INTERDISCIPLINARY PERSPECTIVES on the BUILT ENVIRONMENT

doi: 10.37947/ipbe.2022.vol2.2

Application of Cross-Laminated Timber furniture as Earthquake Shelter: A public domain release of the Lifeshell concept

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ABSTRACT

An earthquake is an unpredictable and potentially deadly phenomena. Building with anti-seismic technology can effectively reduce the risk of injuries; however, the adoption of this technology on a large scale is difficult because of funds, logistics, and bureaucracy. As a result, there are critically seismic zones where residential and nonresidential buildings are not safe. The concept of wooden-based furniture used as an anti-seismic shelter is released here under the Creative Commons licence as a low-cost, natural-based, open-source, copyright-free solution. The so-called "Life in Shell", or Lifeshell, concept has been independently funded and developed, and it is presented here in its engineering characteristics. Lifeshell depicts an alive human-being protected by wood during an earthquake. Lifeshell is furniture in the shape of a school desk, wardrobe, table, or bed made of cross-laminated timber panels. A school desk prototype was tested. The desk was to resist a total impact energy of 40,000 joules without collapsing. Lifeshell concept comprehends various types, sizes, weights, finishings, and accessories. Cost-effective solutions are foreseen for being assembled and finished by the final user; they also include a basic survival kit. On the other end, top-range versions can be aesthetically pleasant and enriched with high-end accessories. Lifeshell concept is ready to be adopted by the industry for further development. By this publication, authors release this potential life-saving technology using the Creative Commons CC BY 4.0 License (public domain), which allows the engineering, production, and selling of this furniture without any royalty fee for the authors.

Keywords: anti-seismic, furniture, cross-laminated timber, shelter, creative commons

Received 09.02.2020
Published 26.03.2022
https://ipbe.innorenew.eu • ISSN 2738-5418

1. Introduction

This paper presents a concept for wooden-based affordable earthquake shelters, a solution to protect humans from building collapse during a seism. The public domain release (no copyright, patent nor royalty fees) allows an immediate use of the concept for both personal use and industrial development.

Earthquake is an unforeseeable, deadly phenomena; in the 2000-2015 period alone, they caused globally 800,000 fatalities. Each year, an average of 2,000 events over Richter's scale 5 and above happen, causing severe damages to poorly constructed buildings (USGS, 2018).

Nowadays, even in the so-called developed countries, fatalities and major personal injuries frequently occur due to building collapses. As a matter of fact, an avoidable death toll and injuries still happen even when a moderate earthquake hits countries that are unprepared. Taking Italy as an example of a seismic-prone "developed" country, between 2000 and 2015, three moderately intensive earthquakes shocked that nation, causing a total of 635 victims. These events occurred in a country where anti-seismic building technologies should have been well developed and used, and we should have expected only little damage to buildings and almost no fatalities. In October 2002, in San Giuliano di Puglia, a magnitude 5.8 ML earthquake caused a school collapse, and 27 children and a teacher were killed (INGV, 2002). In 2009, the Aquila earthquake (5.9 ML magnitude) caused 309 fatalities and 1600 wounded, including eight people killed during the university residence collapse (INGV, 2009; Di Francesco and Tiberii, 2010). In May 2012, in Emilia, 5.8 ML and 5.9 ML earthquakes caused 27 fatalities and highly damaged the school buildings: 28 schools reported major damage and were closed, while dozens of others reported damage and only partial collapse (INGV, 2012). In 2016 and 2017, a seismic sequence named Amatrice-Norcia-Visso with a magnitude ranging from 5.1 ML to 6.0 ML caused 299 fatalities (INGV, 2017 and Avellani, 2018).

Despite these tragedies and the existence of anti-seismic construction technologies, the anti-seismic performance of many buildings in Italy and in other countries is still weak. As a general indication, lack of funds, logistics, and bureaucracy can be the main reasons for delayed adoption of a proper anti-seismic technology on a large scale. Every day, people spend hours in private and public buildings (including schools), which can be dangerous places for the possibility of a partial or total collapse during an earthquake. On average, spending 86.9 % of our day in an indoor environment (Klepeis et al., 2001) makes the danger evident.

All the main international earthquake guidelines (Ready, 2020; FEMA, 2020; CDC, 2020; Red Cross, 2020; Wei-Haas, 2020) suggest population shall find shelter under solid furniture during a seismic event, using the furniture as protection from building collapse. Historically, several people have been saved from beneath the rubble even several days after the seismic event.

Pondering over the above facts, in 2013, the first author of this paper had the idea to use cross-laminated timber (CLT) panels for sturdy furniture that acts as a shelter during earthquakes. CLT technology and its related metal connections were already used for constructing earthquake-proof buildings (Ceccotti and Bonamini, 2007; Ceccotti, 2008; Ceccotti et al., 2013). Using CLT for creating small, economic furniture would help create many scattered survival cells in existing buildings when there are no funds or time for expensive refurbishing or rebuilding entire structures. The Lifeshell concept would prevent injuries or death caused by falling objects or collapse of buildings and would help the localization of survivors, reducing the risk of casualties. This conceptual solution can be developed in several versions; it can be a table, a desk, a bed, a wardrobe, or even a portion or an entire room. It can be installed at home, in workplaces, at school or university, and no structural modification of existing buildings is needed.

The proposed concept is mainly suitable for those schools and private houses that are still lacking a proper earthquake-proof reinforcement. It is a practical and economical solution that can be realized in a few days instead of the years needed for an entire building reinforcement. However, this technology should not be used in substitution of a proper building assessment and consolidation, but it can surely help to reduce the risk.

From 2013 to 2017, an informal working group had evaluated the possibilities for releasing the idea: publications, patents, creative commons. The research in the patent database revealed several anti-seismic furniture designs, all built using materials other than CLT (patent list in references). In 2013, none of those technologies were promptly available on the market, despite an Israeli company beginning production of a metal frame-based table in that year (Brutter and Bruno, 2010). Similarly, an American company (LifeGuard Structures; Von Bereghy, 2010) was on the market with a metal desk. Therefore, the first author opted for avoiding the patent on a life-saving technology, choosing the Creative Commons licence instead. This choice allows anyone to make their own furniture, and it also allows enterprises to develop, modify, test, build, and sell it without paying any royalty. This public domain release prevents any future patent process and makes Lifeshell a gift for humanity.

The name "Lifeshell", short for "Life in Shell", depicts an alive human being protected during an earthquake by a wooden shelter, and its letters remind one of the inventor's surname. The Lifeshell concept has been developed with independent funds by (former) wood scientists.

The publication of this article has two purposes: spreading the idea among experts in both academia and industry and as a constitution of public domain information for avoiding any further patent registration over this idea.

2. Materials and method

The principal building characteristics of the concept are presented. Other options and variations are possible, addressing a wide variety of use, design, or destination needs.

The concept can be applied mainly to three types of furniture: tables, wardrobes, beds. Tables can be designed for kitchen, bedroom, living room, classrooms, office; wardrobes shall be designed with light removable doors and a quick unlock mechanism for the clothes pipe; beds can be designed for hosting people below it or as a canopy bed. The design can also be applied to other furniture or to reinforce a part or an entire room.

The basic shape of the Lifeshell is a parallelepiped with five sides made by CLT. The sixth side could be closed by materials different from CLT (as for wardrobe doors, made in particleboards) or left open (as for a desk, where the sixth side should be left open for allowing the right legroom). Openings in vertical panels can be realized for increased aesthetics, breathability, and for reducing weight.

Lifeshell furniture is made by CLT panels connected with metal hardware. Typical panels are 80 or 100 mm thick, constituted by three or five bonded wooden layers arranged at right angles to each other. Connections are made by using wooden houses' typical metal hardware. Two, right-angle connectors join the CLT vertical panels to CLT horizontal panels with dedicated screws or nails. Hardware manufacturers often provide a dedicated catalogue for CLT buildings and many reinforced angle brackets are available on the market.

Especially in the case of a wardrobe-style Lifeshell, a suitable anchoring to wall, ceiling, or floor should be done to prevent falling together with an assessment of the weight added to the building. Where panels span over 1.5 m without any inner support (as in the bed concept, for instance), a perforated tape (zinc-plated carbon steel coiled straps) should be nailed to the top CLT panel to help prevent panel bending failure (see Figure 2 and Annex 3). The system can be enriched by applying inner handles to help people hold tight during an earthquake.

Any Lifeshell furniture is intended to be developed in a basic, low-cost version in order to increase the affordability of this life-saving technology. This can be made possible by producing do-it-yourself kits of raw CLT panels and by keeping CLT panels as linear as possible. Nevertheless, several other finishing are possible, offering the same construction type and protection with an upgraded design and finishing.

Lifeshell concept measurements, volumes, weights, and costs are presented in Tables 1, 2, and 3. These indicative values are based on a 450 kg/m3 (UNI 11035-1, 2010, Giordano, 1983) CLT spruce density at 12 % moisture content and on a CLT panel cost of 500 €/m3. The real cost should be calculated by adding the cost of the metal hardware, the emergency kit, transport, and mounting. Heavy panels (over 20 kg) should be lifted by two or more persons (NIOSH, 1994; Snook, 1991).

Lifeshell concept renderings and technical drawings are presented in Figures 1 to 3 and Annexes 1 to 3.

Lifeshell furniture should be equipped with a basic or advanced survival kit (as in Figure 4). A basic (and affordable) kit would include a torch, glowing sticks, a whistle, bottled water, dust masks, a laminated emergency guide, energy bars, plastic bag(s), disposable urinal, an emergency blanket, and paper tissues; a more advanced kit (e.g., one per classroom) would include a first aid kit, an oxygen mask, an avalanche beacon, a two-way radio, a hand crank power generator, and so on.

Table 1: Lifeshell desk concept indicative panel dimensions, mass, and cost.

Desk panels	Dimensions (mm) a	b	c	Openings type & size (mm)	(m^3)	Net volume (m^3)	Mass (kg)	Cost (€)
left side	720	540	100	1 hole, diameter 200	0.003	0.036	16.1	18
right side	720	540	100	1 hole, diameter 200	0.003	0.036	16.1	18
back	1000	540	100	1 hole, 300 × 500	0.015	0.039	17.6	20
top	1200	720	100	none	0.000	0.086	38.9*	43
bottom	1200	720	100	½ hole diameter 700	0.019	0.067	30.2*	34
					Total	0.264	119	132

**2 persons assembly*

Table 2: Lifeshell wardrobe concept indicative panel dimensions, mass, and cost.

Wardrobe panels	Dimensions (mm) a	b	c	Openings type & size (mm)	(m^3)	Net volume (m^3)	Mass (kg)	Cost (€)
left side	2200	600	100	none	0.000	0.132	59.4**	66
right side	2200	600	100	none	0.000	0.132	59.4**	66
back	2200	1300	100	2 holes, 300x500	0.030	0.256	115.2**	128
top	1500	600	100	none	0.000	0.090	40.5*	45
bottom	1500	600	100	none	0.000	0.090	40.5*	45
					Total	0.700	315	350

**2 persons assembly, **2+ persons assembly*

Table 3: Lifeshell bed concept indicative panel dimensions, mass, and cost.

Bed panels	Dimensions (mm) a	b	c	Openings type & size (mm)	(m3)	Net volume (m3)	Mass (kg)	Cost (€)
left side	900	400	100	none	0.000	0.036	16.2	18
right side	900	400	100	none	0.000	0.036	16.2	18
back	1900	400	100	1 hole, 300x500	0.015	0.061	27.5*	31
top	2100	900	100	none	0.000	0.189	85.1**	95
bottom	2100	900	100	none	0.000	0.189	85.1**	95
					Total	0.511	230	256

**2 persons assembly, **2+ persons assembly*

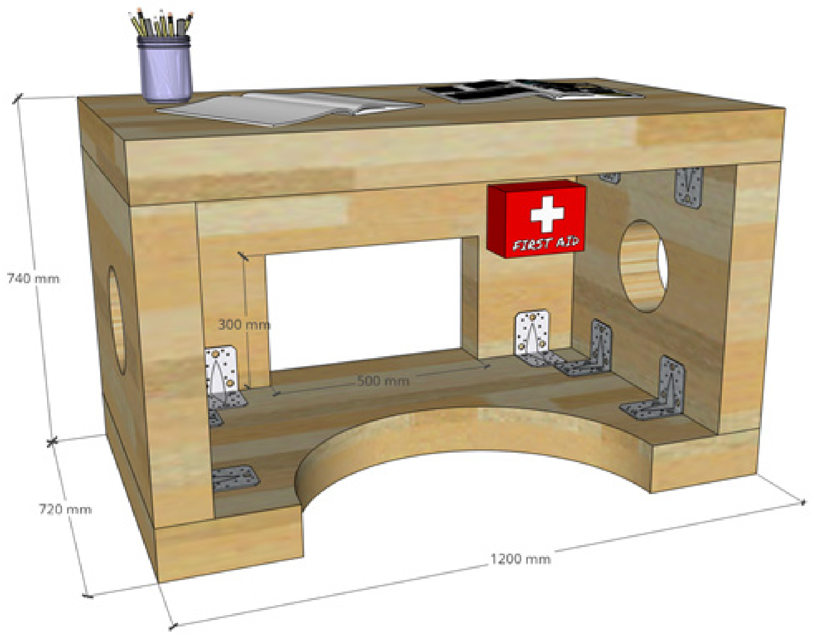
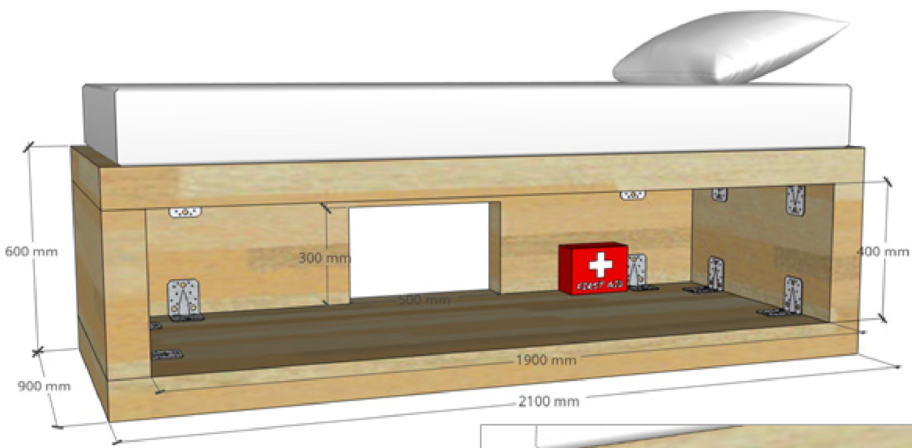


Figure 1:
Rendering of a Lifeshell desk.



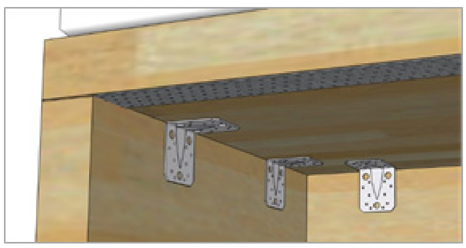


Figure 2:
Rendering of a Lifeshell bed. A perforated tape is nailed to the top CLT panel to help prevent panel crushing (bottom image detail, as seen from the floor).

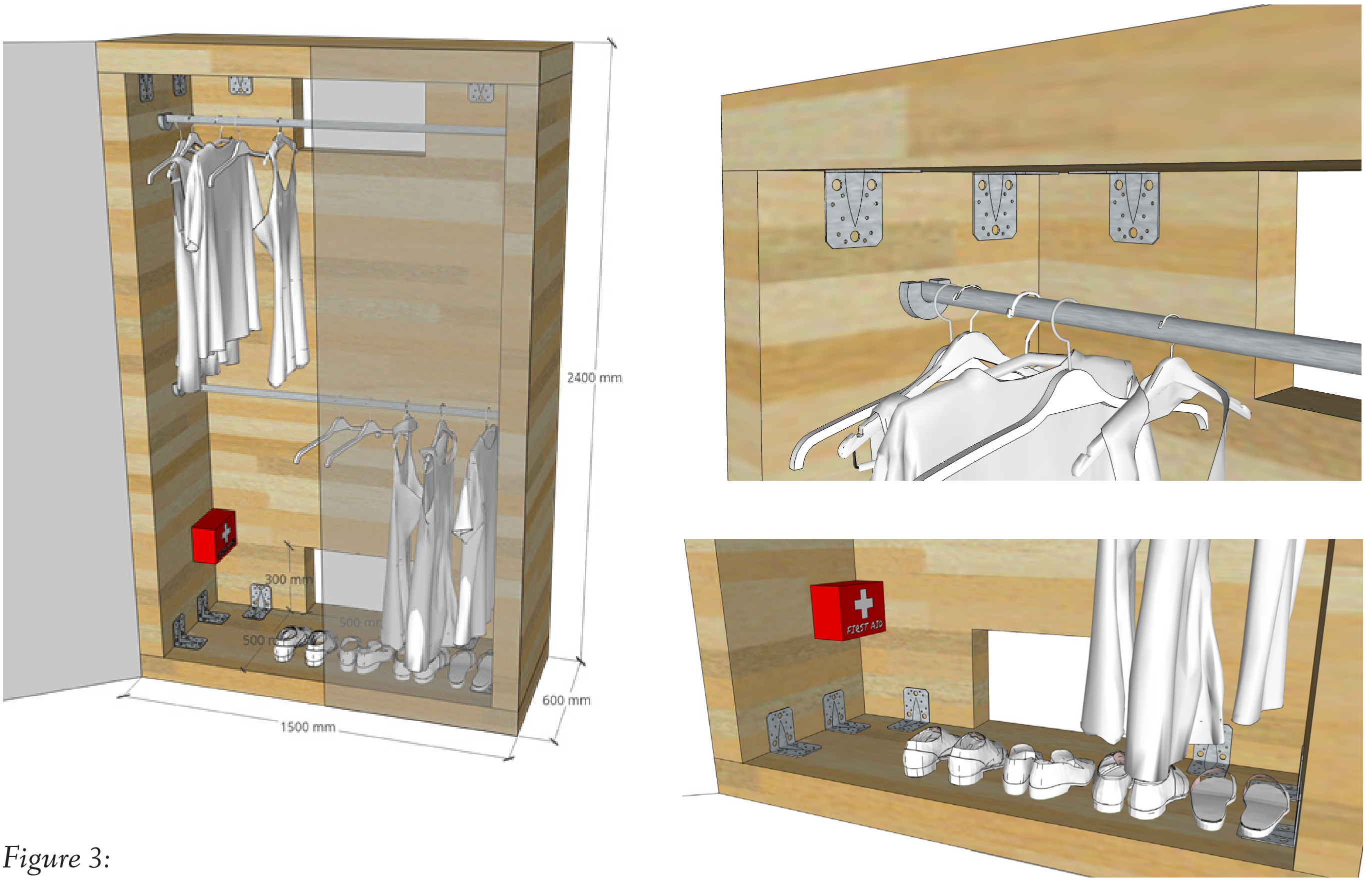


Figure 3:
Rendering of a Lifeshell wardrobe. In the detail (bottom image), the metal hardware, the opening, and an easily removable clothes hanger are shown.

Figure 4:
An example of survival kit composed of both basic (first aid, water, masks, torch, whistle, glowing stick, energy bars) and advanced (avalanche beacon, two-way radio) equipment.

3. Prototype development

In September 2017, a first series of prototypes was developed by the authors for the sake of primary and secondary schools in Vaglia Municipality (Florence Province, Italy). In Figure 5, the first two rows are reported in a visual synthetic way: the conceptual sketches for the testing prototype (first row) and the prototype setting and testing outcome (second row). Specifically, one, two-place school desk was prepared for the impact test. Dimensions of the prototype were 1500 x 750 x 750 mm; thickness of CLT elements were 100 mm for the desk plate and transversal walls, 60 mm for the longitudinal wall.

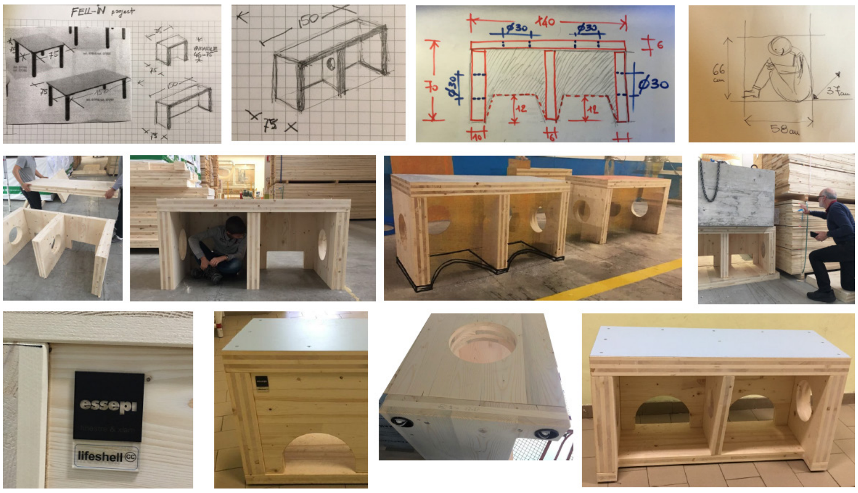


Figure 5:
First row, conceptual design for the testing prototype; second row, prototype setting; third row, final product from ESSEPI srl Italy.

4. Results and discussion

The prototype was subjected to an impact load equivalent to a fall of one tonne mass from four meters height, i.e., 40,000 joules of energy. The actual mass was 2,800 kg and the fall height 1.45 m. The prototype was damaged by the impact but successfully resisted without collapsing and without critical damage, as shown in Figure 6.

According to test results, it is possible to conclude that there is room for optimal design, reducing the weight of the desks, by adopting thinner wood elements. In any case, proper experimental tests should be conducted in order to validate the design ("design by testing").

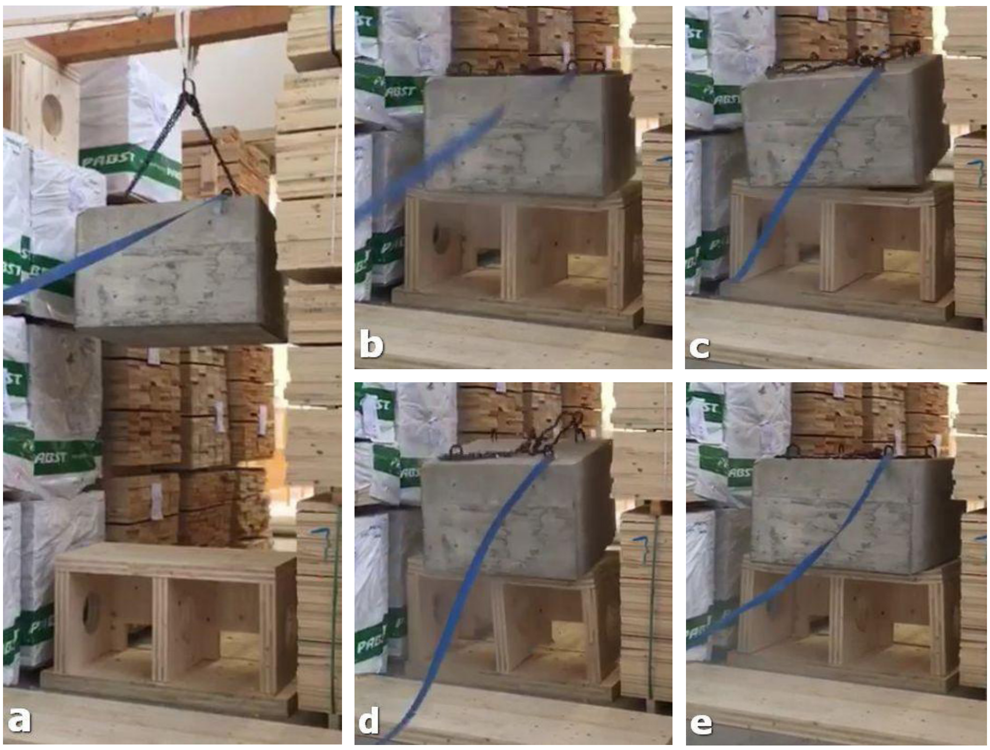


Figure 6:
The prototype test phases (performed by ESSEPI srl, Cavedine [TN] Italy), a) the test setup, b) the first concrete block hit, c) the block bounce at its highest peak, d) the second hit, e) the final resting position.

It is suggested to adopt roller bearings at the bottom of the desks in order to get a sort of "base isolation" of the desks themselves that will not influence the seismic weight of the host building (see Figure 5, row three, position two).

5. Conclusions

Lifeshell concept can provide a safe shelter during earthquake in an effective, affordable, quickly applicable, natural-based manner. Authors do not endorse this technology in replacement of a proper anti-seismic building technology, despite its features having been successfully demonstrated with a shock absorption test. This technology should be used temporarily where the socioeconomic context impedes an effective application of the anti-seismic building engineering standards. Authors encourage further research and developments on the topic.

6. Terms of use and attribution

Even though this technology can be effectively used for providing a shelter during earthquakes, authors cannot take any responsibility for injuries or fatalities related to its use. This technology should not be intended for replacement of proper anti-seismic building technique.

This technology can be crafted and used by anyone, anywhere. The idea is open source, free, public domain, and licensed under the Attribution 4.0 International (CC BY 4.0; Creative Commons, 2021). Anybody is free to share (to copy, redistribute the material in any medium or format), to adapt (to remix, transform, and build upon the material) for any purpose, even commercially. This license is acceptable for Free Cultural Works. The licensor cannot revoke these freedoms as long as you follow the license terms. The following terms apply: Attribution—you must give the appropriate credit (e.g., citing the original name "Lifeshell CC BY Marco Fellin" or this paper) and provide a link to the license (www.lifeshell.net); you must indicate if changes were made; you may do so in any reasonable manner but not in any way that suggests the licensor endorses you or your use. No additional restrictions—you may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Authors of Lifeshell do not claim any income for this project and beg interested industries in making business with it to always follow the ethic logic more than the profit one (e.g., consider producing a low-cost version as an unassembled kit), allowing even low-income families to access this technology.

ACKNOWLEDGEMENTS

Authors gratefully acknowledges Silvio Pedrotti and the ESSEPI Srl for the prototype and idea development; Jakub Sandak and Martino Negri for inspiration; 3D model of clothes, hangers, and shoes were made by Pasang Ihamo S.; mattress and pillow by Jocelyn C. Drawings made with SketchUp 3D by Trimble, Inc.

SUPPLEMENTARY MATERIAL

Technical drawings of the Lifeshell desk, wardrobe, and bed concept are presented in Annexes 1, 2, and 3.

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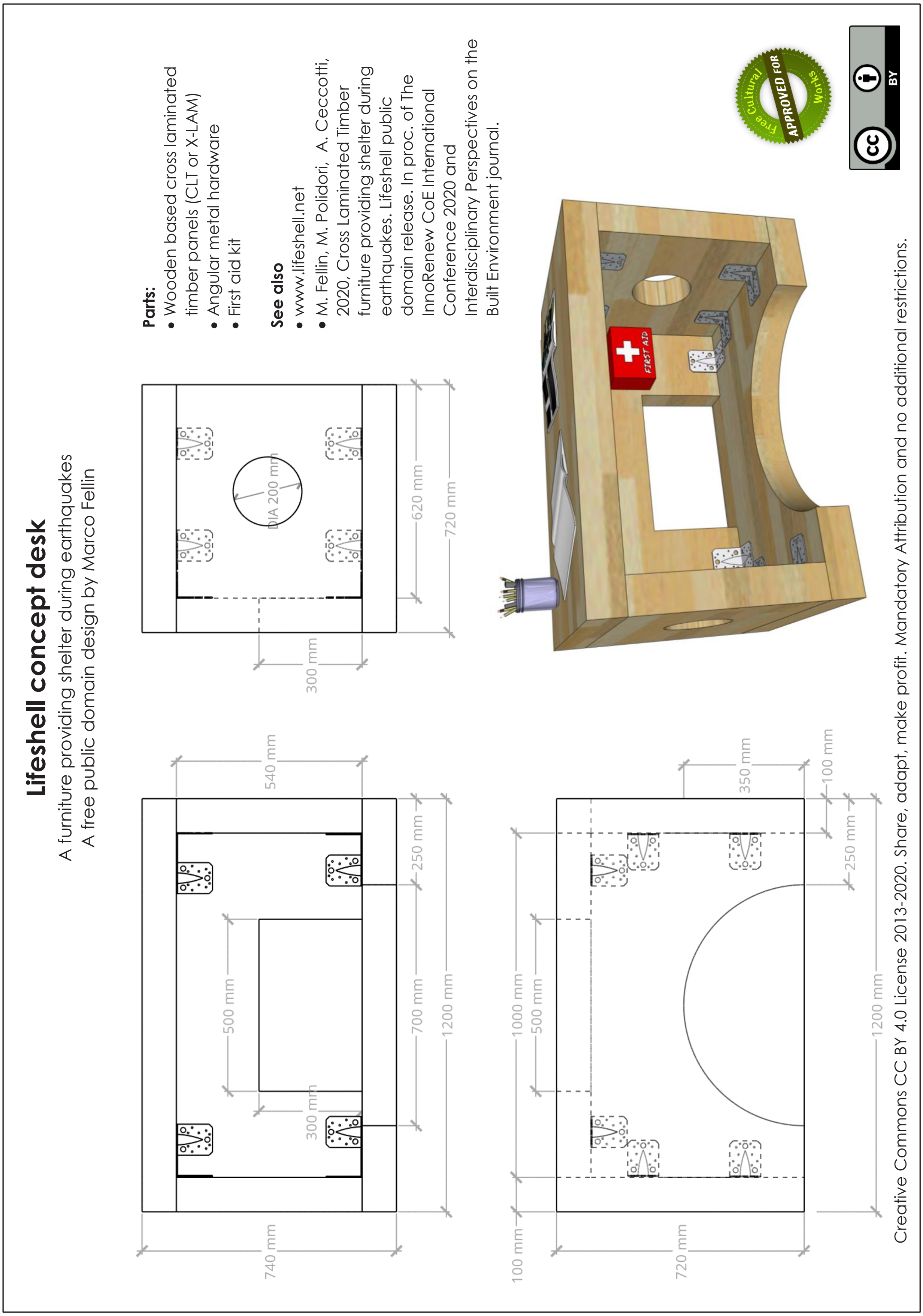
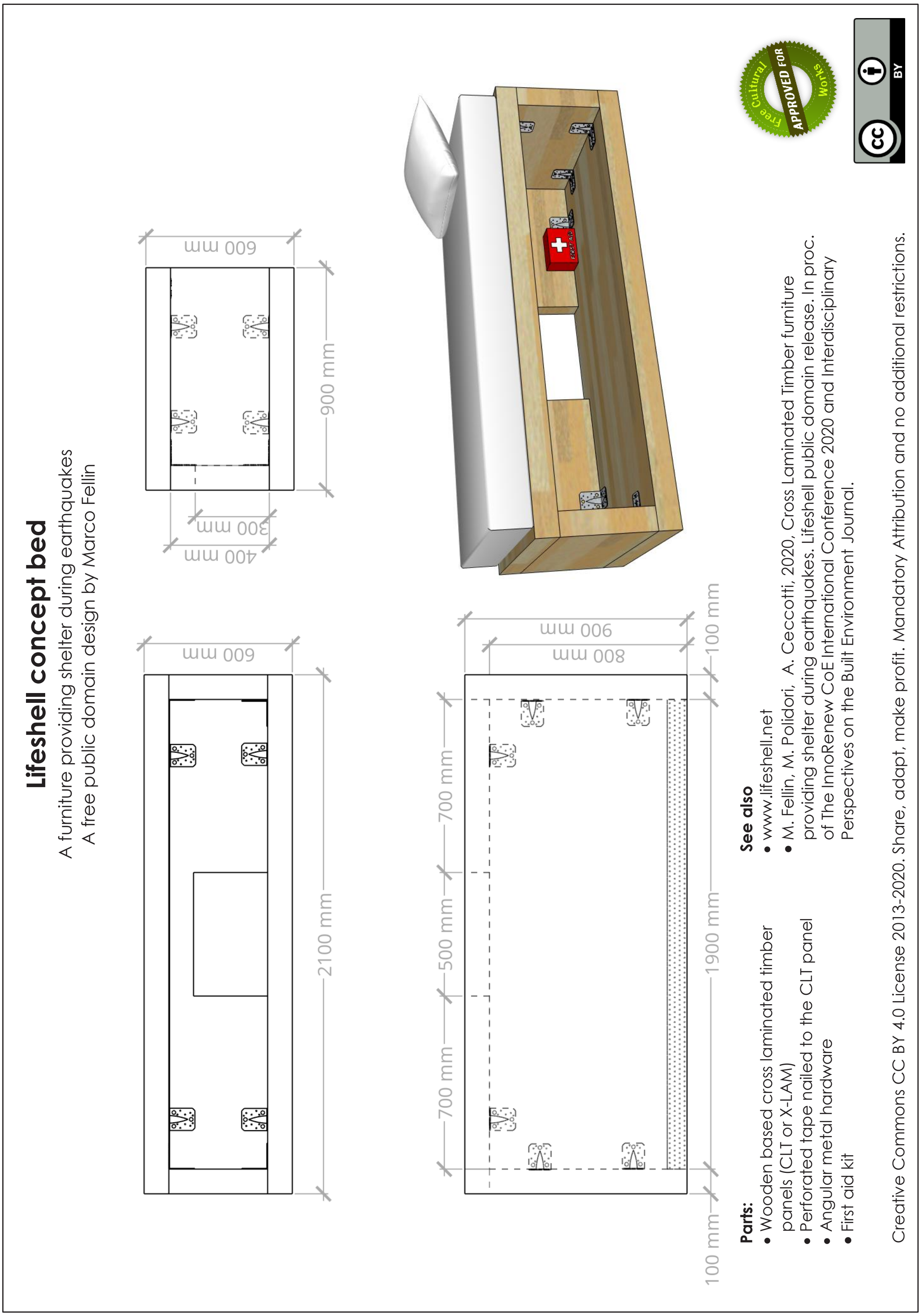
ANNEX 1: TECHNICAL DRAWING OF THE LIFESHELL DESK CONCEPT



ANNEX 2: TECHNICAL DRAWING OF THE LIFESHELL BED CONCEPT



ANNEX 3: TECHNICAL DRAWING OF THE LIFESHELL WARDROBE CONCEPT

Lifeshell concept wardrobe

A furniture providing shelter during earthquakes. A free public domain design by Marco Fellin

Parts:

- Wooden based cross laminated timber panels (CLT or X-LAM)
- Angular metal hardware
- Easily removable clothes hanger
- First aid kit

See also

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