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LIFESHELL: CLT FURNITURE AS LIFE-SAVING TECHNOLOGIES

Edoardo Giacobbo[1], Jarno Bontadi[1], Andrea Polastri[1], Emanuele Sartori[2], Roberto Scotta[2], Marco Fellin[1]

ABSTRACT: Earthquakes are unpredictable and deadly phenomena. Several events occur each year that cause serious damage to poorly constructed buildings. This project aims to develop open-source, affordable wooden furniture that acts as shelters to protect humans from building collapse during an earthquake. The concept, named Lifeshell (life in a shell), is based on the use of Cross Laminated Timber (CLT) to create robust and economical furniture (e.g. desk and closet). This system serves as a local survival cell inside existing buildings, promptly deployable while waiting for expensive and time consuming refurbishments or rebuilding. A preliminary design of a school desk has been calculated by means of analytical and numerical models and then will be experimentally tested. After having defined the geometric characteristics of the desk for load-bearing capacity and ergonomics, non-linear analyses were performed. Following the estimation of static and dynamic behavior, monotonic and impact tests are planned. The data was then processed in an optimal design cycle to obtain a refined version of the desk and its variants. The project also aims to establish a standard proposal for testing and evaluating the capabilities of such furniture.

KEYWORDS: CLT, furniture, earthquake, collapse.

1 – INTRODUCTION

Despite the development of building codes that emphasize seismic safety, the seismic performance of many buildings in various countries remains inadequate. Some of the most devastating earthquakes of the past decade, characterized by a large number of inadequate buildings involved, include the 2023 earthquake in Turkey and Syria, the 2015 earthquake in Nepal and the 2010 earthquake in Haiti. From 2001 to 2024, more than 300,000 people lost their lives due to earthquakes [1].

During an earthquake event, in situations where a quick escape route cannot be found, international earthquake guidelines suggest that people take shelter under solid furniture, using the furniture itself as protection from building collapse.

The Lifeshell project proposes the use of Cross-Laminated Timber (CLT) panels for such furniture. The positive features related to this project are the simplicity of assembly of the furniture structure, the extensive use of renewable materials (wood), and an open-source Creative Commons license, which avoids patenting a life-saving technology. The furniture guarantees breathable air volume, and will includes accessories to facilitate localization, communication and rescue, water, food and even a kit for physiological needs.

From the structural point of view, the objective is to develop a system that ensures adequate resistance to the collapse of one or more upper floors and to the possible failure of the lower floor or side walls of the building in which it is housed. Multiple designs of the furniture are proposed and classified in terms of performance according to the load that may bear on it and thus based on the characteristics of the building in which they are contained. The design is carried out for mainly desk-shaped furniture, that will be used in the work, school and domestic environment. The mechanical and geometric properties of the furniture are designed in accordance with the requirements and limitations set by European standards, with the goal of providing a compliant ergonomic and durable design.

After considering different versions using various materials, it was concluded that wood, in the form of Cross Laminated Timber (CLT) optimally fits the case study application for its high strength-to-weight ratio, sustainability and reusability, versatility and durability.

[1]National Research Council of Italy, Institute of BioEconomy (CNR IBE), San Michele all'Adige, Italy, edoardogiacobbo@cnr.it jarno.bontadi@cnr.it andrea.polastri@cnr.it marco.fellin@cnr.it

[2]University of Padova, Padova, Italy, emanuele.sartori@unipd.it roberto.scotta@unipd.it

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Initially, the design process of the table was similar to that of a box-type building with CLT walls. Calculations were performed according to the European standard like Eurocode 5 (EC5) [2] or European Technical Assessments (ETAs) for wooden constructions. Then, in order to have adequate dissipative capacity, the design was conceived to guarantee that the ductile failure mechanisms occur always before the fragile ones. Once the preliminary geometry of the desk had been established, numerical analyses were carried out using finite element software. Nonlinear analyses were developed to account for both material and geometric nonlinearities.

The same configuration and conditions will be replicated through a series of quasi-static and dynamic experimental tests at the CNR-IBE laboratories. With the dynamic tests, it is possible to simulate the impact of a mass falling from a certain height onto the middle of the top panel. Since nowadays there are no standards for assessing and certifying the capabilities of these pieces of furniture, the project also aims to define experimental test procedures for assessing their capabilities that can serve as pre-standards in preparation for shared international regulation.

2 – BACKGROUND

In the literature, a few studies propose furniture or group of furniture designed to protect people against building collapse [3]. However, none of these design seems nowadays available on market. In the recent past some technology was shyly on the market: an Israeli company produced a metal frame table [4], but despite winning the prestigious Red Dot Design award and being acquired at MoMa museum the table seems unavailable for being bought and used. Similarly, LifeGuard Structures was in production for just a few years [5]. However, so far these technologies are not made of wood, making them 5 to 10 times more expensive than the expected cost of a Lifeshell desk. Moreover, they are patented, which significantly limits their industrial application potential. Regulations do not provide any information, guidelines, or prescriptions for the development of such furniture which work as seismic shelters.

3 – PROJECT DESCRIPTION

At this early stage of research, the design was limited to studying the case of a work table, but the criteria adopted in this case can also be extended to other types of furniture such as beds or cabinets.

The generic desk under study consists of five CLT panels rigidly connected to each other to achieve a box-like behavior. These panels are made in three (or five) layers with lamellar thicknesses varying from 20 or 33 mm to achieve a total thickness of 60 or 100 mm depending on the performance demand to be guaranteed. Starting from the base, a horizontal panel forms the lower support plane. Connected to the three edges of the base panel are three vertical septa. These three panels realize the support of the upper panel (worktop). Possible connection systems between panels include the use of elements with coupling between threaded metal insert and screw (to ensure simple disassembly without damaging the wood) or the use of other traditional systems (traditional screws or coach screws). Given the weight of the structure (about 120 kg), movement of the desk is made possible by a system of four spherical casters. Small openings can be made in the vertical panels to increase the possible volume of breathable air and to create additional paths for communicating with first responders. With the aim of increasing the bending strength of the panel and ensuring adequate energy dissipation, the insertion of a steel plate at the intrados of the panel itself is proposed. Specifically, this plate, positioned at a certain distance from the front edge, is developed between the two lateral vertical panels and at the ends is bent and ribbed so as to create cooperation with the upper horizontal panel (Fig. 1).

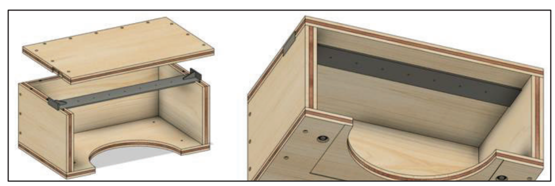


Figure 1. Steel reinforcement plate under the top panel of the desk

A notch is required on the base panel to allow the chair to be advanced under the desk. Then, a thin plate of a light material is inserted below. Thereafter, two desk configurations (DESK60 and DESK100) are analyzed (Fig.2).

DESK 60		DESK 100	
Panel thickness t_p	60	Panel thickness t_p	100
Lamellae thickness t_l	20	Lamellae thickness t_l	33
Outer length L	1200	Outer length L	1200
Inner length l	1080	Inner length l	1000
Outer depth B	720	Outer depth B	720
Inner depth b	660	Inner depth b	620
Outer height H	740	Outer height H	740
Inner height h	620	Inner height h	540

Figure 2. Geometrical properties of the desk configurations analyzed (dimensions in mm).

4 – DESIGN PROCESS

Initially, the design process of the table was similar to that of a box-type building with CLT walls. The geometric features of the desk were defined in accordance with the ergonomic limits set by various European standards for school or office desks.

4.1 REGULATORY LIMITS AND STUDY POPULATION

Depending on the context in which the table is used, there are specific standards that indicate minimum requirements for safety, strength and durability, as well as geometric limits. For the office environment, the reference standard is the UNI EN 527-1 [6]. Regarding tables for school environment, the reference standard is UNI-EN 1729-1 [7]. The continuation of the preliminary practical desk design is limited in considering the larger size of school desks classification that, compared to the others, are more limiting in terms of strength.

4.2 LOAD CONFIGURATIONS AND INPUT ENERGY ESTIMATION

A key step in the design process of a structure concerns the analysis and estimation of the type and magnitude of collapse load that may affect the structure. The total or partial collapse of a building can result from the failure of its vertical structural elements (walls, columns) and/or its horizon elements (floors and/or floor beams). During a seismic event, the elements that are first involved are the vertical ones, which, having to carry the horizontal action all the way to the foundation, will have a higher probability of being damaged.

Regarding vertical structural elements, several studies in the literature have classified existing buildings based on their construction materials and structural types [8]. These studies highlighted the vastness of typologies of existing buildings that, also, present many different types of vulnerability. In addition, different types of buildings can be characterized by various deficiencies, weaknesses and defects which are the result of a bad design (e.g., exclusively static design), construction deficiencies (poor materials, inadequate construction methods) or due to the inevitable obsolescence of the building (decay). Then, as a result of damage to vertical elements or due to inadequate or obsolete construction details (poor reinforcement or almost nonexistent connections), involvement of floor elements can occur. The Figure 3 summarizes the most likely collapse scenarios in ascending order by severity and danger of damage.

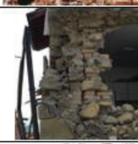
Part of the building / damage type		*Exemplifying picture*
Furniture/ objects and non-structural elements	Tipping over of furniture elements, detachment of accessory elements Collapse of false ceiling or partitioning walls	
Heavy non-structural elements	Infill walls	
Walls	Partial/ fragmented collapse	
	Total rigid collapse	
Roof	Partial roof collapse	
	Total roof collapse (and pancake)	
Combined walls-roof	Loss of floor support (collapsed wall)	
Total	Total collapse of the building	

Figure 3. Classification of types of seismic collapse

In order to estimate the load that can bring the desk to failure, only the last load configurations of Figure 3 were taken into account. Specifically, in the load estimation analysis, only collapses of portions of floor slabs or entire floor blocks, possibly combined with the collapse of parts of walls, were considered. In the worst cases, these loads could be compounded by loads from collapses of one or more floors above the reference floor. This analysis procedure resulted in estimating eligible collapse load values on the desk: for partial collapse loads (acting punctually on the top of the desk), the value is assumed to be between 170 kg and 560 kg; for total collapse loads (acting uniformly on the top of the desk), the value is between 1325 kg and 3810 kg.

Once the types of collapse that can occur in a building had been clarified, it was necessary to translate the phenomenon into load acting on the desk. The loads are applied to the desk randomly depending on the manner in which the collapse occurs and depending on the geometry of the load and the geometry of the building involved. Therefore, a series of simplifications are applied in order

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to obtain load configurations that are elementary but maintain an adequate margin of safety at the design stage. In particular, simplifications are applied on: load movement (direction, height of fall, etc.), position of impact with the table, and type of load. As for the motion of the load, the only load directions considered will be the vertical and horizontal ones, treated totally separately. For loads applied in the horizontal direction, it can, also, be assumed that the table has the freedom to slip and, therefore, with high probability, such load may not become stress on the desk. Both the loads resulting from the collapse of the floor and those resulting from the collapse of the walls will be assumed to be applied as a vertical free fall from above. The height of the fall is assumed to be equal to the inter-story height of the building reduced by the height of the top of the desk. The impact always occurs on the work surface (top horizontal panel of the desk) and here it will be considered punctual in the middle zone or uniformly distributed.

For the two load cases (point and uniformly distributed), estimates of the amount of energy involved in the impact event are shown in the following tables:

Table 1: Input energy estimation for punctual collpase

Parameter	Value		Min/Max of the range
Total mass m_s	170	kg	Min
Falling height h_f	2.25	m	
Energy of impact E_f	3800	J	
Total mass m_s	560	kg	Max
Falling height h_f	2.25	m	
Energy of impact E_f	12400	J	

Table 2: Input energy estimation for distribuited collapse

Parameter	Value		Min/Max of the range
Total mass m_s	1325	kg	Min
Falling height h_f	2.25	m	
Energy of impact E_f	29200	J	
Total mass m_s	3810	kg	Max
Falling height h_f	2.25	m	
Energy of impact E_f	84000	J	

4.3 STRENGTH CHARACTERIZATION OF THE DESK

Mechanical characteristics in terms of resistance and dissipative capacity are then evaluated. Assuming that the desk remains within the elastic range for every load case would result in an ultra-resistant, heavy, and expensive desk. To this end, once adequate resistant capacity is ensured, action is taken by requiring that ductile failure mechanisms, which should have sufficient post-elastic resources, develop in anticipation of brittle ones.

The main expected failure mechanisms are: a) Bending failure in the middle of the upper panel; b) Shear failure of the upper panel; c) Compression perpendicular to the grain failure; d) Buckling failure of the vertical panels; e) Failure by lateral forces.

Such collapse modes can occur for different specific loading conditions. In accordance with the simplifications reported above, the three most critical load configurations are vertical point load in the middle of the working plane (a, b), vertical load uniformly distributed on the superior panel (c, d) and lateral load (e).

Regarding vertical load cases, the two mechanisms selected to provide dissipative capabilities to the table are the first (a) and third (c) ones. The first involves plastic deformation of the reinforcing steel plate and the third involves plastic deformation of the fibers by crushing in the orthogonal direction.

Bending failure in the middle of the upper panel

As mentioned, the upper panel is reinforced by a steel plate inserted at the intrados (Fig.1). The calculation is carried out assuming a strut and tie functioning for which a compressed arch develops in the thickness of the wood that generates horizontally thrusts at the supports that are absorbed by the tension plate. Considering the DESK60 configuration, the mechanism components are characterized by the following quantities:

Table 3: Properties for the strut-tie model of the reinforced CLT panel

Comp.	Parameter	Value	
Steel plate	Plate thickness t_s	5	mm
	Plate width b_s	200	mm
	Characteristic yield stress value f_{yk}	275	Mpa
CLT panel	CLT panel height H_w	60/100	mm
	Width of compressed wood b_c	400	mm
	Characteristic compression failure stress parallel to the grain $f_{c,0,k}$	24	Mpa

From the analysis of the strut-and-tie mechanism under a vertical point load Q, the ultimate concentrated load obtained for the DESK60 configuration is 48.0 kN. To ensure a ductile failure mode, the calculation was performed so that the first failure mechanism involves the yielding of the steel plate. For the DESK100 table, the ultimate concentrated load is approximately 107.0 kN.

Shear failure of the upper panel

Shear failure can occur in the upper panel at the supports for the case of concentrated load in the midsection. According to EC5 formulations, the ultimate force expected for shear failure of the panel (rolling shear) results in 75 kN for DESK60 and 122 kN for DESK100. In accordance with the principles of the hierarchy of strengths, the ultimate shear force (brittle failure) is greater than the respective ultimate force involving bending failure (ductile failure).

Compression perpendicular to the grain

Another failure mechanism is the grain crushing by orthogonal loading. Such failure occurs mainly with a distributed load configuration on the top panel. Both horizontal panels (top and bottom) are involved in the contact strips with the vertical panels. The calculation of the resistance force for this mechanism is summarized in Table 4.

Table 4: Compression perpendicular to the grain resistance

Parameter	Value	
Vertical panel thickness t_s	60 - 100	mm
Total compressed length L_{tot}	2520	mm
Mean compressive failure stress orthogonal to grain $f_{c90,m}$ (min. value)	3.00	Mpa
Total resistance force F_{tot}	450 - 760	kN

Buckling failure of the vertical panels

For the distributed load case, the possibility of early failure of the desk due to buckling of the vertical panels is considered. Since the latter is a brittle failure mode, we proceed to verify that the desk develops early failure by compression orthogonal to the fibers instead. The compression stability problem is believed to be limited to the side panels, since the back panel is well constrained on all four sides. Following EC5 formulations, the ultimate buckling loads for DESK60 and DESK100 are very high, and so this failure mechanism can be neglected.

Failure by lateral forces

The lateral stability of the desk is a function of the strength of the connection system. The three different connection alternatives proposed and analyzed are shown in the following figure (Fig.4)

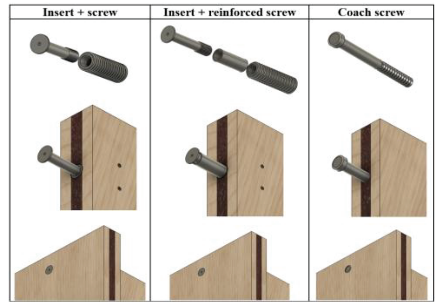

Figure 4. Types of connections analyzed

The first two types involve a threaded insert (d = 25 mm) coupled with a screw (d = 16 mm). In the second case, the screw is reinforced with a metal tube in order to achieve a larger resistant diameter. Whereas the third system involves a traditional screw (coach screw) with a partial thread diameter of 16 mm.

According to the formulation of Johansen [9], the shear strength is equal to the lower strength values of the six failure mechanisms per connector with one shear surface (Fig.5).

Failure type	Insert + screw	Insert + reinf. screw	Coach screw
a	14.40	18.00	14.40
b	15.09	15.09	10.46
c	4.82	6.76	5.86
d	8.45	14.23	7.00
e	12.64	14.11	5.37
f	15.88	21.81	8.03
Fv,Rk [kN]	**4.82**	**6.76**	**5.37**

Figure 5. Six Johansen failure mechanism of the connections

Considering the strengths of the individual connectors shown above, the total desk strength to lateral loads is estimated to be between 30 kN and 50 kN. As it can be seen from Figure 5, for all three connection systems analyzed, the weakest failure mechanism is the one involving rigid rotation of the connector within the wood. It should be pointed out that this connection system is designed to provide adequate lateral resistance, but

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without being involved in energy dissipation mechanisms. For this reason, it is not strictly necessary to assure that the weak failure mechanism involve connector yielding.

The types of connection analyzed above will be tested experimentally. Thanks to the experimental tests, it will be possible to understand the reliability of the estimates obtained analytically.

4.4 CHARACTERIZATION OF DISSIPATIVE CAPACITY OF THE DESK

Once it is ensured that the ductile mechanism develops in anticipation of the brittle mechanism, the amount of energy that the system is able to dissipate in the inelastic field is evaluated. Meeting the demand in terms of energy can be achieved by exploiting two mechanisms: fiber crushing by orthogonal compression and by formation of a plastic hinge on the working plane by reaching the yield stress in the reinforcing plate.

Energy dissipation from compression perpendicular to the grain

When the load is uniformly distributed across the plane of work, failure is expected to involve mainly compression in the direction orthogonal to the fibers. The ductility of this phenomenon has been confirmed by several studies in the literature. Once the elastic limit is exceeded, it is possible to reach deformation rates around 30 percent (Fig.6, Hasuni [10]), and for that reason high energy dissipation resources can be counted on.

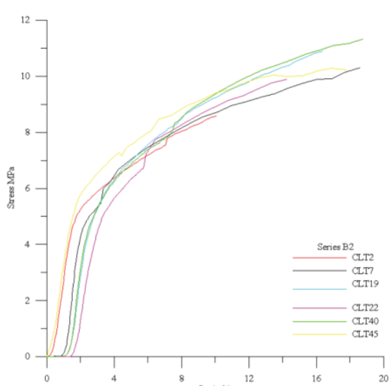


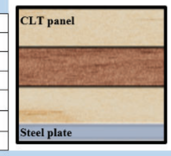
Figure 6. Stress-strain diagram of a CLT element compressed in direction parallel to the grain.

Given the three vertical panels involving a compressed length of 2.6 meters on top and bottom panel, it is estimated that the system can achieve a dissipated energy of 22500 J for the DESK60 configuration and 60000 J for the DESK100 one.

Energy dissipation from plastic deformation of the steel plate

If failure occurs by bending in the centerline at the desk, then it is possible to rely on the plasticization of the steel plate inserted at the bottom of the upper panel (Fig.7). This mechanism involves in a limited way the compression orthogonal to the grain, which is therefore neglected.

Material	Parameter	Value	Unit
Wood GL24h	E_0	11500	N/mm^2
	$f_{m.k}$	24	N/mm^2
	ε_m	0.21%	-
Steel S275	E	210000	N/mm^2
	$f_{y.k}$	275	N/mm^2
	ε_y	0.13%	-
	ε_u	6.0%	-



Parameter	Value	Unit	Notes
L	1200	mm	Length of the work surface
b_w	400	mm	Width of collaborating compressed wood
b_s	200	mm	Plate width
h_w	60	mm	CLT panel height
h_s	5	mm	Plate thickness

Phase	Parameter	Value	Unit
Elastic phase	Neutral axis	28.65	mm
	Resisting moment	11873698	Nmm
	Concentrated load at yielding	39580 - 79158	kN
	Yield curvature	7.9E-05	$1/mm$
	Yield deflection	7.08	mm
Plastic phase	Ultimate curvature	1.4E-03	$1/mm$
	Length of plastic hinge	60.00	mm
	Plastic deflection	48.93	mm
	Total deflection	56.01	mm

Figure 7. Calculation of energy dissipation from the plastic deformation of the steel plate.

The amount of dissipated energy estimated for this failure mechanism for the DESK60 desk version ranges from 2217 to 4434 J. As for the DESK100 configuration, the value rises above 7000-14000 J.

4.5 NUMERICAL ANALYSIS

Description of the numerical model

Since analytical methods may have limited validity when applied to complex systems such as the one examined, numerical analyses have been conducted. In addition, experimental methods will be employed in future investigations. Nonetheless, the analytical results provide valuable support for the validation and calibration of the numerical model presented below.

Nonlinear dynamic analyses are implemented in order to estimate the behavior of the desk when the latter is subjected to an impact load from a point mass released in the centerline of the work surface from different heights. The same loading conditions will then be reproduced for experimental-type tests.

As far as CLT panels are concerned, the desk model is made with orthotropic “plate” elements. Whereas one-dimensional "truss" elements are used for the representation of the steel plate inserted beneath the top of

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the desk. The interface between the top of the desk and the vertical septa is modeled with "link" elements to which a constitutive law, that can simulate the orthogonal fiber compression generated at these points, is assigned. The connection between the steel plate and the working plate is made with rigid elements at the edges to ensure the generation of the strut-tie mechanism between the two systems. Truss elements are also inserted throughout the plate development between the working plate and the plate itself to maintain the actual distance between the two systems, but without creating cooperation (Fig. 8 and Fig. 9). The vertical panels are also represented by "plate" elements. While the connection between them is made by elastic link elements in order to represent their lateral stiffness. However, it is expected that such a connection system will not come into play for point impact loading.

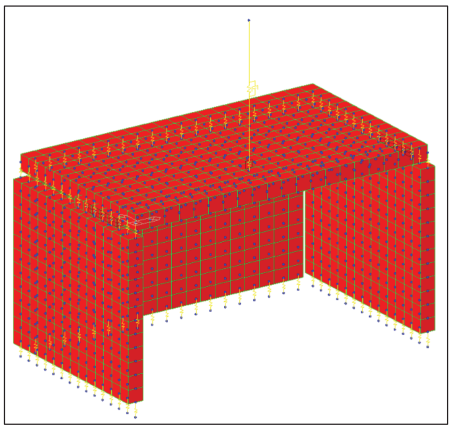

Figure 8. DESK60 numerical model (top view)

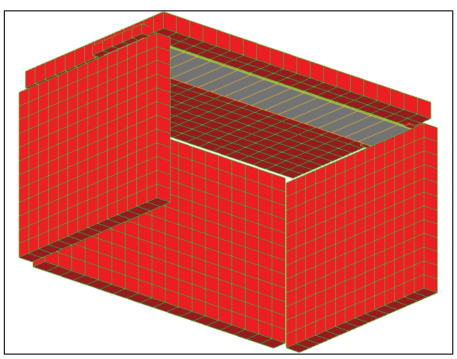

Figure 9. DESK60 numerical model (bottom view)

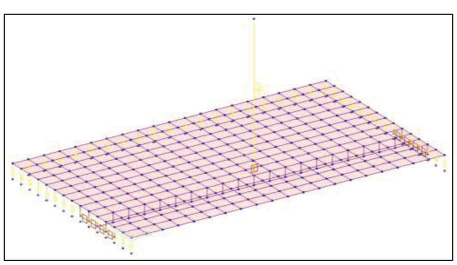

Figure 10. Detail of the DESK60 top panel in the numerical model

The plate elements representing CLT were assigned a material with the properties of Gl24h wood. In particular, they were assigned a plastic-type law, so as to represent their failure. With the aim of simulating the brittle type failure of wood, a Concrete-Damage plastic law was used (Fig. 11). In this way, it was also possible to assign different tensile and compressive behavior. While a plastic hinge with bilinear steel law (Fig. 12) was introduced in the centerline of the steel plate.

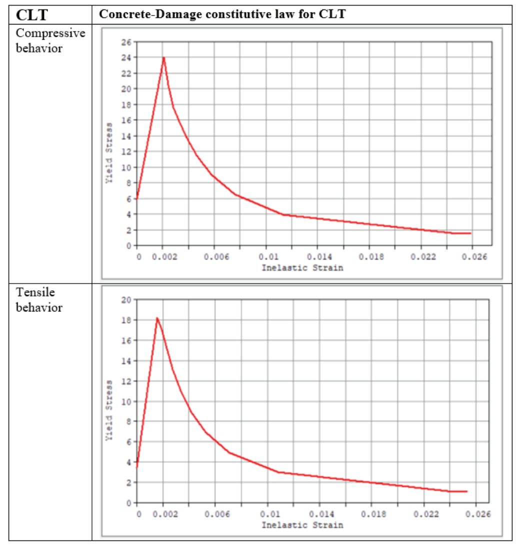

Figure 11. Concrete-Damage constitutive law for CLT (N/mm²)

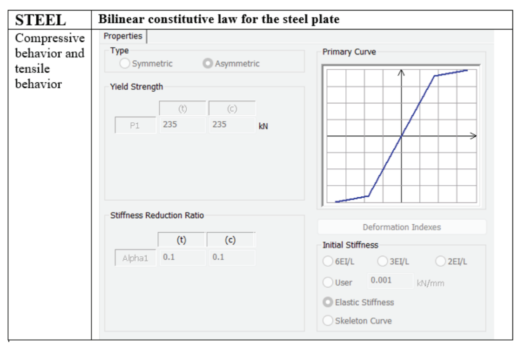

Figure 12. Bilinear constitutive law for steel

The impact load resulting from the free-falling mass is realized by connecting an airborne node (falling mass) with the collision point on the working plane, via a link element to which a gap-type law has been assigned. This type of link element is characterized by an initial zero stiffness that becomes very high when the distance between the two connected nodes approaches to zero.

A nonlinear time history analysis was implemented, applying a vertical acceleration of 9.81 m/s^2 downward. Geometric nonlinearities (effects of large displacements) were also considered. The fall of a mass of 100 kg from a height of 500 mm, 1000 mm and 2500 mm was simulated.

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Results of the numerical analysis

Starting with the stress response, Figure 13 shows plots of the "xx" stress contours (direction orthogonal to the user's legs). A stress contour limitation of 24 Mpa allows the areas of the panel brought to failure to be highlighted. It should be noted that the areas of the panel at the ends of the steel plate develop very high stresses while remaining in the elastic range. In such zones, the plasticity of the material is not included. Such stresses are an artifice due to the type of modeling and not due to the actual operating mechanism.

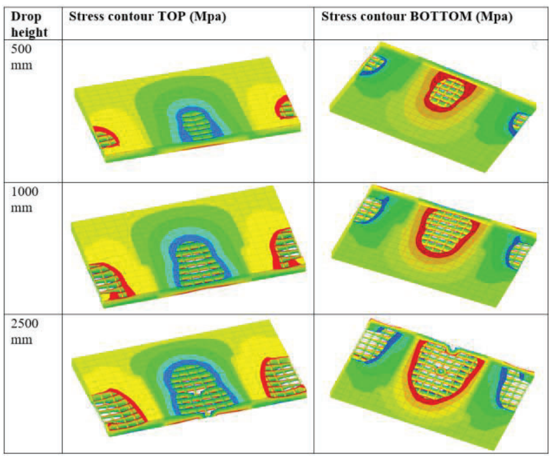

Figure 13. Top and bottom surface axial stresses on the CLT panel for different drop heights tests

It is then interesting to observe the involvement of the steel plate (Fig. 14). For the first two drop heights, the steel plate does not enter plastic phase, while for drop heights above 2 meters, yielding is obtained.

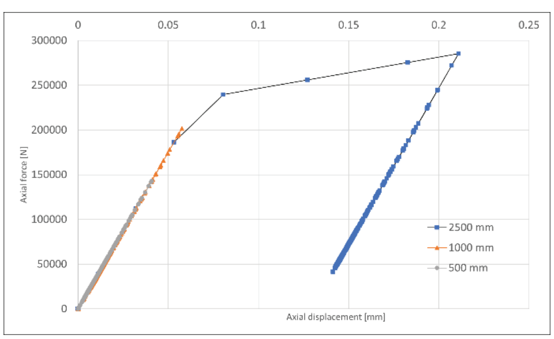

Figure 14. Axial force-displacement plot of the steel plate for different drop heights tests

The trends of the vertical displacements of the impact point in the working plane are shown in Figure 15, for 500 mm, 1000 mm and 2500 mm drop heights. At the instant of impact, there is a peak vertical displacement value of 9.7 mm, 14 mm and 22 mm and a residual displacement value of 2.4 mm, 3.8 mm and 8.5 mm, respectively. The graphs (Fig. 15) also show the multiple bounces of the mass on the table after the first impact, which is responsible for all the damage to the specimen.

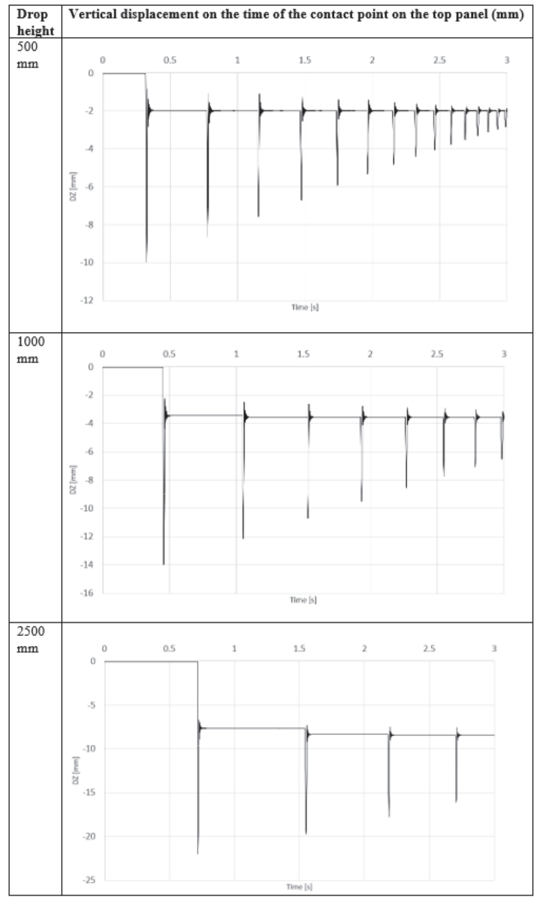

Figure 15. Impact point deflection on the CLT panel for different drop heights tests

The deflection caused by a statically applied load of 100 kg is 0.15 mm. The maximum deflections due to impact from different drop heights are respectively 64.7, 93.5, and 146.7 times the static deflection. These values approximately coincide with the dynamic force amplification, which can be evaluated using (1), under the assumption of elastic material behavior, a structure with a negligible mass compared to that of the falling mass, and undamped natural vibrations [11]. Specifically, the analytically estimated dynamic amplification factors are 65.6, 93.1, and 147.8, respectively.

$$f_{din} = 1 + (1+ 2h/\delta_{st})^{0.5} \qquad (1)$$

with f_{din} dynamic amplification factor, h mass drop height and δ_{st} deflection of the impact point for statically applied load.

5 – CONCLUSION

The LifeShell project aims to create a simple and accessible life-saving technology, thus transforming ordinary furniture into CLT shelters which can protect from partial collapse of a building during an earthquake event. The use of CLT, which significantly reduces costs compared to metal solutions, and an open-source approach which allows royalty-free dissemination are the main innovations brought by the project.

Through a series of preliminary analyses made by using analytical and numerical methods it was possible to develop an initial version of the desk. The results obtained from these preliminary design procedures are promising. By comparing what was estimated for the input energy in Section 4.2 and what was estimated for the dissipative capacity of the desks (Section 4.4), it can be seen that the two categories considered (DESK60 and DESK100) are able to cover most of the range of possible collapses.

The results obtained from the numerical analysis are in line with those obtained from the analytical procedure. Both calculation procedures introduced several simplifications and, therefore, will be supported by further experimental tests.

Quasi-static tests and dynamic tests are ongoing. Dynamic tests will be performed to simulate the impact resulting from a point load. Specifically, a steel sphere (100-200 kg) will be released from different heights in the centerline of the work plane, similar to what was simulated numerically. Then, a quasi-static test will be used to simulate the drop of a uniformly distributed load.

The aesthetic design of the desk is under review and update through a bottom-up cooperation that involves schools and universities. Educational desks are ameliorated by students and personnel who may use the desk in the future. The overall goal is to create a complete product, considering the structural, aesthetic and ergonomic aspects, and maintaining every project output freely available [12] and replicable under a Creative Commons License CC BY 4.0 International.

6 – ACKNOWLEDGEMENTS

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