Chapter 2
Impact of Semi-rigidity of Joint on Timber Composite Truss Beam

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Abstract The DOREAN design system is based on a wood structure made with girder trusses. This paper quantifies the contribution of the OSB panels on the load carrying capacity of the trusses in the DOREAN house structure. On the one hand, by experimental tests carried out on double shear specimens, and on the other hand by modelling a T-beam including the stiffness of the assembly between the panel and the truss beam. The connexion between the OSB panel and the upper chord of the lattice beam is realized by staples. Shear tests are performed varying the number of fasteners with three thicknesses of panel and three different orientations of the staples. This last parameter is of high importance because of the short loaded edge distance in the narrow wood element of the chords. Strength and stiffness of the stapled joint are obtained from tests and the interaction between fasteners is analysed. The T-beam obtained by the connexion between the OSB panels and the DOREAN lattice beam is modelled using beam elements. The semi-rigid behaviour is taken into account for all the connexions between the lattice beam elements and the OSB panels. Conditions of serviceability and ultimate strength are analysed with the influence of the variability of the T-beam parameters.

2.1 Introduction

It is known that the use of wood material in the construction has a significant contribution to the stability of the ecosystem. More again, the wood material has a positive impact in the thermic regulation of industrial buildings, small and collectives' houses [1, 2]. Due to the economic demand and to the fact that the energy costs represent a significant part of household expenses, it appears necessary to improve the composition and the assembly of structural elements in timber building [3]. According to its assembly and building mode, the DOREAN's beam can contribute to solving a part of this problem.

Figure 2.1 presents the dimensions of a typical truss beam and the equipment used to realise the assembly of the truss members. These beams are generally built from low-size timber members, assembled by nails, by plates with metal teeth or by adhesives. The efficiency of this assembly is obtained by the control of the manufacture process and the knowledge of the joints behaviour [4, 5]. These beams can be used in the frame systems or slabs in combination with OSB panels.

The present investigation is focused on the semi-rigid behaviour of the nailed and glued connexion between the lattice beam members and the OSB panels. In the literature framework, few authors have discussed the influence of these connections in the global behaviour of the structures and especially timber structures. Among them, Zhu et al. [6] have proposed numerical study of OSB webbed timber I-beams with interactions between openings and Feraboli [7] has performed experimental test of notched response of OSB wood composites.

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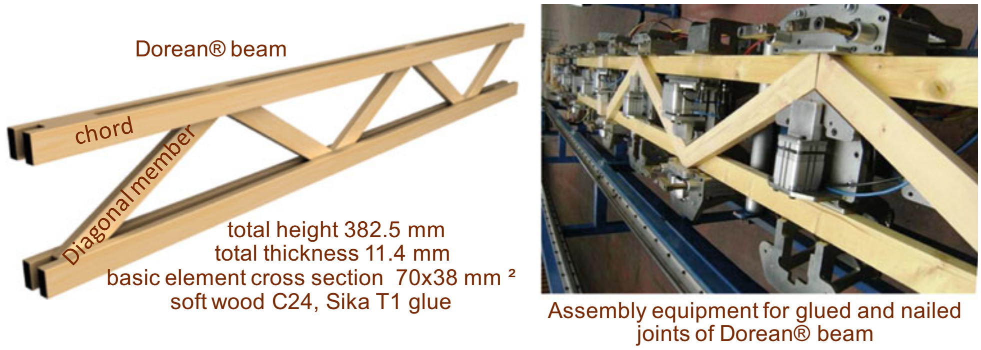

Fig. 2.1 DOREAN beam

The experimental tests performed on push-out specimens provide the load–displacement curves of the connections between the wood members and the OSB panels. Thus, various configurations of connections are tested changing the thickness of the panels and the connection type (number and orientation of staples, glue, panel thickness). The experimental results are used as input data in a simple numerical finite element model. The comparison of experimental test and simulation are presented and discussed.

2.2 Experimental Program

Previous experimentations on lattice beams [2] provided the ultimate and the serviceability mechanical properties of Dorean beams without OSB panels. In this paper, a new experimental program is performed to obtain the strength and the rigidity of the connection between the two parts of a T-beam composed by Dorean beam and OSB panels. This T-beam is used in slab application with composite effect due to the association of truss beam and OSB panels. Tests are carried-out on double shear push-out specimens with glued, nailed or glued and nailed joints (see Table 2.1).

2.2.1 Specimen Dimensions and Set-up

The push-out specimens are tested in universal press under compression loading to obtain the shear load on the connection. Figure 2.2 shows a shear specimen loaded in the direction parallel to grain and its load–displacement curve. The static loading history (Fig. 2.3) includes a preloading phase, a partial unloading and finally a re-loading phase until failure or excessive displacement. The specimens are loaded in the direction parallel to grain or perpendicular to grain of the wood members. The first plateau after preloading (Fig. 2.3) is defined as 1,200 N and 600 N for the specimens loaded in the directions parallel to grain or perpendicular to grain, respectively. The second plateau, after unloading phase, is defined as 200 N in both cases. The dimensions of the two types of specimens loaded in the directions parallel and perpendicular to grain with the measurement devices of load and displacements are shown in Fig. 2.3. The relative displacements between the OSB panels and the wood member are measured on four points around the wood member using LVDT sensors. Thus, for each test, the mean value of displacement measured by the two transducers for each interface between OSB panel and wood member is considered to represent the behaviour of the connection. The orientation of the staple is defined as the angle between the longitudinal axis of the staple and the longitudinal axis of the timber element.

The configurations of specimens tested are summarized in Table 2.1. Three specimens are tested in each configuration. For all the specimens the staples are positioned on one line parallel to the wood member. The spacing between the staples is equal to 150 mm (see Fig. 2.4) for all the specimens except for the configurations "2" and "6–3" respectively with 7 or 3 staples and a half spacing.

Table 2.1 Various configurations of connections between the panels and the wood member of lattice beam

	Specimen orientation	Staples	Number of staples	Glue	Staple orientation	OSB thickness
1-1	//	Yes	4	No	45	18
1-2	//	Yes	4	No	90	18
1-3	//	Yes	4	No	0	18
2	//	Yes	7	No	0	18
3	//	No	0	Yes	0	18
4-1	//	Yes	4	No	0	15
4-2	//	Yes	4	No	0	10
5	//	Yes	4	Yes	0	18
6-1	⊥	Yes	2	No	0	18
6-2	⊥	Yes	2	Yes	0	18
6-3	⊥	Yes	3	No	0	18

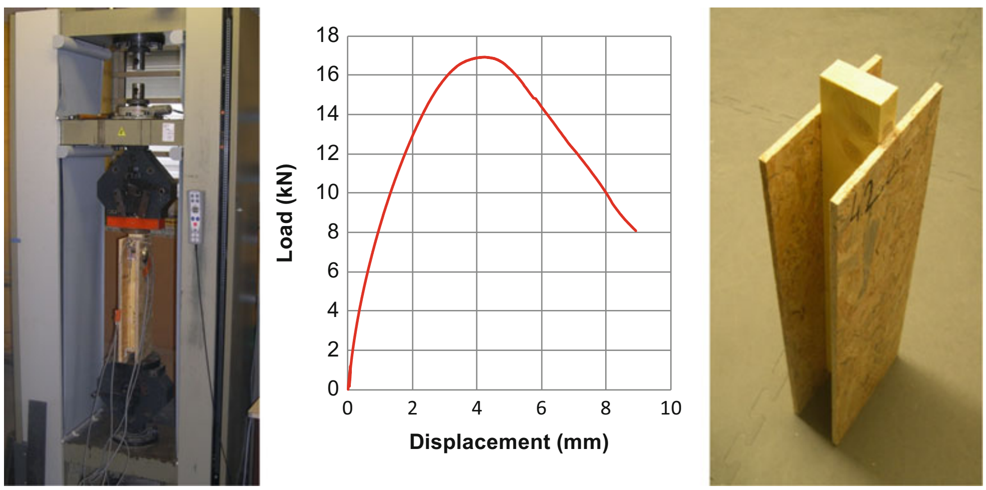

Fig. 2.2 Universal press, load–displacement curve and push-out shear specimen

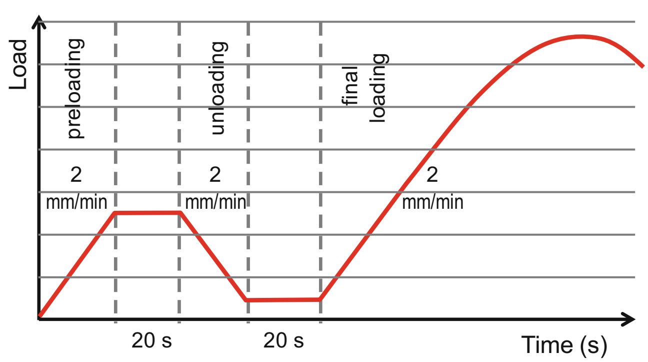

Fig. 2.3 Loading history used for the experimental program

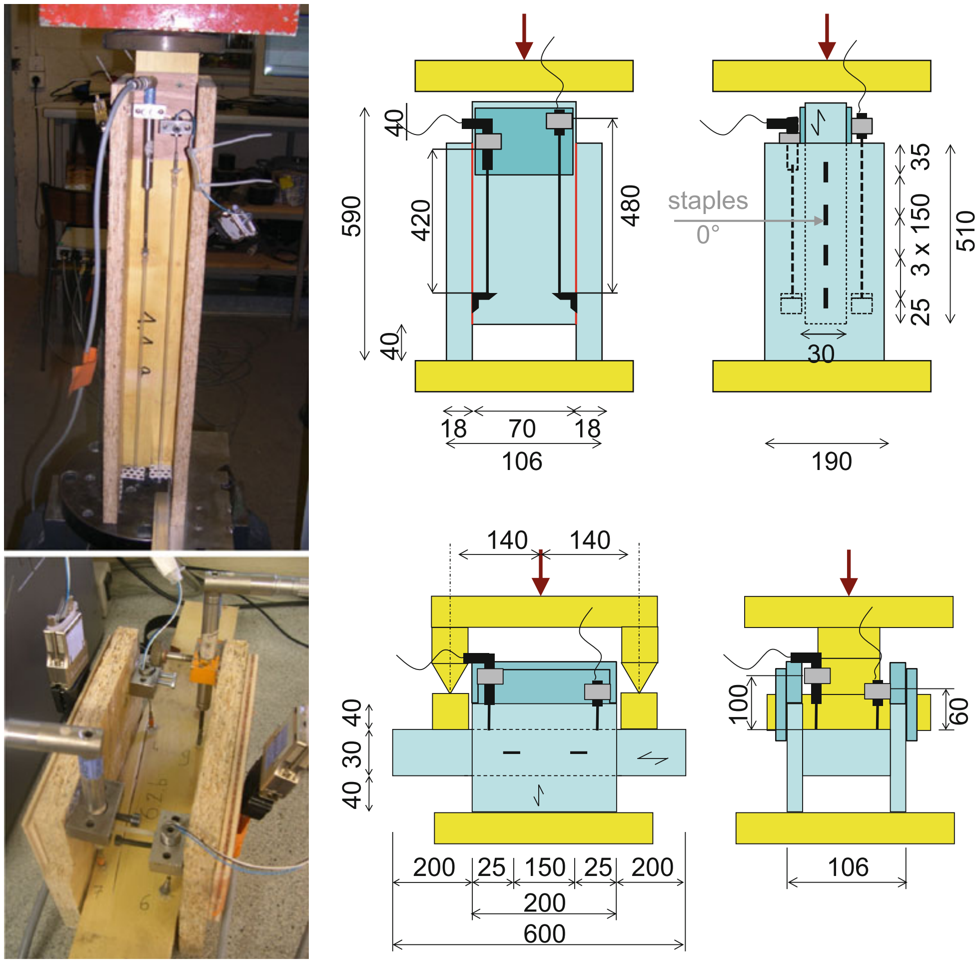

Fig. 2.4 Dimensions of specimens with the measurement devices of load and displacement

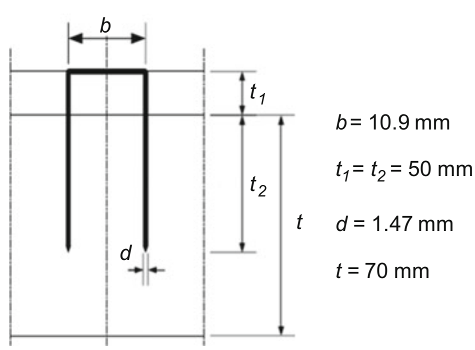

Fig. 2.5 Dimensions of the staples

2.2.2 *Material Characteristics*

Timber elements are made of spruce of C18 class resistance [8, 9]. The mean value of density is 435 kg/m^3 (standard deviation of 15 %) with average value of moisture content equal to 7.2 % (standard deviation of 12 %). The panels are made of OSB3 [10] with an average density of 640 kg/m^3 [11]. The staples defined on Fig. 2.5 are made from steel with ultimate stress f_u equal to 540 MPa. The shear strength of such staple using the Eurocode 5 requirements is about 0.5 kN for the 3 thicknesses of panels used in the tests. This strength is given for one staple and one shear plan between the wood member and the wood OSB panel. The polyurethane glue used in the tests is characterized by a shear strength of 1.2 MPa.

2.3 Discussion of Experimental Results

Examples of load- displacement relationship are plotted on Fig. 2.6. The displacement for each index a, b and c is the mean value of the four LVDTs around the wood member. The indexes a, b and c represent the three specimens tested for each configuration. The zoom on the beginning of the curve with the effect of unloading and reloading is illustrated for one specimen (index a). This figure allows comparing the mechanical behaviour between the 45° and 90° orientation of staples. Table 2.2 gives a synthetic overview of experimental results on the whole set of specimen. The parameters defined in the Table 2.2 can be defined as follows: F_{max} is the maximum load during test, F_y and dep_y are defined by the intersection between the lines tangent to the initial and final phases (1/6 of initial tangent) of the load–displacement curves, F_u is the ultimate value of the force and dep_u is defined as the lowest value between the displacement for F_u and the displacement corresponding to a decreasing of 20 % of the load compared to F_{max}, the ductility is the ratio dep_u/dep_y, the rigidity is defined by the initial phase of the load–displacement curve.

- Shear in the direction parallel to the main axis of timber element

The strength of mechanically connected joints (without glue) is between 6.8 and 8.5 kN for 4 staples. The higher values of strength are obtained for OSB 18 and the lower values for OSB 10. The best orientation of staple is an angle of 90 ° (staples perpendicular to the grain direction of timber element). Doubling the number of staples with half spacing induces an increasing of strength of about 75 %. With the same number and orientation of staples, the presence of glue allows reaching strength between 17.3 and 19 kN, but the static ductility is slightly reduced in comparison with the staples. For these configurations of joints in shear, the values of rigidity is between 5.3 and 13.9 kN/mm.

- Shear in the direction perpendicular to the main axis of timber element

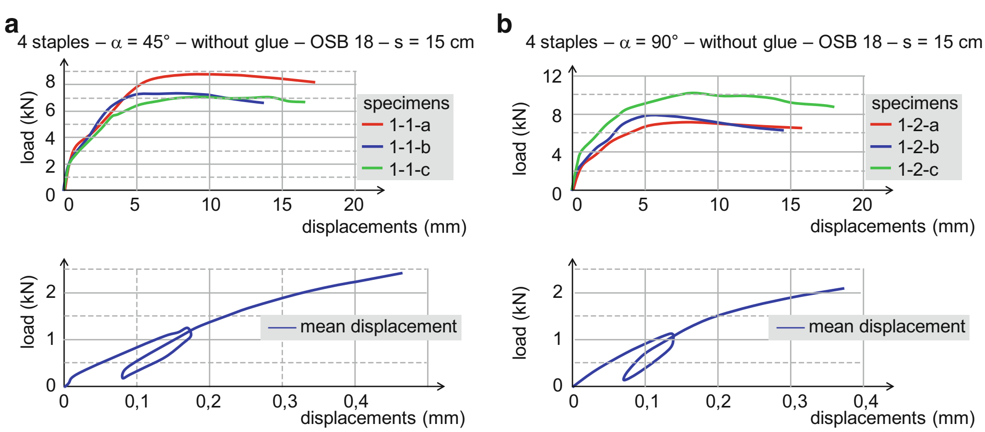

Fig. 2.6 Examples of push-out test in parallel configuration (whole curves and zoom on the initial phase of specimen "a"). (**a**) Specimens 1-1, α = 45°, (**b**) specimens 1-2, α = 90°

Table 2.2 Synthetic table of results

	Specimen orientation	Staples	Number of staples	Glue	Staple orientation	OSB thickness	F_{max} (kN)	F_y (kN)	F_u (kN)	dep_y (mm)	dep_u (mm)	Rigidity (kN/mm)	Ductility
1-1	//	Yes	4	No	45	18	7.7	3.2	6.9	0.6	>18	5.3	>30
1-2	//	Yes	4	No	90	18	8.5	4.1	6.8	0.7	>18	5.9	>26
1-3	//	Yes	4	No	0	18	7.3	3.7	5.9	0.6	>18	6.2	>30
2	//	Yes	7	No	0	18	12.8	7.3	10.2	0.8	>18	9.1	>23
3	//	No	0	Yes	0	18	19	15.9	15.2	1.4	5.8	11.4	4
4-1	//	Yes	4	No	0	15	7.8	2.5	6.3	0.3	>18	8.3	>60
4-2	//	Yes	4	No	0	10	6.8	3.7	5.5	0.9	8.8	4.1	10
5	//	Yes	4	Yes	0	18	17.3	12.5	13.1	0.9	6.8	13.9	8
6-1	⊥	Yes	2	No	0	18	3.8	1.8	3.1	0.7	10.3	2.6	15
6-2	⊥	Yes	2	Yes	0	18	10.7	5.8	8.5	1.2	7.2	4.8	6
6-3	⊥	Yes	3	No	0	18	6	2.8	4.8	0.6	10.2	4.7	17

The strength obtained with 2 staples is around 4 kN and that of 3 staples is about 6 kN. With the same number and orientation of staples, the presence of glue increases the strength to reach more than 10 kN with a significant decrease of the static ductility. For these configurations of joints in shear, the values of rigidity are between 2.6 and 4.8 kN/mm.

2.4 Composite Beam Simulation

In order to take into account the composite behaviour of a T-beam realized with a Dorean lattice beam and OSB panels connected by staples or glue, a finite element model is realized using beam elements. The mechanical properties of the Dorean beam, obtained in a previous study [1, 3], are used in the numerical simulation of the present study. Thus, simple beam elements are used. Truss elements with semi-rigid behaviour at the end of the members and between the wood member and the OSB panel are considered (Fig. 2.7).

2.4.1 FEM Model

Truss assumptions are considered for Dorean beam, with or without semi-rigidity of the joints between chord and diagonal elements. The span of the beam considered in the model is equal to 3.60 m as the one tested in a previous study concerning a truss beams without OSB panels [3]. A modulus of elasticity of 10,000 MPa is assumed for wood in the lattice beam. The analysis of the influence of semi-rigid connections in the lattice beam on its stiffness determined by inverse analysis on bending test showed that the initial stiffness of the connection varies between 4.1 and 10 kN/mm. The vertical and diagonal elements are with a cross section of 38 × 70 mm^2, the chord is with a cross section of 2 × (38 × 70) mm^2. OSB panel cross section is equal to (10, 15 or 18) × 625 mm^2. Its MOE is taken equal to 2,000 MPa corresponding to the low boundary value from standards. This low value is coherent with complex modelling including contact between panels along the span of the floor.

The mesh is illustrated on Fig. 2.7 and the loading is a uniformly distributed force applied on the panel elements. The interface between panels and the Dorean beam is modelled by three beam elements as shown on Fig. 2.8. AB and CD elements are rigid beam in order to assume Navier-Bernoulli hypothesis. BC element is rigid in bending and semi-rigid in longitudinal direction. This rigidity K is defined as following:

$$F_V = K \cdot \delta \Rightarrow K = \frac{F_V}{\delta} = \frac{E_C \cdot A_C}{l_C} \tag{2.1}$$

with, K the value obtained from experiments with a spacing between connectors equal to the connected length on push-out specimens.

To represent the composite effect between the upper chord of the truss beam and the OSB panel, short beam element is used to represent the semi-rigid behaviour between the panel and the wood member (Fig. 2.8). The initial stiffness of the connection is obtained from the tests on shear specimens. The OSB panel is represented by equivalent beam element.

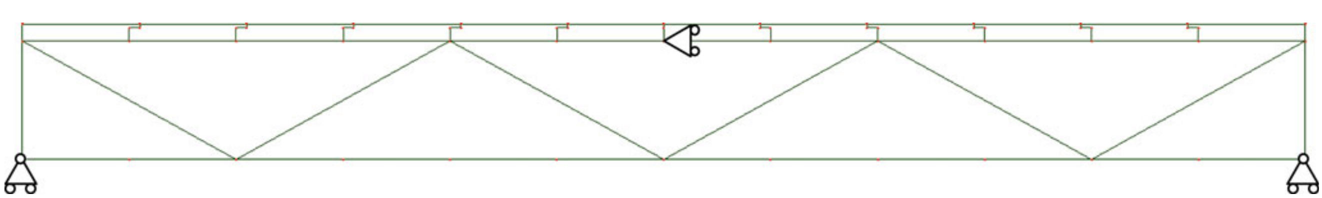

Fig. 2.7 DOREAN beam's mesh with shear connection (panel to upper chord)

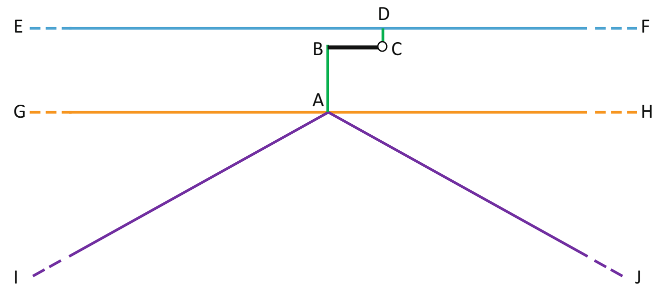

Fig. 2.8 Mechanical characteristics of the elements, boundary conditions

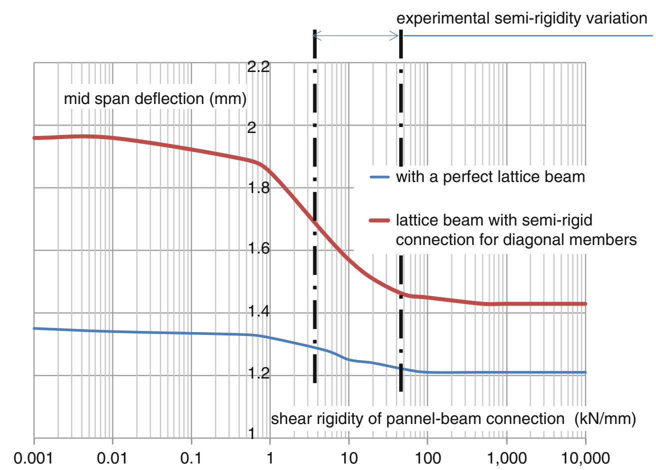

Fig. 2.9 Comparison of experimental and numerical results

2.4.2 *Comparison of Experimental and Numerical Results*

The simple finite element model is performed to analyse the influence of the axial semi-rigid behaviour at the end of the members and the shear semi-rigid behaviour at the interface between the OSB panels and the upper chord of the lattice beam. Figure 2.9 shows the influence of the shear semi-rigidity at the interface on the global deflection, at linear phase, of a T-beam combining lattice beam and OSB panel. The axial connections at the end of the truss members are considered rigid or semi-rigid. The comparison shows that the lattice beam with axial semi-rigidity at the end of the members is more sensitive to the evolution of the shear semi-rigidity at the interface between the panel and the upper chord. Besides, the increase of the shear rigidity increases the global stiffness of the T-beam. Here, for a span of 3.36 m, this increase is equal to 12 % and 37 % respectively for the perfect lattice beam and for the truss beam with semi rigid shear connection between the panel and the upper chord. This increase reaches 41 % for a span of 4.45 obtained adding 2 diagonals.

2.5 Conclusion

The tests on lattice timber beams (DOREAN®) manufactured with various techniques of connections showed the influence of the connection on the beam behaviour. This beam is associated with OSB panels to obtain a wooden floor. Tests realized on push-out shear specimens between OSB panels and beam members using staples and glue provided the load-slip curves at the interface between the two materials. In comparison with the connections using only staples, the glue showed an increase of the strength and the stiffness of the connection with a decrease of the ductility. The test provided the load-slip curves used in the simple finite element model. The results of the simple simulations illustrate the effects of shear semi-rigidity on the global behaviour of the T-beam combining lattice beam and OSB panels. This preliminary study will be extended to analyse different ratios of stiffness between the truss beam and the panels. The stiffness at the interface will be analysed considering real non-linear behaviour of materials and connections.

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