

**FULL PAPER**

# Prolongation of the life cycle of wooden structures due to the use of joints on aluminum connectors

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Collapsible joint systems always have benefits in speed and ease of installation; consequently, they are in demand in modern construction. The present article aims to describe one of the possible types of connection based on aluminum connectors. It is attempted to determine the mechanical strength of the connection with different types of connectors. To meet the aim of the study, methods of numerical and full-scale experiments with the comparison of the obtained research results are utilized. Moreover, the experimental study was carried out on the test bench of the VISU laboratory. It has been established that the destruction of the joint is plastic in nature and is expressed in the gradual pulling out of the angels from the body of the wood beams. The correlation between the increase in load and deformations in the numerical and laboratory experiments is close; the discrepancies are 7-11%. The potential destruction in the numerical experiment was recorded with the values of forces 17-23% higher than the experimental data, which is justified by the greater magnitude of the removal of the nails from the body of the wood. The use of connections on aluminum connectors increases the operational reliability of structures by increasing their life cycle.

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**Introduction**

The joints of wooden structures with connectors are not widely utilized in modern construction practice, and, therefore, not much scientific research has been carried out on this issue [1-3] Research executed by scientists on the joints of wooden beam structures has revealed several design solutions aimed at their strength boost and

experimental and theoretical data comparison [4-6]. Manfred Augustin and Georg Flatscher carried out a theoretical study of SHERPA connections based on German DIN standards made of aluminum connectors and steel dowels. Thus, it was found that the use of this structural unit is justified, and the wide variability of its elements makes it possible to modify it. The authors also noted the possibility of using

this design solution not only for joints of wood elements. The study made it possible to compare the results of theoretical studies of Sherpa joints and their experimental tests. In 2015, at St. Petersburg State University of Civil Engineering, Xu Yun conducted a study of Sherpa joints reinforced with metal-toothed plates [7]. Thus, a mathematical model was designed to calculate the load-bearing capacity of a screw from a connection on metal plates of SHERPA type for pulling out of wooden materials from cross-laminated wood and laminated veneer lumber based on various standards and models, mathematical model was developed to calculate the load-bearing capacity of shear screw without reinforcement and with a metal toothed plate in wooden elements made of cross-laminated wood and laminated veneer lumber based on the theory by Johansen, K.W, and EC5 by the types of joint breakage [8-15]

An improved model of a dowel rod is proposed, which consists of a steel pipe with a screw thread on the outer surface. There are grooves at the ends of a pipe into which a drilling tip made of a steel plate with cutting edges and a centering point is inserted on one side, like a flat drill for wood. The grooves at the opposite end of the pipe are designed to impart torque to a dowel rod [16-18].

There is a known model of a prefabricated nodal connection of a wooden rafter structure, which includes wooden lattice elements fastened together with a nodal bolt and rectangular metal plates on cylindrical dowels, characterized by fastening each lattice element to the lower chord of the structure using metal plates in which longitudinal cut is performed to the coupling bolt (utility model patent No. 47397) [19-22].

It has been established that the joint destruction is not brittle, and the angle of

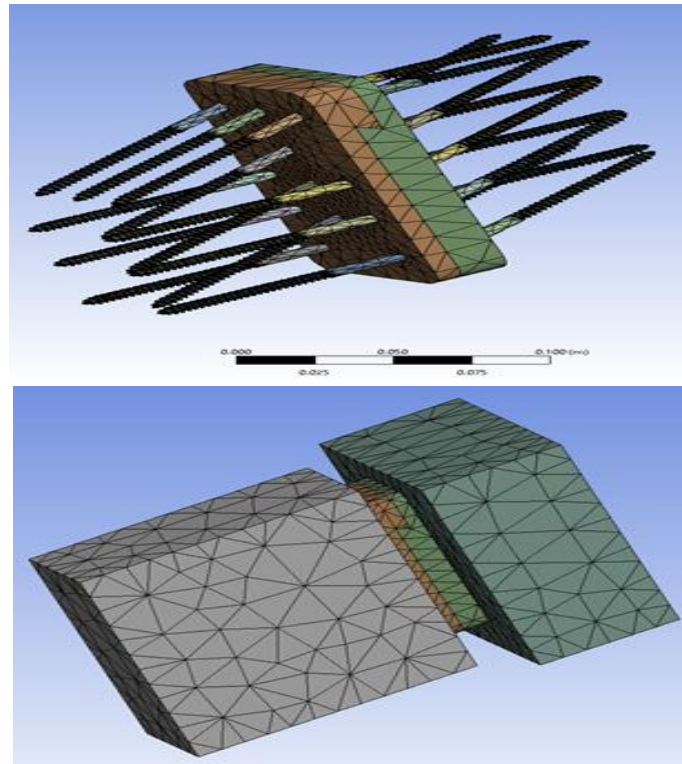
screw inclination makes it possible to increase the overall strength of the joint [21].

As part of this study, the junction of the main and secondary wooden beams was studied. To analyze the stress-strain state of the dowel joint and verify the obtained experimental data, a calculation model of the samples (wood-steel and wood-aluminum) was created in the ANSYS Workbench software package [23-28].

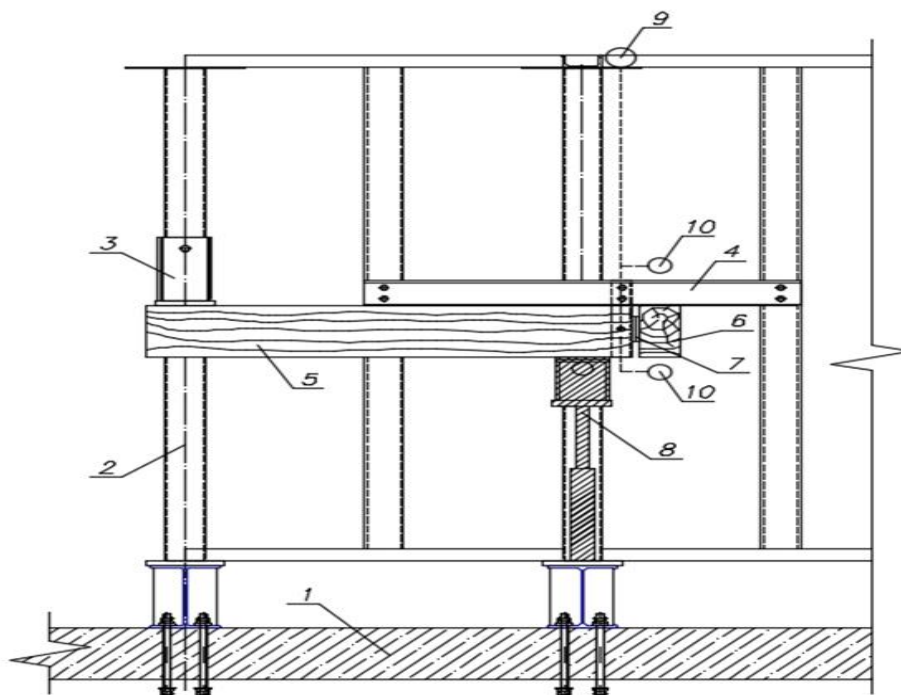
The purpose of the numerical studies was to assess the load-bearing capacity of a node connection depending on varied parameters

## Methods

The calculations conducted preceded the full-scale experiment and were carried out to the extent planned in the combination square drawn up during the experiment planning. The calculations took into account the actual characteristics of the materials to allow further comparison with the experimental results the experimental study was carried out on the test bench of the VISU laboratory. Stand design: the main element that absorbs force impacts is a force floor made of reinforced concrete with a maximum concentrated load of 100 tf at any point of its structure. I-beams with reinforcements in the form of transverse ribs in areas of the maximum load are screwed to the load-bearing floor through load-bearing rods with a diameter of 20 mm. Steel guides in the form of rectangular pipes with a width of 120 mm are screwed to the I-beams. During the test, a traverse with a movable roller moves along these guides, under which a jack with a fixing nut with a maximum force of 20 tf is located. Figure 1 presents the scheme of finite-difference discretization of a node connection. The installation diagram and placed measuring equipment are presented in Figure 2.



**FIGURE 1** Scheme of finite-difference discretization of a node connection



**FIGURE 2** Diagram of the test installation and installed equipment: (1) Power floor; (2) stand frame; (3) support of the secondary beam; (4) support of the main beam; (5) secondary beam; (6) main beam; (7) connector; (8) hydraulic jack connected to a dynamometer; (9) deflector PAO 6; and (10) dial indicators

Due to the presence of a movable roller, the load is transferred from the jack to the

beam through the hinge. The side supports absorb the loads from the beam and are also

guides made of rectangular pipes with a movable crossbeam, which is fixed at the required height using a through pin with a diameter of 20 mm. Hydraulic jacks with a fixing nut and rod spring return DG20P320G are installed as the main sources of force. The pressure creation device is a manual hydraulic pump NRG-7160. Accuracy class (EN837-1\6)-1.6. Measuring range, 0-1000 bar. Control and measuring elements are the load cells with electronic indication. There are dynamometers (strain gauges connected to electronic measuring indicators) for each jack. Accuracy class according to ISO 376-1. The largest measurement limit is 20 tf. Model-DEP/3-2D-200S-1. Tests were carried out for four types of connectors. Connectors are made of two types of alloys AD 33 and B95. The geometry of connectors for various kinds of alloys is assumed to be the same. The series K-1 and K-3 are adopted with holes of 8 mm in diameter from alloy AD33 and V95, respectively, and series K-2 and K-4 are adopted with holes of 6 mm in diameter from alloy AD33 and V95, respectively. The operating principle of the connector is based on the "dovetail" principle when a plate with a spike is put on a plate with a groove. The accepted type of connector makes the beam joint dismountable and simplifies the installation process. "Groove" type plates have 13 holes for screws, with 8 screws screwed at an angle of 60 degrees to the

beam plane, and 5 screws are perpendicularly screwed. The spike-type plates have 12 holes for screws, with 6 screws screwed at an angle of 60 degrees to the beam plane, and 6 screws screwed perpendicularly. The connector plates are rectangular and have dimensions of 150x80 mm. The total thickness of the plates is 18 mm, while the thickness of the solid slab part is 9 mm, and the thickness of a groove or a spike is also 9 mm. To acquire correct and accurate results and remove scattering of readings, each type of connection has been tested on three samples, after which the indicators have been averaged. Twelve tests of nodal connections of beams have been performed in total, on twelve pairs of connectors. The load on the node connection was applied utilizing a hydraulic jack through a metal distribution plate in equal steps. The steep pitch was 2 kN. After applying the load, the connection was held for 10 minutes, after which readings were taken from the deflection meter and dial indicators and the next stage of load application followed. The duration of each test was four to five hours, not counting the time to prepare the beams for testing. The nodal connection test was carried out until the steel dowels- screws began to be pulled out from the bodies of the wooden beams. A photo. of a beam with a connector attached to it organized for testing is depicted in Figure 3.



**FIGURE 3** Installation of the groove-type plate on the main beam of the joint

Based on the results of calculations in the ANSYS software package, the values of maximum normal stresses, maximum shear stresses and deformations were obtained. A general view of the characteristic

deformations of the connection is shown on Figure 4. The program also took into account the step-by-step connection load increase.

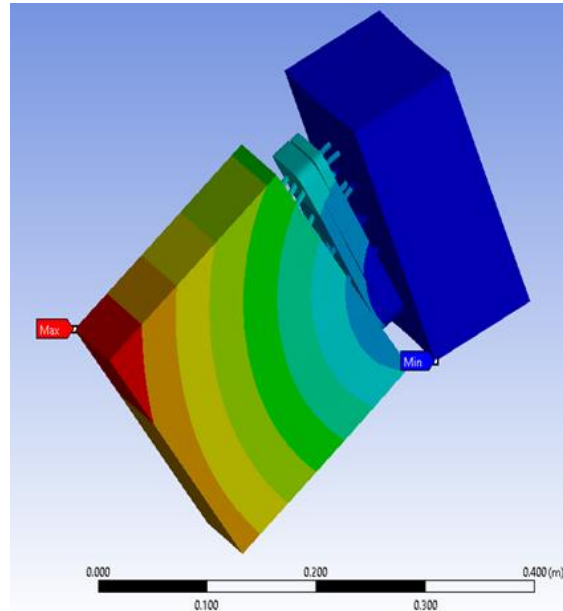


FIGURE 4 General view of characteristic joint deformations

The calculation results are presented on epy graphs of stresses and deformation distribution, as well as on epy graphs of

maximum deformation dependence on the applied load.

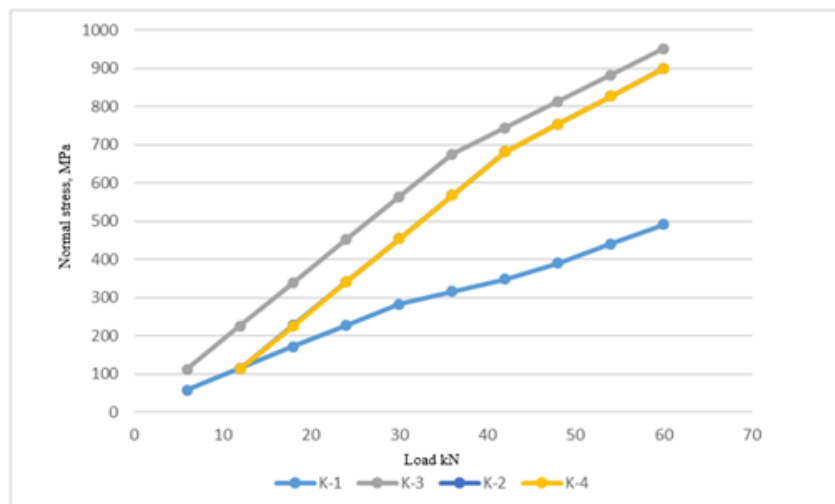
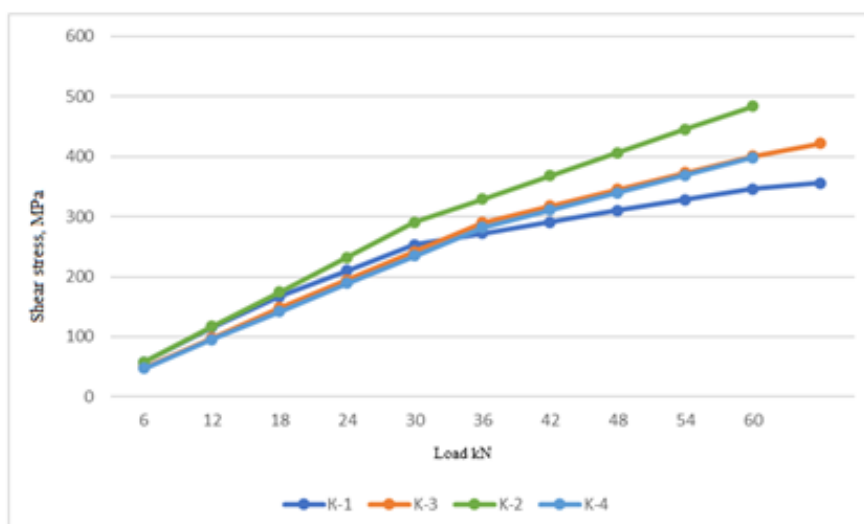


FIGURE 5 Normal stress distribution graphs



**FIGURE 6** Shear stress distribution graph

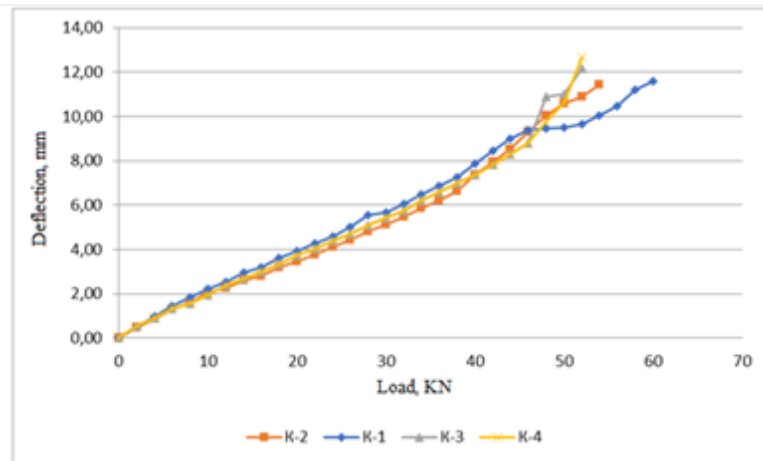
For ease of analysis, the data are summarized in Table 1.

**TABLE 1** The data summarized

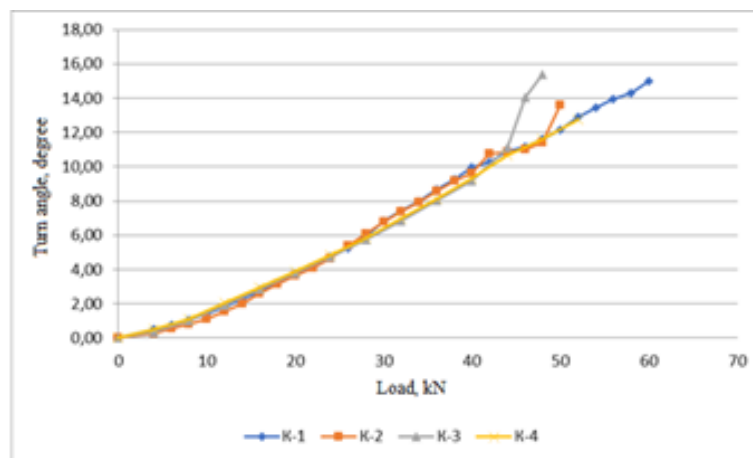
No. by order	Sample mark	Maximal deformations, cm	Maximum normal stresses, Pa	Maximum tangential stress, Pa	Breaking load, kN
1	2	3	4	5	6
1.	K-1	0.12003149	518832267	356173300	63.2
2.	K-2	0.15854239	449769700	513056021	64.6
3.	K-3	0.14687365	1027313445	422852220	63.9
4.	K-4	0.11117675	983742750	412700830	62.85

Potential destruction in the numerical experiment was recorded at force values 17-23% higher than the experimental data, which is justified by the plastic nature of the beam destruction, expressed in the gradual tearing out of the dowels from the wood body. As a result of the full-scale experiment,

three tests for each series of connectors were performed. Based on the results, average graphs of deflection with increasing load and the graphs of changes in the rotation of the secondary beam relative to the main one were developed. The graphs are shown in Figures 5 and 6.



**FIGURE 7** Graph of beam deflection change with increasing load



**FIGURE 8** Graph for measuring the secondary beam rotation relative to the main beam as the load increases

According to Figures 8 and 9, the destruction of the beams was plastic and started with the pulling out of the screws from the beam bodies, which resulted in the collapse of the wood; there was no

deformation of the connectors at the time of joint destruction. General views of the main and secondary beams after the joint destruction are illustrated in Figure 9.



**FIGURE 9** The nature of beam joint destruction:( a) secondary beam and (b) main beam

The summary results of load-bearing capacity and deformation tests are presented in Table 2.

**TABLE 2** Results of load-bearing capacity and deformation tests

Connector type	K-1	K-2	K-3	K-4
Average breaking load, kN	52	49	53	50
Deflection value at break, mm	9.68	10.9	11.58	10.61
Rotation value at permission, °	11.27	11.12	11.88	11.61

For convenience, a comparative analysis between the results of a laboratory

experiment and the results of numerical studies is summarized in Table 3.

**TABLE 3** A comparative analysis between the results of a laboratory experiment and the results of numerical studies

No. by order	Sample mark	Method	Breaking load, kN	Deformations, mm
1	2	3	4	5
1.	K-1	Experimental	52	9.68
		Numerical	63.2	12.0
2.	K-2	Experimental	49	10.9
		Numerical	64.6	15.8
3.	K-3	Experimental	53	11.58
		Numerical	63.9	14.6
4.	K-4	Experimental	50	10.61
		Numerical	62.85	11.1

## Conclusion

Throughout this study, it was attempted to evaluate the load-bearing capacity of a node connection depending on different parameters. Therefore, numerical and full-scale experiment methods with a comparison of the acquired research results are employed to reach an informed conclusion. Numerical calculations were conducted to determine the load-bearing capacity of joints on aluminum connectors for all four types of connectors. The possibility of their use at the joints of structures in wooden housing construction has been determined. They determined the dependences of deformations and normal and shear stresses on increasing forces at the nodal joint. The destruction of a joint is plastic and is expressed in the gradual tearing out of the dowels from the beam wood body. The comparative analysis of theoretical and experimental study results was conducted as well. It has been demonstrated that the correlation between the load increase and deformation in the numerical and laboratory

experiments is close and the discrepancies make 7-11%. Potential destruction in the numerical experiment was registered at a force value that was 17-23% higher than the data in the full-scale experiment, which is explained by the more significant amount of dowels being torn out from the wood body. Ultimately, it can be concluded that utilizing connections on aluminum connectors can increase the operational reliability of wooden structures, leading to an increase in their life cycle.

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### Authors' contributions

All authors have contributed equally

### Conflict of interest

The authors had no competing interests in the process of writing the article.

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### References

- [1] B. Ndiwe, P. Kah, F.M.N. Bayock, D.A. Uchekukwu, H. Onyeji, Numerical and experimental investigations of mechanical properties of AW 6005-T6 Aluminium alloy butt weld joint using GMAW process, *Metallurgical and Materials Engineering*, **2023**, *29*, 16-36. [Crossref], [Google Scholar], [Publisher]
- [2] S. Maksymova, V. Voronov, P. Kovalchuk, A. Larionov, Structure and properties of graphite-molybdenum brazed joints. *Metallurgical and Materials Engineering*, **2023**, *29*, 115-128. [Crossref], [Google Scholar], [Publisher]
- [3] Y.A.D. Ladi, N.D. Lamso, M.N. Ado, D.G. Iro, Y. Guero, Restitution of fresh organic matter

to the soil by woody plants in the fields of ANR in the Maradi region of central eastern Niger, *International Journal of Sustainable Agricultural Research*, **2023**, *10*, 42-51. [Google Scholar], [Publisher]

[4] E.A. Obidiebube, H. Okolie, C.C. Obasi, K.L. Ochuenwike, Effects of different rates of wood ash on the growth and yield of carrot (*Daucus Carota*) in Awka, South Eastern Nigeria, *Current Research in Agricultural Sciences*, **2022**, *9*, 13-21. [Crossref], [Google Scholar], [Publisher]

[5] S.T.R.O.I.A.N.O.V.S.K.Y.I, Dmytro, The study of welding requirements during construction and installation of seismic-resistant steel structures, *Journal of Research in Science, Engineering and Technology*, **2020**, *8*, 17-20. [Crossref], [Google Scholar], [Publisher]

[6] M. Yu, Q. Yu, M. Li, Joint Estimation for Battery Capacity and the State of Charge Based on Variable Time Scale, *Iranian Journal of Chemistry and Chemical Engineering*, **2021**, *40*, 1943-1959. [Google Scholar], [Publisher]

[7] A. Hafiz, T. Schumacher, A. Raad, A self-referencing non-destructive test method to detect damage in reinforced concrete bridge decks using nonlinear vibration response characteristics, *Construction and Building Materials*, **2022**, *318*, 125924. [Crossref], [Google Scholar], [Publisher]

[8] A. Tolstoy, A. Gridchin, E. Glagolev, R. Lesovik, N. Shapovalov, Efficient construction composites for construction in the North and the Arctic, *International Conference Industrial and Civil Construction*, Cham: Springer International Publishing, **2021**, 15-22. [Crossref], [Google Scholar], [Publisher]

[9] O. Faroque, S. Hasan, K.R. Hossain, R.K. Sheikh, Fabrication and characterization of wood fiber reinforced polymer composites, *Al-Bahir Journal for Engineering and Pure Sciences*, **2023**, *3*, 1. [Crossref], [Google Scholar], [Publisher]

[10] R.V. Lesovik, M.S., Ageeva, A.A. Matyukhina, E.V. Fomina, On the issue of designing structures of composite binders,

- In *International Scientific Conference on Innovations and Technologies in Construction*, Cham: Springer International Publishingm **2020**, 246-252 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [11] E. Mullen, Saving a 15th-century nave roof from structural collapse at the Abbey Church of St Mary and St Melor, Amesbury, Wiltshire, *Journal of Building Survey, Appraisal & Valuation*, **2023**, *12*, 6-24. [[Google Scholar](#)], [[Publisher](#)]
- [12] O.V. Vaganova, N.E. Solovjeva, R.V. Lesovik, S.L. Lesovaya, Digital transformation of Russia's agricultural sector, *Utopía y praxis latinoamericana: revista internacional de filosofía iberoamericana y teoría social*, **2020**, *12*, 397-406. [[Google Scholar](#)], [[Publisher](#)]
- [13] H.C. Biscaia, C. Chastre, D. Cruz, A. Viegas, Prediction of the interfacial performance of CFRP laminates and old timber bonded joints with different strengthening techniques, *Composites Part B: Engineering*, **2017**, *108*, 1-17 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [14] C. Málaga-Chuquitaype, J. Ilkanaev, November. Novel digitally-manufactured wooden beams for vibration reduction. In *Structures*, Elsevier, **2018**, *16*, 1-9 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [15] A.S. Griбанov, V.I. Rimshin, S.I. Roshchina, Experimental investigations of composite wooden beams with local wood modification. In *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, **2019**, *687*, 033039 [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [16] M. Sergeev, V. Rimshin, M. Lukin, N. Zdravovic, July. Multi-span composite beam, In *IOP Conference Series: Materials Science and Engineering*, **2020**, *896*, 012058. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [17] V.I. Rimshin, B.V. Labudin, V.I. Melekhov, A.O. Orlov, V.L. Kurbatov, Improvement of strength and stiffness of for Shell and Spatial Structures (IASS), **2023**, 2023, 1-11. [[Google Scholar](#)], [[Publisher](#)]
- components of main struts with foundation in wooden frame buildings. *ARNP Journal of Engineering and Applied Sciences*, **2018**, *13*, 3851-3856. [[Google Scholar](#)], [[Publisher](#)]
- [18] A.A. Koshcheev, S.I. Roshchina, A.Y. Naichuk, N.I. Vatin, The effect of eccentricity on the strength characteristics of glued rods made of steel cable reinforcement in solid wood. In *IOP conference series: materials science and engineering*, **2020**, *896*, 012059. IOP Publishing. [[Crossref](#)], [[Pdf](#)], [[Publisher](#)]
- [19] S. Merkulov, V. Rimshin, E. Akimov, V. Kurbatov, S. Roschina, 2020, July. Regulatory support for the use of composite rod reinforcement in concrete structures, In *IOP Conference Series: Materials Science and Engineering*, **2020**, *896*, 012022. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [20] M. Lukin, V. Martynov, V. Rimshin, I. Aleksiievets, Reinforced concrete vertical structures under a gently sloping shell of double curvature under the influence of progressive collapse, In *Proceedings of MPCPE 2021: Selected Papers*, Cham: Springer International Publishing, **2022**, 577-587. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [21] V.I. Rimshin, S.I. Roshchina, E.S. Ketsko, P.S. Truntov, I.S. Kuzina, Engineering calculations of acidifier retaining walls during water treatment facilities designing, In *Proceedings of MPCPE 2021: Selected Papers*, Cham: Springer International Publishing, **2022**, 55-73 [[Google Scholar](#)], [[Publisher](#)]
- [22] J. Zheng, M. Wang, T. Yao, Y. Tang, H. Liu, Dynamic mechanical strength prediction of BFRC based on stacking ensemble Learning and genetic algorithm optimization, *Buildings*, **2023**, *13*, 1155. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]
- [23] S. Yang, New carbon paradigm: applications of carbon composite materials in the building industry, In *Proceedings of IASS Annual Symposia*, International Association
- [24] X.Z. Lu, J.F. Chen, L.P. Ye, J.G. Teng, J.M. Rotter, RC beams shear-strengthened with FRP: Stress distributions in the FRP

reinforcement, *Construction and Building Materials*, **2009**, *23*, 1544-1554. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[25] I.R. Kliger, R. Haghani, M. Brunner, A.M. Harte, K.U. Schober, Wood-based beams strengthened with FRP laminates: improved performance with pre-stressed systems, *European Journal of Wood and Wood Products*, **2016**, *74*, 319-330. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[26] A. Wdowiak-Postulak, Strengthening of structural flexural glued laminated beams of ashlar with cords and carbon laminates. *Materials*, **2022**, *15*, 8303. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[27] R.M. Gutkowski, J. Balogh, C. Rogers, R. SaRibeiro, Laboratory tests of deep composite wood-concrete beam and deck specimens. In *Proceedings of the 4th Structural Specialty Conference of the*

*Canadian Society of Civil Engineering*, **2002**, 1-9. [[Google Scholar](#)], [[Publisher](#)]

[28] M. Popova, M. Sergeev, A. Lukina, M. Shunqi, July. Strength and deformability of lightweight metal trusses with elements from cut I-beams. In *IOP Conference Series: Materials Science and Engineering*, **2020**, *896*, 012061. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

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