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THE ANALYTICAL METHODOLOGY USED TO EVALUATE THE BEARING CAPACITY FOR HYBRID STRUCTURAL ELEMENTS SUCH AS THE COLUMN AND THE BEAM MADE FROM OSB 3 LAMELLAE

BY

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Abstract. In the building industry, wood began being more utilized in recent years and this lead to the development of finite products from engineered wood. By processing wood in the factory, less carbon dioxide is released and therefore pollution is reduced. The current research wants to establish the bearing capacity of hybrid structural elements, such as columns and beams, with a new configuration. The proposed assemble is in form of OSB 3 glued beams and columns. The analysis presented in this paper wants to be a landmark for experts in wood industry and for engineers or architects who design wood constructions, and a guide for those who want to extend the actual research in this domain. The engineered wood has superior properties compared to other traditional materials. Using these preformed OSB 3 hybrid elements, the building time on site is reduced and the final structure can be defined as sustainable.

Keywords: OSB 3; structural hybrid element; beam; column; engineered wood.

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1. Introduction

Wood is a natural material used in constructions for many years. Wood is important because it stores CO_2 before and after it is processed into building materials. Although it is a renewable resource, it must be exploited only from sustainably managed forests. Furthermore, the wood exploitation must be reduced with the help of the principles of Circular economy, (website Circular economy).

In the building industry, this means to recover and recycle wood in order to obtain another building material. Wood can be recovered from formwork waste, wood pallets, wood packaging, old wood furniture, unused wood bridges or railways, demolition or deconstruction sites, (website Sustainable forest management; website Oriented strand board).

Recycled wood comes from raw products like branches chopped after felling and grooming or fallen trees with very small diameter that cannot be used for solid timber elements. After the logs are processed in the mill, the remaining parts can be transformed into products like wood chips, shavings and sawdust, used for manufacturing other building materials. Industrialized or engineered recycled wood is used to manufacture new building materials and new processed elements.

One of these building materials is OSB – Oriented Strand Board, which is made of various technical classes: OSB 2, OSB 3 and OSB 4. These classes are according to the field of use (class of services): OSB 2 is used in structural interior application in dry environments SC1 (RH $\leqslant$ 65%), OSB 3 and OSB 4 are used in protected interior and exterior application in humid environments SC1 and SC2 (65% $\leqslant$ RH $\leqslant$ 85%). For the current study, OSB 3 was chosen due to its bearing capacity and versatility, as it can be used both indoors and outdoors, in dry or humid environments. OSB 3 is a multipurpose panel used in constructions for walls, formwork, ceilings, floors and roofs, (website Egger).

Wood used to manufacture the OSB 3 is around 70% pine and spruce, the rest of 30% are species like: beech, birch, lime tree and willow. This ratio of softwood and hardwood species, in addition to the surface-to-core ratio and the pressing parameters determine the quality and characteristics of the products. OSB 3 can be used to create hybrid elements similar to GLULAM, by superposing several OSB 3 lamellae and gluing them together using polyurethane adhesive.

The present study is focusing on such hybrid elements, formed from 6 OSB 3 lamellae, of equal width, b, and height, h, 140x140 mm cross-section. The OSB 3 glued members are used as beams and columns with lengths of 300 cm and 250 cm, respectively, Figs. 1, 2, 3 and 4.

Table 1 presents the mechanical properties of OSB 3 lamellae used in the presented analysis, as given by the manufacturer, (website Egger).

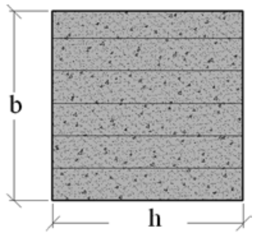

Fig. 1 – OSB 3 glued elements cross-section.

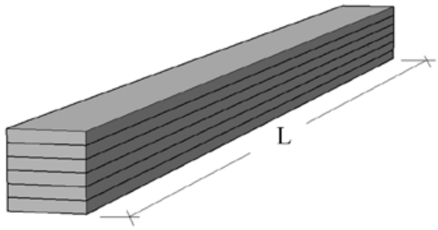

Fig. 2 – OSB 3 glued beam or column.

Table 1
Mechanical Properties of OSB 3

OSB 3 property	Symbol	Unit of measurement	Board thickness		
			>6-10	>10<18	18 – 25
Characteristic bending strength	f_m^k	N/mm^2	18	16.4	14.8
Characteristic compressive strength parallel to fibres	f_c^k	N/mm^2	15.9	15.4	14.8
Longitudinal elasticity modulus in bending	E_m	N/mm^2	4930	4930	4930
Elasticity modulus in compression parallel to fibres	E_c	N/mm^2	3800	3800	3800

According to SR EN 408 – 2004: “Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties”, (website Sustainable forest management), to determine beams bearing capacity, the four-point bending test is performed, and to evaluate the capable compressive force of columns, the elements must be subjected to central compression parallel to fibres. Therefore, static schemes considered in the calculus are presented in Figs. 3 and 4.

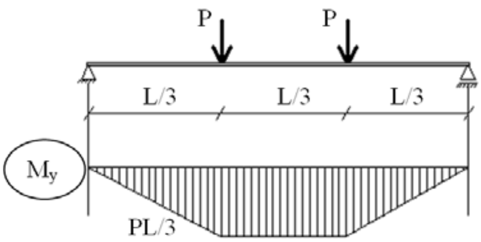

Fig. 3 – OSB 3 glued beam subjected to four-point bending.

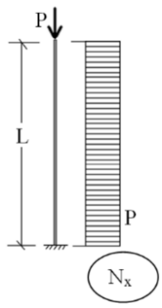

Fig. 4 – OSB 3 glued column subjected to axial compression.

2. OSB 3 Glued Beams

The theoretical approach presented hereinafter will be calibrated and validated with experimental investigations. As previously described, OSB 3 lamellae can be glued to form OSB 3 hybrid beams or columns, with a cross-section of 140x140 mm and 300 cm length. These beams are to be subjected to four-point bending at the "Gheorghe Asachi" Technical University of Iaşi, Faculty of Civil Engineering and Building Services, following a static scheme presented in Fig. 3. The beam span is considered to be *L*=270 cm and the loads are applied at *L*/3 and 2*L*/3, respectively.

2.1. OSB 3 Glued Beams Bearing Capacity

The OSB 3 glued beam has 6 lamellae of 23.33 mm height and a cross-section of 140x140 mm. The OSB 3 characteristic bending strength, f_m^k, is declared at 14.8 N/mm^2, (website Egger). To determine the bearing capacity of the OSB 3 glued beams, the following formulae were used, (SR EN 408: 2004; CR 0: 2012; SR EN 1990–1–1: 2004; SR EN 1995–1–2: 2004; SR EN 338: 2010; Neculai and Isopescu, 2017):

$$\sigma_x^{max} = \frac{M_y^{max}}{k_w \cdot k_f \cdot W_y} \le f_m^k \quad (1)$$

$$P_{cap}{}^{OSB} = \frac{f_m^k \cdot k_w \cdot k_f \cdot b \cdot h^2}{2 \cdot L} \quad (2)$$

where: $\sigma_x{}^{max}$ is the maximum bending stress along x (longitudinal) axis of the beam, in N/mm^2; $M_y{}^{max}$ is the maximum bending moment, $M_y{}^{max}$ = PL/3, in Nm; L is the distance between bearing supports, of 270 cm; k_w is a coefficient that takes into account the ratio between the height and the width of the cross-section, and for this particular cross-section, h=140 mm, b=140 mm, it has the value 1.00; k_f is a coefficient that takes into account the shape of the cross-section, for rectangular or square sections, it has the value 1.00; W_y is the section modulus, $W_y = bh^2/6$; b, h are the width and height of the beam, in m; $P_{cap}{}^{OSB}$ is the bearing capacity of the OSB 3 glued beams, extracted from Eq. (1) and calculated according to Eq. (2).

The resulted bearing capacity for the OSB 3 glued beams is $P_{cap}{}^{OSB}$= 7.521 kN.

The maximum instantaneous deflection, denoted according to NP 005-2005, (NP 005-2005), $f_{max,inst}$, subjected to two external loads equal to the bearing capacity, $P_{cap}{}^{OSB}$, was determined using Eq. (3).

$$f_{max,inst} = \frac{23}{648} \cdot \frac{P_{cap}^{OSB} \cdot L^3}{E_m \cdot I_y} \quad (3)$$

where E_m is the longitudinal modulus of elasticity presented in Table 1, of 4930 N/mm^2, and I_y is the moment of inertia of the cross-section, equal to bxh^3/12, in mm^4.

The resulted maximum deflection was 33.3 mm. The allowable deflection, as given by standards, is $f_{allowable}$= L/250= 10.8 mm, which makes the maximum deflection 3.08 times bigger than the allowable one.

2.2. OSB 3 Glued Beams vs. Solid Timber Beams Bearing Capacity

Considering the same element dimensions, but analyzing a solid timber beam, after applying Eqs. (4) and (5), the following results were obtained for different strength classes of timber, Table 2, with L as the span of 270 cm:

$$\sigma_x^{max} = \frac{M_y^{max}}{W_y} \leq f_m^k \tag{4}$$

$$P_{cap}{}^{timber} = \frac{f_m^k \cdot b \cdot h^2}{2 \cdot L} \tag{5}$$

Table 2

Bearing Capacities and Maximum Deflections Obtained for Strength Classes of Timber

Strength class	Characteristic bending strength, $f_m{}^k$, [N/mm^2]	Bearing capacity, $P_{cap}{}^{timber}$, [kN]	Maximum deflection, $f_{max}{}^{timber}$, [mm]	Percentage of OSB 3 glued beam from timber beam bearing capacity
C14	14	7.114	22.178	105.7%
C16	16	8.130	22.178	92.5%
C18	18	9.147	22.179	82.2%
C22	22	11.179	24.396	67.3%
C24	24	12.195	24.194	61.7%
C27	27	13.720	24.951	54.8%
C30	30	15.244	27.722	49.3%
C35	35	17.785	29.855	42.3%
C40	40	20.326	31.684	37%

After analysing the results presented it Table 2, it can be observed that the OSB 3 glued beam has a higher bearing capacity compared to solid timber class C14. Therefore, it can be safely said that the OSB 3 glued beam can be used to replace wood with the strength class C14, offering a bearing capacity of 5.7% higher than the solid timber beam. In addition, the OSB 3 glued beam presents 92.5% of the bearing capacity of wood class C16 and 37% of the highest softwood class C40. From the stiffness point of view, considering the bearing capacities for each timber class, it can be observed that the maximum deflection in case of solid timber is also from 2.05, in case of C14, to 2.93, in case of C40, times higher than the allowable deflection. This behaviour is similar to OSB 3 glued beams.

2.3. OSB 3 Glued Beams vs. GLULAM Beams Bearing Capacity

Approaching the subject from another perspective regarding the type of wood product, the OSB 3 glued beams were then compared to GLULAM beams. The smallest strength class for GLULAM elements is GL20, presenting a characteristic bending strength, f_m^k = 20 N/mm^2, (website GLULAM). The formula used for this analysis is presented in Eq. (6), from which the bearing capacity for GLULAM beams was extracted, in Eq. (7), considering L of 270 cm, (SR EN 408: 2004):

$$\sigma_x^{max} = \frac{k \cdot M_y^{max}}{k_w \cdot k_f \cdot W_y} \leq f_m^k \tag{6}$$

$$P_{cap}{}^{GLULAM} = \frac{k \cdot f_m^k \cdot k_w \cdot k_f \cdot b \cdot h^2}{2 \cdot L} \tag{7}$$

where the notations are the same as presented in Eq. (1), except: k is a coefficient that takes into account the type of joint, for finger joint, it has the value 0.90; $P_{cap}{}^{GLULAM}$ is the bearing capacity of the GLULAM beams, with a calculated value of $P_{cap}{}^{GLULAM}$ = 9.147 kN.

Therefore, the OSB 3 glued beam presents a bearing capacity 17.78% lower than that of GLULAM beams.

Considering the same strength class GL20, the OSB 3 glued beam can have the same bearing capacity as the GLULAM beam, if the GLULAM element has its cross-section dimensions reduced to 115x140mm. In this situation, the GLULAM bearing capacity would be of $P_{cap}{}^{GLULAM}$ = 8.513 kN.

For this GLULAM beam, the maximum deflection is 26.92mm, which is 2.49 times higher than the allowable deflection.

Therefore, the OSB 3 glued beams of 140x140 mm cross-section present similar bearing capacities and stiffness behaviour as a GLULAM beam of 115x140 mm cross-section.

2.4. Methods for Improving OSB 3 Glued Beams Bearing Capacity

Considering that glued elements can reach virtually infinite widths, heights and lengths, the following question emerged: what would the bearing capacity be if the beam had more than 6 OSB 3 lamellae? Table 3 presents how the bearing capacity changes for OSB 3 glued beams with 6 up to 12 lamellae.

The thickness of an OSB 3 glued element is of 23.33 mm.

As shown in Table 3, by adding only one lamella, the bearing capacity improved by 36.1%. By doubling the height of the OSB 3 glued beam, from 140 mm to 280 mm, the bearing capacity tripled.

Analyzing the values obtained in Tables 2 and 3, it can be noted that by adding one more lamella, the bearing capacity of the beam becomes higher than that of a solid timber beam of strength class C18. In addition, this value exceeds the bearing capacity of GLULAM beam of class GL20 by 11.9%.

Table 3
Bearing Capacities of Various OSB 3 Glued Beams

Number of lamellae	Cross-section dimensions, *b* x *h*, [mm]	Bearing capacity, P_{cap}^{OSB}, [kN]	Improved bearing capacity
6	140x140	7.521	0%
7	140x163.33	10.236	36.1%
8	140x186.66	13.369	77.8%
9	140x209.99	16.920	125%
10	140x233.32	20.888	177.8%
11	140x256.65	25.274	236%
12	140x280	30.078	300%

An OSB 3 glued beam with 8 lamellae reaches a bearing capacity higher than a solid timber beam of strength class C24, while 9 lamellae ensure a higher bearing capacity than C30, which is a considerably high strength class for production. A total of 10 lamellae ensure a bearing capacity bigger than the highest softwood strength class C40.

Another method for improving the bearing capacity of an OSB 3 glued beam is by using thinner lamellae. A comparison between the bearing capacities of the analyzed OSB 3 glued beam and for OSB 3 glued beams made of thinner lamellae are presented in Table 4 (website Egger).

Table 4
Bearing Capacities and Maximum Deflections of OSB 3 Glued Beams with Various Lamellae Thickness

Number of lamellae	Thickness of lamella, [mm]	Characteristic bending strength, [N/mm^2]	Bearing capacity, P_{cap}^{OSB}, [kN]	Improved bearing capacity	Maximum deflection, f_{max}^{OSB}, [mm]
6	23.33	14.8	7.521	0%	33.292
10	14	16.4	8.333	10.8%	36.887
14	10	18	9.147	21.6%	40.49

As presented in Table 1, the characteristic bending strengths given by the manufactures vary for different lamellae thicknesses, from 18 N/mm^2 for thickness 6-10 mm and 16.4 N/mm^2 for thickness 11-18 mm. Table 4 shows that by using lamellae of 14 mm thickness, the bearing capacity increases by 10.8%, which is close to the values attained by timber strength class C16, while using lamellae of 10 mm thickness, the bearing capacity is improved by 21.6%, equal to timber strength class C18.

The maximum deflections were computed using the bearing capacities of the beams. It can be stated that varying the lamellae thickness does not improve the stiffness behaviour of the OSB 3 glued beams, as the material characteristics are the same for all OSB 3 lamellae.

3. OSB 3 Glued Columns

Similarly, the analytical analysis on OSB 3 glued columns, solid timber and GLULAM columns will be validated by experimental tests in the near future. The columns were considered subjected to axial compression, Fig. 4, and the maximum capable compressive force was computed.

The characteristic compressive strength for OSB 3, f_c^k, is declared at 14.8 N/mm^2 and the elasticity modulus E_c is of 3800 N/mm^2. The cross-section area of the column was 140x140 mm, giving a cross-sectional area A=19600 mm^2. The maximum capable compressive force for the OSB 3 glued column was computed using Eqs. (8) and (9), (SR EN 408: 2004; CR 0: 2012; SR EN 1990–1–1: 2004; SR EN 1995–1–2: 2004; SR EN 338: 2010; Neculai and Isopescu, 2017):

$$\sigma_x^{max} = \frac{N_c}{k_c \cdot A} \leq f_c^k \tag{8}$$

$$N_{cap} = k_c \cdot A \cdot f_c^k \tag{9}$$

where: k_c = 0.637 is a coefficient which takes into account the possibility of buckling, and it was determined according to SR EN 1995, using Eq. (10):

$$k_c = \frac{1}{k + \sqrt{(k)^2 - \lambda_{rel}^2}} \tag{10}$$

where: k is given by Eq. (11):

$$k = 0.5 \cdot \left[1 + \beta_c(\lambda_{rel} - 0.3) + \lambda_{rel}^2\right] \tag{11}$$

where: β_c is a coefficient equal to 0.2, in case of solid timber and to 0.1 in case of glued laminated timber, LVL or OSB; λ_{rel} = 1.156 is the relative slenderness ratio, given by Eq. (12)

$$\lambda_{rel} = \frac{\lambda}{\pi}\sqrt{\frac{f_c{}^k}{E_c}} \tag{12}$$

where: λ is the slenderness coefficient, and it is the ratio between the buckling length, L_{ef}, which in the case of columns fixed on the bottom and pinned to the top, $L_{ef} = L$= 2350 mm, and the gyration radius, i, given by Eq. (13):

$$i = \sqrt{\frac{I}{A}} \tag{13}$$

where: I is the moment of inertia and A is the cross-section area for the column;

The values for f_c^k and E_c were presented in Table 1. The resulting capable compressive force is N_{cap}^{OSB}= 0.637 x 290.08= 184.64 kN.

3.1. OSB 3 Glued Columns vs. Solid Timber Columns Capable Compressive Force

The capable compressive force for a solid timber column, with the constant cross-section of 140x140 mm, is determined using Eq. (8) for solid timber, and the values obtained for various strength classes, are presented in Table 5. The coefficient β_c in the case of solid timber has the value of 0.2.

Table 5
Capable Compressive Forces Obtained for Strength Classes of Timber

Strength class	Characteristic compressive strength, $f_{c,0,k}$, [N/mm^2]	Modulus of elasticity $E_c = E_{0.05}$, [N/mm^2]	k_c	Capable compressive force, N_{cap}^{timber}, [kN]	Percentage of OSB 3 glued column from timber beam capable compressive force
C14	16	4700	0.629	197.4	93.5%
C16	17	5400	0.660	219.99	83.9%
C18	18	6000	0.679	239.45	77.1%
C22	20	6700	0.681	266.79	69.2%
C24	21	7400	0.699	287.86	64.1%
C27	22	8000	0.711	306.46	60.2%
C30	23	8000	0.695	313.12	59%
C35	25	8700	0.695	340.44	54.2%
C40	26	9400	0.709	361.13	51.1%

Therefore, the capable load for OSB 3 glued columns is 93.5% of the capable compressive force for the weakest timber strength class, C14, and is 51.1% of the highest softwood strength class, C40.

3.1. OSB 3 Glued Columns vs. GLULAM Columns Capable Compressive Force

The same study was made on GLULAM columns, considering the weakest strength class, GL20, at which the characteristic compressive strength is declared at 20 N/mm^2 and the elasticity modulus $E_{0.05}$ is of 7000 N/mm^2. The capable compressive load was determined for the GLULAM column, using Eq. (8), at N_{cap}^{GLULAM} = 304.31 kN. Hence, the OSB 3 glued column presents 60.7% of the capable compressive force of the GLULAM element. By reducing the size of the cross-section, a GLULAM element of 85x140 mm would present the same capable compressive force as the OSB 3 glued column.

3.2. Methods for Improving OSB 3 Glued Columns Capable Compressive Force

Table 6 presents the capable compressive force of OSB 3 glued columns for different cross-sections, considering a constant width, *b*=140 mm, and varying the height, h, by gluing additional lamellae.

The capable compressive force reached by glued one more lamella reaches 262.51 kN, which is similar to a solid timber column of strength class C18, even C22.

By adding 2 more lamellae, the capable compressive force becomes higher than a GLULAM column of strength class GL20 and higher than solid timber strength class C30. Using 9 OSB 3 lamellae, the capable compressive load becomes bigger than the highest strength class for softwoods, C40.

By making the cross-section height double, the capable compressive force of the OSB 3 glued column becomes 201.9% higher than the initial column.

Table 6
Capable Compressive Forces of Various OSB 3 Glued Columns

Number of lamellae	Cross-section dimensions, *b* x *h*, [mm]	Capable compressive force, N_{cap}^{OSB}, [kN]	Improved capable compressive force
6	140x140	184.64	0%
7	140x163.33	262.51	42.2%
8	140x186.66	333.21	80.5%
9	140x209.99	394.83	113.8%
10	140x233.32	451.23	144.4%
11	140x256.65	504.98	173.5%
12	140x280	557.36	201.9%

A comparison between the capable compressive forces of OSB 3 glued columns made of OSB 3 with various thicknesses is presented in Table 7.

Table 7
Capable Compressive Force of OSB 3 Glued Columns with Various Lamellae Thickness

Number of lamellae	Thickness of lamella, [mm]	Characteristic compressive strength, [N/mm^2]	Bearing capacity, N_{cap}^{OSB}, [kN]	Improved capable compressive force
6	23.33	14.8	133.75	0%
10	14	15.4	134.3	0.41%
14	10	15.9	134.71	0.72%

Analysing Table 7, the improvement given by using thinner lamellae is small, from 0.41% up to 0.72%. From capable compressive force point of view, lamellae with 10 mm thickness are similar to the lowest timber class C14.

4. Conclusions

OSB 3 glued beams present bearing capacities higher than solid timber of class C14, and lower with 17.78% than the weakest class of GLULAM, GL20. Nevertheless, by increasing the OSB 3 glued beam cross-section height with only one lamella, its bearing capacity becomes higher than that of a solid timber beam of strength class C18, and is higher than GLULAM beam of strength class GL20. By using thinner lamellae, the bearing capacities of the OSB 3 glued beams can be similar to solid timber class C16 and even C18. The OSB 3 glued beam made of the thinnest lamellae reaches a bearing capacity equal to GL20.

From columns behaviour point of view, using more than 7 lamellae makes the OSB 3 glued columns capable compressive force higher than that of solid timber class C18, and close to C22. Using 8 lamellae makes the OSB 3 glued column present higher the capable compressive forces than GLULAM columns of class GL20. By using 9 OSB 3 lamellae, the compressive capacity becomes bigger than the highest softwood strength class, C40.

According to the result for maximum deflection it is supposed that the optimum height, h, will be the answer of solving the system of conditions regarding the resistance, stability and rigidity of the laminated beam made of OSB 3 lamellae. Thus, optimization is achieved in the dimensioning phase, reducing the number of iterations needed to obtain an efficient element.

For all these conclusions to be validated, the presented analytical analysis is to be calibrated and checked by an experimental program on OSB 3 glued beams and columns tested at the "Gheorghe Asachi" Technical University of Iaşi, Faculty of Civil Engineering and Building Services.

Using OSB 3 as structural elements brings certain challenges, as the material characteristic properties have lower values than those of solid timber or GLULAM, and their structural behaviour has not yet been experimentally tested. Nevertheless, the presented analytical analysis brings hope towards using this eco-friendly material for structural elements, thus introducing recycled and left-over wood as components for structural materials of future constructions.

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METODOLOGIA ANALITICĂ UTILIZATĂ PENTRU A EVALUA CAPACITATEA PORTANTĂ A ELEMENTELOR STRUCTURALE HIBRIDE CUM SUNT STÂLPII ȘI GRINZILE REALIZAȚI DIN LAMELE DE OSB 3

(Rezumat)

În industria construcțiilor, lemnul a început să fie tot mai utilizat în ultimii ani și acest lucru a dus la dezvoltarea de produse finite din lemn prelucrat. Prin prelucrarea lemnului în fabrică, se eliberează mai puțin dioxid de carbon și, prin urmare, poluarea este redusă. Acest studiu dorește să stabilească capacitatea portantă a elementelor structurale hibride, cum sunt stâlpii și grinzile, cu o nouă configurație. Ansamblu propus este din lamele de OSB 3 lipite pentru a forma grinzi și stâlpi. Analiza prezentată în această lucrare dorește să fie un reper pentru experții din industria lemnului și pentru inginerii și arhitecții care proiectează construcții din lemn, și un ghid pentru cei care doresc să extindă studiul actual în acest domeniu. Lemnul industrializat are proprietăți superioare comparat cu alte materiale tradiționale. Folosind aceste elemente structurale hibride prefabricate din OSB 3, timpul execuției construcției este redus și structura finală poate fi definită ca fiind sustenabilă.