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Calculation algorithm of the building of CLT for the Russian Federation

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Abstract. The design of modern CLT structures in Russia is still under development. This calculating algorithm is proposed for designing of the CLT structures in Russia. The calculation of the CLT was carried out in accordance with the Russian codes of SP 64.13330.2017 Timber structures. The calculation algorithm allows, on the one hand, to automate the design and, on the other hand, to calculate the CLT according to the existing Russian codes of SP 64.13330.2017 Timber structures, and from the third, to obtain some necessary value of compression stress perpendicular to the CLT plane. In our case modelling was done in the Revit software for computer-aided design that implements the principle of building information modelling. For comparison internal stresses (shear, tensile and compressive) with the design resistance accordance with Russian codes "СП" calculation results were obtained from the program Dlubal RFEM (finite element structural analysis program).To obtain new values of compression stress perpendicular to the CLT plane and its subsequent verification, there is a branch in the algorithm.

1. Introduction
Nowadays, the newest technology of multi-storey wooden housing – CLT-technology has gained great popularity in Europe. Advantages of CLT and CLT-technology: environmental friendliness, low heat conductivity, high fire resistance, high sound insulation, shrinkage resistance, short construction period, high seismic stability of the building. Since wood is a lightweight material, CLT is also suitable for multi-story construction. The algorithm for designing of buildings based on the CLT structure is presented in the form of a flowchart in Figure 1.

2. Materials and methods
CLT panels is considered as pine lumbers glued together with two-component glue. Characteristics for each layer were calculated manually using SP 64.13330.2017 "Timber structures". CLT is a composite multimodular material and therefore the theory of the reduced section method was used. In this study the CLT manual calculation is considered with both beam and slab theories. Calculaton method of CLT using software is also discovered.

3. Theory of the reduced section method
Due to the fact that the directions of the fibers in the CLT layers changes, and the wood has different elastic module in different directions, CLT is a composite multimodular material, i.e. a material with non-uniform thickness properties. The calculation of the material is carried out according to the method of reduced section.

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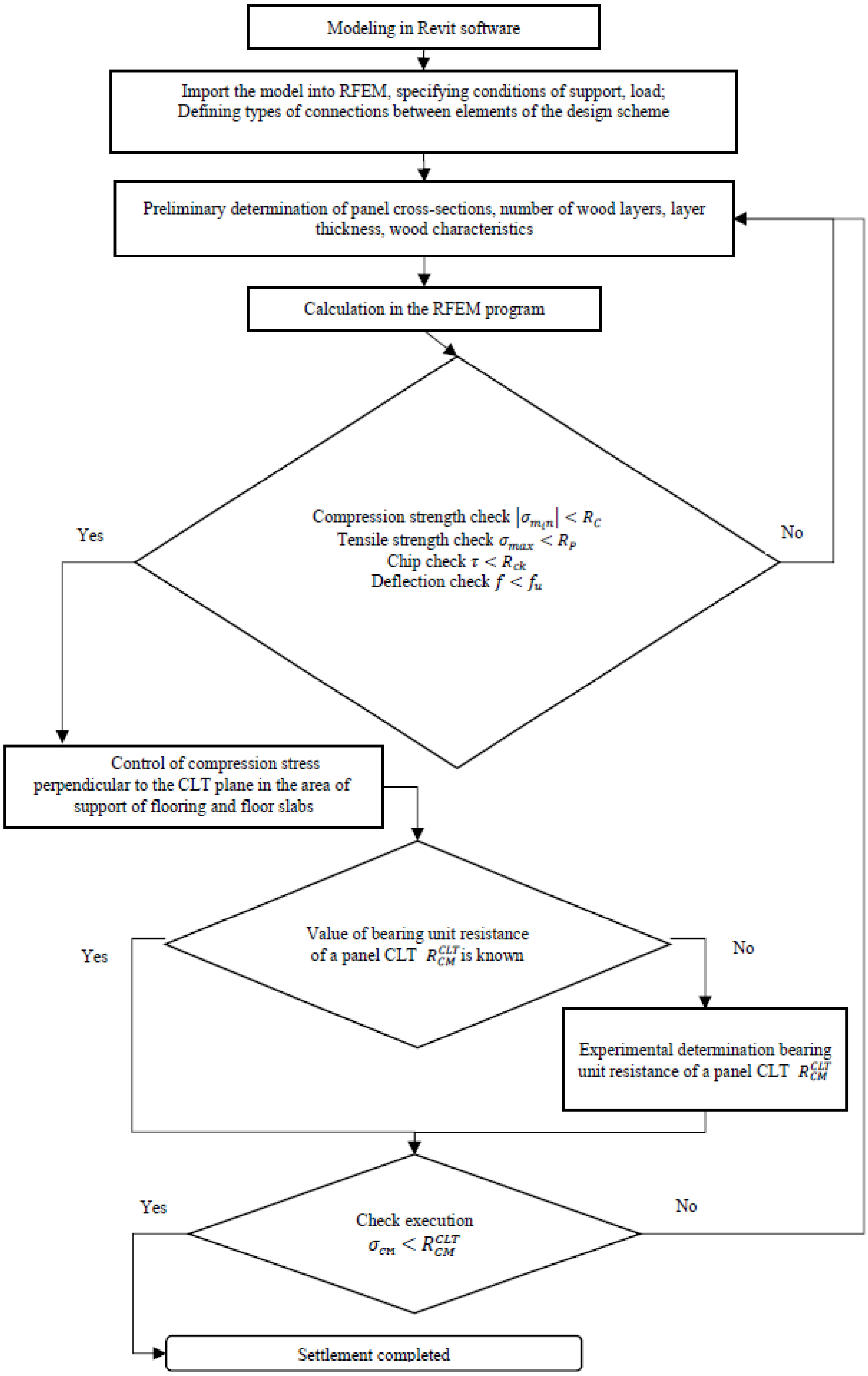

Figure 1. Control flow chart of the CLT building design

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4. The main idea is the calculation of CLT (reduced section method with assumptions). Manual calculation of CLT using beam theory

The geometrical characteristics of CLT, as well as the subsequent calculation, are determined using the reduced section method [2] with the following assumption: 1) the modulus of elasticity perpendicular to the grain is negligible, i.e. E mm90 = 0.

5. CLT as two-dimensional load-bearing slabs or panels

CLT can also act in two directions as a slab and take loads in different directions or as a panel and transfer shear forces and axial forces at the same time.

Biaxial loading effect of the panel is considered in cases with multiple load directions. It can be openings, point or angle support, local area loads. There are two common models, lattice (grid) and orthotropic CLT panel. In this case, the cross-section values are stated for CLT as a shell structure.

The modeling is based on stiffness values collected in a matrix, what makes it easier to exploit all specific properties of the CLT. There is no representation of internal stresses for individual layers in two-dimensional model, so designing should be based on the level of force or the load-bearing capacity.

6. Design CLT in software

Modeling in Revit software: creating a model with wall elements, roof and floor elements considering openings is presented on the Figure 2.

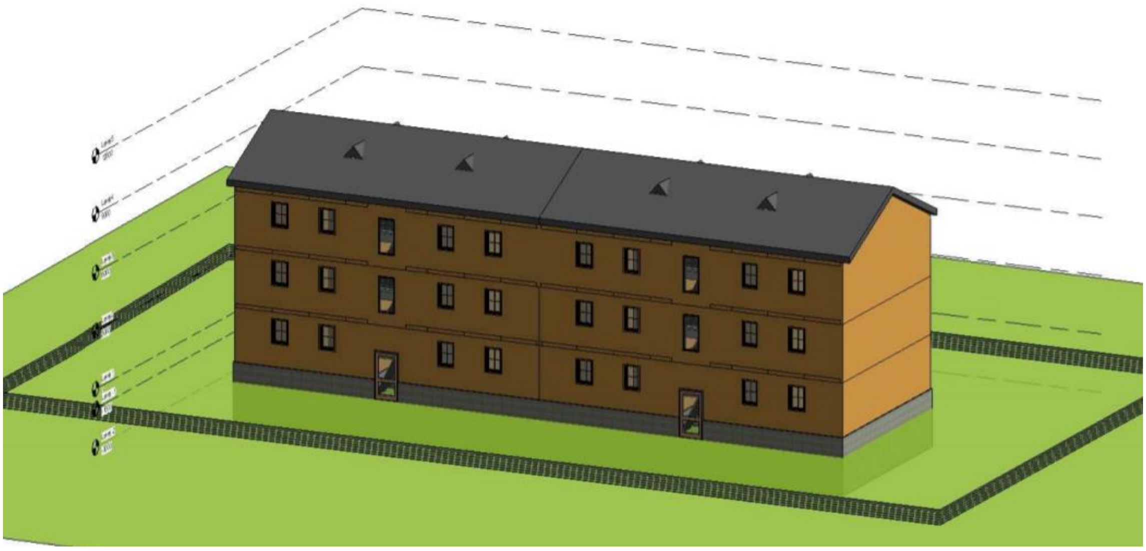

Figure 2. Model of a building in Revit

In this case, the use of the Revit program allows creating a spatial model of the building with following export to the RFEM program.

Model import into RFEM and further calculation. The design scheme in RFEM (walls, floor and roof elements) is imported to the program as plate elements (Figure 3).

The design scheme of a frameless building is calculated in the Dlubal RFEM software using the finite element method by using RF LAMINATE module for calculating laminated surfaces. The design spatial scheme is represented in this project by a plate system. After obtaining the values of the loads acting on the structure, the corresponding load combinations are created. Support conditions of walls on the foundation: linear hinges are placed as a support along the wall panels, restricting movement in all directions and allowing rotation. All the panels are connected by linear hinges. Wall and floor elements are defined by rectangular surfaces.

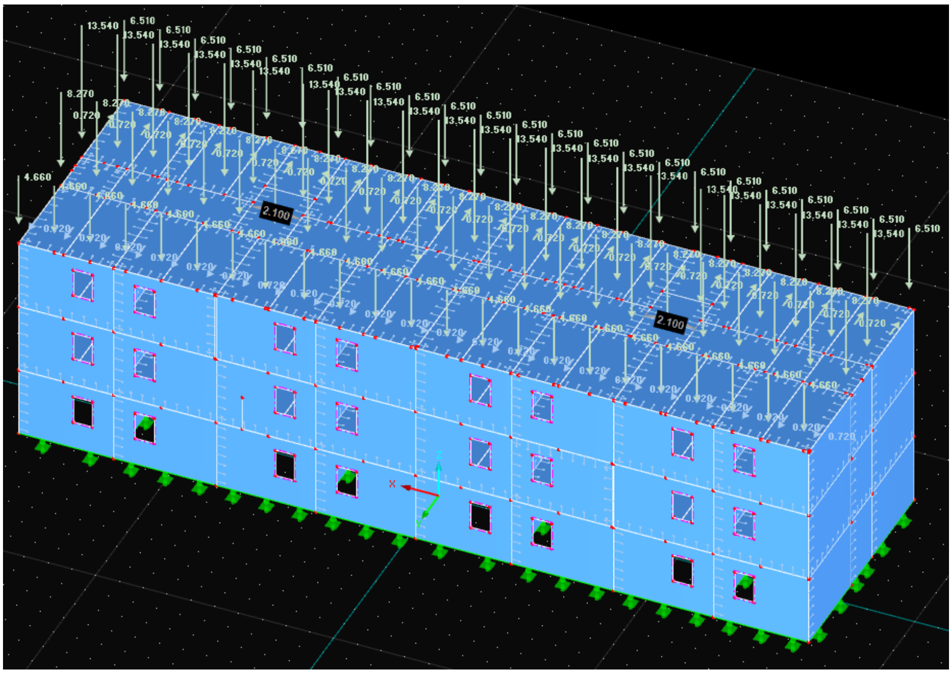

Figure 3. Design scheme of a building in Dlubal

The initial data for design are the characteristics of every single wood layer. At this point the cross-section of the panels is pre-assigned (Figure 4).

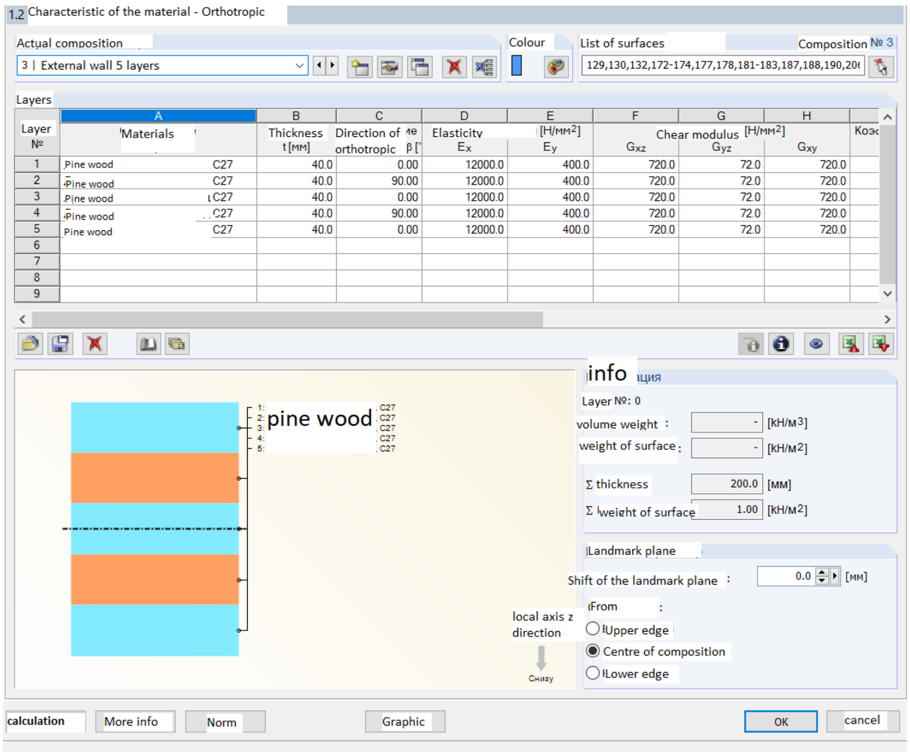

Figure 4. Setting wood characteristics of each layer for CLT panels

The load of the main relevant effects of actions is determined by the formula 6.1 [1]

$$C_m = P_d + (\psi_{l1}P_{l1} + \psi_{l2}P_{l2} + \psi_{l3}P_{l3} + ...) + (\psi_{t1}P_{t1} + \psi_{t2}P_{t2} + \psi_{t3}P_{t3} + ...),$$

In accordance with the formula above, a design value of the relevant effects of actions was compiled. A design value of the relevant effects of actions for the roof element includes: a dead load, self-weight of structure and environmental loads (snow, wind loads and probabilistic loads) [3]. Calculation results: as a result of the calculation, stress iso-fields of shear and lateral stresses in each layer of panels are obtained. RF-LAMINATE converts the resulting internal plate stresses into the internal stresses of every single layer. The internal stress distribution across the entire cross-section is represented graphically. Then, the software module isolates the bending, compressive, or tensile components of the internal stresses as shown in Figure 5.

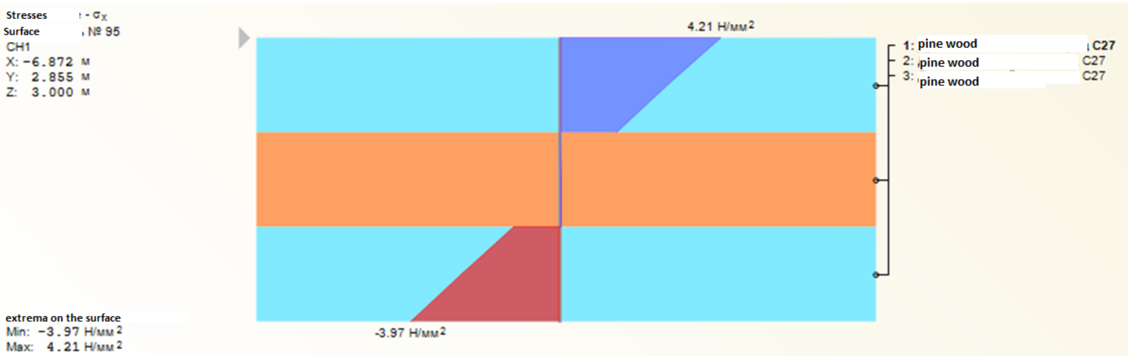

Figure 5. Graphical representation of the distribution of normal stresses over the section of the panel.

The shear, tensile, compressive, and deflection checks in accordance with Russian codes “СП”. When using the Dlubal RFEM software the only thing is left - to compare the obtained internal stresses with the design resistance in accordance with Russian codes “СП” [4]. The design wood resistance according to par. 6.2 [4], sorted by strength classes is determined by the formula: $R^p = \frac{R^H m_{дл} \cdot Пmi}{\gamma_m}$. Calculation of floor slabs: Calculation of elements in bending and shear plates was carried out in accordance with Russian codes “SP” [4]. An example of a normal stress distribution diagram in the floor element is represented in the Figure 5.

$\sigma = \frac{M}{W_{calc}} \leq R_u$ according to paragraph 7.9 [4]. It is necessary to fulfill the conditions$\sigma < R_u$, R_u – design bending resistance; Shear strength calculation of bending elements: $\tau = \frac{QS_b'}{I_b b_{calc}} \leq R_{ck}$ according to paragraph 7.9[4].

It is necessary to fulfill the conditions $\tau < Rss$, R_{ss} – design shear strength in bending. The chip resistance test perpendicular to the fibers for a panel element Figure 6.

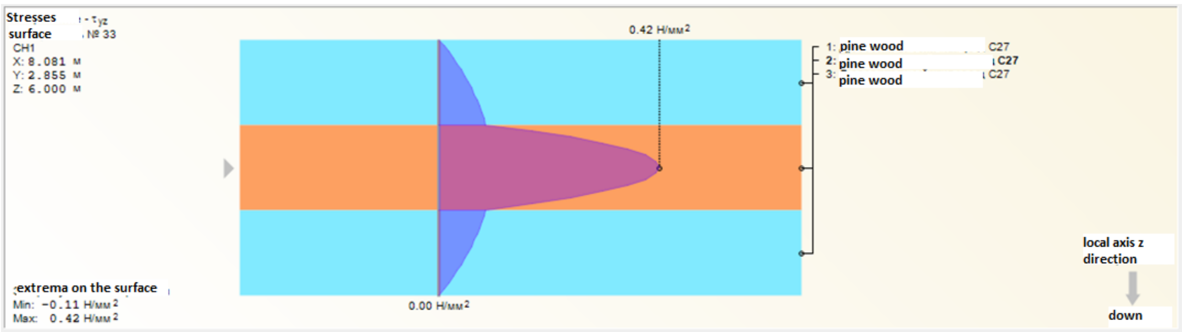

Figure 6. Graphical representation of shear stress distribution over a panel section.

For the service limit state [4], the total relative deflection of the slab under the dead load (combination of loads from its own weight, partitions and people) and ultimate deflections (physiological) are subject to verification. The actual deflection value can be obtained from the program $f < f_u$ (see Figure 7).

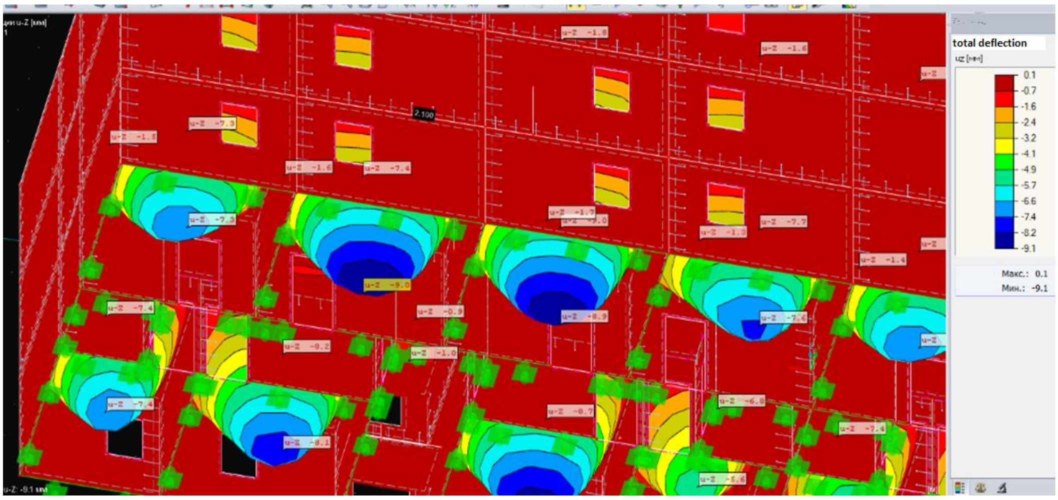

Figure 7. Values of vertical deflections

Calculation of roof elements: According to Russian codes “SP” [4], bending elements should be calculated considering both service and ultimate limit states. Therefore, the normal and shear stress tests as well as the deflection test should be held. According to the service limit state, the total relative deflection of the slab under the dead load (combination of loads of its own weight, snow loads) is subject to verification. The calculation of wall elements: Wall elements are considered as compressed-bent elements. The design strength test and stability test should be provided. Horizontal cross-sections of the walls are designed considering strength test. According to paragraph 7.17 [4], when calculating strength, the normal stress test of compressed-bent elements should be performed according to the following formula: $\sigma = \frac{N}{F_{calc}} + \frac{M_d}{W_{calc}} \leq R_c,$ It is necessary to fulfill the conditions $\sigma < R_c$, Rc – design compression strength. An example of the normal stress distribution diagram across a wall panel is presented in the Figure 8.

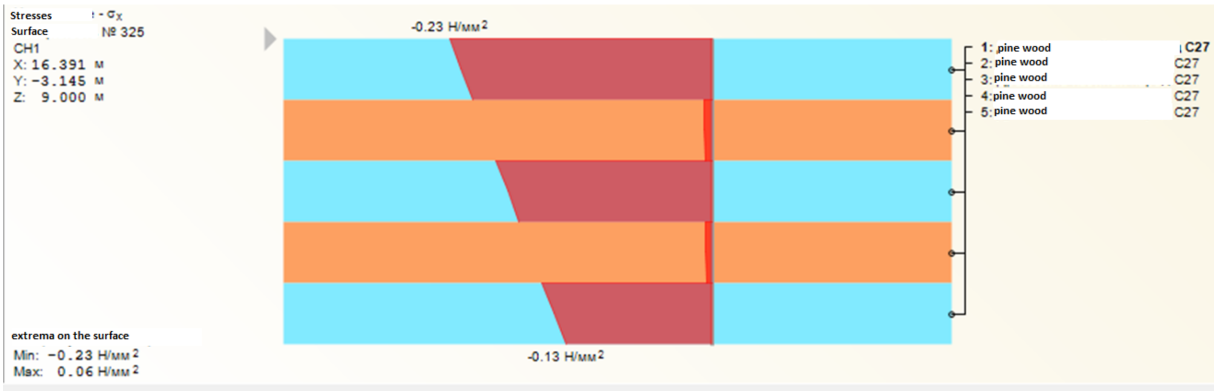

Figure 8. Graphical representation of the distribution of normal stresses over a section of an exterior wall panel

Shear strength calculation of the elements in is performed according to paragraph 7.10 [4].

Bearing strength test is performed for the area of bearing between roof and floor elements. Bearing unit stress checks are provided in floor and roof elements. The theoretical value of the vertical force arising in floor and roof elements is necessary. The figure 9 shows the internal stress iso-field arising along the vertical axis in the floor elements. As it can be seen the maximum values fall on the supports.

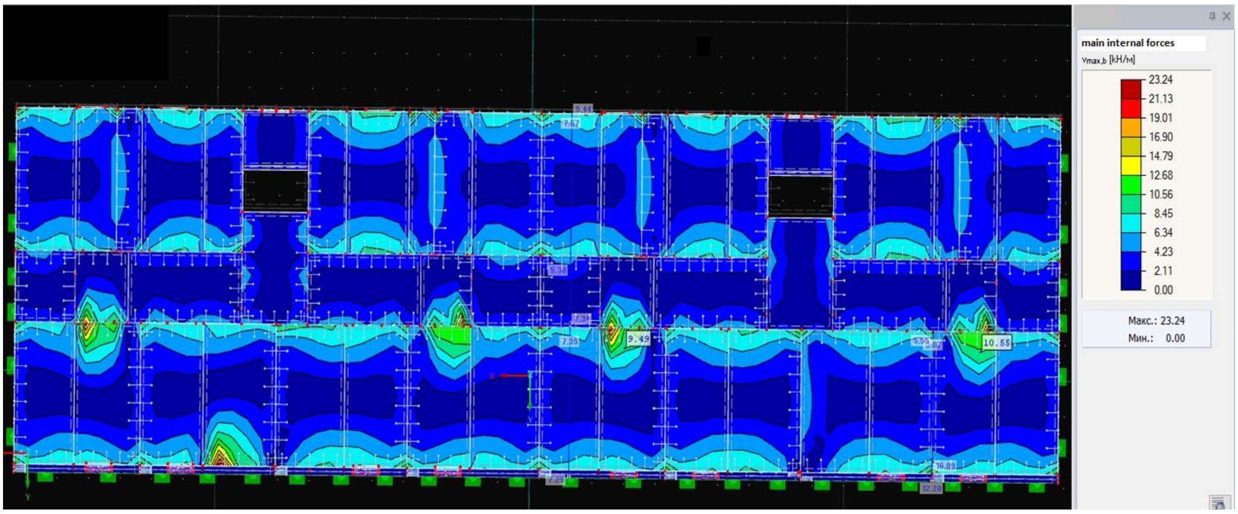

Figure 9. Internal stresses iso-fields arising along the vertical axis in floor elements.

Experimental obtaining of the compression stress values perpendicular to the CLT plane in floor and roof elements. Due to the lack of Russian codes "GOST" in the area of CLT technology, it is proposed to conduct tests for local collapse. As a result of the study of compression stress perpendicular to the CLT plane, the support between a 5-ply floor slab and a wall panel as shown is modeled in Figure 10. The determination of stress values at which local strain occurred is proposed.

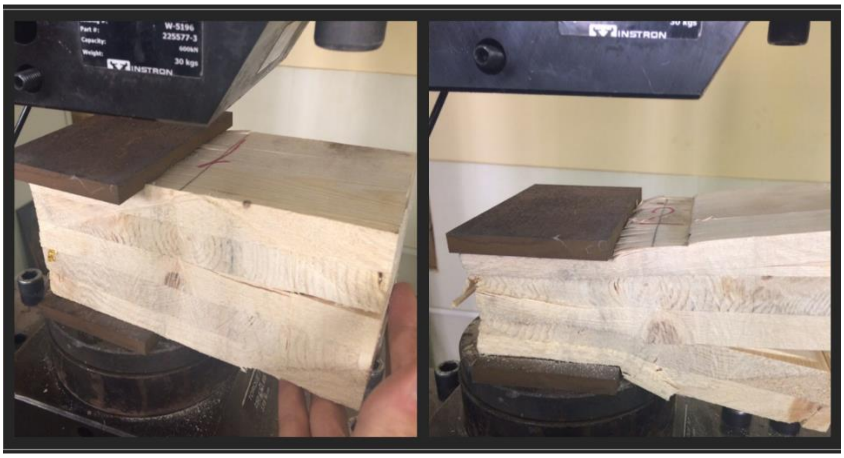

Figure 10. Modeling the support of a 5-ply floor slab on a wall panel

The comparison of theoretical values and ultimate values (experimental) of compression stress perpendicular to the CLT plane. After obtaining theoretical and experimental values, the verification of bearing unit stresses is performed. Converting the experimental values of the bearing unit stress to a load distributed along the length, a comparison can be made. In case of support between hip rafter and roof panel, a check of the local bearing unit stresses in the area of support between hip rafter and roof panel is performed. Figure 2 shows the load from a hip rafter in the design scheme. The most loaded hip rafter is checked.

Table 1. Results of stress values. The 5-ply CLT panel 100 mm is subjected to local deformations

№	Dimensions			Ultimate breaking load Pmax kN	Ultimate strength, MPa
	a, mm	b, mm	h, mm		
1	97,04	79,00	98,89	43,82	5,72
2	102,43	79,00	98,72	39,82	4,92
3	102,05	79,00	98,56	42,97	5,33
4	95,42	79,00	98,82	43,32	5,75
The average strength of the samples in the party, MPa					5,43
Root mean square deviation, MPa					0,39
Variation coefficient					0,07
The average error of strength, MPa					0,19
Young's modulus perpendicular to fibers, MPa					301,21
Ultimate strength is in the interval; 5,04-5,82 MPa					

If the average width of samples is 99,2 mm, the distributed force, conforming the ultimate strength, is in the interval 499,96 -577,36 kN/m

The comparison with the maximum allowable value: $\sigma_{c\text{м}} < R_{CM}^{CLT}$, $\sigma_{c\text{м}}$- actual bearing unit stress, R_{CM}^{CLT}- bearing unit resistance of a panel.

7. Conclusion

Thus, this technique allows calculating a multi-storey building of CLT using Revit, RFEM programs as well as the research results to determine the value of allowable local bearing unit stresses. Further material tests of tensile stress, compressive stress, chip resistance, deflection and local deformation in joints can be handled in the RFEM (finite element structural analysis program).

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