаются время индукционного периода и время достижения 50 % от максимального значения тепловыделения цемента в 1,34 и 1,76–1,79 раз соответственно.

***Обсуждение и заключение***. В ходе проведенных исследований описана кинетика тепловыделения механоактивированной цементно-песчаной композиции. Установлено уменьшение индукционного периода процесса гидратации при механической активации цемента, что подтверждает эффективность механоактивации исходных сухих компонентов бетонов. Полученные результаты могут иметь практическое применение на заводах по производству сухих строительных смесей и бетонов при внедрении технологии механической активации компонентов бетонных композитов.

**Ключевые слова:** цемент, реакция гидратации, скорость реакции, механическая активация, цементно-песчаная композиция, кинетика тепловыделения

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**Introduction.** Cement is the major binder characterizing structure formation of concrete as a whole. The initial Portland cement powder commonly consists of four main phases: alite ($C_3S$), belite ($C_2S$), aluminate ($C_3A$) and ferrite ($C_4AF$) [1]. When the cement binder is mixed with water, a hydration process occurs accompanied by heat release. Varying intensity of the reaction and its high dynamism over time was the rationale for dividing the entire hydration process into separate periods that are easy to record while analyzing changes in the heat release of the system [2].

When the binder is mixed with water, intense but short-term heat generation occurs, lasting only a few minutes (initial stage). This stage is associated with the initial activity of $C_3S$ due to the wetting effect, as well as the reaction of the aluminate phases. The heat release is then stabilized to a relatively constant rate during the induction period, and the solution is stored in a relatively ductile liquid state for about 2 hours. The reasons for the induction period and its completion are extensively discussed, and the most popular hypothesis is currently the formation of protective membranes around cement particles, which requires the expenditure of thermal energy [2; 3]. Notwithstanding a specific mechanism, the end of the induction period is characterized by a sharp increase in the rate of heat release largely caused by the formation of reaction products: calcium hydrosilicates (HSC) and calcium hydroxide (GC). This acceleration period ends with the maximum heat release (after about 10-12 hours). After that, heat generation slows down (the deceleration stage) to a steady level (the period of hardening or slow interaction) when hydration continues for a period of several months to several years. As a result of the long reaction period, the structure and, more importantly, the porous structure of the hardened cement paste will constantly change over time.

Concrete heat generation and strength gain are known to be closely linked [4, 5]: the faster the hydration process occurs, the more intense the growth of crystallohydrates becomes forming the solid structure of cement stone and the entire composite. The degree of hydration $\alpha_\tau$ associated with the reaction rate can be determined based on the mechanical and physical properties represented by the kinetics of strength gain and heat release kinetics:

$$\alpha_\tau = \frac{R_\tau}{R_{28}} = \frac{Q_\tau}{Q_{max}},$$

where $\tau$ — solidification time, days; $R_\tau$ — strength at the age of $\tau$, MPa; $R_{28}$ — strength at the age of 28 days, MPa; $Q_\tau$ — the value of the integral heat dissipation at a time $\tau$, J/g; $Q_{max}$ — maximum value of cement heat release at the age of 28 days, J/g.

In order to describe the heat release kinetics related to that of strength gain, an equation similar in structure to EN 1992-1-1[6; 7] is used[1]:

$$\frac{Q_\tau}{Q_{max}} = \exp\left(k \cdot \left(1 - \left(\frac{28}{\tau}\right)^d\right)\right), \quad (1)$$

where *k, d* — are the equation parameters.

There are a few more equations used in order to describe the heat release rate of the binder during hardening. In the Russian literature, the formula by I.D. Zaporozhets is used in order to describe the heat release kinetics [8, 9]:

$$\frac{Q_\tau}{Q_{max}} = 1-(1 + A \cdot \tau)^{-n}, \quad (2)$$

where *A* — coefficient of growth rate of heat release at the hardening temperature *t* +20 ºC, $h^{-1}$; *n* — indicator depending on the properties of the cement.

In overseas practice a formula by T. Knudsen [10–12] is used:

$$\frac{1}{Q_\tau} = \frac{1}{Q_{max}} + \frac{\tau_{50}}{Q_{max} \cdot (\tau - \tau_s)}, \quad (3)$$

where $\tau_{50}$ — release time of 50 % from $Q_{max}$; $\tau_s$ — duration of the induction period.

The heat release of cement depends on a host of factors, such as the phase composition, the amount of mixing water, storage and hardening conditions, etc. Another major factor is the surface condition of the cement grains and their size. Cement is known to have the highest chemical activity immediately following its manufacture and to decrease over time. In order to increase the reactivity of the binder, there are some methods of its activation, mechanical activation being the most common one [13]. During mechanical activation, a fresh, developed and chemically active particle surface is formed helping to increase thehydration reaction rate and change the nature of heat release.

The authors have developed a mechanically activated cement-sand composition (CSC) that has been proven to be efficient in the production of cement composites [14]. It is shown that the preliminary joint mechanical activation of the dry components (cement and sand) that constitute the concrete mixture increases the initial strength of the composite by more than 2 times, improves the rheological characteristics of the mixture and reduces the setting time. The heat release kinetics of components of cement composites modified by mechanical activation methods is insufficiently investigated and studying its changes is an urgent task.

The aim of the study is to investigate heat release of a mechanically activated cement-sand composition as well as to identify the parameters of the equations describing the heat release kinetics.

**Materials and Methods.** The investigated mechanically activated composition consists of cement and sand with a weight ratio of 1:2.14. In the experiments, Portland cement Eurozem 500 super, CEM I 42.5H manufactured by Petersburg Cement LLC, Russia was utilized. Construction sand, fractional composition: 70% is a fraction of 2.5–1.25 mm, 30% is a fraction of 0.63–0.315 mm. The mechanical activation was performed in a Retsch Emax laboratory ball mill designed for ultrafast and ultrafine grinding. The activation mode is 5 minutes long at a speed of 1000 rotations/min. The specific surface area of the mechanically activated composition is 3690.8 $cm^2/g$ [14].

As part of the study, a calorimetric analysis of the mechanically activated CSC was conducted in compliance with GOST 310.5-881[2]. This method enables us to investigate the kinetics of the cement hydration reaction by analyzing the hardening thermodynamics of the solution. In order to examine the processes of heat release, an 8-channel TAM Air isothermal calorimeter was used allowing analyzing the heat release of reactions in the isothermal mode, as well as the kinetics of exothermic and endothermic reactions. In the isothermal mode of operation of the device, the thermostat maintains a constant system temperature throughout the entire experiment with any thermal effects associated with a chemical or physical process in the sample being recorded. Isothermal measurements provide quantitative information reflecting the rates of the investigated processes.

All of the channels of the calorimeter are double, including a sample and a reference standard in 20 ml ampoules. The principle of operation of the calorimeter is to compare and then record the heat flow velocity of the test sample with a reference standard represented by an inert material. 6 grams of the investigated mechanically activated CSC and 3 grams of water were placed in each ampoule. Quartz sand was used as the reference standard with its mass calculated based on ensuring the equivalence of the heat capacity of the components of the investigated sample and the reference standard, and in this study it is 21 grams. The experiment was 120 hours long. The accuracy of the device temperature setting is ± 0.02 °C, the sensitivity limit is 4 μW, the error is ± 23 μW. The heat dissipation was investigated using 4 samples of a mechanically activated CSC, and the experimental results waswere statistically processed in order to adequately evaluate the resulting data.

[1] EN 1992-1-1 (2004) (English): Eurocode 2: Design of Concrete Structures — Part 1–1: General Rules and Rules for Buildings. European Committee for Standardization Edt; 2004. 227 p.

[2] GOST 310.5-88 "Cements. Method for determining heat dissipation": introduction. 01.01.1989. Moscow: Publishing House of Standards; 1988. 6 p.

Considering that in the investigated mechanically activated composition, it is only cement (as a reactant) that has heat generation when mixed with water, the obtained values of the integral heat generation of the mixture were recalculated by 1 gram of cement. In order to compare the processes taking place in the activated and non-activated system and to confirm the efficiency of mechanical activation relative to the rate of hydration reaction, a calorimetric analysis of untreated cement was also performed.

**Research Results**. The result of the calorimetric analysis of the investigated samples was a set of heat flow data that was used to obtain integral heat dissipation data, which is subject to further processing. As the most active heat release of the investigated systems takes place in the first 24 hours, the values of integral heat release were selected for further research in 2-hour increments on the first day, then in 12-hour increments at the age of 2–5 days. Table 1 shows the values of the integral heat release of the mechanically activated CSC ($Q$), the recalculated values of heat release per 1 g of cement ($Q_{отн.CEM}$) and the values of relative heat release obtained by dividing the values of heat release at time τ by the maximum value of heat release of cement at the age of 28 days ($Q/Q_{max}$). The value of the maximum heat release of cement CEM I 42.5N (M500) in compliance with SP 41.13330.20121 is $Q_{max}$ = 385 J/g (kJ/kg) SP 41.13330.2012[3] is $Q_{max}$ = 385 J/g (kJ/kg).

Table 1

Heat dissipation indicators of a mechanically activated CSC

| $\tau$, h | $Q$, J/g | $Q_{отн.CEM}$, J/g | $Q/Q_{max}$ | $\tau$, h | $Q$, J/g | $Q_{отн CEM.}$, J/g | $Q/Q_{max}$ |
|---|---|---|---|---|---|---|---|
| 2 | 0.951 | 2.988 | 0.008 | 22 | 49.511 | 155.465 | 0.404 |
| 4 | 2.976 | 9.346 | 0.024 | 24 | 51.834 | 162.758 | 0.423 |
| 6 | 7.246 | 22.752 | 0.059 | 36 | 62.415 | 195.984 | 0.509 |
| 8 | 13.692 | 42.993 | 0.112 | 48 | 69.605 | 218.560 | 0.568 |
| 10 | 20.969 | 65.843 | 0.171 | 60 | 74.738 | 234.677 | 0.610 |
| 12 | 28.257 | 88.728 | 0.230 | 72 | 78.786 | 247.387 | 0.643 |
| 14 | 34.909 | 109.613 | 0.285 | 84 | 82.000 | 257.481 | 0.669 |
| 16 | 39.881 | 125.226 | 0.325 | 96 | 84.320 | 264.763 | 0.688 |
| 18 | 43.712 | 137.257 | 0.357 | 108 | 85.911 | 269.761 | 0.701 |
| 20 | 46.847 | 147.100 | 0.382 | 120 | 87.000 | 273.180 | 0.710 |

The values of the integral heat dissipation of the activated CSC represent the average values for 4 samples. Integral heat dissipation data was statistically processed for each time point, the average values of statistical indicators for the entire array of processed data are: standard deviation of the arithmetic mean $m$ = 0.29; accuracy index $\varepsilon$ = 0.59%; coefficient of variation $V_c$ = 1.18%.

In order to determine the nature of the thermicity of the activated cement-sand composition, the values of integral heat generation at the age of 3 and 7 days were identified. Heat dissipation at the age of 3 days was 247 J/g, the value at the age of 7 days was obtained by means of extrapolation and amounted to 281 J/g. According to GOST 23464-79[4] , low-thermal cements include cements with heat release up to 230 and 270 kJ/kg in 3 and 7 days, respectively, and moderate-thermal cements — up to 315 kJ/kg in 7 days [7]. Hence the cement in the composition of the mechanically activated cement-sand composition is moderately thermal.

Table 2 shows the values of the integral heat release of inactive cement and those of the relative heat release.



[3] SP 41.13330.2012 "Concrete and Reinforced Concrete Constructions of Hydraulic Structures": introduced on 01.01.2013. Moscow: Ministry of Regional Development of the Russian Federation; 2012. 72 p.

[4] GOST 23464-79 "Cements. Classification": introduced on 01.07.1979. Moscow: Standardization Publishing House; 1985. 11 p.

Table 2

Indicators of heat release of cement CEM I 42,5N

| $\tau$, h | $Q$, J/g | $Q/Q_{max}$ | $\tau$, h | $Q$, J/g | $Q/Q_{max}$ |
|---|---|---|---|---|---|
| 2 | 1.328 | 0.003 | 22 | 107.582 | 0.279 |
| 4 | 4.829 | 0.013 | 24 | 116.539 | 0.303 |
| 6 | 10.538 | 0.027 | 36 | 153.226 | 0.398 |
| 8 | 19.580 | 0.051 | 48 | 175.406 | 0.456 |
| 10 | 31.527 | 0.082 | 60 | 191.484 | 0.497 |
| 12 | 43.570 | 0.113 | 72 | 201.146 | 0.522 |
| 14 | 57.606 | 0.150 | 84 | 206.723 | 0.537 |
| 16 | 71.197 | 0.185 | 96 | 211.234 | 0.549 |
| 18 | 83.883 | 0.218 | 108 | 214.707 | 0.558 |
| 20 | 95.495 | 0.248 | 120 | 217.540 | 0.565 |

The values of the integral heat release of the inactive cement represent the average values for 5 samples. Integral heat dissipation data was statistically processed for each time point, the average values of statistical indicators for the entire array of processed data are: the standard error of the arithmetic mean $m$ = 1.55; the accuracy index $\varepsilon$ = 2.30%; the coefficient of variation $V_c$ = 4.29%.

Fig. 1 shows graphs of the heat release kinetics of a mechanically activated cement-sand composition (activated CSC) and non-activated cement (CEM I 42.5N). The integral heat release curves obtained experimentally and the theoretical values obtained by means of calculation using the equations of function (1), (2), (3) are shown.

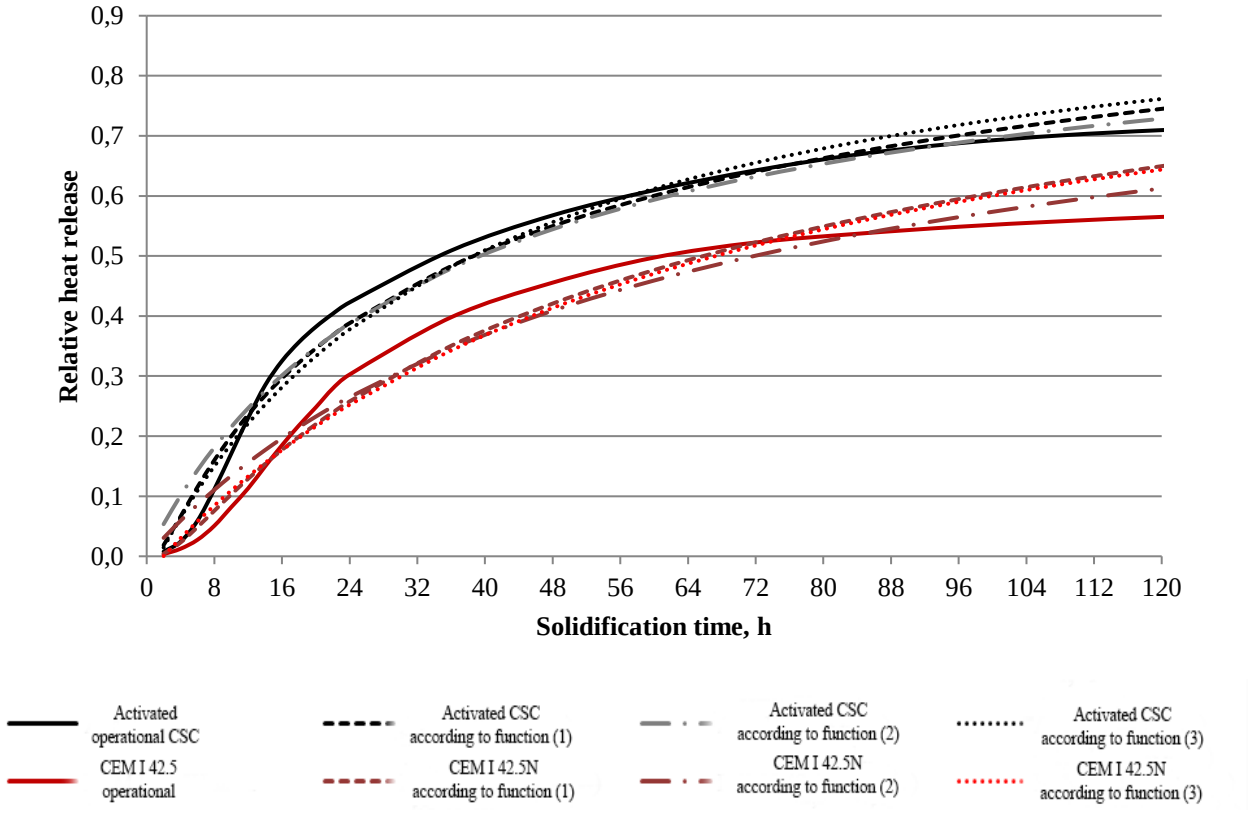


Fig. 1. Experimental and calculated relative heat releases of mechanically activated CSC and inactive cement

Parameters of the equations of functions (1), (2), (3) for the results shown in Fig. 1 are in Table 3 which also provides a comparison of the obtained parameter values with other researchers' data.

Table 3

Parameters of the equations of the heat release kinetics

| Equation | $\frac{Q_\tau}{Q_{max}} = \exp(k \cdot (1 - \left(\frac{28}{\tau}\right)^d)$ | | $\frac{Q_\tau}{Q_{max}} = 1-(1 + A \cdot \tau)^{-n}$ | | $\frac{1}{Q_\tau} = \frac{1}{Q_{max}} + \frac{\tau_{50}}{Q_{max} \cdot (\tau - \tau_s)}$ | |
|---|---|---|---|---|---|---|
| Designation | function (1) | | function (2) | | function (3) | |
| Parameter | $k$ | $d$ | $A$ | $n$ | $\tau_{50}$ | $\tau_s$ |
| Calculated for activated CSC | 0.20 | 0.52 | 0.037 | 0.77 | 37.13 | 1.45 |
| Calculated for CEM I 42,5N | 0.32 | 0.5* | 0.018 | 0.83* | 65.30 | 1.97 |
| G.V. Nesvetaev et al., for CEM I 42,5N [6, 15] | 0.16–0.21 | 0.46–0.51 | 0.022 | 1.55 | 44.5 | 6 |

*The parameter is taken as [16]

According to the data, the value of the induction period for the activated cement-sand composition is $\tau_s$ = 1.45 hours. The estimated time of the induction period for the inactive cement was 1.97 hours. The end of the induction period of the activated composition occurs 1.34 times faster relative to the inactive cement.

The obtained parameter $\tau_{50}$ of the mechanically activated composition for equation (3) is 37.13 hours, which correlates with the experimental value of the time to achieve 50% heat release, which, according to experimental data, is 34.45 hours, the discrepancy between the results is 2.68 hours or 7.2%. The cement parameter $\tau_{50}$ for equation (3) is 65.30 hours, which also correlates with the experimental value, which is 61.59 hours, the discrepancy between the results is 3.71 hours or 5.7%. The time to reach 50% of the heat dissipation value for the activated composition is reduced by 1.76 and 1.79 times for the calculated and experimental values, respectively. Hence the efficiency of mechanical activation of cement is confirmed in relation to reducing the induction period and earlier start of the structure formation of a cement composite modified by means of mechanical activation of the components.

**Discussion and Conclusion.** As a result of the study, the values of integral heat generation for a mechanically activated cement-sand composition were obtained. It was found that the cement in the mechanically activated composition is moderately thermal in terms of heat release, with heat release values of 247 J/g and 281 J/g at the age of 3 and 7 days, respectively. The parameters of the equations describing the heat release kinetics are obtained. The values of the duration of the induction period for the mechanically activated composition (1.45 hours) and the inactive cement (1.97 hours) were identified. The time to reach 50% of the maximum heat release value of cement for the activated composition is 34–37 hours, while for the non-activated cement it is 61–65 hours.

The data obtained in the course of the study confirm the efficiency of mechanical activation of the initial dry components of concrete in terms of assessing the heat release kinetics and changes in the nature of thermality. When the cement-sand composition is mechanically activated, the time of the induction period and the time to reach 50% of the maximum heat release of the binder are reduced by 1.34 times and 1.76–1.79 times, respectively, indicating the efficiency of using the mechanically activated cement-sand composition as an additive in concrete. The results can be practically applied in plants for producing dry building mixtures and concretes while introducing the technology of mechanical activation of the components.

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# BUILDING MATERIALS AND PRODUCTS
# СТРОИТЕЛЬНЫЕ МАТЕРИАЛЫ И ИЗДЕЛИЯ





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*Original Empirical Research*

EDN: EYPYUM

## Decoration of the Front Ceramic Brick by the Method of Engobing

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**Abstract**

***Introduction.*** The ceramic face brick, which comes with a range of surfaces, shapes and color palettes, is highly sought in the Russian construction market. Engobing is an effective method of color decoration of ceramic bricks, however, an individual selection of an engobe composition for each type of product in a factory setting is critical considering a raw material base used, production modes and a necessary aesthetic solution. In the context of import substitution, the issue of replacing European manufacturers of decorative coatings and organizing the manufacturing of engobes at Russian enterprises has gained relevance. The aim of the study is a comprehensive investigation of the engobing method in order to obtain face bricks with high aesthetic characteristics, stable performance and its introduction into production in view of the domestic construction market.

***Materials and Methods.*** For the experiments, two types of 1NF face bricks with a smooth surface were selected as the basic products for applying an angular layer: red and brown one produced by means of the plastic molding technology. The compositions of engobes for decoration were developed using frit from the Dulevsky Paint Factory in three main colors: white-beige, brown and graphite. Laboratory studies of engobe coatings, semi-industrial tests of compositions with various options for applying to bricks, as well as of the properties of finished products were performed as part of the research.

***Research Results.*** As a result, 8 compositions of engobes were developed and approved that after burning provided a defect-free and durable coating of the spoon and poke surfaces of the bricks, and methods of applying engobes were set forth for aesthetic expressiveness of the product itself as well as the brickwork.

***Discussion and Conclusion.*** One of the brick factories in the south of Russia was tasked with developing non-ferrous cast compositions considering studies and analysis of global trends in brick design and consumer demand as well as with decorating ceramic face bricks in production conditions. These experiments were successfully implemented in production, which boosted the volume of products sold in the construction market of the south of the Russian Federation, expanded architectural and design possibilities for new planning solutions. The results obtained in the field of brick color decoration are in alignment with the factory parameters, marketing goals as well as economically profitable allowing for expansion of the range of manufactured and sought products in the domestic construction market.

**Keywords:** brick, engobe, composition, angobirovanie, production technology, color, shade, surface, decorative masonry

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*Оригинальное эмпирическое исследование*

## Декорирование лицевого керамического кирпича методом ангобирования

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**Аннотация**

***Введение.*** Лицевой керамический кирпич, имеющий варианты разных поверхностей, форм и цветовой палитры в настоящее время очень востребован на строительном рынке России. Ангобирование является эффективным

методом цветного декорирования керамического кирпича, однако необходим индивидуальный подбор ангобного состава для каждого вида изделий на заводе с учетом используемой сырьевой базы, производственных режимов и необходимого эстетического решения. В условиях импортозамещения важным стал вопрос замены европейских производителей декоративных покрытий и организации производства ангобов на российских предприятиях. Целью работы является комплексное исследование метода ангобирования, направленное на получение лицевого кирпича с высокими эстетическими показателями, устойчивыми эксплуатационными качествами и внедрение его в производство с учетом отечественного строительного рынка сбыта.

***Материалы и методы***. Для проведения экспериментов в качестве базовой продукции для нанесения ангобного слоя выбраны два вида лицевого кирпича формата 1 НФ с гладкой поверхностью: красный и коричневый, производимые по технологии пластического формования. Составы ангобов для декорирования были разработаны на основе фритт «Дулевского красочного завода» в трех основных цветах: бело-бежевый, коричневый и графитовый. В ходе работы были проведены лабораторные исследования ангобных покрытий, полупромышленные испытания составов с различными вариантами нанесения на кирпич, а также исследования свойств готовой продукции.

***Результаты исследования.*** В результате было разработано и утверждено 8 составов ангобов, которые после обжига обеспечивали бездефектное и прочное покрытие ложковой и тычковой поверхностей кирпича, предложены способы нанесения ангобов для достижения эстетической выразительности как самого изделия, так и кирпичной кладки.

***Обсуждение и заключение.*** В рамках проведенной работы с одним из кирпичных заводов юга России была поставлена задача по разработке составов цветных ангобов с учетом изучения и анализа мировых тенденций в области брик-дизайна и потребительского спроса, и проведению работ по декорированию лицевого керамического кирпича в условиях производства. Данные экспериментов успешно внедрены в производство, что значительно увеличило объем продаваемой продукции на строительном рынке юга Российской Федерации, расширило архитектурно-дизайнерские возможности для новых планировочных решений. Полученные результаты в области цветового декорирования кирпича полностью соответствуют заводским параметрам, маркетинговым задачам, экономически выгодны и позволяют расширить ассортимент производимой и востребованной продукции на отечественном строительном рынке.

***Ключевые слова:*** кирпич, ангоб, состав, ангобирование, технология производства, цвет, оттенок, поверхность, декоративная кладка

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**Introduction.** Brick has been the major building material for many centuries. Its technical and aesthetic characteristics enable architects to convey a range of architectural forms: from simple cube-shaped buildings to those with a changeable facade line. The face brick is employed as a durable structural material with high decorative properties. Its variety of shapes, sizes, colors and textured surfaces allows a unique facade decor to be designed. Even the smooth facade lined with bricks of not the traditional red brick color, but, e.g., with shades of beige or dark gray, already contributes to making the building distinct and stand out. The choice of color is also impacted by the global architectural trends, offering colors, shades, textured "drawings" and their combinations. Let us not forget about the general psychological component of the architectural and spatial environment. Modern urban culture is increasingly lifting people up from the ground: both in terms of number of floors and landscaping [1]. An architect's task used to be fitting the building into the landscape and making it comfortable, whereas there is now a desire to recreate "green" areas in the urban environment, to create environmentally friendly solutions (even the "green architecture" style has emerged) and restore natural harmony by means of color [2].

Since ancient times, color has been given prominence in architecture. The ancient Egyptian and Greek temples, which have been preserved in the color of gray stone or sandstone, were bright and colorful in their authentic form. Facades and architectural decor were covered with murals, stone of a range of colors and shades as well as ceramic cladding were masterfully employed in building decoration. If the color of the stone is inherent in nature, ceramic products were given a stable color by means of different decoration methods: mass staining, gluing, glazing, shotcrete, etc.

Engobing is the oldest way of color-coding the surface of a ceramic product. Engobe is a clay suspension applied in a thin layer to a raw, leathery, or baked product with further burning. It is an excellent coating layer that smooths out surface irregularities lending the product color and texture.

The term "engobe" comes from the French "engobe", from the Italian "ingobbio" meaning "surfacing" or "coating". The ancient masters of Mesopotamia, Egypt, China, Greece and Rome commoly made use of engobe for painting ceramic dishes, sculpture and ceramic architectural decoration (Fig. 1). Engobe as an archaic natural clay-based paint has been used to decorate adobe houses in West Africa (Fig. 2). By adding kaolin, charcoal, or crushed multicolored stone to the angob, Yoruba women paint the walls with sacred patterns of white, black, brown, or ochre [3–5].

Fig. 1. Decorative elements of the roof — antefixes of Maenad and Silenus, Cerveteri, IV century B.C.

Fig. 2. Painted huts of the village of Tibele, Burkina Faso, XXI century

Since antiquity, ceramic bricks, tiles and other architectural ceramics have been covered with colored engobe. White engobe was typically used as a substrate for further painting or glaze coating. Against a white background, all the colors show their full brightness.

According to their composition, engobes are divided into clay-sand, flux and antique varnishes. In manufacturing ceramic products for architectural and construction purposes, a flux angus is used. A glass bead (5–20% of the total weight of the bead) or a colorless glaze is commonly used as a flux. The flux lends a stable, non-fading saturated color to products, improves the adhesion of an engobe layer to the shard and reduces the water permeability of a product. In order to improve the quality of the engobe, frit is added, sometimes up to 50% of the total weight of the angoba. Frit is a granular glass mass obtained by fusing a charge followed by a sharp cooling of the hot glass mass.

It is critical to match the raw materials of engobe and brick so that there are no defects in the form of peeling, caulk, discoloration. The quality of bricks with an engobated coating is also impacted by whether engobe is correctly applied, the thickness of the layer (no more than 0.2 mm), the angle of inclination while spraying the composition, compliance with a drying and burning regime[1] [6].

The color of the building material is a major component in architectural and construction design. Ceramic materials have a long-lasting color coating due to a manufacturing and decoration technology with further color-fixing burning. The choice of color for decoration and coating schemes depends on consumers' demand, marketing research and recommendations, fashion trends and definitely the technical capabilities of an enterprise interacting with scientific teams in the field of modern ceramics [7, 8].

The major suppliers of engobes and glazes for the Russian ceramic industry were enterprises from Italy and Spain, however, due to the sanctions, they were forced to reduce supplies resulting manufacturers of ceramics, mostly of bricks, facing the problem of a lack of high-quality engobe compounds on the market causing a reduction in the product range and the task of developing their own formulations based on available raw materials being set. In order to address the problem, it was necessary to develop scientifically solid recommendations on compositions of engobes, burning modes, and the use of engobing technology in order to modify the appearance of bricks, improve their technical and operational characteristics in order to further expand the range and increase the competitiveness of manufactured brick products.

The staff of the Department of "Building Materials" of DSTU with many years of experience in the field of scientific research for the ceramic industry, the development of coating compositions for ceramic tiles, bricks and tiles along with top enterprise for ceramic bricks production under their belt, carried out scientific and production experiments to solve the urgent problem of manufacturing engobes and methods of their application. The existing formulations of engobe coatings and their component composition were systematized, the optimal parameters of the technological process (the



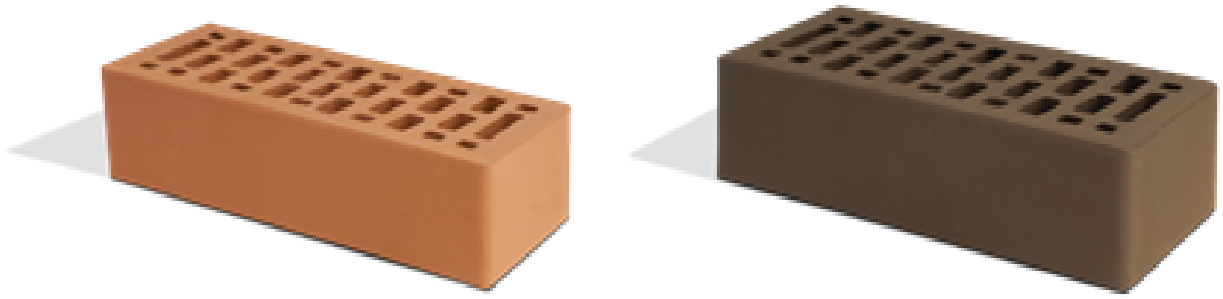
[1] Zakharov AI *Fundamentals of Ceramics Technology: a Textbook.* Moscow: Russian Chemical Technology. D.I. Mendeleev University; 2001. 79 p.

method of applying an engobe, the drying and burning mode) were identified, the decorative and protective possibilities of engobing were examined, and a comparative analysis of the economic efficiency of the engobing method was performed considering environmental safety in modern production conditions.

The color trend in Pantone's architectural design in 2024 was graphite gray, white, and peach. Dark grey and white are currently relevant and sought as well as highly popular colors widely used in exterior and interior design. In 2025, according to the Pantone Color Institute, Mocha Mousse, a light brown or chocolate—brown color that embodies natural harmony, is trending. It was exactly the shades of these colors that we set forth to develop for decorative decoration of the front brick.

**Materials and Methods.** Two types of 1NF format products with a smooth surface were selected as the face brick for engobing: red and brown one produced using plastic molding technology followed by drying and burning (Fig. 3). The brick in its appearance and physical and mechanical characteristics is in compliance with the requirements of GOST 530-2012 "Ceramic Bricks and Stones. General Technical Conditions" for face bricks: strength grade M150; frost resistance grade F75; water absorption of at least 5% and no more than 10%; initial water absorption rate is 0.90–1.35 kg/($m^2$·min). The brick is hollow, the voidness is 40%, it has 3 front surfaces: 1 spoon and 2 pokes, with a chamfer.

The engobing process consists of applying a thin colored front angob layer to a freshly formed or dried brick with an airbrush enhancing or masking the structure and color of the shard after burning.



*a)* *b)*

Fig. 3. Ceramic face brick approved for operation: *a* — 1 NF red smooth; *b* — 1 NF brown smooth

While developing engobe compositions for a specific ceramic mass, the following factors are considered:

– desired decorative effect (color, shade, volume, etc.);

– coefficient of linear thermal expansion of the shard (CLTE);

– technological modes and capacities of the production line;

– economic factors.

As arranged with the manufacturer, the major task was to develop engobe coatings of a specific color palette: white, beige, brown, dark gray and achieve the effect of degradation (transition from a light to a dark shade) on the front surface of the brick, as well as to develop schemes of Bavarian decorative masonry (multiclaying) with the obtained color options.

The compositions of engobes for decorating white-beige, brown and dark gray colors were developed based on the frit from the Dulevsky Paint Factory using microcline, colemanite, zinc oxide, kaolin, clays from JSC Vladimirovsky Quarry of Refractory Clays of grades HCN and VKS, very fine quartz sand of Class I, barium carbonate and ceramic pigments.

The method of airbrushing was chosen as for applying engobes to the brick surface. For a decorative degrade effect, light shades of an engobe coating are applied to the brick that subsequently gradually overlap with the dark ones. It is necessary that the front surface of the brick has a color stretch from a light to a dark shade. Such a smooth color transition can be expressed horizontally, vertically or diagonally on the painted front surface.

The plan of the research at the first stage was to develop the engobic compounds in the laboratory and test them on tile samples made from the molding masses of the factory. The drying and burning modes in the laboratory were as close as possible to the technological ones. The second stage was engobing in the laboratory followed by burning in a laboratory furnace of the bricks selected after drying on the line, and testing it. At the third stage, the brick was tested in production conditions with an expert assessment and approval of the appearance as well as a set of physical and mechanical tests for all the indicators in compliance with the requirements of GOST 530-2012. Masonry schemes were developed and set forth for the approved variants of the engobed face brick.

**Research Results.** According to the technical and economic indicators, flux brackets are the most suitable coatings for ceramic bricks considering a single burning. According to the technical specification, the main color palette of bricks should be from white-beige to dark brown and graphite, and there should also be color "stretches" from light to dark shades. The face brick must have 2 front engobed surfaces — 1 spoon and 1 poke.

Based on the investigated and selected raw materials, the compositions of flux engobes were developed as shown in Table 1.

Table 1

Laboratory compositions of fluxic engobes

| Engobe code | Color | Composition, % by weight per dry substance |
|---|---|---|
| B-0 | White | Frit — 30, microcline — 20, colemanite — 10, kaolin — 20, HCN — 10, $TiO_2$ — 10 |
| B-1 | Beige | Frit — 30, microcline — 20, colemanite — 10, $BaCO_3$ — 5, ZnO — 5, kaolin — 20, HCN — 10 |
| B-2 | Beige 1 | Frit — 30, microcline — 20, colemanite — 10, burnt kaolin — 25, HCN — 15 |
| K-1 | Brown Chestnut | Frit — 30, microcline — 20, colemanite — 10, $BaCO_3$ — 5, ZnO — 5, kaolin — 10, HCN — 10, red iron oxide pigment — 10 |
| K-2 | Brown Chocolate | Frit — 30, microcline — 20, colemanite — 10, $BaCO_3$ — 5, ZnO — 5, kaolin — 10, HCN — 10, red iron brown pigment — 10 |
| K-3 | Brown Terracotta | Frit — 30, microcline — 20, colemanite — 10, $BaCO_3$ — 5, ZnO — 5, kaolin — 10, HCN — 10, $Mn_3O_4$ — 10 |
| K-4 | Brown Cinnamon | Frit — 30, microcline — 20, colemanite — 10, $BaCO_3$ — 5, ZnO — 5, kaolin — 10, HCN — 10, iron scale — 10 |

The engobe compounds were applied by airbrushing to the dried product. The thickness of the angular layer was 0.5–1 mm. A layer which is too thick might cause the engobe to peel off during burning. It is important to keep a watchful eye on the pneumatic spray gun so that the head does not clog, the spray gun itself must be kept at a distance of 25–30 cm from the brick. In laboratory conditions, when applied to tile samples and to bricks, the developed compositions were in agreement with the declared parameters in terms of color solutions and the quality of the front surface.

In production conditions, after decoration, the bricks were moved to a tunnel kiln for burning at a maximum temperature of 940°C (Fig. 4). After burning, the investigated bricks were sent for visual inspection in order to analyze the result. The engobe compounds B-0, B-2, K-3 and K-4 performed well on the brick and distributed evenly, there was no technological defect on the surface, and the color corresponded to the identified technical specifications. The engobe compositions B-1, K-1 and K-2 did not match the color scheme, this decorative layer was not concealable and not sufficiently baked. Hence technological defects and fingerprints were found on the front surface of the bricks.

The production experiment showed that due to the difference in the cross-section of the furnace, for the brick surface to be concealed better, it is necessary to increase the burning temperature to 970°C or adjust the compositions. Analyzing the data and carrying out a technical and economic calculation, it was decided to adjust the compositions B-1, K-1 and K-2 and develop an additional graphite-colored engobe composition (Table 2).

For the second stage of the factory testing, it was decided to reapply the B-0, B-2, K-3 and K-4 engobe compounds and the newly developed B-1, K-1, K-2 and G-1 compositions. The decorative compositions were also applied by means of airbrushing. The decoration of the brick, depending on the planned decorative effect, was complete or partial, one or two faces were covered, and there was also an angled or straight color filling.

Fig. 4. Engobing by means of airbrushing in the factory setting

Table 2

Engobe correction compositions

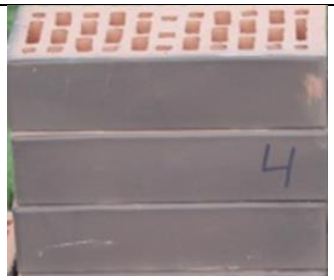
| Engobe code | Color | Composition, % by weight per dry substance |
|---|---|---|
| B-1 | Beige | Frit — 40, microcline — 15, colemanite — 10, HCN-2 — 15, ZnO — 5, kaolin — 20, TiO — 10, glue — 1 |
| K-1 | Brown Chestnut | Frit — 45, microcline — 10, colemanite — 15, VKS — 20, coloring pigment — 10, glue — 1 |
| K-2 | Brown Chocolate | Frit — 40, microcline — 15, colemanite — 10, VKS — 20, coloring pigment — 10, glue — 1 |
| G-1 | Dark grey Graphite | Frit — 40, microcline — 10, colemanite — 10, VKS — 15, copper oxide — 15, iron scale — 5, iron oxide — 5, glue — 1 |

Burning was in a factory furnace at a temperature of 940–950 °C. After burning, the engobed bricks were sent for visual inspection. Table 3 shows the main conclusions made following the semi-factory tests.

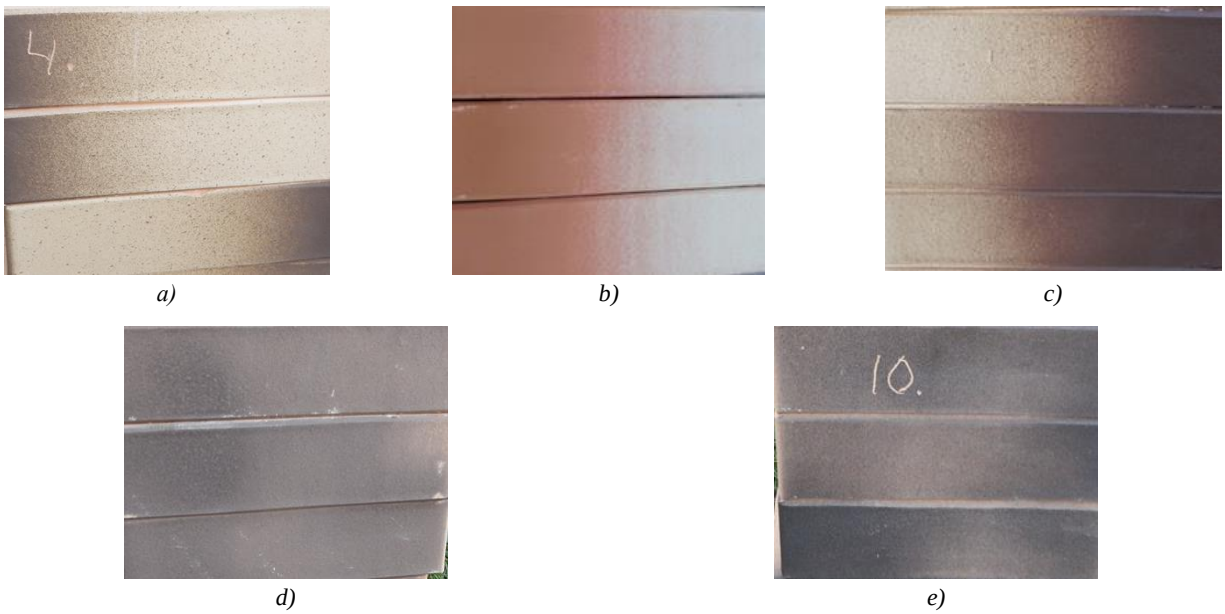
Table 3

Results of the second stage of the semi-factory tests

| Engobe code | Color | Photo of an engobed brick | Result of the factory tests |
|---|---|---|---|
| B-0 | White |  | Uneven layer, there is a factory defect (chips, scuffs), the color corresponds to the planned tone, not suitable for a solid coating, can be used for color transitions as an additional color. |

| Engobe code | Color | Photo of an engobed brick | Result of the factory tests |
|---|---|---|---|
| B-1 | Beige |  | A smooth, concealable engobe layer, the color corresponds to the planned tone, and there is no factory defect on the surface |
| B-2 | Beige with a yellow shade Beige 1 |  | A smooth, concealable engobe layer, the color corresponds to the planned tone (there is a yellow shade), there is no factory defect on the surface |
| K-1 | Brown Chestnut |  | A smooth, concealable engobe layer, the color corresponds to the planned tone (brown), there is no factory defect on the surface |
| K-2 | Brown Chocolate |  | An even, sheltering engobe layer, the color corresponds to the planned tone (brown, dark brown), there are areas of the non-baked engobe layer, but these areas are not visible at a distance of 1 meter and do not impact the durability of the layer |
| K-3 | Brown Terracotta |  | A smooth, concealable engobe layer, the color corresponds to the planned tone (red-brown), there is no factory defect on the surface |
| K-4 | Brown Cinnamon |  | A smooth, concealable engobe layer, the color corresponds to the planned tone |
| G-1 | Dark gray Graphite |  | A smooth, concealable engobe layer, the color corresponds to the planned tone (dark gray) |

By combining the developed angobic compounds, a range variety of color solutions is obtained. While decorating bricks, it is important to have prior understanding of the scheme of applying the engobe to the front surface. Fig. 5 shows the options for combining angobic compounds to achieve a degrade effect on the front surface of the brick.




*a)* *b)* *c)* *d)* *e)*

Fig. 5. Brick decoration options with the degrade effect based on the developed engobe compositions: *a* — B-0 + K-1; *b* — *B*-1 + color of the burned brick; *c* — B-2 + K-3; *d* — K-1 + K-2; *e* — K-2+G-1

The next step was to develop decorative masonry schemes made of the engobed bricks based on Bavarian masonry, which seems reasonable in terms of combinatorics and design. It is possible to achieve the effect of Bavarian masonry using degrade-colored bricks by combining bricks of the same color or different ones by laying them in a few ways: by connecting spoons of the same shade, alternating light and dark shades. Using a range of decorative masonry (chain, Old Russian, Flemish, cross, etc.), it is possible to increase the variants of combinatorial solutions. Only one spoon-shaped masonry with an offset of ½ brick was examined.

Bavarian brickwork is a special type of decorative masonry based on the principle of chaotic combination of several shades of the same color. In this case, the main tone should be about half of the scheme, and auxiliary colors are used for the remainder of the styling. There should be no separate dark and light spots in the facade cladding, they should alternate instead creating smooth transitions of color shades throughout the facade with no crowding of one color to emphasize the overall harmony of the front masonry and fit it into the architectural space. Bricks of the same shade should not be replicated in the masonry, but alternate with the other shades, thus generating a feeling of chaotic, "spontaneous" facade masonry or look like arbitrary color spots [9, 10].

Taking into account the principles of "Bavarian" masonry and the resulting color palette in the form of angob compounds, Figure 6 shows the developed masonry using angobated ceramic bricks with the degrade effect. As can be seen from Fig. 6, the main color in this "Bavarian" masonry is red-brown (K-3), and the auxiliary color is graphite (G-1). The main task in the development of this masonry is not to overload the future facade. The combination of dark brown and red-brown appears to be interesting in its decorative characteristics, but it might be difficult to take in a complete facade. Therefore, it was decided to develop a "lighter" color version of the "Bavarian" masonry (Fig. 7).

Fig. 6. Bavarian masonry using the engobated ceramic bricks (acid composition G-1, K-3 + the color of the baked brick)

Fig. 7. Bavarian masonry using the engobated ceramic bricks (similar composition of K-2, K-3 + own brick color)

As can be seen in Fig. 7, the combined bricks are half decorated with an engobe coating — there is a rich brown color to the edge of the brick, and the main shade remains "natural". This color technique is attained by means of the airbrushing technique of applying an engobe. As can be seen, there are already three shades where the main color is the one of the baked clay itself, and the auxiliary engobe layers are K-2 and K-3.

Interesting color transitions can be attained using the degrade effect in the masonry itself, where bricks with the same coating effect alternate. Fig. 8 and 9 show the color transitions from dark brown to beige and from brown to light beige. In the masonry in Fig. 8, the color decoration of the brick itself can be observed, where there is a different intensity of brown color in filling the front side of the brick, which lends the masonry a unique character.

Fig. 8. Decorative bricklaying using the degrade effect (B-3, K-2, K-4 engobe compositions)

Fig. 9. Decorative bricklaying using the degrade effect (engobe compositions B-2, K-4)

Based on Fig. 9, the main color in the developed masonry is beige (B-2), the additional one is brown (K-4). As can be seen, brown is not intense in terms of tone saturation, thereby it does not overload the masonry.

Fig. 10 shows the Zebra decorative masonry on contrasting solutions, where beige is the main color, while dark brown and graphite are auxiliary ones. However, due of the richness of dark brown and the layout of the pattern, it draws attention to itself, thereby emphasizing the pattern of the masonry.

Fig. 10. Decorative bricklaying (engobe compositions B-2, K-4 and G-1)

There can be an infinite number of color variaties of artistic brickwork, the main thing is to stay on top of the latest global trends and accommodate consumers' needs, or to create and promote new trends in the brick market of southern Russia.

**Discussion and Conclusion.** Ceramic bricks have been and still are a high-quality, durable, environmentally friendly and aesthetically attractive building material with a steady demand in the construction market. It is ceramic bricks that can be as changeable as they are traditional. This shows in the aesthetic appearance of the brick and its price. Brick decoration is a relevant task, as brick is no longer only a structural material, but has been promoted into the category of elite building materials with a wide range of possibilities in the field of color and textured surface design. A brick design direction has been formed to identify new and expand the traditional aesthetic possibilities of ceramic bricks [11, 12]. The active development of the ceramic industry in the Russian Federation calls for a joint coordinated effort of managers and technologists of enterprises with scientific organizations, marketers and distributors. Such a professional tandem will make it possible to release successful brick collections, be ahead of the latest trends in brick design and timely prepare raw materials and technological equipment for production of face bricks with specific aesthetic characteristics. Using the example of our team's work on introducing engobed bricks into a technological process of an operating enterprise, the consistency and effectiveness of the chosen schemes, laboratory and semi-factory testing methods considering financial capacities of an enterprise have been proven. The results have been implemented, the company has been able to launch the production of engobed bricks and has formed a new stable cluster for producing decorative face bricks with specific aesthetic characteristics in the southern Russian market.

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**YuV Terekhina:** analysis of domestic and foreign experience in the production of facing bricks considering the features of decoration and marketing trends, the formation and design of the references.

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# URBAN PLANNING, PLANNING OF RURAL SETTLEMENTS

# ГРАДОСТРОИТЕЛЬСТВО, ПЛАНИРОВКА СЕЛЬСКИХ НАСЕЛЕННЫХ ПУНКТОВ





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## Legal Problems of Reconstruction and Redevelopment of Premises

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**Abstract**

***Introduction.*** The article examines the issues related to the amendments to the housing legislation that came into force on April 1, 2024 regarding regulating relations for reconstruction and redevelopment of premises in apartment buildings. The topic is relevant as the changes made in scientific and educational literature have not been properly comprehended. The aims of the work include the analysis of legislative innovations and development of proposals for improving the standards of the Housing Code of the Russian Federation.

***Materials and Methods.*** The object of the research is the legal institute of reconstruction and redevelopment, its relationship with reconstruction and with the system of technological inventory of the housing stock. The following methods are used: general scientific (dialectical materialistic), specific scientific (logical (analysis, synthesis), concrete historical, systematic method) and other scientific discovery methods.

***Research Results.*** The paper sets forth specific proposals for changing the standards of the housing and communal services of the Russian Federation in order to eliminate the problems of legal regulation of reconstruction and redevelopment.

***Discussion and Conclusion.*** The results of the study hold a promise of being implemented into the current housing legislation and enable us to improve the mechanism of legal regulation of reconstruction and redevelopment.

**Keywords:** reconstruction, redevelopment, reconstruction, technological inventory, housing stock

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*Оригинальное эмпирическое исследование*

## Правовые проблемы переустройства и перепланировки помещений

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**Аннотация**

***Введение.*** В статье рассматривается проблематика вступивших в силу с 01.04.2024 года изменений жилищного законодательства в части регулирования отношений по переустройству и перепланировке помещений в многоквартирных домах. Значимость темы обусловлена недостаточным уровнем осмысления внесенных изменений в научной и учебной литературе. В числе целей работы — анализ законодательных новелл и выработка предложений по совершенствованию норм Жилищного кодекса Российской Федерации.

***Материалы и методы***. Объект исследования — правовой институт переустройства и перепланировки, его соотношение с реконструкцией и связь с системой технического учета жилищного фонда. Используются: общенаучные (диалектико-материалистический), частно-научные (логические (анализ, синтез), конкретно-исторический, системный метод) и другие методы научного познания.
***Результаты исследования*.** В работе сформулированы конкретные предложения по изменению норм ЖК РФ, направленные на устранение проблем правового регулирования переустройства и планировки.
***Обсуждение и заключение.*** Результаты, полученные в ходе исследования, имеют перспективу имплементации в действующее жилищное законодательство и позволяют усовершенствовать механизм правового регулирования отношений по переустройству и перепланировке.

**Ключевые слова:** переустройство, перепланировка, реконструкция, технический учет, жилищный фонд

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**Introduction.** New additions to the housing legislation regarding reconstruction and redevelopment of premises that came into force on April 1, 2024, have not been comprehended by scholarly community: at least anyone with an interest in the topic searching the Internet for relevant publications fails to get any satisfactory results. One explanation from the Federal Registration Service (Rosreestr), a couple of reviews in the reference legal systems and a summary of the adopted changes on the websites of regional prosecutors' offices are probably the only available reading a year following the introduction of the norms of interest.

The relevance of the topic is also due to the almost complete absence of the latest publications on state technological inventory of the housing stock. However, it must be noted that this is for a reason as how is one supposed to write about something that is no longer there? At the same time, the concept of "technological passport of a premises" is still to be found more than once in the text of Chapter 4 of the Housing Code of the Russian Federation (hereinafter referred to as the HC of the RF)[1], and "accounting of the housing stock", "state accounting of housing stock" also including technological inventory and certification are part of housing relations as a subject of housing legislation (Paragraph 5 of Artice 4(1); Artice 9(5) of the HC of the RF).

The analysis of the new additions to the legal regulation regarding reconstruction and redevelopment is inseparable from the study of the current state of the state inventory of the housing stock. This will allow us to arrive at conclusions that will hopefully be instrumental to the law enforcement officer, but more so to the legislator, if, of course, they find it necessary to make use of these.

**Materials and Methods.** The methods to be used are conventional for the humanities. Along with the basic general scientific dialectical materialistic method, which involves the study of a phenomenon in its constant evolution, logical methods will be extensively used in the research, i.e., a system of techniques that are a comprehensive objective reality and explore its internal structural relationships: analysis and synthesis, induction and deduction. Such techniques as classification, generalization, analogy, and comparison play a major role in the system of applied logical methods (particularly while considering the differences between redevelopment and reconstruction). The comparison method will help us to identify the distinctive features of the legal regulation of relations on reconstruction and redevelopment before and after the changes to the HC of the RF. Using the historical and legal method, the problems of state accounting of the housing stock and the system of technological inventory will be examined.

In our case, the modeling method will be employed to design the most viable ways to resolve situations that are frequent in practice and require simplification and removal of unnecessary legal restrictions. The study is structured as

[1] *Housing Code of the Russian Federation.* Code of the Russian Federation № 188-FZ from 29.12.2004. URL: http://pravo.gov.ru/proxy/ips/?docbody=&nd=102090645 (accessed: 10.03.2025).

follows: first, individual issues of redevelopment and then those pertaining to reconstruction are considered. The proposals made in the course of the study in order to improve the institute of reconstruction and redevelopment are grouped in the final part of the article as the conclusions.

**Research Results.** According to the Federal Law No. 608-FZ from 12/19/2023 "On Amendments to the Housing Code of the Russian Federation and the Federal Law on State Registration of Real Estate"[2] which came into force on April 1, 2024 the concept of redevelopment has undergone significant changes.

In the previous edition of Article 25(2) of the HC of the RF, the redevelopment of a room was concisely defined as "a change in its configuration requiring changes to the technological plan of a premise in an apartment building."

The current version of Article 25(2) of the HC of the RF has a lot to say on that, "Redevelopment of premises in an apartment building is a change in the boundaries and (or) the area of such a premises and (or) the formation of new premises, including in cases provided for in Article 40 of this Code, and (or) a change in its internal layout (including with no changes to the boundaries and/or area of the premises). As a result of the redevelopment of the premises, the boundaries and/or the area of adjacent premises might also be changed. Redevelopment entails the need to introduce changes to the information of the Unified State Register of Real Estate on the boundaries and (or) the area of the premises or to conduct state cadastral registration of the formed premises and state registration of the right to the formed premises." In turn, Article 40 of the HC of the RF mentioned in the definition discusses the unification of a few adjacent premises: now this is a particular case of redevelopment.

Setting aside the question of how appropriate it is to define the redevelopment of a premises as a "change in its internal layout" (through "buttery butter"), the following is to be noted:

1. The legislation has so far failed to eliminate a serious oversight from back in 2018, when such an object of housing rights as an apartment building was unintentionally removed from the scope of the rules of the HC of the RF on redevelopment and reconstruction.

It is to be remembered that Federal Law No. 558-FZ from December 27, 2018 "On Amendments to the Housing Code of the Russian Federation in Terms of Regulating the Rules Governing the Reconstruction and (or) Redevelopment of Premises in an Apartment Building"[3] replaced the words "residential premises" with the words "premises in an apartment building" in the standards of Chapter 4 of the Housing Code of the Russian Federation. It was with a good purpose in mind that it was done.

According to the explanatory note to the draft of this federal law (the number of the draft law on the website "Legislative Support System" is 107661-7)[4], the legislation sought to extend the rules on redevelopment and redevelopment to non-residential premises in an apartment building, "There is currently a legislative gap in the legal regulation of the issue of redevelopment of non-residential premises in apartment buildings that are not classified as a common property in these houses leading to abuse by the owners of non-residential premises while arranging them. In some cases, supervisory authorities cannot hold accountable owners of non-residential premises in apartment buildings who are engaged in illegal redevelopment of their premises and take other measures to prevent these actions."

Editing of the words "residential premises" with the words "premises in an apartment building", on the one hand, equalized residential and non-residential premises in an apartment building, but, on the other hand, removed residential buildings from the scope of the standards on redevelopment and reconstruction, which, being a type of objects of housing rights, are residential premises as well!

The rules on redevelopment and reconstruction now do not formally apply to residential buildings. The extension of the analogy of the law in this case is not acceptable, as these rules are of a public law nature and thus do not allow for either an extended interpretation or their application to objects not explicitly specified in the law. A serious legal gap emerged: today, even the transfer of an apartment building from stove heating to gas, which is certainly a reconstruction and might be associated with redevelopment, is not in compliance with the standards of Chapter 4 of the HC of the RF! There are lots of examples where owners of residential buildings are interested in reconstruction and redevelopment:

[2] *On Amendments to the Housing Code of the Russian Federation and the Federal Law "On State Registration of Real Estate"*. Federal Law № 608-FZ from 19.12.2023. URL: https://www.consultant.ru/document/cons_doc_LAW_464790/ (accessed: 10.03.2025).

[3] *On Amendments to the Housing Code of the Russian Federation Regarding Regulating the Rules Governing Reconstruction and (or) Redevelopment of Premises in an Apartment Building.* Federal Law from 27.12.2018 № 558-FZ. URL: https://www.consultant.ru/document/cons_doc_LAW_314689/#dst100024 (accessed: 10.03.2025).

[4] *Draft Federal Law "On Amendments to the Housing Code of the Russian Federation Regarding Regulating the Rules Governing Reconstruction and (or) Redevelopment of Premises in an Apartment Building"* №107661-7. URL: https://sozd.duma.gov.ru/bill/107661-7 (accessed: 10.03.2025).

changing the boundaries of premises in an apartment building; installing or eliminating window and door openings; increasing the area of an apartment building; equipping the house with new types of landscaping, etc. If such actions were always safe, it would be possible to agree with a voluntary appeal of the owner of the apartment building to the Federal Register with a plea to change the characteristics of the object, but the lack of minimal control by the local authorities coordinating the reconstruction and redevelopment might result in both harmless abuse by the owners and serious implications. In the meantime, the executive authorities are stating that there is a legal gap and the explanations provided are vague. Hence in the letter from the Ministry of Economic Development of the Russian Federation from 04/22/2019. No. OG-D23-3767 says, "Regarding reconstruction and (or) redevelopment of other premises — non-residential or residential, but not located in an apartment building, there is no special regulation in the Urban Planning and Housing Codes»[5].

In view of the above, it is proposed that the effect of Chapter 4 of the Housing Code of the Russian Federation is extended not only to premises in apartment buildings, but also to residential houses.

2. "Redevelopment entails the need to introduce changes to the information of the Unified State Register of Real Estate (hereinafter — USRRE) on the boundaries and (or) the area of the premises or to conduct state cadastral registration of the formed premises and state registration of the right to the formed premises" is stated in Article 25(2) of the HC of the RF.

The literal interpretation of the above standard means that changes are subject to the USRRE only in the following cases:

– changing the boundaries and/or area of the premises;

– designing new premises.

As the redevelopment of the premises is possible, including with no changes in the boundaries and (or) the area of the premises, as explicitly stated in the first sentence of Article 25(2) of the HC of the RF, there is a question of the need to introduce changes to the USRRE in the event that the redevelopment does not involve a change in such a significant parameter for the USRRE as the area or boundaries.

For example, redevelopment might involve installing a doorway or arch in a curtain wall, dismantling doors in a pantry in order to create a niche, etc. actions that do not cause a change in the area and boundaries of the premises. In this case, it seems reasonable to consider the approval of the act of the acceptance commission as the moment of completion of the redevelopment, as in the case of reconstruction, without forwarding the documents to the the Federal Registration Service (Rosreestr).

Considering that the USRRE does not even reflect the number of rooms in the premises, it is fairly possible to look at the option of completely removing from the norms on redevelopment any actions that have no impact on the supporting structures and do not change the boundaries and area of the premises. At the same time, it is advisable to reflect in the law a ban on changing the design configuration of ventilation ducts and chimneys, auxiliary rooms with gas equipment, as well as the boundaries of bathrooms and toilets (except in the case of their combination or located on floors under which there are no living quarters).

According to a private survey, albeit not a very representative one, at least 40% of citizens have had redevelopment done at least once[6]. Approximately the same order of numbers is indicated by realtors analyzing their practice of real estate turnover[7].

It seems that with the suggested approach to redevelopment, the scope of redevelopment legislation will be narrowed down to the following:

– changing the area of the premises when their boundaries change;

– forming new premises;

– using load-bearing structures.

This will relieve the financial and administrative burden on the owners of the premises[8] and the legislation as well as facilitate the work of local governments and the Rosreestr.

[5] *On the Documents Used to Prepare the Technological Plan of a Premises, an Object of Individual Housing Construction during Redevelopment (Reconstruction) for State Cadastral Registration.* A letter from the Ministry of Economic Development of the Russian Federation № OG-D23-3767 from 22.04.2019 https://base.garant.ru/400767521/ (accessed: 10.03.2025).

[6] *New Rules for Redevelopment and Registration of Real Estate are to Come into Force on April 1: What is in Store for Tenants.* URL: https://vk.com/wall-24199209_20644244 (accessed: 11.03.2025).

[7] *Almost half of Russia's apartments have been redeveloped and remodeled.* URL: https://sevastopol.su/news/pochti-polovina-kvartir-v-rossii-s-pereplanirovkami-i-peredelkami (accessed: 11.03.2025).

[8] *More than 10% of Apartment Buyers in New Buildings Redevelop Right Away.* URL: https://www.vedomosti.ru/realty/articles/2019/05/20/801931-novostroikah-pereplanirovku (accessed: 11.03.2025).

3. One of the problems of modern legislation is the insufficiently clear distinction between the concepts of "redevelopment" and "reconstruction".

The definition of reconstruction is contained in Paragraph 14 of Article 1 of the Urban Planning Code of the Russian Federation, "Reconstruction of capital construction premises is a change in the parameters of a capital construction premises, its parts (height, number of floors, area, volume), including superstructure, reconstruction, expansion of a capital construction premises, as well as replacement and (or) restoration of load-bearing building structures of a capital construction premises, except replacement of individual elements of such structures for similar or other elements that improve the performance of such structures and (or) restoration of these element"[9].

It is plain to see that the concept of reconstruction partially overlaps with that of redevelopment provided in the HC of the RF. For example, reconstruction involves changing the parameters of both the entire capital construction premises and its parts which are the premises in an apartment building. The parameters that can be changed during the reconstruction of a part of the building include, among others, the area and volume. The problems of distinguishing between these concepts are commonly tackled in the literature [1–3].

Based on a formal and logical comparison of the scope of the concepts of "reconstruction" and "redevelopment", it becomes clear that redevelopment encompasses reconstruction, but is not limited to it, the scopes of these concepts overlap to an extent.

In which case can the actions of the owner be qualified as redevelopment, and in which ones as reconstruction?

Of great interest is therefore the Review of legal practices on disputes related to reconstruction and redevelopment of premises in an apartment building approved by the Presidium of the Supreme Court of the Russian Federation on 12/13/2023[10] (hereinafter — Review).

The reconstruction in the Review includes, in particular, the following:

– designing of an extension to the apartment on the ground floor;

– designing a separate entrance by destroying some of the exterior wall of the house;

– combining a few apartments into one;

– divided an apartment into two separate ones;

– converting the terrace of the technical floor into a premises.

It is known that the Review was adopted a year before the change in the norms of the HC of the RF. This further accentuates the urgency of searching for a new approach to the differentiation of the concepts of "reconstruction" and "redevelopment". It seems correct to suggest the following.

As the concept of reconstruction contained in the Urban Planning Code of the Russian Federation excludes from its scope the replacement of individual elements of load-bearing structures with similar or other elements to improve the performance of such structures and (or) the restoration of these elements, individual operations with load-bearing structures that do not impact their full scope are not formally deemed as reconstruction.

Hence considering the current wording of Article 25 of the HC of the Russian Federation, e.g., it would be wrong to qualify the opening in the load-bearing wall of an apartment building as reconstruction rather than redevelopment.

In its Review, the Supreme Court of the Russian Federation is unequivocally in favour of applying the legal regime of reconstruction to any actions involving the supporting structures of an apartment building. Hence the installation of a doorway in a load-bearing wall for a separate entrance to a non-residential building, transferred from a residential one, entails, in the view of the court, the recognition of such actions as reconstruction and the need to obtain a building permit in compliance with Article 51 of the Urban Planning Code of the Russian Federation, as Paragraph 4 of Article 17 of this article excludes the need to obtain a construction permit only if changes to capital construction premises or their parts do not impact the structural and other characteristics of their reliability and safety. This is how the court argues its position (Paragraph 4 of the Review), "Due to the fact that the construction of a separate entrance to a premises is associated with the destruction of part of the wall of an apartment building and might impact the structural and other characteristics of reliability and safety of the house, such work is deemed possible by means of major repairs or reconstruction of an apartment building, the production of which is regulated by legislation on urban planning, including pertaining to architectural

[9] *Urban Planning Code of the Russian Federation*. Code of the Russian Federation No. 190-FZ from 29.12. 2004. URL: https://www.consultant.ru/document/cons_doc_LAW_51040/ (accessed: 11.03.2025).

[10] *Review of Legal Practices on Disputes Related to Reconstruction and Redevelopment of Premises in an Apartment Building.* Presidium of the Supreme Court of the Russian Federation from 12/13/2023. URL: https://www.vsrf.ru/documents/all/33237/ (accessed: 11.03.2025).

and construction design, state expert evaluation of project documentation, issuing permits for the construction and commissioning of the premises."

In this case the owner of the premises received an approval from the local governments for redevelopment in compliance with Chapter 4 of the HC of the RF, but the Supreme Court of the Russian Federation considered that the approval of the project was not acceptable. That was despite the fact that both the approval of redevelopment and construction permits are issued by the same local governments and, which is quite likely, by the same officials!

According to the logic of the court, any interference with load-bearing structures in the course of redevelopment is not acceptable and is subject to regulation by reconstruction standards with all the implications, which largely restrains the scope of redevelopment standards and practically paralyzes it (development of the project documentation — expert evaluation — construction permit — all the owners' consent — reconstruction - commissioning permit into operation).

In order to optimize the procedures, tackle the administrative barriers and unnecessary restrictions of the rights of the owners of premises, it is suggested that only such a change in the internal parameters of a premises in an apartment building should be attributed to reconstruction accompanied by one in the external parameters of this house (extension, superstructure, etc.). We therefore agree with Paragraph 3 of the above Review examining the case when a person erected an extension to an apartment belonging to them located in an apartment building by means of a common capital wall, as well as by installing a doorway by dismantling part of the outer wall of this house below their apartment window. We assume that the court was right to point out that "such actions changed not only the internal parameters (configuration) of the dwelling, but also the expansion of the entire capital construction premises — an apartment building (particularly, its area increased)." A similar situation is described in Paragraph 8 of the Review on the addition by the owner of a part of the technical floor and the completion of another one, which also resulted in some changes in the parameters of the entire apartment building and should certainly be classed as reconstruction.

We believe that due to the change in the legal regulation of redevelopment, a lot of positions of the Supreme Court of the Russian Federation expressed in the Review will obviously be adjusted.

In order to regulate the legislation, it is suggested that references to the reconstruction of premises and common property are completely excluded from the HC of the RF and the concept of "reconstruction" is applied only to an apartment building as a whole.

It is thus suggested that Article 36(3) of the HC of the RF is rephrased as follows:

"3. Reducing the area of the premises that are part of the common property in an apartment building is possible only with the all the owners' consent by means of reconstructing it."

The suggested revision to the standard in practice is long overdue. Firstly, it will exclude the application of urban planning legislation to redevelopment, and secondly, it will make it no longer necessary to obtain 100% consent of the owners in the case of any, even minor, reduction in the size of the common property (which in law enforcement practice is regarded differently — volume, quantity, area): replacement of a half-meter section of the pipeline, two bricks on the parapet, etc.

Part 2 of Article 40 of the HC of the RF should be rephrased as follows:

"2. If the reconstruction, reconstruction and (or) redevelopment of a premises is not possible without attaching some of the area that is part of the common property in an apartment building, the all the owners' consent in an apartment building must be obtained for such reconstruction, reconstruction and (or) redevelopment of a premises".

The land plot in the suggested version of the standard is intentionally omitted, since if the redevelopment "breaks through" beyond the boundaries of the existing contour of an apartment building, it will inevitably be classed as reconstruction. If necessary, issues of land use can be resolved by interested parties at the owners' general meeting, which does not require a unanimous decision (Paragraph 2, Article 44(2) of the HC of the RF — land use restrictions).

4. There is no longer a requirement to amend a technological plan of a premises in an apartment building in the concept of redevelopment. This is one of the novelties that needs to be reflected on.

As was seen above, the concept of "a technological passport of a premises" is repeatedly found in Chapter 4 of the HC of the RF, and "accounting of the housing stock", "state accounting of the housing stock", including technological inventory and certification, are part of housing relations as a subject of the housing legislation (Paragraph 5, Article 4(1), Article 9(5) of the HC of the RF).

In Paragraph 4, Article 26(2) of the HC of the RF a technological passport of a reconstructed and (or) redeveloped premises in an apartment building is indicated as a document submitted to the local government body for reconstruction (redevelopment) approval.

According to Article 25(1) of the HC of the RF, reconstruction of a premises in an apartment building is installation, replacement or transfer of engineering networks, sanitary, electrical or other equipment requiring changes to a technological passport of a premises in an apartment building. Hence a technological passport is still mentioned as part of the reconstruction concept.

What is a technological passport, what is its legal status and significance for the reconstruction and redevelopment relationship? Let us try to answer these questions in this section of the study.

In compliance with Paragraphs 3, 4 of the Standard on State Accounting of the Housing Stock in the Russian Federation approved by a Decree of the Government of the Russian Federation from 10/13/1997 No. 1301, state accounting of the housing stock in the Russian Federation includes technological inventory, official statistical accounting and accounting inventory [11].

The foundation of the state accounting of the housing stock is technological inventory conducted in compliance with the regulatory legal acts in the field of state technological accounting and technological inventory of capital construction premises.

Specialized state and municipal organizations are tasked with technological inventory of the housing stock — unitary enterprises, services, departments, centers, bureaus (hereinafter — BTI). The second major document in the field of technological inventory is the Instruction on Housing Stock Accounting in the Russian Federation (approved by a Decree of the Ministry of Land Policy, Construction, Housing and Utilities (Minzemstroy) of the Russian Federation from 08/04/1998 № 37)[12]. It contains the procedure for conducting technological inventory, designing technological passports, and requirements for their content.

The legislation does not contain a legal definition of a technical passport, however, from the analysis of regulatory material, it can be concluded that a technological passport is a document with the results of a technological inventory.

The Instruction indicated provide the forms of technological passports of a household, building and residential premises, respectively, in its appendices 11, 12, 13.

At first glance, there do not seem to be any problems with the legal foundation for issuing technological passports, execpt a subtle yet significant nuance: in compliance with Article 47(8) of the Federal Law "On Cadastral Activity" (formerly known as "On the State Cadastre of Real Estate"), regulatory legal acts in the field of state technological accounting and technological inventory of capital construction premises are valid only until January 1, 2013[13].

This decision of the legislator has been known since 2009 when this standard first appeared in the text of the law. Apparently, a temporary backlash was planned in advance in order to reform state technological accounting. However, those 3 years were unproductive. Moreover, even today we can safely declare there is no system of state technical accounting of housing stock in place whatsoever, which occasionally becomes a subject of discussion in high offices. For example, a round table held on October 31, 2023 in the Federation Council of the Federal Assembly of the Russian Federation, with a title that speaks for itself, "On the Formation of a System of Technical Inventory of the Housing Stock: Problems and Solutions," stated there was no system of technological inventory of the housing stock in place[14]. The recommendations of the round table contain a reference to the list of measures to design a system of technological inventory of the housing stock developed by the Ministry of Construction of the Russian Federation for up to 2029. Given the common bureaucratic practices, concrete decisions in the field of technological inventory are unlikely to be made earlier than this.

Is there currently a legal foundation for technological passports which are mentioned in the HC of the RF time and time again?

[11] *On State Accounting of the Housing Stock in the Russian Federation.* Decree of the Government of the Russian Federation № 1301 from 13.10.1997. URL: https://docs.cntd.ru/document/9049996?ysclid=m7eoybt1ia410823836 (accessed: 11.03.2025).

[12] *On the approval of the Instructions on Accounting of the Housing Stock in the Russian Federation.* Decree of the Ministry of Land Policy, Construction, Housing and Utilities (Minzemstroy) of the Russian Federation № 37 from 04.08.1998. URL: https://docs.cntd.ru/document/901739482 (accessed: 11.03.2025).

[13] *On Cadastral Activity.* Federal Law № 221-FZ from 24.07.2007. URL: https://www.consultant.ru/document/cons_doc_LAW_70088/?ysclid=m8a3m2i7tm262917606 (accessed: 11.03.2025).

[14] *Recommendations of a Round Table "On the Formation of a System of Technological Inventory of the Housing Stock: Problems and Solutions."* Approved at a meeting of the Federation Council Committee on Federal Structure, Regional Policy, Local Self-Government and Northern Affairs (protocol № 320 from 20.11.2023.). URL: http://council.gov.ru/activity/activities/roundtables/150380/ (accessed: 12.03.2025).

This question should perhaps be answered in the negative. The standard of Article 47(8) of the Federal Law "On Cadastral Activity" on the termination of the application of regulatory legal acts in the field of state technological accounting and technological inventory of capital construction premises has been valid since January 1, 2013.

Despite the fact there is no direct repeal of the Regulation on State Accounting of the Housing Stock in the Russian Federation approved by a Decree of the Government of the Russian Federation from 13.10.1997 No. 1301, and the Instructions on Accounting of the housing stock in the Russian Federation (approved by a Decree of the Ministry of Land Policy, Construction, Housing and Utilities (Minzemstroy) of the Russian Federation from 04.08.1998 No. 37), these acts should undoubtedly be considered invalid.

According to a recent letter from the Ministry of Construction of the Russian Federation from 08/20/2024 No. 47894-AF/04, our assumption is substantiated, "... the BTI authorities have lost the function of state technological accounting and (or) technological inventory… Therefore as of January 1, 2013 Decree No. 1301 has not been used for state cadastral registration of real estate objects, technological inventory and technological passports of such real estate objects are not provided for by current legislation."[15]. The literature has time and time again emphasized the importance of resuming the work of a comprehensive mechanism of state technological accounting and technological inventory [4, 5].

Nevertheless, up to present the former state and municipal enterprises of technicological inventory reorganized from 2025 into privately owned organizations have been using the above regulations. The conclusion that regulations in the field of state technological accounting are in force is found in the educational literature and some publications [6, 7].

It can be understood where practitioners from the BTI system who survived the scrapping of the technological inventory system are coming from: technological passports are still in demand, and in the regulatory sense, the performers simply have nothing to hold onto. This is not the case, however, for theorists who are "reviving" dead documents [8].

In this case, an analogy with the Civil Code of the Russian Federation springs to mind, which still contains rules on mandatory state registration of real estate transactions repealed on March 1, 2013 by Federal Law No. 302-FZ from 30/12/2012 "On Amendments to Chapters 1, 2, 3 and 4 of Part 1 of the Civil Code of the Russian Federation"[16]. Section 3 of Article 574 of the Civil Code of the Russian Federation, which for more than 10 years contained an invalid standard on state registration of an agreement on donation of property, was edited only in the late 2024, and it was only due to the need to establish notarization of such transactions[17].

There is currently no existing regulatory act in the field of state technological accounting of the housing stock and technological inventory. It should be noted, though that the legislator chose what was by no means the best decision from the view of legal technology to repeal such regulations.

In the light of the latest developments in the housing legislation based on the results of the redevelopment, it is no longer necessary to introduce changes to a technological passport of a premises. Instead, a new technical plan is designed and submitted to the Federal Registration Service (Rosreestr) [9].

It should be remembered that in compliance with Article 24(1) of Federal Law No. 218-FZ from July 13, 2015 "On State Registration of Real Estate", a technological plan is a document that reproduces specific information entered into the Unified State Register of Real Estate and provides information about a building, structure, premises, parking space, an unfinished object or a single immovable complex required for the state cadastral registration of such a real estate object.

Therefore a technological plan is a document of the state cadastral registration that in its role and structure does not replicate a technological passport.

It makes sense to design it during redevelopment only when the characteristics of a premises change and are essential from the view of state cadastral registration. It was thus previously suggested that any actions are deemed as redevelopment that do not impact the supporting structures and do not change the boundaries and area of a premises.

The conclusion will be made straight away based on the analysis of the basic and additional information about the real estate object provided in the real estate cadastre (Article 8 of the Federal Law "On State Registration of Real Estate"), as

[15] *On Specifications of the Standards of the Legislation Regulating State Accounting of the Housing Stock in the Russian Federation.* Letter from the Ministry of Construction of the Russian Federation № 47894-AF/04 from 20.08.2024. URL: https://rulaws.ru/acts/Pismo-Minstroya-Rossii-ot-20.08.2024-N-47894-AF_04/ (accessed: 12.03.2025).

[16] *On Amendments to Chapters 1, 2, 3 and 4 of Section 1 of the Civil Code of the Russian Federation.* Federal Law № 302-FZ from 30.12.2012. URL: https://base.garant.ru/70291432/ (accessed: 12.03.2025).

[17] *On Amendments to Article 574 of Section 2 of the Civil Code of the Russian Federation.* Federal Law № 459-FZ from 13.12.2024. URL:https://ivo.garant.ru/#/document/411108286/paragraph/1/doclist/3634/2/0/0/гражданский%20кодекс%20рф%20часть%202:4 (accessed: 12.03.2025).

well as the Requirements for preparing a technological plan (Rosreestr decree No. P/0082 from 03/15/2022[18]), Requirements for identifying the area of a building, structure, premises, parking space (Rosreestr decree from 10/23/2020 No. P/0393[19]): regarding redevelopment, a technological plan is only concerned with the area of the premises, the location of window and door openings along the outer perimeter of the walls, as well as the internal walls (partitions), and that of the premises.

The remaining characteristics of the premises changed during the redevelopment make no difference to the real estate cadastre and technological plan.

In general, such a simplified approach should be considered fairly useful.

The role of a technological passport considering the reform of legislation on redevelopment is reduced to a document provided to local governments at the stage of submitting an application for approval of redevelopment and is informative in its nature. After all, local governments will have nothing to compare the current and design condition of the premises with unless there is a technological passport.

However, considering that there has been no regulatory framework for designing technological passports since 2013, as well as liberal requirements for the content of the technological plan, it is suggested that Paragraphs 4, and Paragraph 2, Article 26(2) of the HC of the RF (list of documents provided by the applicant for reconstruction) are rephrased as follows, "a technological plan of the reconstructed and (or) redeveloped premises in an apartment building". If implemented, the proposal will make it possible to make use of both technological passports designed before 01/01/2013 and modern technological plans while submitting an application.

So far, the standards of the legislation on redevelopment have been our focus. Let us now move on to reconstruction.

Legal regulation of reconstruction has experienced no changes. As before, reconstruction refers to installation, replacement, or transfer of engineering networks, sanitary, electrical, or other equipment that require changes to a technological plan of a premises in an apartment building (Article 25(1) of the HC of the RF).

The above pretty much applies to reconstruction, but the specifics of this institution are to be considered. Here, a technological passport appears both on the list of documents sent by the applicant for approval, and as a document to be modified based on the results of the reconstruction.

It should be noted that the standards of Chapter 4 of the HC of the RF are formulated so that making changes to a technological passport based on the results of the reconstruction is not tracked in any way. In compliance with Article 28(3) of the HC of the RF, reconstruction of a premises in an apartment building is considered completed from the date of approval of the act of the acceptance commission. At the same time, the law does not require the applicant to submit to the acceptance commission an updated technological plan indicating the results of the reconstruction, which we think should be addressed.

While discussing reconstruction, we are again compelled to refer to a technological passport as a "living" document.

Based on the definition of the concept of reconstruction, it requires changes to a technological plan. In order to make sense of the essence of reconstruction, it has to be investigated what changes should be reflected in a technological plan. This, in turn, suggests an answer to what a technological plan typically contains. After all, it is only after learning about it that we will be able to grasp the reconstruction impact.

To this end, let us turn to the Instructions on the housing stock accounting in the Russian Federation (Decree of the Ministry of Land Policy, Construction, Housing and Utilities (Minzemstroy) from 08/04/1998, No. 37) as it is the only solution there is.

Hence, for example, according to Paragraph 3.16 of the specified Instructions, the following is to be found on the floor plan:

– stoves, kitchen fireplaces;

– pits, loading hatches, manholes of basements and basement floors;

– heating boilers, etc.;

– sanitary and fire-fighting equipment (water taps, sinks, bathtubs, toilets, gas and electric stoves, etc.).

Pipelines for cold and hot water, sewerage, heating, gas, etc., as well as central heating radiators are not shown on the floor plans.

[18] *On the Form of a Technological Plan, Requirements for Preparing it and the Information Contained.* Rosreestr decree № P/0082 from 15.03.2022. URL: https://www.garant.ru/products/ipo/prime/doc/403720102/ (accessed: 13.03.2025).

[19] *On the Approval of the Requirements for Accuracy and Methods for Identifying the Coordinates of the Characteristic Points of the Boundaries of a Land Plot, Requirements for Accuracy and Methods for Identifying the Coordinates of the Characteristic Points of the Contour of a Building, Structure or an Object under Construction on a Land Plot, as well as the Requirements for Identifying the Area of a Building, Structure, Premises, Parking Space.* Rosreestr decree № P/0393 from 23.10.2020. URL: https://base.garant.ru/74912016/f7ee959fd36b5699076b35abf4f52c5c/ (accessed: 13.03.2025).

According to Paragraph 3.19 of the specified Instruction, "the floor plans are to indicate heating appliances, ventilation appliances, ventilation ducts (unless they are made in the wall), bathtubs, toilets, sinks, washbasins, etc."

As heating devices are mentioned in Paragraph 3.19 of the Instructions, it is not entirely clear which devices these are, as Paragraph 3.16 states that radiators are not shown. Apparently, these are boilers, columns, etc. devices, as technological plans have always been designed with no locations of radiators, etc. heating devices included as understood in the classical meaning of GOST 31311-2022 "Heating Devices"[20] .

The next group of information to be indicated in a technological plan is found in the Parameters of the technological description of the main structural elements of a building (Appendix 2 of the specified Instructions), as well as in the forms of a technological plan (Appendices 11, 12, 13 of the specified Instructions). Using the legal concept of reconstruction, we selected information from them about those objects with which operations such as "installation, replacement or transfer of engineering networks, sanitary, electrical or other equipment" can be performed:

– heating stoves and kitchen fireplaces — area of tile cladding, plaster, a type of hearth (gas, electric, solid fuel);

– heating is the source of heat supply: a thermal power plant; an industrial boiler house; a quarterly, group or local boiler house; a water-heating gas device; an individual boiler or a boiler mounted in a heating furnace;

– electric lighting — open or hidden wiring;

– gas supply — mains (natural) or bottled gas;

– water supply — from the city's central network or a local source;

– sewerage — discharge into the city network or a local sump;

– bathtubs — cast iron, steel, plastic, etc.;

– hot water supply is centralized or provided with local water heaters.

This is perhaps an almost complete list of what might be impacted during reconstruction and there is thus the need to introduce changes to a technological plan.

As can be seen, even the transfer of radiators and other types of heating devices, as well as of pipelines of engineering systems, in the strict sense, does not apply to reconstruction, if its legal definition is to be literally interpreted.

It is rightly noted in the literature that "in the HC of the RF there is no sufficient information on the types of work pertaining to reconstruction and redevelopment, which, in turn, makes these categories evaluational and results in additional difficulties for law enforcement" [10].

The above indicates that there are problems with formally qualifying individual actions as reconstruction, and in conditions of paralysis of the regulatory framework for technological inventory, it is directly impossible for certain works to be classified as reconstruction.

The following are suggested as a solution:

1. Defining in Chapter 4 of the HC of the RF the concept of remodeling premises in an apartment building and an apartment building as "installation, replacement or transfer of engineering networks, sanitary, electrical or other equipment defined by a regulatory legal act of the federal executive authority responsible for developing and implementing state policies and regulation in the field of housing and communal services", eliminating the need to introduce changes to a technological plan.

2. We consider it necessary to identify a list of reconstruction cases at the federal level in order to design a uniform approach to solving reconstruction problems nationwide. The experience of the regulation of the relations of reconstruction in the city of Moscow can be taken as an example, which, albeit controversial, can be generally deemed positive. Therefore in the decree of the Government of Moscow from 25.10.2011 No. 508-PP "On Organizing Reconstruction and (or) Redevelopment of a Premises in Apartment Buildings"[21] an attempt was made to summarize the experience of reconstruction and provide a list of cases that fall under the concept at hand.

3. Considering the approval of the act of the acceptance commission as the moment of completion of the reconstruction, however, obliging local governments to send the act and the draft of the reconstruction to Rosreestr for marking in the USRRE about the reconstruction, for which it is necessary to make appropriate amendments to the Federal Law "On State Registration of Real Estate" and departmental acts of the Rosreestr.

[20] *GOST 31311-2022 „Heating Devices“.* URL: https://gostassistent.ru/doc/8515d4f8-cbd3-412a-96f9-bbc8ebb180fe (accessed: 14.03.2025).

[21] *On Organizing Reconstruction and (or) Redevelopment of Premises in Apartment Buildings.* Decree of the Government of Moscow № 508-PP from 25.10.2011 URL: https://docs.cntd.ru/document/537907820?marker=7D20K3 (accessed: 13.03.2025).

**Discussion and Conclusion.** Summing up the results of the study, it is noted that the use of the categories "reconstruction" and "redevelopment" is complicated by the lack of a system of state technological accounting and technological inventory of the housing stock, and a number of practical solutions necessary for adoption before the restoration of this system have been thus suggested. In addition, we suggest the following:

1. Extending the effect of Chapter 4 of the HC of the RF not only to premises in apartment buildings, but also to residential houses.
2. Considering completely removing from the legal regulation of redevelopment relations any actions that do not impact the supporting structures and do not change the boundaries and area of the premises.
3. Defining as reconstruction only such a change in the internal parameters of a premises in an apartment building accompanied by a simultaneous change in the external parameters of this house (extension, superstructure, etc.). Applying the concept of reconstruction only in relation to an overall apartment building.
4. In the legal regulation of reconstruction, it is suggested that a technological passport is no longer used and a list of cases falling under the concept of "reconstruction" is identified at the federal level.

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# LIFE CYCLE MANAGEMENT OF CONSTRUCTION FACILITIES

# УПРАВЛЕНИЕ ЖИЗНЕННЫМ ЦИКЛОМ ОБЪЕКТОВ СТРОИТЕЛЬСТВА





*Original Empirical Research*

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## Creating a Tool for Transforming Digital Requirements when Uploading Digital Information Models in IFC Format

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**Abstract**

***Introduction.*** Modern computer-aided design (CAD) systems make use of digital information models (DIM) depending on the aims of a project. According to the Decree of the Government of the Russian Federation No. 614, Section 7, Subsection D, the use of information modeling technologies (IMT) does not always imply designing a DIM. However, making sure DIM attribute data are in compliance with a customer's requirements or those of expert evaluation remains time-consuming and prone to technical errors. The relevance of the study is due to the need automated DIM parameter matching based on the technical specification requirements, which would reduce time costs and improve the quality of uploading the model. The study looks into the problem of the lack of tools for automated parameter matching based on machine-readable requirements. The aim of the study is to develop an application providing programmatic comparison of CIM attribute data in compliance with the technical specification requirements.

***Materials and Methods.*** The software solution is being developed for a range of CAD systems, such as Renga Professional, CADLib "Model and Archive", Autodesk Revit. The article examines methods for generating parameter matching files specifically for Renga Professional. Throughout the study the following software was used: Renga Professional, Visual Studio Code, BimVision. In order to develop the application and algorithms, the Python programming language was used with the following libraries: PyQt6, openpyxl, et_xmlfile.

***Research Results.*** A software solution has been developed that enables one to automatically match the DIM attribute data with the specified ones based on machine-readable requirements. The application provides the conversion of machine-readable requirements into a machine-readable DIM attribute data mapping file. Testing has shown a reduction in the time required to create parameter matching files in comparison with manual file generation. The resulting tool has the flexibility of implementation allowing one to upload existing requirements, as well as create one's own and use them while uploading a model.

***Discussion and Conclusion.*** From a practical standpoint the resulting application is highly significant for an investment and construction project, where, while designing a DIM in compliance with the current regulations, it is necessary to make use of an open standard for the data presentation format - Industry Foundation Classes (IFC). The application allows one to minimize routine operations while designing a DIM from a proprietary format into the IFC format. The research is promising as its future directions include expanding the functionality to be able to work with additional data formats and integration with other BIM platforms. The research results contribute to the development of methods for automated processing of DIM requirements.

**Keywords:** automated mapping, mapping, parameter matching, Python, machine-readable requirements, IFC, IDS

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*Оригинальное эмпирическое исследование*

# Создание инструмента для преобразования цифровых требований при выгрузке цифровых информационных моделей в формате IFC

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**Аннотация**

***Введение.*** Современные системы автоматизированного проектирования (САПР) используют цифровые информационные модели (ЦИМ) в зависимости от задач проекта. Согласно Постановлению Правительства Российской Федерации № 614 ч. 7 п. Д. применение технологий информационного моделирования (ТИМ) не всегда подразумевает формирование ЦИМ. Однако процесс соответствия атрибутивных данных ЦИМ требованиям заказчика или экспертизы остается трудоемким и подверженным техническим ошибкам. Актуальность исследования обусловлена необходимостью автоматизации сопоставления параметров в ЦИМ с требованиями технического задания, что позволит сократить временные затраты и повысить качество выгрузки модели. Исследование затрагивает проблему отсутствия инструментов для автоматизированного сопоставления параметров на основе машиночитаемых требований. Цель работы — разработка приложения, обеспечивающего программное сопоставление атрибутивных данных ЦИМ согласно требований технического задания.

***Материалы и методы***. Программное решение разрабатывается для разнообразных САПР систем, таких как Renga Professional, CADLib «Модель и Архив», Autodesk Revit. В статье будут рассмотрены методы формирования файлов сопоставления параметров именно для Renga Professional. В процессе выполнения работы было использовано следующее программное обеспечение (ПО): Renga Professional, Visual Studio Code, BimVision. Для разработки приложения и алгоритмов применялся язык программирования Python со следующими библиотеками: PyQt6, openpyxl, et_xmlfile.

***Результаты исследования.*** Разработано программное решение, позволяющее автоматически сопоставлять атрибутивные данные ЦИМ с заданными на основе машиночитаемых требований. Приложение обеспечивает преобразование машиночитаемых требований в машиночитаемый файл сопоставления атрибутивных данных ЦИМ. Тестирование показало сокращение времени создания файлов сопоставления параметров по сравнению с ручным формированием файлов. Разработанный инструмент обладает гибкостью внедрения и позволяет как загрузить существующие требования, так и создать собственные и использовать их при выгрузке модели.

***Обсуждение и заключение***. Реализованное приложение обладает высокой практической значимостью для инвестиционно-строительного проекта, где при формировании ЦИМ в соответствии с действующими нормативными актами необходимо использовать открытый стандарт для формата представления данных — Industry Foundation Classes (IFC). Приложение позволяет минимизировать рутинные операции при формировании ЦИМ из проприетарного формата в формат IFC. Перспективы исследования включают расширение функционала для работы с дополнительными форматами данных и интеграцию с другими BIM-платформами. Результаты работы вносят вклад в развитие методов автоматизированной обработки требований к ЦИМ.

**Ключевые слова:** автоматизированное сопоставление, мапирование, сопоставление параметров, Python, машиночитаемые требования, IFC, IDS

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**Introduction.** Modern computer-aided design systems (CAD) [1] have a key role to play in designing and maintaining a digital information model (DIM) [2] at the stages of the life cycle of a construction object [3]. The development of a range of automation and optimization methods helps to reduce the time spent on routine operations, improve the quality of a project and mitigate the human error factor. The relevance of the research is due to the growing complexity of projects calling for a high implementation quality, as well as the need for all DIM components to be in compliance with the regulatory standards, technical specifications and expert evaluation requirements.

The scientific obstacle lies in the lack of automated parameter matching solutions in DIM in the process of unloading. A range of CAD systems, such as Autodesk Revit, Renga Professional, Model Studio "Building Solutions", etc., only

provide methods for manually configuring parameter matching rules, which impacts time and thereby financial costs. In CAD systems produced by CSoft, there are simplified methods for matching parameters based on a table of all existing model attribute parameters, but the necessary ones have yet to be selected manually. There are no ready-made solutions available for automating the conversion of machine-readable requirements into machine-readable files for matching attribute data in DIM.

The aim of the study is to create a ready-made product for parameter automation based on machine-readable requirements provided by the customer or expert evaluation in the technical specification. To this end, the following problems are to be solved:

1. Analysis of the structure of machine-readable DIM requirements.
2. Development of algorithms for data collection from machine-readable requirements.
3. Development of algorithms for generating parameter matching files for diverse CAD systems.
4. Testing algorithms for the correctness of data collection and file generation.

The novelty of the research lies in creating algorithms for processing machine-readable requirements for DIM followed by formation of attribute data matching files based on the collected information for both domestic and foreign software in a single software solution.

**Materials and Methods.** The object of the study was digital information models formed at the stage of the life cycle of a building "Design" (Table 1) in compliance with Decree of the Government of the Russian Federation of 05/17/2024 No. 614 Section 7 Subsection d [4]. The following software solutions were used:

1. BimVision is a software package for viewing uploaded DIM in IFC format.
2. Renga Professional is a national BIM system for integrated building design and DIM upload into IFC.
3. Visual Studio Code is a development environment where the program code was written and the algorithms were debugged.

Table 1

Practical significance of the tool being developed in the life cycle of an object

| **Phases** | **PRE-INVESTMENT** | | | | | | | **INVESTMENT** | | | | | | | | | | **POST-INVESTMENT** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STAGES** | PRODUCT DESIGN | | PREPARING THE LEGAL PAPERWORK | | INVESTMENT | | | ENGINEERING EXPLORATION | DESIGN | | TENDER | | CONSTRUCTION AND ASSEMBLY | | | | OBJECT COMMISSIONING | | | OPERATION | DEMOLITION |
| **STAGES** | Designing technical and economical indicators | Project budgeting | Legal paperwork | Technical conditions | Concept project design | Budgeting | Project work budgeting | Conducting engineering exploration | Designing project paperwork | Project work expert evaluation | Detailing project solutions | Detailing estimated project costs | Designing target power spots | Starting construction and assembly | Performing construction and assembly | Funding construction and assembly | Object commissioning | Funding construction and assembly | Paperwork termination | Operation | Operation |

Python was chosen as the programming language due to its flexibility to various tasks and support of a wide range of libraries. The main libraries used in the project are

1. PyQt6 is a library for creating a graphical user interface (GUI).
2. Openpyxl is a tool for working with Excel files.
3. Et_xmlfile is a tool for working with XML data.

The application was developed based on modern programming paradigms [5]. The entire program code is based on the object-oriented programming (OOP) approach [6] (Fig. 2) allowing one to structure the code in the form of classes based on their methods and data processing logic. An event-oriented model [7], characteristic of the PyQt6 library, was used for the implementation of the graphical interface (Fig. 3). This enabled user actions to be associated with the corresponding class methods by means of the mechanism of signals and slots.

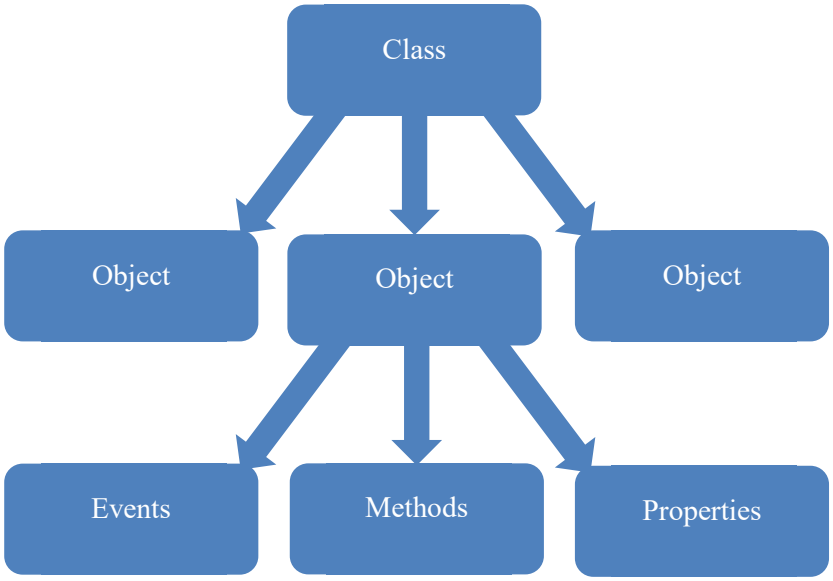


Fig. 2. OOP scheme

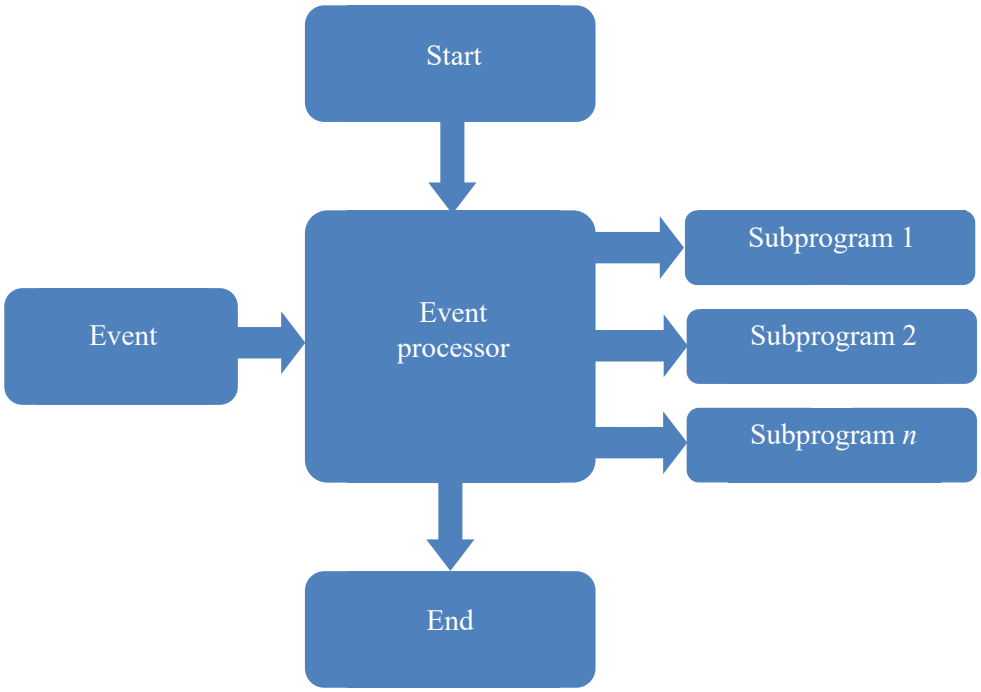


Fig. 3. Event-driven model scheme

The main research material is the machine-readable format of the requirements for filling attributive data, the CIM IDS file. Using data processing and sampling algorithms, it is from the IDS file that all the necessary information about the requirements for the digital information model is extracted. Later, using algorithms, a parameter matching file is generated based on the IDS file samples.

**Research Results.** This research enabled us to develop a software solution for the problem of automating the comparison of parameters of digital information models in compliance with the machine-readable requirements of the technical specification. In the process of analyzing the life cycle of the building and considering the stage when the digital information model is formed, a wide range of errors were identified while checking the DIM against the expert evaluation requirements. One of the most common errors is incorrect matching of the DIM parameters in a proprietary format while uploading a model into the international Industry Foundation Classes (IFC) format [8]. IFC is a standard developed by buildingSMART International designed for information exchange among construction participants. The IFC model is a collection of a geometric model in a proprietary format and the attribute data of this model (Fig. 4).

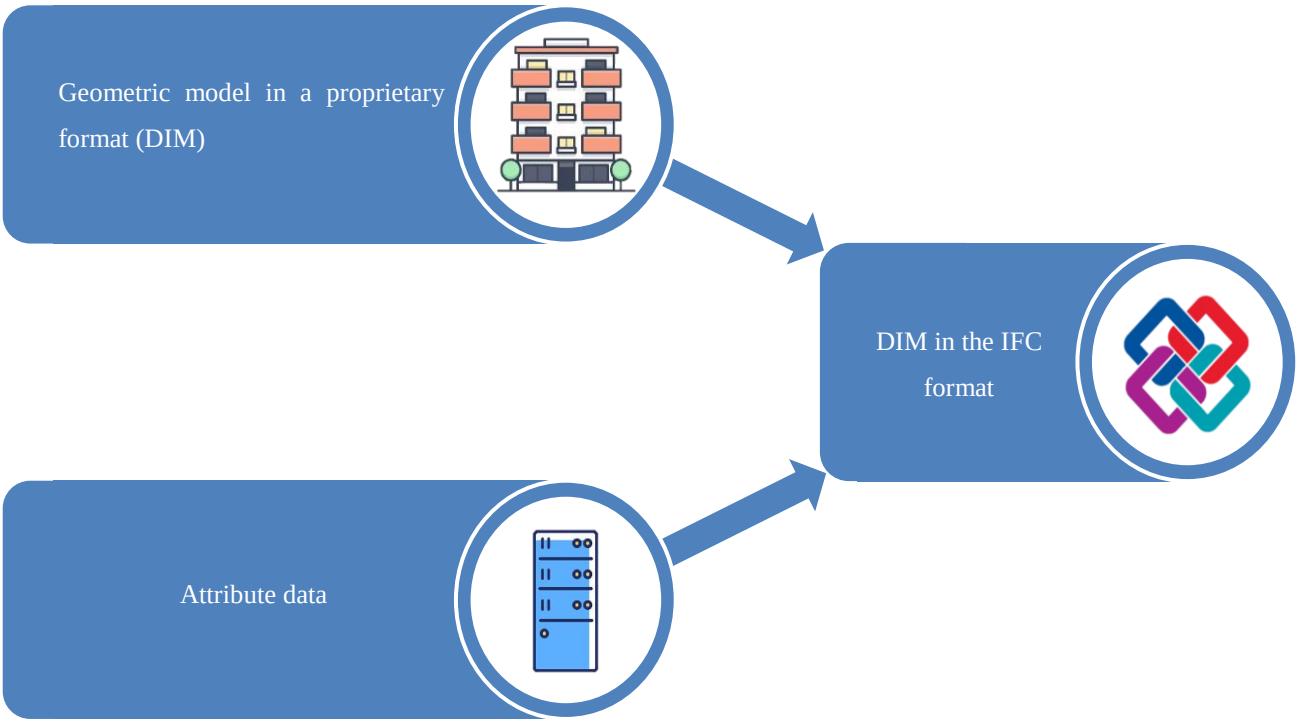


Fig. 4. IFC-model design scheme

While investigating the models that failed the examination by means of BimVision, it was found that the main error made while exporting the model to the IFC format was incorrect attribute data names in the parameter matching file caused by the human factor. The solution is to create a software product that allows one to automate and eliminate the human factor of making mistakes in writing the parameter matching file.

Before writing the basic algorithm for generating the parameter matching file, it is essential to decide where all the necessary data will be extracted from. At the moment, there is already an international data transmission format in a machine-readable representation in the form of XML markup, where all the necessary requirements are stored. This is the Information Delivery Specification (IDS) [9] — a standard from buildingSMART International that automates the formation of requirements for model exchange. By studying the structure of the IDS file, it can be clearly identified where in the file all the necessary data is located (Fig. 5). Each aspect of the attribute parameter group (IFC class, attribute data group name, and attribute data name) is located under its own tag in the IDS file. Having written algorithms and using the existing library for working with XML markup (et_xmlfile), all the necessary information is automatically searched for in the file by tags and create a "dictionary". The "dictionary" acts as a repository for all the parameters of machine-readable requirements.

```
<?xml version="1.0" encoding="utf-8"?>
<ids xmlns:xs="http://www.w3.org/2001/XMLSchema" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:sch
  <info>
    <title>Требования к элементам ЦИМ (Архитектурные решения)</title>
    <copyright>Отдел ТИМ, СПб ГАУ "ЦГЭ"</copyright>
    <version>3.1</version>
    <description>ЦГЭ.ЦИМ.3.0 Часть 3. АРХИТЕКТУРНЫЕ РЕШЕНИЯ</description>
    <author>bim@spbexp.ru</author>
    <date>2024-12-09</date>
    <purpose>Проверка атрибутивного состава, по требованиям СПб ГАУ "ЦГЭ"</purpose>
    <milestone>Проектирование</milestone>
  </info>
  <specifications>
    <specification name="Таблица 3.А.3 – Имена атрибутов для элемента «Стена» (IfcWall)" ifcVersion="IFC4" ide
      <applicability minOccurs="1" maxOccurs="unbounded">
        <entity>
          <name>
            <xs:restriction base="xs:string">
              <xs:enumeration value="IFCWALL" />
              <xs:enumeration value="IFCWALLTYPE" />
              <xs:enumeration value="IFCWALLSTANDARDCASE" />
              <xs:enumeration value="IFCWALLELEMENTEDCASE" />
            </xs:restriction>
          </name>
          <predefinedType>···
          </predefinedType>
        </entity>
      </applicability>
      <requirements>
        <property cardinality="required" instructions="Указывается номер корпуса, в котором находится элемент.
          <propertySet>
            <simpleValue>Местоположение</simpleValue>
          </propertySet>
          <baseName>
            <simpleValue>Номер корпуса</simpleValue>
          </baseName>
        </property>
        <property cardinality="required" instructions="Указывается номер секции, в которой находится элемент.
          <propertySet>
            <simpleValue>Местоположение</simpleValue>
          </propertySet>
          <baseName>
            <simpleValue>Номер секции</simpleValue>
          </baseName>
        </property>
```

Fig. 5. Machine-readable format of the expert evaluation requirements

Further development includes the formation of a parameter matching file. In order to create it, it is essential to investigate the structure of the standard parameter file provided by the CAD documentation. In our case, the standard attribute mapping file for Renga Professional will be considered [10]. It is an XML-marked file that stores basic information about the file itself (file name, creator, version, file type) and all the necessary information for parameter matching and exporting DIM to IFC (Fig. 6*a*).

There are 3 ways to generate parameter matching files:

1. Forming a file based on the names of the properties.
2. Forming a file based on the GUID numbers of the properties.
3. Generating a file using the Renga API.

Next, the algorithm for forming a file based on property names will be considered. This method is the most effective one as there is no need to interact with Renga Professional project files, and it also ensures the user that their data will not be used without them knowing.

The attribute data mapping file itself has the JSON format, which is an advantage as the standard Python libraries already know how to work with this file format. The program algorithms structure all the data based on the previously created "dictionary", and the program outputs a ready-made attribute data mapping file in a necessary extension (Fig. 6*b*).

```
{
  "name": "Renga View",
  "type": "export",
  "version": "4",
  "IfcWall": {
    "attributes": {
      "Name": "{a4bc7f50-463e-48f6-b829-795d4e0a1160}",
      "Tag": "{99ffedaa-c1bb-4a48-b9c2-4ecc23866830}"
    },
    "psets": {
      "Pset_WallCommon": {
        "Reference": "{ff2e904e-04e4-4f6e-b5d4-a6fa7a7d2cda}",
        "FireRating": "{5c0fffed-5c9b-4540-bd80-6227cf87d635}",
        "ThermalTransmittance": "{eb3cbb1b-18ef-4299-aace-32bc2109e325}",
        "GOST": "{08fffd93-d0a8-4c7d-aea7-13e6194055f1}"
      },
      "Pset_ReinforcementBarPitchOfWall": {
        "BarAllocationType": "{8f747ef8-457b-43e7-bc03-afbddcb5a40f}"
      }
    },
```

```
{
    "name": "Renga_mapping",
    "type": "export",
    "vesion": "1",
    "creator": "Sysolov Nikita",
    "IFCWALL": {
        "attributes": {},
        "psets": {
            "Местоположение": {
                "Номер корпуса": "Номер корпуса",
                "Номер секции": "Номер секции",
                "Этаж": "Этаж"
            },
            "Маркировка": {
                "Позиция": "Позиция",
                "Обозначение": "Обозначение",
                "Наименование": "Наименование"
            },
```


*a)* *b)*

Fig. 6. File for mapping export parameters to IFC for Renga Professional:
*a* — standard mapping file; *b* — matching file based on the expert evaluation requirements

The final stage of the development of a ready—made solution is the creation of a clear and simple graphical user interface (GUI). All the necessary buttons have been added to upload the IDS file and create a parameter mapping file for Renga Professional.

**Discussion and Conclusion.** The aim of the study has been achieved by creating algorithms for processing and analyzing IDS files and generating structured parameter matching files for exporting CIM to the IFC format.

The developed application eliminates the manual generation of attribute data matching files minimizing the risk of errors related to the human factor, as well as reduces the time for the CIM export operation to IFC.

Testing on a variety of different machine-readable requirements in the IDS format and also templates provided by the IDS format developers dispalyed correct operation of data extraction algorithms and generation of parameter matching files.

The software solution involves further development with other CAD systems. The generated parameter matching files for Autodesk Revit and CADLib "Model and Archive" are being actively tested.

Collecting data from human-readable formats (PDF, xlsx) using artificial intelligence (AI) is one of the pillars of software solution development.

The study contributes to developing methods for automating BIM processes indicating the efficiency of developing solutions for automating routine tasks. The software solution can already be employed as a ready-made solution for a limited number of CAD systems.

In conclusion, the developed tool makes it possible to improve the quality of DIM formation. There will be focus on the flexibility of the software solution for a wide range of CAD systems and the integration of AI to work with diverse formats of human-readable requirements.

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# LIFE CYCLE MANAGEMENT OF CONSTRUCTION FACILITIES

# УПРАВЛЕНИЕ ЖИЗНЕННЫМ ЦИКЛОМ ОБЪЕКТОВ СТРОИТЕЛЬСТВА



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## Problems and Prospects of Risk-Oriented Management in Construction: a Review of Current Research

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**Abstract**

***Introduction.*** The construction industry has a major role to play in the global economy due to its multiplier effect, high volatility and complexity of production relations, however, existing risk management techniques, particularly those at the stage of investment justification, are still insufficiently developed. The aim of the study is to systematize modern approaches to risk-based lifecycle management of construction facilities, identifying gaps and promising areas of development, including the use of digital technologies. The main tasks include an analysis of the regulatory framework, a review of risk assessment methods and development of strategies for minimizing them for different types of real estate.

***Materials and Methods.*** A comprehensive bibliometric study of modern approaches to construction risk management using VOSviewer software has been performed. The most authoritative publications from the international Scopus and Web of Science databases, as well as prominent Russian scientific papers, have been selected to be analyzed. The study covered peer-reviewed articles, monographs, and dissertations from the last decade for a representative sample. Special attention is paid to a critical analysis of methodological approaches to risk assessment at the pre-project stage, where traditional methods show the greatest limitations. The study makes use of a systematic approach combining a quantitative analysis of publication activity with a qualitative assessment of the research content. On top of that, successful cases of the introduction of modern risk-oriented practices in real construction projects are explored.

***Research Results.*** The analysis has enabled the key trends in the field of construction risk management over the past decade to be identified. The results of the analysis are indicative of a stable relationship between the quality of the risk management system and success of construction projects, which comes to the fore while investigating modern digital technologies, including artificial intelligence and machine learning methods that are increasingly used for processing large amounts of data in the construction industry. The greatest methodological difficulties are faced with at the stage of investment justification, where traditional expert approaches require mandatory addition of digital analysis tools as confirmed by the practical cases of implementation of risk-oriented approaches explored in the study. The development of adaptive techniques is particularly relevant that takes into account both traditional types of construction risks and new challenges associated with the digital transformation of the industry and taking into account ESG factors, while bridging the existing gap between scientific developments and their practical implementation is becoming a major condition for successful modernization of risk management, which calls for taking coordinated actions by all involved in the construction industry and improving the regulatory framework in compliance with modern technological capacities.

***Discussion and Conclusion.*** The bibliometric analysis has displayed the transition from traditional risk management methods to digital solutions, while indicating the continuing gap between theory and practice, particularly at the stage of investment justification. Modern approaches are actively integrating BIM, decision support systems and AI, but there is a problem of the lack of qualified employees. Hybrid methods combining expert assessments with machine learning and considering new risk factors such as sanctions and environmental requirements are becoming particularly relevant, which calls for modernization of the regulatory framework and professional standards.

**Keywords:** risk-oriented construction management, capital construction objects, ISO 31000 standards, bibliometric analysis, VOSviewer, investment justification, life cycle of an object

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*Оригинальное эмпирическое исследование*

# Проблемы и перспективы риск-ориентированного управления объектом строительства: обзор современных исследований

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**Аннотация**

***Введение.*** Строительная отрасль играет ключевую роль в мировой экономике благодаря мультипликативному эффекту, высокой волатильности и сложности производственных взаимосвязей, однако существующие методики управления рисками, особенно на этапе инвестиционного обоснования, остаются недостаточно разработанными. Цель исследования — систематизировать современные подходы к риск-ориентированному управлению жизненным циклом строительных объектов, выявив пробелы и перспективные направления развития, включая применение цифровых технологий. Основные задачи включают анализ нормативной базы, обзор методик оценки рисков и разработку стратегий их минимизации для различных типов недвижимости.

***Материалы и методы***. Проведено комплексное библиометрическое исследование современных подходов к управлению строительными рисками с использованием программного обеспечения VOSviewer. Для анализа отобраны наиболее авторитетные публикации из международных баз Scopus и Web of Science, а также значимые российские научные работы. Исследование охватило рецензируемые статьи, монографии и диссертации последнего десятилетия, что обеспечило репрезентативность выборки. Особое внимание уделено критическому анализу методологических подходов к оценке рисков на предпроектной стадии, где традиционные методы показывают наибольшие ограничения. В работе применен системный подход, сочетающий количественный анализ публикационной активности с качественной оценкой содержания исследований. Дополнительно рассмотрены успешные кейсы внедрения современных риск-ориентированных практик в реальных строительных проектах.

***Результаты исследования.*** Проведенный анализ позволил выявить ключевые тенденции в области управления строительными рисками за последнее десятилетие. Результаты анализа демонстрируют устойчивую взаимосвязь между качеством системы управления рисками и успешностью реализации строительных проектов, что особенно заметно при рассмотрении современных цифровых технологий, включая методы искусственного интеллекта и машинного обучения, которые находят все более широкое применение при обработке больших массивов данных в строительной отрасли. Наибольшие методологические сложности сохраняются на этапе инвестиционного обоснования, где традиционные экспертные подходы требуют обязательного дополнения цифровыми инструментами анализа, что подтверждается рассмотренными в исследовании практическими кейсами внедрения риск-ориентированных подходов. Особую актуальность приобретает разработка адаптивных методик, способных учитывать как традиционные виды строительных рисков, так и новые вызовы, связанные с цифровой трансформацией отрасли и учетом ESG-факторов, при этом ключевым условием успешной модернизации риск-менеджмента становится преодоление существующего разрыва между научными разработками и их практическим внедрением, что требует согласованных действий всех участников строительной отрасли и совершенствования нормативной базы в соответствии с современными технологическими возможностями.

***Обсуждение и заключение***. Библиометрический анализ показал переход от традиционных методов управления рисками к цифровым решениям, выявив при этом сохраняющийся разрыв между теорией и практикой, особенно на этапе инвестиционного обоснования. Современные подходы активно интегрируют BIM, системы поддержки решений и ИИ, но сталкиваются с проблемой нехватки квалифицированных кадров. Особую актуальность приобретают гибридные методы, сочетающие экспертные оценки с машинным обучением, и учет новых факторов риска, таких как санкции и экологические требования, для чего требуется модернизация нормативной базы и профессиональных стандартов.

**Ключевые слова:** риск-ориентированное управление строительством, объекты капитального строительства, стандарты ISO 31000, библиометрический анализ, VOSviewer, инвестиционное обоснование, жизненный цикл объекта

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**Introduction**. The construction industry has a strategically important position in the global economy due to its three major characteristics. Firstly, it has a distinct multiplier effect, stimulating the development of related sectors from production of building materials to financial services. Secondly, the industry is characterized by high volatility of market conditions due to cyclical demand, dependence on the investment climate and regulatory changes. Thirdly, the construction complex is a n intricate system of industrial relations that unites numerous participants at all stages of the life cycle of objects - from design to operation. These characteristics are corroborated by modern economic studies [1] that accentuate the system-forming role it plays in the global economy.

The aim of the study in the framework of the research specialty 2.1.14 "Life Cycle Management of Construction Objects" is to develop and improve methods of risk-based management of real estate at all stages of their life cycle — from design and construction to operation, reconstruction and decommissioning [2].

The following research tasks can be addressed:

1. Analysis and systematization of risks typical for different stages of the life cycle of construction facilities with a focus on gaps in assessment methods at the investment justification stage.
2. Development of methods for assessing and ranking risks considering their impact on the economic efficiency and sustainability of construction projects.
3. Design of risk management algorithms, including methods for minimizing, transmitting, and monitoring risks.
4. Exploring the capacities of using digital technologies (BIM, Big data, AI) for forecasting and risk management, including the development of investment risk analysis tools.
5. Development of differentiated risk management strategies for different types of real estate (residential, commercial, industrial) considering their specific vulnerabilities and life cycle features.

The aim of the study is to review modern methods of risk-based lifecycle management of capital construction objects (CCO) with a focus on analyzing gaps in risk assessment methods at the stage of investment justification.

The key question is how risk management methods are to be developed in order for them to effectively cover all stages of the life cycle, particularly at the stage of pre-design solutions.

**Materials and Methods.** In an increasingly intricate business environment, risk management is becoming a major element of strategic management. It is to be noted that different international standards offer their own interpretations of the basic concept of risk. Based on the methodology of bibliometric analysis, this study is thus aimed at systematically identifying key trends in developing a risk-based approach to managing construction objects at all of their life cycle stages.

The analysis of international standards displays considerable differences in conceptual approaches to defining the basic concept of risk. E.g., ISO 31000:2018 Risk Management — Guidelines (ISO 31000) defines risk as "the impact of uncertainty on achieving goals, where impact is seen as any deviation from expected outcomes, both positive and negative ones." This definition accentuates the dual nature of risks that can not only jeopardize, but also create new opportunities for an enterprise.

In contrast, the Enterprise Risk Management — Integrated Framework (COSO ERM) focuses on negative aspects seeing risks as "events that might hinder value creation or cause its reduction." This approach reflects the traditional orientation of the American model towards protecting shareholder value and business sustainability.

The European standard of the Federation of European Risk Management Association (FERMA) actually offers a more neutral definition, "the combination of the probability of an event and the scale of its consequences." Unlike COSO ERM, this does not divide risks into "good" and "bad" ones, but focuses on the mechanisms of their quantification instead.

The practical importance of these differences becomes obvious while analyzing specific cases. E.g., while implementing ESG strategies (environmental, social and management factors), ISO 31000 allows companies to take into consideration environmental initiatives not only as costs, but also as an opportunity to create a new value. At the same time, COSO ERM is still preferred for financial institutions where minimizing losses is a key objective.

It should be noted that modern organizations are increasingly combining the above approaches. Hence 67% of Fortune 500 companies are employing COSO ERM in order to assess traditional risks, while simultaneously applying ISO 31000 to manage innovative projects, where "positive" risks might become a source of competitive advantages.

Hence the choice of risk definition depends not only on regulatory requirements, but also on the strategic priorities of the organization, which is a testimony of the need for a flexible approach to building risk management systems.

The current Russian regulatory and methodological framework for risk management in the construction industry is a multi-level system based on the principles of consistent detail and specialization.

The system relies on three key regulatory documents forming the methodological foundation for effective risk management. The first and fundamental is GOST R ISO 31000-2019 "Risk Management. Principles and Guidelines" that establishes the conceptual framework and principles for risk management. This standard defines fundamental approaches to identying, analyzing and assessing potential threats, sets forth a methodology for developing and implementing preventive measures and formulates requirements for integrating risk management into the overall management system of an organization. Special attention is paid to forming a risk-oriented corporate culture, which is of particular importance for construction companies operating in high-risk environments.

The second critical element of the system is GOST R 51897-2021 "Risk Management. Terms and Definitions" is an adapted international standard ISO Guide 73:2009. Its major function is to ensure the terminological unity and clarity of the conceptual framework. The document contains rigid definitions of key terms helping to avoid discrepancies and ensure consistency in interpreting the fundamental concepts of risk management at all levels of management of a construction organization. On top of that, the standard assists harmonization of Russian practice with international approaches, which is of particular importance for companies engaged in international projects.

The third component of the methodological triad is GOST R 58771-2019 "Risk Management. Risk Assessment Technologies", which is a practical toolkit for risk assessment. Unlike the first two documents, which are conceptual in nature, this standard contains specific technologies and methods for risk analysis, algorithms for choosing optimal assessment methods depending on the type and nature of the risk, as well as criteria for the efficiently of the approaches being used. Practical mechanisms for both quantitative and qualitative assessment are particular significant allowing construction companies to obtain reliable data for management decision-making.

The interaction of the three standards creates a comprehensive regulatory platform where each document performs its own unique function: GOST R ISO 31000 sets strategic guidelines and general principles, GOST R 51897 provides terminological clarity and unity of the concepts, and GOST R 58771 offers specific tools for practical work. Such a system enables construction organizations to build effective risk management, starting from forming a common strategy and ending with implementing specific assessment procedures, while ensuring terminological consistency at all stages of the life cycle of construction objects and compliance with the international standards.

For the practical implementation of a risk-based approach, a set of methodological documents has been developed, including GOST R 51901.7-2017 "Risk Management. Guide to Implementing ISO 31000" (adaptation of ISO/TR 31004:2013) and a series of recommendations R 50.1.068-2009, P 50.1.069 2009 and R 50.1.070-2019. These standards contain detailed guidelines for implementing a risk management system considering the specifics of construction activities, providing methodological support at the stage of practical application.

In the system of regulatory regulation of risk management processes, a group of standards regulating formation and maintenance of risk registers is particularly significant which includes: GOST R 51901.21-2012 "Risk Management. Risk Register. General Provisions" establishing the basic requirements for the structure and content of the registry; GOST R 51901.22-2012 "Risk Management. Risk Register. Design Rules" defining the procedures for updating data;

GOST R 51901.23-2012 "Risk Management. Risk Register. Guidelines for Assessing the Risk of Dangerous Events for Inclusion in the Risk Register" establishing the methods of ranking and prioritization; GOST R 50.1.084-2012 "Risk Management. Risk Register. Guidelines for Creating the Risk Registry of an Organization" taking into consideration the industry-specific features of building registers. At the same time, private risk assessment methods such as GOST R are of great methodological importance. IEC 62502-2014 "Risk Management. Event Tree Analysis" describing the methodology of event tree analysis, GOST R 51901.12-2007 "Risk Management. A method for Analyzing the Types and Consequences of Failure" containing principles for assessing the reliability of technical systems, and GOST R 54141-2010 "Risk Management. Guidelines for Applying Organizational Security Measures and Risk Assessment" offering comprehensive risk analysis techniques.

The GOST R series standards are an integral component of the system. ISO 9000 "Quality Management Systems. Basic Provisions and Glossary" ensuring harmonization of a risk-based approach with the requirements of quality management. Among them are GOST R ISO 9000-2015 laying the terminological foundations; GOST R ISO 9001-2015 "Quality Management Systems. Requirements" formulating mandatory requirements; GOST R 57189-2016/ISO/TS 9002-2016 "Quality Management Systems. Guide to Applying ISO 9001:2015" containing practical recommendations for implementation; GOST R ISO 9004-2019 "Quality Management. Quality of an Organization. Guide to Achieving Sustainable Success of an Organization" describing methods for achieving sustainable results.

The presented regulatory documents form an integrated system where risk registers serve as an information foundation, assessment methods provide an analytical component, and ISO 9000 standards create an organizational and methodological context for efficient implementation of the principles of a risk-based approach. Such a comprehensive regulatory framework allows for the consistent implementation of modern risk management methods at all levels of the organizational structure of a construction company, while ensuring the necessary consistency with the international standards and industry requirements.

In industrial and construction risk management, industry standards that take into account the specifics of production activities are of particular importance. GOST R 14.09-2005 "Environmental Management. Environmental Management Risk Assessment Guide" regulates risk management processes in construction in detail, covering all stages — from design to commissioning of objects. This document contains methodological recommendations for identifying and minimizing typical construction risks, including technological, organizational and environmental aspects. Along with it, there is GOST R 12.0.010-2009 "Occupational Safety Standards System. Occupational Health and Safety Management Systems. Hazard Identification and Risk Assessment" that establishes requirements for occupational health and safety management systems, which is of particular importance for the construction industry with its high level of occupational risks.

As the construction industry is experiencing active digitalization, the role of GOST R ISO/IEC 27005-2010 "Information Technology. Methods and Tools of Ensuring Safety. Information Security Risk Management" providing a methodological framework for information security risk management. This standard is particularly significant in implementing BIM technologies and digital platforms for construction project management. GOST R IEC 62198-2015 "Project Management. Guidelines for Applying Risk Management in Design" complements the regulatory framework and offers an integrated approach to project risk management throughout the entire life cycle of a construction object.

The final and integrating element of the entire system is GOST R ISO 19011-2021 "Compliance Assessment. Guidelines for Management System Audit" that serves the crucial function of monitoring and improving risk management. The standard does not only establish uniform audit requirements, but also creates an efficient mechanism for:

– objective assessment of efficiency of the applied risk management methods;

– identifying weaknesses and potential growth opportunities;

– development and implementation of corrective measures;

– ensuring transparency and accountability of all the processes.

This integrated approach enables construction companies not only to comply with the current safety and quality requirements, but also to continuously improve their risk management systems adapting to changing conditions and new challenges facing the industry. The above systematization demonstrates a holistic methodological platform combining the universal principles of risk management with industry-specific construction activities. The multi-level structure of the

regulatory framework enables a risk-based approach to be consistently implemented from strategic planning to operational management at the level of specific construction projects.

Hence while aligning with the international practices, Russian risk management standards offer tools for working in turbulent conditions. Their rational combination allows organizations not only to minimize threats, but also to transform risks into growth opportunities ensuring long-term sustainability in a multi-crisis environment.

Risk management in construction covers a wide range of factors, including economic, technical, technological, organizational, environmental, social and legal aspects, which calls for an integrated interdisciplinary approach combining economic analysis, technical expertise, legal regulation and environmental monitoring by means of modern digital technologies and machine learning methods. Analysis of the works by leading foreign and domestic scientists, including P. Grabovoy [2], Ye. Altman [3, 4], L. Bernstein [5], F. Knight [6], Brigham [7], A. Lapidus [8], etc. demonstrate three main vectors of scientific research: study of the genesis of risk factors, development of their classification systems and search for efficient management methods. At the same time, in the field of construction projects, special attention is being paid to the issues of permanently clarifying risk classification [9], predicting potential damage, optimizing control systems and developing risk mitigation mechanisms at different stages of the life cycle of an object. However, the existing concepts are considerably different both in terms of the terminology, where there are discrepancies in the definition of the fundamental concepts of "risk" and "uncertainty", and in terms of the methodological tools ranging from traditional quantitative methods to modern neural network technologies.

In modern studies of assessment of risks of construction projects, special attention is being paid to the issue of the lack of reliable statistical data for quantitative analysis. Expert assessments are commonly used in analyzing complex technical problems, but they call for formalization and rigorous methodology in order to ensure reliable outcomes.

As noted in [10], as there are no representative samples for assessing new, unique construction technologies, expert assessments are becoming an essential tool for risk management. Expert methods are of particular significance in analyzing rare events, complex risks with lots of interrelated factors, as well as in the early stages of the life cycle of an object when statistical data have not been accumulated yet.

A major aspect while using expert assessments is meticulous selection of specialists. According to research, the optimal criteria are professional recognition in the industry (confirmed by a membership in specialized associations, scientific publications or participation in significant projects), practical work experience of no less than 5–10 years in a specific field of construction, as well as reputation among colleagues. According to common practice, the most reliable sources for seeking for experts are databases of professional associations, top construction consulting companies and academic institutions focusing on research in the field of construction technologies.

In order to minimize the subjectivity of expert assessments, modern research is making use of special techniques, including anonymous Delphi surveys allowing reaching consensus with no pressure from authorities, a system of weighting factors that takes into consideration each expert's level of competence, as well as validation procedures by comparing against the known cases and historical data. An interesting example from [21] shows that while analyzing high-rise construction risks, expert assessments indicated 37% of potential threats that were not reflected in the available statistics, but were subsequently confirmed in actual incidents. This case clearly indicates how well-organized expert analysis can compensate for the lack of statistical data, especially while working with new or unique construction technologies and objects.

According to R. Keeney et al. [11], despite the wide use of expert assessments in technical analyses, existing methods for obtaining them frequently prove to be methodologically flawed. Following a comparative analysis of two stages of a large-scale nuclear safety study — using internal experts and involving 40 external specialists from universities, consulting firms and national laboratories — the authors have been able to develop a comprehensive structured approach, including special expert training, decomposition of assessments and formalized data collection procedures, which allowed them to obtain more than 1,000 reliable probability distributions and was positively evaluated during an expert review.

According to [12], unlike traditional risk assessment tasks, expert judgments have a special role to play in designing complex systems, from identifying potential failures to developing preventive measures, and justify the need for a holistic approach integrating expert assessments at all stages of the life cycle of a system and minimizes subjective distortions.

The well-known Russian scientist A.A. Lapidus and et al. deal with the problems of a risk-based approach in [13–16] that examines the issues of effective selection of the experts and methodology of a risk-based approach in organizational and technological solutions and construction stages.

In conditions of high dynamics of construction, the technical customer cannot be in continuous control, which calls for a risk-based approach to be introduced in order to prioritize inspections. The aim of the study is to develop a methodology for identifying, analyzing and ranking construction control risks in order to optimize supervisory activities [17].

The authors of [18] developed a practical tool for selecting methods of risk analysis in construction based on the characteristics of a project confirming its efficiency during testing on actual objects by means of data visualization.

A. Chan and et al. [19] presented a systematic review of using fuzzy methods in construction management, analyzing the literature published in the top research journals over the past decade in order to identify the major areas and prospects for further research. During the review, two major areas were identified — fuzzy sets/fuzzy logic and hybrid fuzzy methods, which, in turn, are classified into four key categories: decision making, performance, evaluation/analysis, and modeling. Analyzing the current trends, the authors noted an increasing interest in integrating fuzzy methods with other computational approaches, such as neural fuzzy systems which overcome the limitations of traditional methods. On top of that, there is a tendency to expand the scope of application of fuzzy methods beyond construction management, including environmental disciplines, which emphasizes their relevance and significance in solving complex problems amidst uncertainty.

P.K. Dey in 2001 [20] developed a Decision Support System (DSS) that integrates the Analytical Hierarchy Process (AHP) method and decision trees for risk management at the initial stages of construction projects making it possible to systematize assessment of qualitative and quantitative risk factors. This approach offers a structured representation of the relations between different risks and their possible development scenarios, which is particularly significant for strategic decision-making at the early stages of a project.

In a systematic review by A. Taroun [21] in 2013 there was a comprehensive analysis of the evolution of risk management approaches in the construction industry over a fifty-year period. The study showed that despite the steady prevalence of the traditional P–I (probability–impact) risk assessment model, in recent decades there has been a clear trend towards a shift to more comprehensive and advanced methodologies. The current approaches are increasingly take into consideration the complex interdependencies between different risk categories, as well as their interaction with the parameters of a project environment. Analytical methods such as fuzzy set theory (FST) and hierarchy analysis (AHP), as well as various decision support systems (DSS), have become particularly common. However, the author emphasizes the ongoing major gap between the theoretical developments in the field of risk management and their practical application in actual construction projects. As the major areas of development A. Taroun offers modernization of the traditional P–I model by means of including additional parameters, active implementation of unified assessment metrics (particularly, the concept of "risk-value"), a more complete use of practitioners' professional experience as well as the development of new integrated solutions capable of integrating advanced theoretical developments with the actual needs of construction practice. The key takeway of the study is the need for fundamental rethinking of the existing approaches towards risk management in order to bridge the accumulated gap between theory and practice. A. Taroun's study remains a critical methodological guideline for modern research in the field of construction risk management setting pace for further development of this relevant theoretical and practical discipline.

According to recent studies, emerging risks in construction are increasingly important characterized by nonlinear relations and deviations from classical probabilistic models calling for development of new analysis methods integrated into digital platforms in order to support decision-making amidst uncertainty. It is of particular significance to study the relation of such risks with events such as "a black swan" — rare and disastrous events that are almost impossible to predict by means of classical probabilistic methods [22].

In [23], a digital platform was developed integrating BIM and automatic object monitoring (RFID) technology using radio waves. The solution indicates efficiency in managing construction processes, but it calls for additional adaptation to overcome barriers in terms of the employees' digital skills.

Implementing BIM methodologies entails significant risks that minimize their potential benefits. In [24], the major barriers to digital transformation of construction processes are systematized.

In the context of the mounting pressure of the sanctions, being mindful of political risks is becoming a crucial factor in sustainable development of the Russian construction industry. According to X. Deng and et. al [25], competent management of such risks can prove to be a competitive advantage. An analysis of international experience [26] has revealed the major sources of political risks and effective strategies for mitigating them.

An analysis of research publications on risk management in construction has displayed the following specialized areas: time and budget management [27], integration of knowledge in the field of occupational safety and information and communication technologies [28], environmental aspects of construction [29] and protection from natural disasters [30], which is indicative of the multidisciplinary nature of the latest approaches to construction risk management.

**Research Results.** A systematic manual bibliometric analysis complemented by an analysis using VOSviewer software [31] (Fig. 1) has indicated a complex structure of relations between the major risk management concepts in the construction industry.

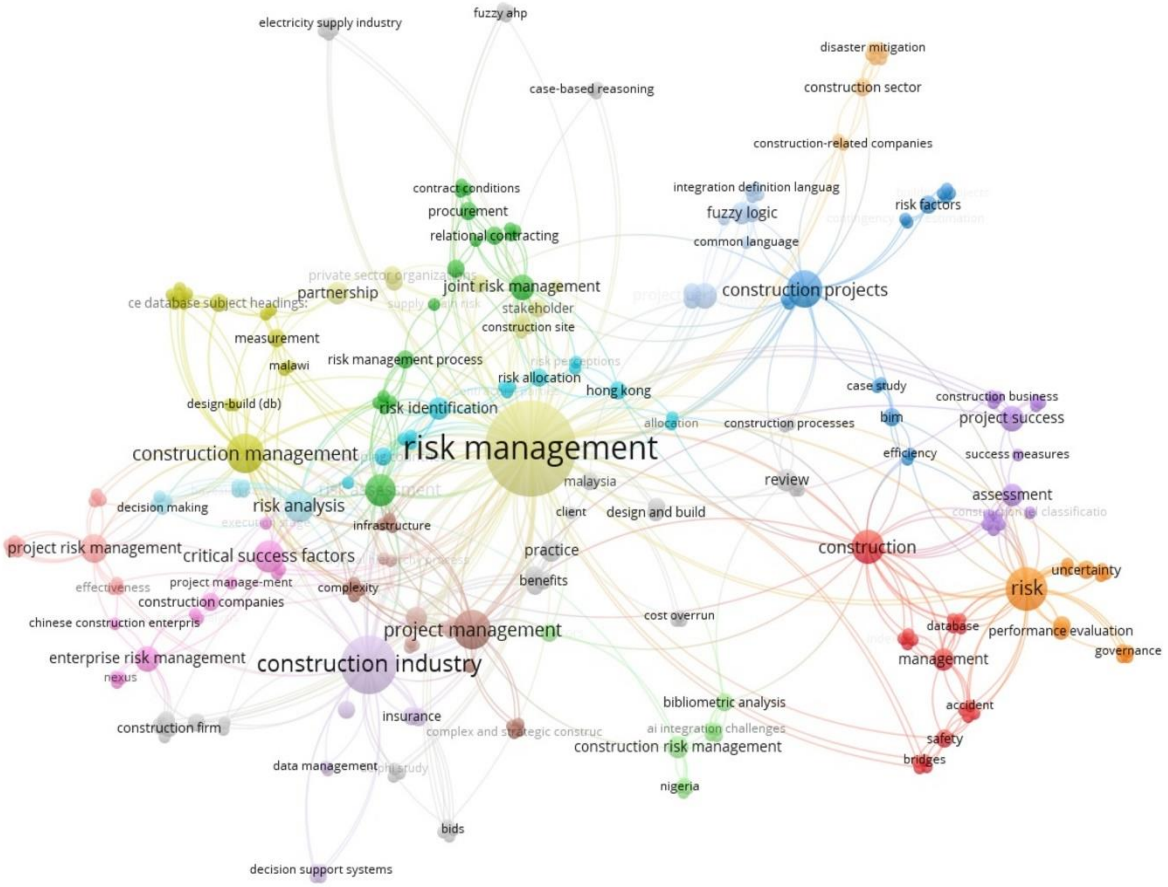


Fig. 1. Analysis of the thematic structure of research in the field of risk management of construction projects based on cluster visualization

Using the text mining feature in VOSviewer, keywords were extracted from titles, annotations, and citation contexts [32]. The central element of the network is the concept of "risk management" indicating the highest frequency of research publications and forms the semantic core of studies. Stable links diverge from this term to four main thematic clusters: "construction industry" (construction industry — the brown cluster), "construction projects" (construction projects — the blue cluster), "critical success factors" (critical success factors — the red cluster) and "risk" (risk — the orange cluster).

The blue cluster is of the greatest methodological importance combining the terms "fuzzy logic", "case-based reasoning" and "BIM-based risk management", which indicates the growing use of mathematical methods and digital technologies for analyzing uncertainties in construction projects. Special attention should be paid to the identified relation between the concepts of "project success" and "risk factors" with a connecting line thickness of 0.78, confirming the significant impact of the quality of risk management on the final results of construction activities.

The red cluster including the terms "governance", "safety" and "cost" reflects the importance of organizational aspects of risk management. It is to be noted that the concept of "decision support systems" forms a bridge between the technical (blue) and the managerial (red) clusters emphasizing the interdisciplinary nature of the recent research.

The analysis enables us to make the following conclusions:

1. The latest research on risk management in construction is characterized by a distinct multidisciplinary approach combining technical, managerial and mathematical ones.

2. There is a steady trend of risk management digitalization, which means active introduction of BIM technologies and decision support systems.

3. Fuzzy logic and case-based reasoning are becoming standard tools for assessing construction risks.

4. The efficiency of risk management directly correlates with the success of construction projects as confirmed by the strength of the identified semantic links.

The results are critical for further development of risk management methodology in construction indicating the need for integrated consideration of technological, organizational and information aspects in developing new management solutions.

**Discussion and Conclusion.** The bibliometric analysis has displayed the evolution of risk management in construction from traditional methods to digital solutions identifying the relationship between the standards, methods and areas of the recent research.

According to the analysis, despite a considerable progress attained in methodological support, including the international and national standards, there is still a major gap between the theoretical developments and their practical application, which is particularly osberved at the stage of investment justification of projects. The latest approaches to risk management are integrating digital technologies to a growing extent, including BIM, decision support systems, and artificial intelligence methods, which might greatly improve prediction accuracy. However, the process of digital transformation is faced with some major organizational and personnel barriers in terms of the lack of the employees' relevant competencies [24, 25].

The current situation has profound methodological roots. The expert assessment methods being widely used in the industry and absolutely practically valuable are displaying systemic limitations associated with the inevitable subjectivity of expert judgments. This is crucial in the context of the uniqueness of construction projects and the lack of relevant statistical data at the pre-project stage.

In this context, the development of hybrid approaches combining the advantages of expert assessments with the capabilities of machine learning is of particular importance. Such integrated approaches are in great demand while assessing complexly formalized risks characteristic to the initial stages of construction projects, where traditional methods often prove to be insufficiently efficient.

The current geopolitical realities, including restrictions imposed by the sanctions [26] as well as the tightening environmental regulations [30] are acting as additional uncertainty factors that are hardly taken into consideration in the traditional risk management models. These changes call for a major revision of the existing approaches to risk assessment and management in construction.

At the same time, risk management in construction calls for a balance between innovation (digitalization, artificial intelligence) and reliability (standards, expertise). Bridging the gap between theory and practice will be a major condition for sustainable development of the industry amidst turbulence.

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# TECHNOLOGY AND ORGANIZATION OF CONSTRUCTION
# ТЕХНОЛОГИЯ И ОРГАНИЗАЦИЯ СТРОИТЕЛЬСТВА





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*Original Empirical Research*

## Research on Budget Control Issues and Strategies in EPC Projects Implemented in People's Republic of China

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**Abstract**

***Introduction.*** The global practice of implementing investment projects distinguishes EPC and EPCM contracts as the most promising strategies for implementing complex infrastructure and industrial projects. In Russia, the EPC contracting scheme is the most common one in the oil and gas industry, largely in implementing foreign projects in the Russian Federation. In other industries, the development of the EPC market in the Russian Federation is in its infancy.

The article looks into the problems during implementing investment and construction projects in People's Republic of China and which should be considered in the Russian Federation. The aim of the study is to identify the existing problems of the EPC contract and set forth some ways of addressing them.

***Materials and Methods.*** A comparative analysis of the construction project management methodology based on signing an EPC contract has been performed.

***Research Results.*** Based on the analysis of the problems of controlling the budget of the EPC contract in China, a methodological guide for working with the budget of the EPC contract has been developed.

***Discussion and Conclusion.*** Enterprises that have signed an EPC contract need, most importantly, to standardize the project's budgeting management system, to improve project change management, to optimize supply chain management of material resources, to develop an algorithm of addressing the problem of exceeding the budget limit and to improve the budget assessment mechanism accounting for the current actual situation. It is assumed that owing to the above measures, the effectiveness of budget control of general contracting enterprises of EPC contracts will be enhanced.

**Keywords:** EPC contract, investment and construction project management, budget control, design errors, construction cost, construction deadlines

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*Оригинальное эмпирическое исследование*

## Исследование проблем бюджетного контроля и стратегий в проектах EPC, реализуемых в Китайской народной республике

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**Аннотация**

***Введение***. Мировая практика реализации инвестиционных проектов выделяет EPC- и EPCM-контракты как наиболее перспективные стратегии реализации сложных инфраструктурных и промышленных проектов. В Рос-

сии в настоящее время схема EPC-контрактования наиболее распространена в сфере нефтегазовой промышленности, в основном при реализации зарубежных проектов на территории РФ. В остальных отраслях развитие рынка по схемам EPC в РФ находится в зачаточном состоянии.

В статье рассматриваются проблемы, которые возникают при реализации инвестиционно-строительных проектов в КНР и которые следует учитывать в РФ.

Цель исследования — выявить существующие проблемы EPC-контракта и предложить пути их решения.

***Материалы и методы***. Проведен сравнительный анализ методологии управления строительным проектом на основе заключения EPC-контракта.

***Результаты исследования*.** По итогам анализа проблем контроля бюджета EPC-контракта в КНР разработано методическое руководство по работе с бюджетом EPC-контракта.

***Обсуждение и заключение***. Предприятиям, заключившим EPC-контракт, необходимо прежде всего осуществить стандартизацию системы управления бюджетированием проекта, улучшить управление изменениями в проекте, оптимизировать управление цепями поставок материальных ресурсов, разработать алгоритм решения проблемы превышения лимита бюджета и улучшения механизма оценки бюджета с учетом сложившейся фактической ситуации. Предполагается, что благодаря этим мерам эффективность бюджетного контроля генподрядных предприятий EPC-контрактов будет повышена.

**Ключевые слова:** EPC-контракт, управление инвестиционно-строительным проектом, бюджетный контроль, ошибки проектирования, стоимость строительства, сроки строительства

**Для цитирования.** Ли Цун, Зеленцов Л.Б., Пирко Д.В., Тузлуков К.В. Исследование проблем бюджетного контроля и стратегий в проектах EPC, реализуемых в Китайской народной республике. *Современные тенденции в строительстве, градостроительстве и планировке территорий*. 2025;4(3):77–84. https://doi.org/10.23947/2949-1835-2025-4-3-77-84

**Introduction.** Since the 1980s, the State Council of the People's Republic of China, various ministries and commissions in the field of construction have prepared and issued documents pertaining to the general contract, and a new trend has emerged in the engineering contracting market, i.e., customers have increasingly been making use of the general contract construction regime in investment projects.

Back then, the government issued regulatory documents regulating the implementation of the EPC methodology. The implementation of the methodology and the implementation of pilot EPC projects in China started in 1984. In September 1984, testing of a general contracting regime got underway at chemical industry facilities. In November 1997, the "Construction Law" came into effect in China showing direct support of the introduction of a general contracting regime, and in August 1999, the Ministry of Construction issued a document "On Guiding Decisions on Promoting Large Design Units for Creating International Engineering Companies." In this document, it was assumed that integrating a number of survey and design departments into international engineering companies with possible signing of a general contract for design, procurement and construction would take about five years. In early 2014, the relevant ministries and commissions of China issued a general directive for further expansion of the application of the EPC contract concept. The directive was aimed at correcting and improving the existing investment and construction project management system, increasing responsibilities of an EPC contractor and management personnel, training a talent pool of the youth, etc. As a result of the activities, an EPC contractor regime started developing rapidly in China.

Design, Procurement and Construction include a general contract, according to which a general contractor takes on full responsibility for implementing a general contract model: design, procurement, construction and commissioning of a premises at a specified time with a fixed cost and ensuring the required work quality and safety. The most critical feature of the EPC regime is to make the most of the role of market mechanisms. The project owner will not firstly only consider it as an investment project, but it is also necessary to account for all the project participants' interests prioritizing designers and contractors.

The aim of the study is to identify and investigate the problems associated of controlling EPC contract budgets.

**Materials and Methods.** The study made use of the methods of comparative analysis of a traditional general contractor agreement with an EPC contract. Given that a fixed contractual price is used while signing an EPC contract, an EPC

contractor has hardly any possibility of changing the price, except for emergencies. This compels an EPC contractor at the tender selection stage to perform a detailed calculation of its price, accounting for a meticulous analysis of prices for building materials and technological equipment, and launch preliminary negotiations with potential subcontractors on pricing policies for certain construction and installation works.

Problems of EPC contract budget control are as follows:

1. Insufficiently justified development of a construction project budget based on the existing methodology of managing it.

First of all, the internal control mechanism of EPC-contract enterprises is flawed. Some EPC contractors choose to ignore the significance of internal control management, and their management system has serious flaws making the company not able to manage budgeting effectively, which ultimately impacts the financial stability and efficiency of a project [1]. In some cases, a project budgeting method is not always scientifically viable. While preparing a project budget, employees of some EPC contractors rely only on historical data, i.e., they budget based on cost data for the previously completed projects neglecting the influence of external factors such as changes in market conditions and introduction of new technologies, which results in budget deviation from the actual costs. Finally, budgeting information is not transparent, and data is not updated in a timely manner leading to incomplete and accurate budgeting information, which increases risks of a project failure.

2. Flawed change management in a project.

EPC contracts involve lots of participants influenced by adjustments to technical parameters, changes in a customer's needs and a market environment, etc. In order to ensure unconditional completion of a project, an EPC contractor might make changes to the scope of work in the course of construction if necessary and on a customer's consent.

Changes in a project will inadvertently impact an EPC contract's budget control system, and there are budget control risk points in each aspect of change management in an EPC contract. Some changes in a project might not be detected in a timely manner resulting in uncontrolled change management; even if changes were identified, due to insufficiently effective assessment methods and the management personnel's professional level, the assessment of changes in a project was insufficiently accurate, which might have a negative impact on management decision-making. On the other hand, communication channels and negotiations between an EPC contractor and interested parties do not always run smoothly, and project changes are not always responded to well, which has further impact on the accuracy and reliability of project budget control [2].

3. Disruptions in the management of supply chains of material resources.

Some EPC contractors do not manage the supply chain of material resources in a proper way frequently causing the following situations to occur. Firstly, delays in the supply chain might result in the equipment and materials needed for the construction of the facility not being delivered to the construction site on time having a serious effect on the progress of a project. Secondly, the quality of the materials or equipment supplied might not comply with regulatory requirements and design solutions so that an EPC contractor has to spend time and/or financial resources on repairing and replacing the equipment at hand increasing the actual cost of a project. Thirdly, a supplier itself might have financial difficulties causing a violation of contractual obligations. On top of that, other unforeseen circumstances might occur during the implementation of the ICP, and an EPC contractor's contingency plan might be flawed, which increases the uncertainty around implementing an EPC contract.

4. An unconventional approach to managing budget overspending.

In the course of project management, it is necessary to constantly keep track of the budget of an EPC contract. A project budget might be seriously affected by changes in market prices for equipment being used that can have a fairly large range of fluctuations compelling an EPC contractor to constantly keep track of the prices and make timely changes to a project implementation strategy [3]. Secondly, some insufficiently substantiated provisions in the tender documentation might also lead to budget overspending, e.g., the subject of a contract is not clear and a contractor will have to take unwise decisions on additional responsibility, etc.

**Research Results**. A strategy for responding to EPC contract budget control issues is as follows.

1. Standardization of project budgeting management procedures.

First of all, while signing an EPC contract, an enterprise should pay attention to an internal control mechanism, specify the responsibilities and powers of each individual department and employee, and comprehensively strengthen control and

management of all the budgeting aspects [4]. Relying only on data from previously implemented similar projects in budgeting might easily lead to bias, so an EPC contractor's management staff should employ a range of budgeting methods. In addition to data on similar projects, the impact of changes in current market conditions, introduction of new technologies and other factors should be considered, data search and analysis methods applied, project characteristics combined with a trend analysis and risk assessment in order for a scientific assement of the cost structure of the budget. Finally, while implementing EPC contracts, an EPC contractor is to identify the channels for collecting and transmitting information so that relevant information can be transmitted to the employees in a timely and accurate manner for decision-making to take place.

2. Improvement of change management in a project.

In order to enhance the quality and effectiveness of project budget control, an EPC contractor is to improve the following aspects of its work. First, an EPC contractor is to come up with comprehensive change management policies and procedures, specify the process of identifying, registering, evaluating, approving, and introducing changes, to ensure consistency and transparency in change management, and reduce the number of unauthorized changes. Secondly, an EPC contractor is to create a project office, i.e., an interdepartmental group for assessing changes that emerge during project implementation including the finance director, the project manager, the heads of the estimated contractual and production departments, the head of construction and other experts.

The Project Office has a special responsibility for assessing the validity, necessity and impact of changes and decides on the approval of certain directives to ensure that the changes are in line with the overall interests of the project. In addition, EPC contractors need to make use of modern information technologies in order to design an intelligent change management system and a system for predicting their impact on a project budget based on accumulated data [5].

3. Optimization of supply chain management of material resources.

While managing logistics, i.e., supply chains of material resources, EPC contractors are to comprehensively assess potential suppliers, i.e., their technical capabilities, reliability, experience, quality management system, etc. Use big data analysis technology in order to improve the efficiency and accuracy of supplier assessment and ultimately design a supplier assessment database. Such a database could be employed in order to select cooperation partners. Partners with a good reputation and reliability should be chosen to ensure the stability of material supply chains. At the same time, EPC contractors are to develop and submit requests for suppling material resources to supplier databases in a timely manner in order to design a long-term supply management mechanism. When it comes to the issues in the existing supply chain, an EPC contractor is expected to switch to alternative suppliers in a timely manner in order to avoid grave consequences jeopardizing a project [6].

4. A viable solution to the problem of project budget excess.

An EPC contractor is to account for a market landscape and actual financial condition of an enterprise, keep track of the budget of each project, increase the ability of integrated management of project, procurement and construction activities, and design and develop a common cost management and budgeting model for a project accordingly. In order to design a profitability management system for the project, identify the point of balance of profit and loss as well as positioning of an enterprise in a market and to create a target budget limit system [7].

In particular, an enterprise management should take the following measures to scientifically address the problem of budget excess. First, an EPC contractor is to design a flexible and dynamic procurement mechanism, establish long-term cooperative relations with suppliers in order to obtain large price concessions, and adjust the procurement plan in a timely manner for adapting to market price changes. Secondly, an EPC contractor is to reinforce the interaction of structural units while drafting tender documents to ensure clarity of the scope of a proposal, viability and feasibility of a customer's requirements, as well as avoid unreasonable provisions on unlimited liability. At the same time, EPC contractors are to build a professional legal team to confirm the compliance of the tender documents in order to avoid legal disputes and increase the costs of an enterprise. Finally, EPC contractors can plan and coordinate budget control work ahead of time, reinforce communications between a contractor and a customer, identify a target date for project completion, forecast and adjust as early as possible during budget preparation in order to facilitate project progress and monitor costs.

5. Improvement of budget assessment mechanisms.

In order to further improve the quality and efficiency of an EPC contract budget control, contractors are to improve the project budget assessment mechanism and comply with the principles of targeted management, as well as to design a personnel management system [8].

On the other hand, EPC contractors are to come up with proper standards and budget estimates for employees in compliance with the content of their work they are held accountable for. For project managers and employees directly accountable for a project workflow, more specific and quantifiable indicators such as cost management levels and work completion levels can be employed to assess budget efficiency [9].

By now, China has already gained positive experience in implementing investment and construction projects based on EPC contracts.

Let us consider as an example an implemented project based on an EPC contract "Construction of a Photovoltaic Power Plant with a Capacity of 50 MW".

The total contract value is 250 million yuan (including design, purchase of equipment and construction).

The duration of an ICP implementation is 12 months.

The aim of budget control is to maintain the cost deviation within ± 3%.

1. Budget preparation stage.

1.1. Detailed budget breakdown by cost items (Table 1).

Table 1

Contract budget

| **Cost item** | **Budget value, yuan** | **%** | **Recommendations** |
|---|---|---|---|
| Project | 12,000,000 | 4.8 | Reducing the number of changes |
| Purchasing photovoltaic modules | 120,000,000 | 48 | Accounting for exchange rate fluctuations |
| Buying an inverter | 30,000,000 | 12 | Receiving discounts for a purchasing volume |
| Construction and installation fees | 60,000,000 | 24 | Time management of workers and construction machines |
| Project management fee | 15,000,000 | 6 | Reduction of optional expenses (e.g., transportation) |
| Risk reserve | 13,000,000 | 5.2 | Reserving financial resources due to weather conditions, increased material prices, etc. |

1.2. Key control indicators.

Project optimization: using a BIM model for more accurate calculation of excavation volumes, which will cut the budget by 2 million yuan.

A contract with a supplier of components is signed according to the "open contract" scheme stipulating a price fluctuation of no more than ± 2% [10].

2. Dynamic control of a project during its execution.

2.1. Monthly expense analysis (month 6).

Table 2 shows the actual figures for the 6 months of a project implementation.

Table 2

Budget: planned, actual, deviation

| Indicators | Budget, thousand yuan | Actual expenses, thousand yuan | Deviation, % | Analysis of the causes | Corrective measures |
|---|---|---|---|---|---|
| Photovoltaic panels. Solar panels | 6 000 | 6 300 | + 5 | Increase in prices for silicon materials causes introduction of price adjustment provision. | Risk reserve budget of 3 million yuan |
| Construction and installation | 3 000 | 2 700 | – 10 | Using ready-made brackets saves time | The remainder of the budget funds is transferred to the risk reserve |
| Design changes | 200 | 500 | + 150 | Owners' new requirements for the storage system energy | Initiating submitting an application for changes |

2.2. Management tools.

Early warning mechanism: if individual expenses exceed the budget by 5%, this automatically triggers management audit.

Purchase record journal: real-time update of information on equipment delivery and payment avoiding overspending on advance payments.

Table 3

Final project indicators

| **Result** | **Data** |
|---|---|
| Total cost | 253 million yuan (+ 1,2 %) |
| Savings | Construction optimization has saved 4 million yuan |
| Overspending | Design changes increased the costs by 3 million yuan |
| Conclusion | The cost deviation is maintained within the target range |

**Discussion and Conclusion.** An analysis of the work of EPC enterprises in China on budget control has shown that there are still some issues to be resolved.

Based on the results of the analysis (Table 3), the following conclusions can be made:

1. Equipment purchasing calls for preliminary price fixing (price calculation based on analyzing market offers).

2. The resulting savings from construction can be employed for overspending compensation caused by the other budget items.

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