THE USE OF ENGINEERED WOOD FOR VOLUMETRIC ADDITIONS TO EXISTING BUILDINGS

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Abstract: *The modern lifestyle in densely populated and urbanized cities demands expanding spaces without land consumption and preserving green spaces. The existing building heritage could become a resource considering the "building on the built" philosophy. Adding new distinct volumes to existing structures represents a possible approach to the problem. Using engineered wood, such as cross-laminated timber (CLT), glulam etc., allows for pursuing this strategy. This proposed type of intervention, often named "parasitic architecture", concretely impacts urban regeneration strategies. Parasitic architecture could be a simple way to increase housing units or to build new shared spaces. Added elements could act furthermore as local reinforcement improving the overall response of existing structures. Because of the low weight, engineered wood for additions does not overload unduly facades and rooftops. Using precast timber elements amplifies the realization speed, reducing the interferences with the surroundings and improving the healthiness and safety of the environment. For these reasons, these interventions also address the issue of sustainability by influencing the life cycle of the industrial process. The present work aims, by varying the position of the added elements on the host structure, to determine the solution that affects the host structure the least, according to the National Technical Code (NTC 2018) in force.*

1. Introduction

The Italian building heritage, more and more frequently, is inadequate to the modern lifestyle that requires more space and different uses. The 2030 Agenda requires preserving green spaces and reducing land consumption. In this scenario, the philosophy of "building on the built" or "Parasitic architecture" would transform the old building heritage into a great resource. The "Parasitic architecture" approach consists of adding new "distinct" volumes to existing structures. These additions increase and require local or global interventions on the host structure, whether in reinforced concrete or masonry (Monaco et al., 2020; Munden et al., 2023). These interventions can be divided into four types (Fig. 1):

- Type 1 - Rooftop architecture (Fig. 1.1). The roof is the base for the volumetric addition (Khalfi, 2019).
- Type 2 - Exoskeleton systems (Fig. 1.2). The addition of volume does not burden the existing structure but has autonomous foundations. It accommodates new spaces and support possible elevations (Bellini, 2020; Di Giulio, 2010).
- Type 3 - Parasitic architecture (Fig. 1.3). The added volumes are anchored to the perimeter walls and/or the roof of the host structure.
- Type 4 - Parasitic architecture (Fig. 1.4). The volumes are "hanged". They are inserted inside the courtyard, ensuring the lighting to the internal parts and without using additional land. This type of intervention is well-suited for schools.

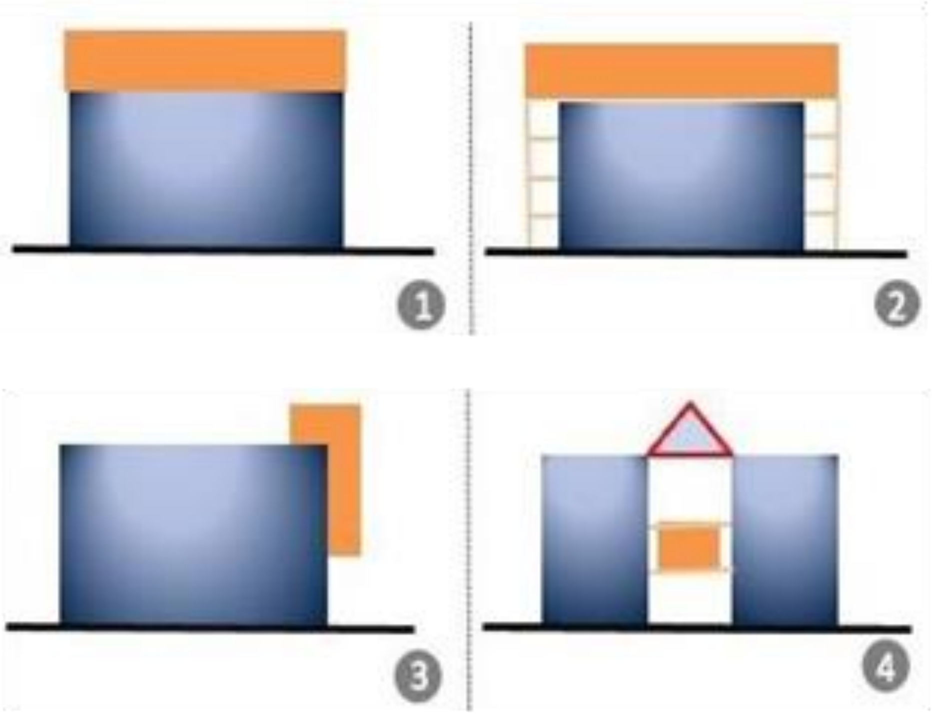


Figure 1. Types of parasitic volumes (Frunzio et al., 2022).

Types 1,3 and 4 involve an increase in mass. This results in a deviation between the centre of gravity of the masses and the centre of gravity of the stiffnesses that affect the seismic response, particularly the torsional behaviour. Therefore, an accurate assessment of the overall response of the building is needed (De Stefano & Mariani, 2014; Faella et al., 2010). These added volumes, usually prefabricated, are anchored to the host structure. If the latter is made of masonry (Di Gennaro, Guadagnuolo, et al., 2023; Frunzio & Di Gennaro, 2021; Guadagnuolo et al., 2023), it must be reinforced at the attachment points (Calderoni et al., 2016; Guadagnuolo & Faella, 2020). Conversely, the added volume in type 2 intervention does not weigh on the original structure and has independent foundations. For interventions on school structures, where courtyards are frequent, type 4 is well-suited.

The type of intervention dictates the choice of building material. Engineered wood can be a good choice for volumetric additions (Margani et al., 2020; Valluzzi et al., 2021), as technological advancement has solved the problems related to the anisotropy of the wood. Cross-laminated timber (CLT), glulam (Glulam), etc., are widely used nowadays both for the construction of new buildings (Faggiano et al., 2022) and for interventions on existing structures (Di Gennaro, Frunzio, et al., 2023; Frunzio et al., 2021; Frunzio & Di Gennaro, 2019; Iovane et al., 2023; Izzi et al., 2018; Massaro et al., 2023, 2024; Sun et al., 2020). The achievable goals using panels CLT regard not only the structural aspect but also the energetic (Smiroldo, Giongo, et al., 2021; Smiroldo, Paviani, et al., 2021) and the comfort indoor (Frunzio et al., 2023). A further advance compared to engineered wood is the Pres-Lam System (Palermo et al., 2005), which was born for interventions on seismic-resilient and sustainable structures (Granello et al., 2020). Several authors have analyzed the behaviour of structures made with this technology (Akbas et al., 2017; Ganey et al., 2017; Hashemi & Quenneville, 2020) with the insertion of internal oscillating dissipative wood elements (Pilon et al., 2019; Sandoli et al., 2021; Sandoli & Calderoni, 2020) with metal connections for reinforcement interventions in its plane with CLT panels (Longarini et al., 2018) or off-plane (Riccadonna et al., 2019). In addition to the structural and energy advantages, wood allows to meet the needs related to climatic emergencies thanks to its natural ability to store CO_2 and minimize the inconvenience to the host structure because the off-site production allows a quick installation. In this way, the structure object of intervention can be kept "in activity".

This paper focuses on school construction with a bearing structure in reinforced concrete. About 40,000 school buildings in Italy were built in the 70s and 80s of the last centuries. These buildings have an average age of over 50 years. About 30% need urgent structural or plant interventions (Legambiente, 2023). Simple monitoring in this scenario is crucial (Di Gennaro et al., 2022; Frunzio et al., 2019; Frunzio & Di Gennaro, 2018; Minutolo et al., 2020). Most of these buildings are designed only for gravitational loads since the regulations in force at the time considered seismic risk only for a few areas of Italy (Fig.2).

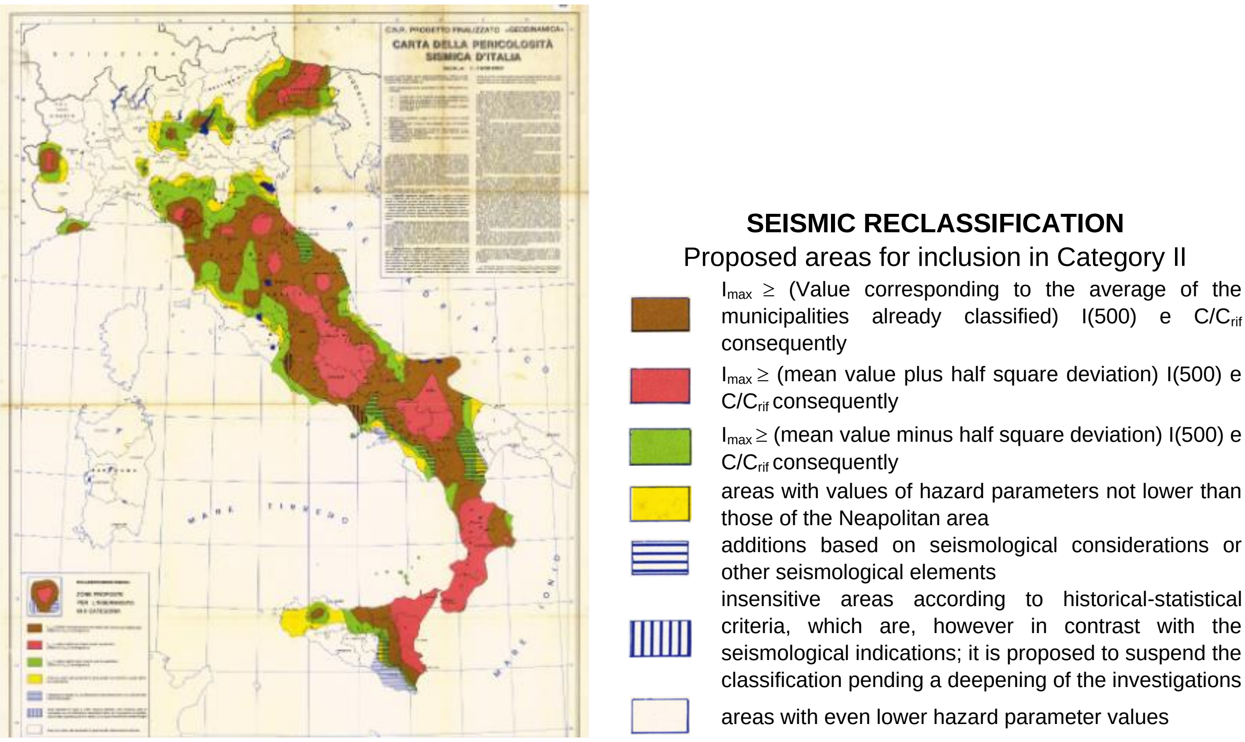


Figure 2. Map of the seismic hazard in Italy (Scandone, 1970).

Unfortunately, the Italian seismic map was completely revised only after a series of natural disasters, consequently, the building regulations. However, the structural adjustments have not followed the evolution of the regulatory system, and too many buildings are "inadequate" to face any seismic actions.

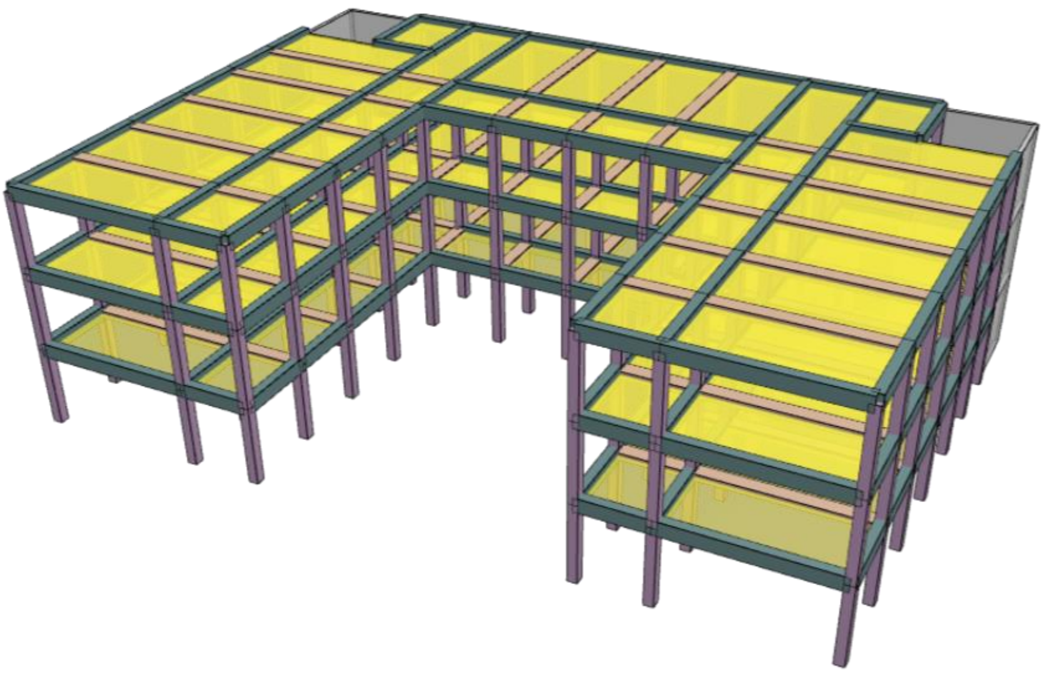


Figure 3. C-shape structure.

The school buildings have different forms and architectural features. This study analyzes the school structures united by a generic C-shape with the staircases positioned at the external corners (Fig.3). Typically, the classroom blocks have a surface varying between 45 sqm and 80 sqm (laboratory classrooms) and structural beams of 6.5-8.5 meters. The C-shape is appropriate for the daily use of schools but presents structural problems in response to torsional stress.

The intervention proposed in the present work is the addition of a "hanged" volume to the top floor inside the courtyard of a C-shape school. This solution falls within the type of intervention 4 (Fig.1). The material chosen is engineered wood: glulam beams, floor slabs and walls in CLT panels. This choice involves an improvement in the torsional response of the structure.

2. Existing building analysis

A typological school building is hypothesized to be located in the municipality of Rivisondoli (Fig.4) in the province of L'Aquila, currently in seismic class 1 (high seismicity).

Municipality of Rivisondoli
Province of L'Aquila

Altitude: 1.320 m

Seismic classification:
Zone 1 (high seismicity)

Climate classification:
Zone F, 3 651 GG

Figure 4. Geografic location of Rivisondoli.

The building, hypothetically designed in 1978, is spread over three floors above ground with horizons placed at an altitude of 3.5 meters, 7.00 meters, and 10.50 meters from the ground floor. The roof is flat (Fig.3). The simulated design was carried out in compliance with the rules of the time. The strength class of the concrete is C20/25, while the reinforcement bars are of the Fe B 32 K type. At the allowable stress (Tab.1), the structure was designed for vertical loads only. The overload agent is equal to 4 KN/m (D.M. 03 ottobre, 1978).

Table 1. Allowable stress.

Materials	Allowable stress
Concrete C20/25	$\overline{\sigma}_c = 6 + \frac{R_{ck} - 15}{4}$ =8,5 N/mm2
Steel Fe B 32 K	$\overline{\sigma}_s$ =155 N/mm2

The floor slab is a reinforced brick concrete slabs (Fig.5) with 24 cm cast-in-place RC joists and 4 cm slab. The RC columns are 40 x 40 cm with reinforcements. The primary beams have 30 x 60 cm dimensions while the secondary is 28 x 60 cm (Tab.2).

Depending on the loads (D.M. 03 ottobre, 1978), the structure is verified under the rules in force at the time.

Table 2. Dimensional properties of structural elements.

Structural Element	Properties
Primary Beams Dimensions	30 x 60 cm
Upper reinforcement of the ground-floor beams	2 ϕ 16
Lower reinforcement of the ground-floor beams	4 ϕ 16
Upper reinforcement of the first-floor beams	2 ϕ 14
Lower reinforcement of the first-floor beams	4 ϕ 14
Upper reinforcement of the last-floor beams	2 ϕ 14
Lower reinforcement of the last-floor beams	4 ϕ 14
Columns Dimensions	40 x 40 cm
Upper reinforcement of ground-floor columns	2 ϕ 20
Lower reinforcement of ground-floor columns	2 ϕ 20
Upper reinforcement of first-floor columns	2 ϕ 16
Lower reinforcement of first-floor columns	2 ϕ 16
Upper reinforcement of last-floor columns	2 ϕ 14
Lower reinforcement of last-floor columns	2 ϕ 14
Secondary Beam Dimensions	28 x 60 cm

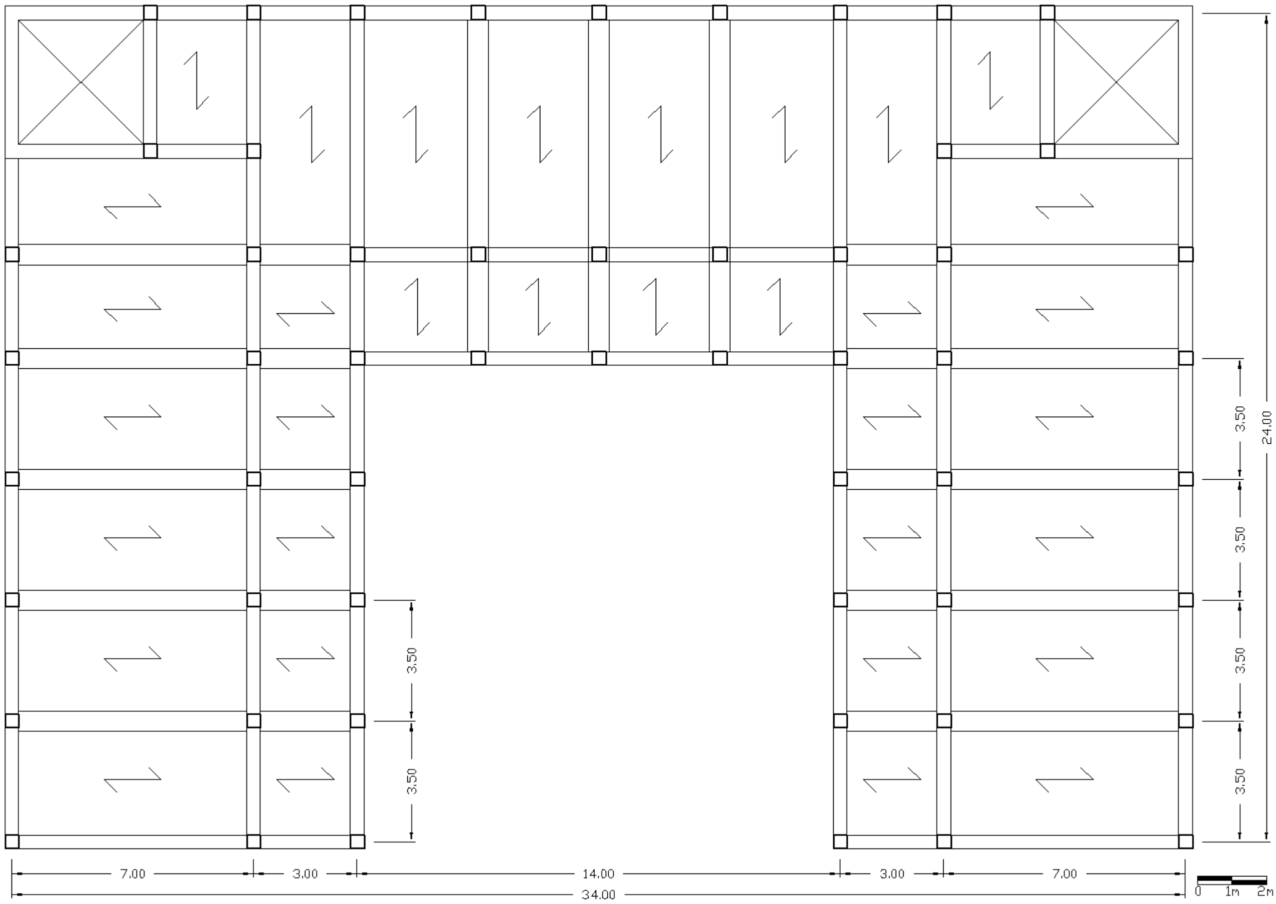


Figure 5. Floor structure.

3. Wooden volume addition

The added volume dimensions (Fig.6) are 14.0 x 7.0 m and a height of 3.5 m. The slab is made up of CLT panels with a thickness of 57 mm while the glulam beams of 200 x 700 mm are placed at a centre distance of 0.7 m. These beams are bound to primary beams which are walls of light 14 meters and consist of CLT panels with a thickness of 252 mm and a height of 3.5 m. Tab.3 summarizes the characteristics of the structural elements constituting the added volume.

Table 3. Wooden structural elements.

Structural Element	Material	Properties
Floor beam (transversal beam)	Glulam	Wood species: spruce E_0 = 14700 MPa Dimensions: 700 x 200 mm
Slab	CLT panels	Wood species: spruce E_0 = 11.000 MPa E_{90} = 370 MPa Thickness = 57
Wall (longitudinal beam)	CLT panels	Wood species: spruce E_0 = 11.000 MPa E_{90} = 370 MPa Thickness = 252 mm

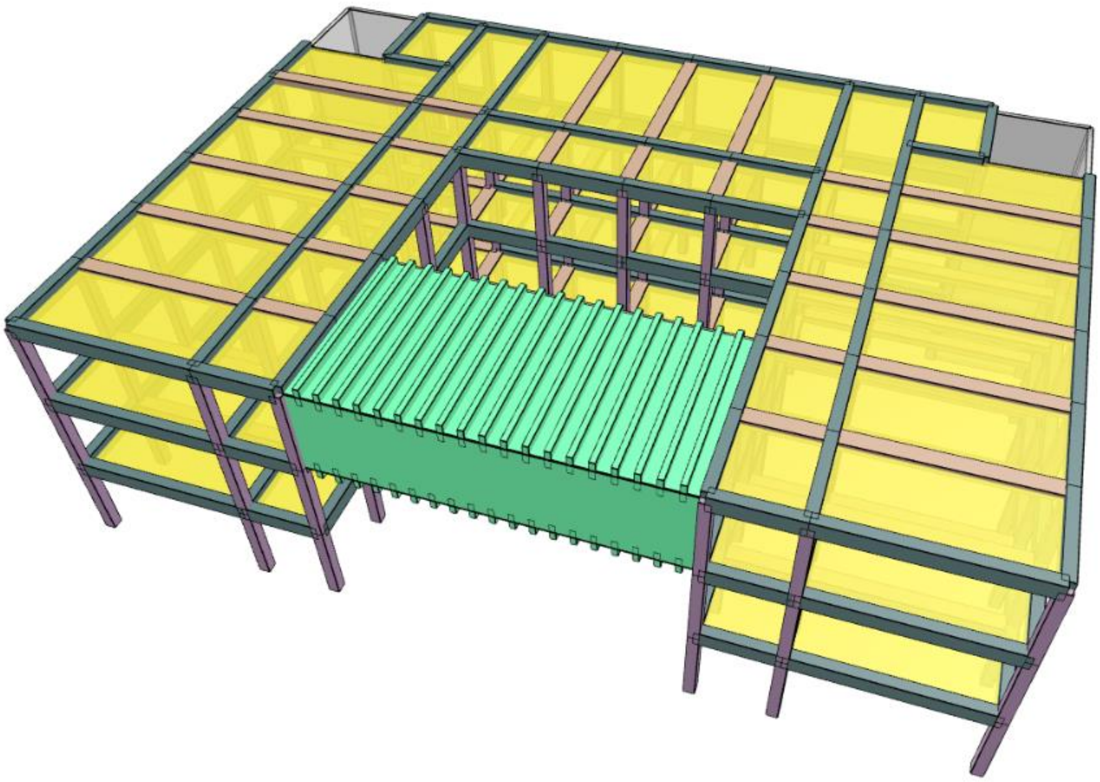


Figure 6. C-shape structure with new wooden volume.

4. Analysis

The existing building is being studied using updated seismic actions to NTC 2018 for the site of interest. The modal analyses (Fig.7) are performed by SkyCiv® software and the structural design of the RC section by VcaSlu (Gelfi, 2021) free software.

The original structure described above has several unverified elements. The addition of the wooden volume improves its seismic response (Smiroldo et al., 2023). In particular, the upper "mesh" closure improves the torsional response. Below is a comparison between the results obtained from the analysis of the original structure and the structure with the added volume.

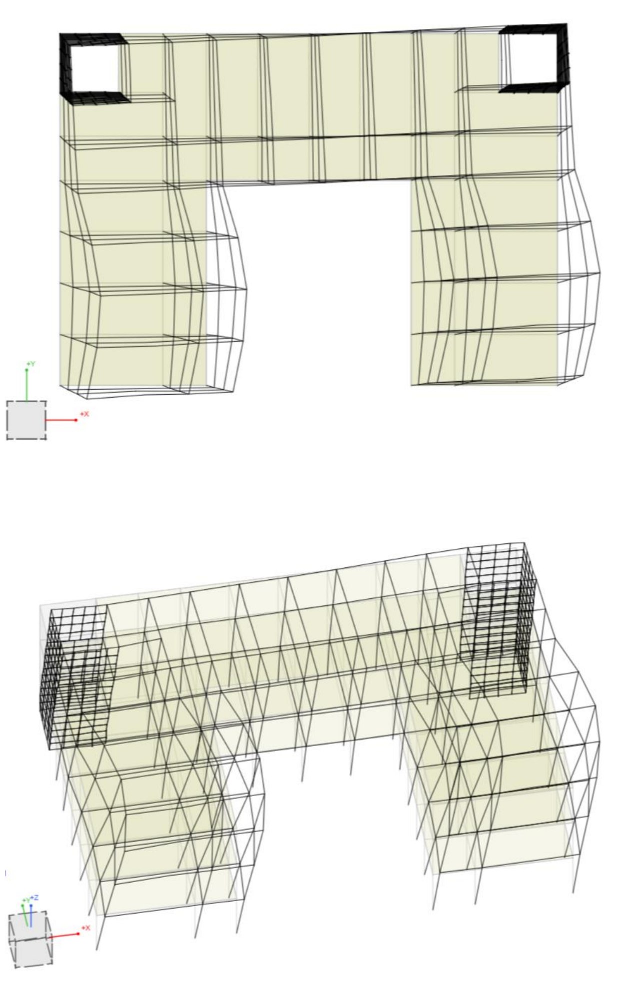
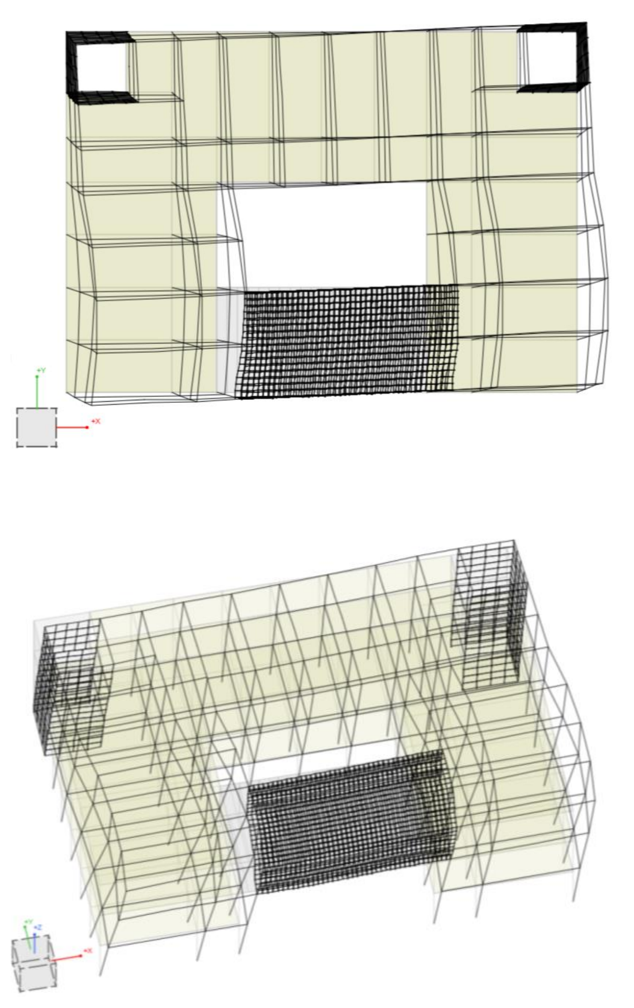
Original Structure	Structure with new volume
	
earthquake x-direction - mode 1	earthquake x-direction - mode 1

Figure 7. Comparison between mode 1 of original structure and structure with new volume.

The control parameters considered are:

1) Maximum bending moment in a primary beam (Fig.8)
2) Maximum combined compressive and bending (N-M) stress in a column (Fig. 9, 10)
3) Maximum horizontal displacement of one of the highest points (Fig.11)

After adding the wooden volume, the previous parameters are compared with those of the reinforced structure. The results are summarised in the (Tab. 4).

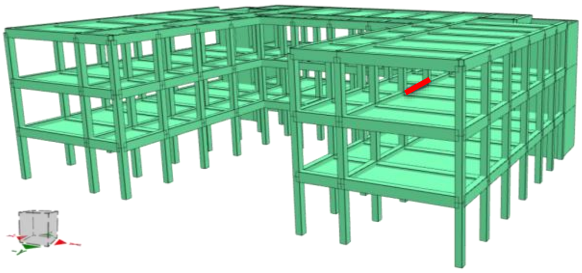
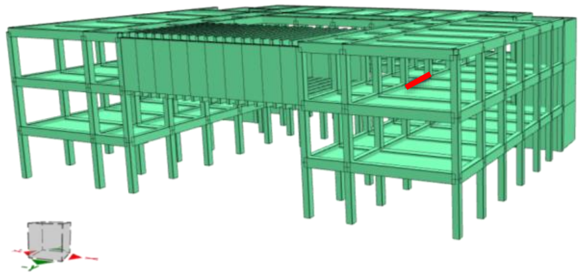
Original structure **second-floor beam 274**	**Structure with new volume** **second-floor beam 274**
	
M_x = 96,27 KNm	M_x = 86,43 KNm

Figure 8. Comparison between the maximum bending moment of the primary beam highlighted.

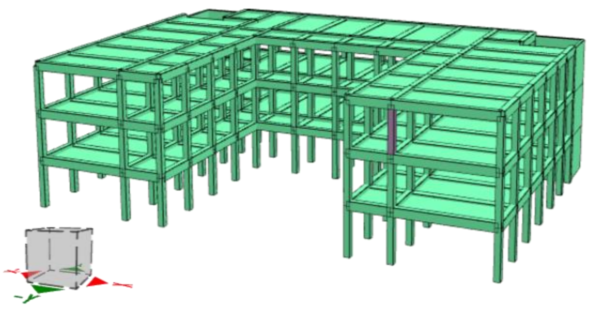
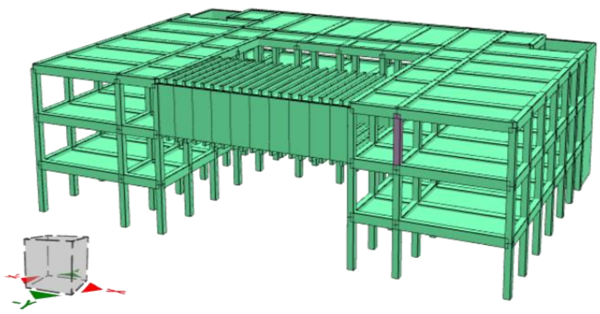
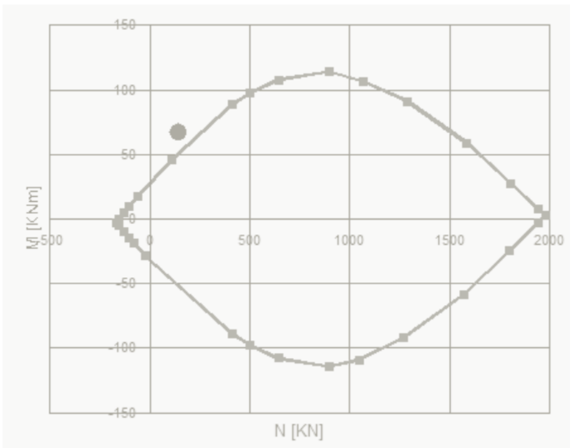
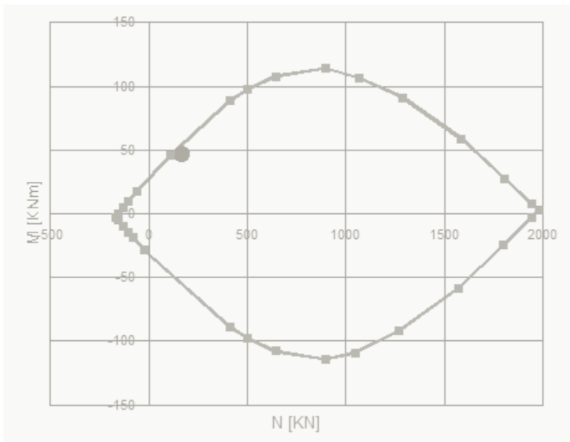
Original structure - 576 column	**Structure with new volume - 576 column**
M_x = 67,21 KNm M_y = 29,03 KNm N = 141,93 KN	M_x = 47,03 KNm M_y = 26,01 KNm N = 167,98 KN
	
	

Figure 9. Comparison between M-N domain of the cross-sectional area of the pilar highlighted.

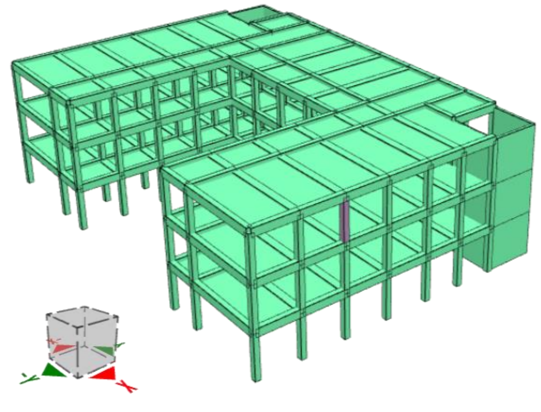
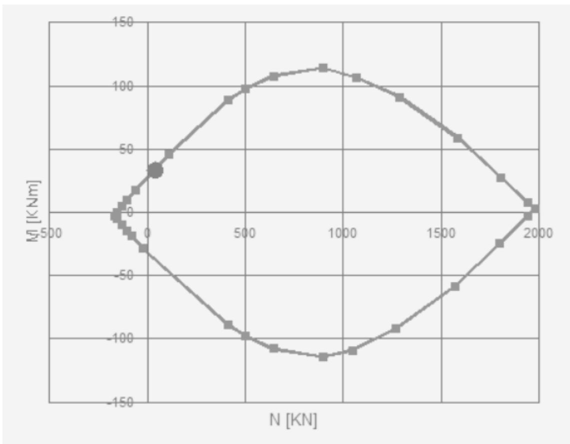
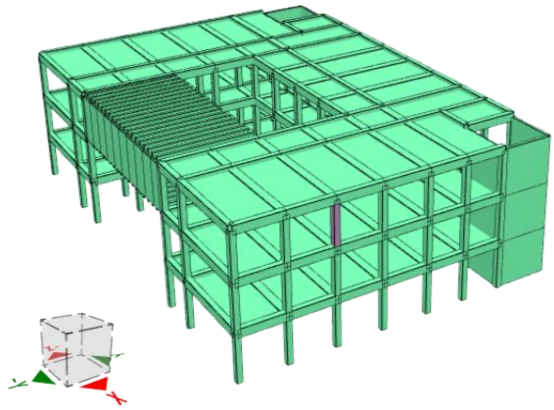
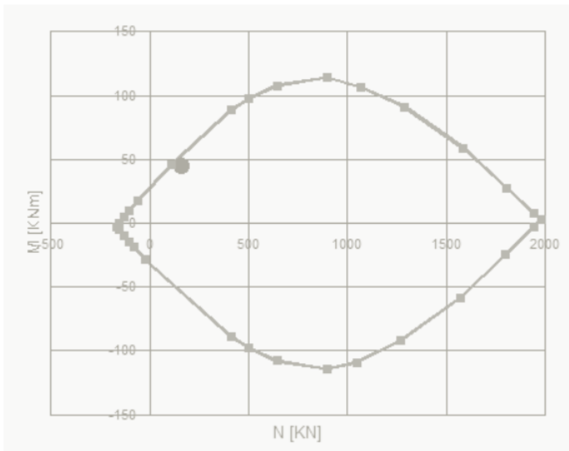
Original structure - column 635	Structure with new volume - column 635
M_x = 63,01 KNm M_y = 33,97 KNm N = 140,26 KN	M_x = 44,50 KNm M_y = 22,90 KNm N = 160,9 KN
 	 

Figure 10. Comparison between M-N domain of the cross-sectional area of the pilar highlighted.

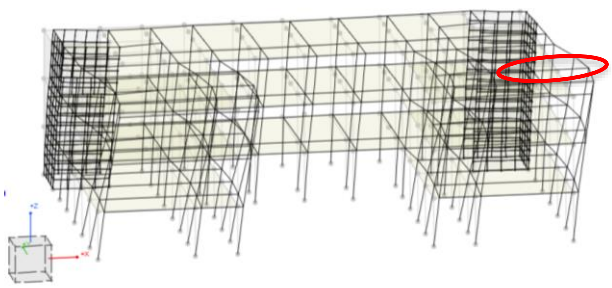
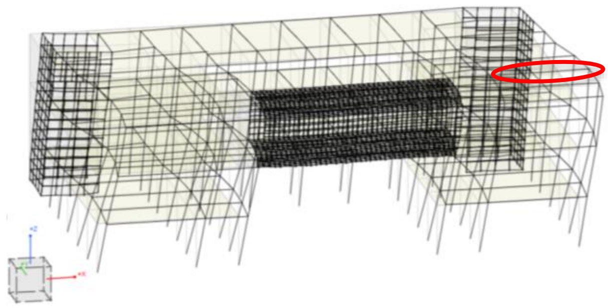
Original structure - last-floor beam 439	Structure with new volume - last-floor beam 439
	
x displacement = 2,553 mm	x displacement = 2,476 mm

Figure 11. Comparison between maximum horizontal displacement at the highest point.

Table 4. Results summary

		Original Structure		Structure with new volume	Variation [%]
Column 576	M_x =	67,21 KNm	Mx =	47,03 KNm	-29,9
	M_y =	29,03 KNm	My =	26,01 KNm	-10,3
	N =	141,93 KN	N =	167,98 KN	18,3
Column 635	M_x =	63,01 KNm	Mz =	44,50 KNm	-29,4
	M_y =	33,97 KNm	My =	22,90 KNm	-32,6
	N =	140,26 KN	N =	160,90 KN	14,7
Beam 274	M_x =	96,27 KNm	M_x =	86,43 KNm	-10,2
Beam 439	x displacement	2,553 mm	x displacement	2,476 mm	-3,0

5. Conclusion

The results of this work show that the appropriate choice of the type of intervention and the building materials allows for multiple benefits. The choice of engineered wood allows light volumes added to the structure with little impact on the original structure. The appropriate placement of these elements allows for a "regularization" in the plan of the building, improving the overall response, especially for the torsional stress. Moreover, the additions do not use free land. Further studies will follow on the connections between the structure and the volume added and for local interventions.

The structural improvements achievable, the reduced CO2 emissions, the possible reuse at the end of life of the wooden elements, the speed of installation due to prefabrication, and the possibility of keeping "usable" the host structure confirm that engineered wood is a good choice for interventions on the building heritage.The structural improvements achievable, the reduced CO_2 emissions, the possible reuse at the end of life of the wooden elements, the speed of installation due to prefabrication, and the possibility of keeping "usable" the host structure confirm that engineered wood is a good choice for interventions on the building heritage.

6. References

Akbas, T., Sause, R., Ricles, J. M., Ganey, R., Berman, J., Loftus, S., Dolan, J. D., Pei, S., van de Lindt, J. W., & Blomgren, H.-E. (2017). Analytical and Experimental Lateral-Load Response of Self-Centering Posttensioned CLT Walls. *Journal of Structural Engineering*, *143*(6), 04017019. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001733

Bellini, O. E. (2020). *Adaptive Exoskeleton Systems: Remodelage for Social Housing on Piazzale Visconti (BG)* (pp. 363–374). https://doi.org/10.1007/978-3-030-33256-3_34

Calderoni, B., Prota, A., Cordasco, E. A., & Sandoli, A. (2016). Seismic vulnerability of “ancient” masonry buildings and strengthening intervention strategies. In *Brick and Block Masonry*. CRC Press, Taylor & Francis Group.

De Stefano, M., & Mariani, V. (2014). Pushover Analysis for Plan Irregular Building Structures. *Geotechnical, Geological and Earthquake Engineering*, *34*, 429–448. https://doi.org/10.1007/978-3-319-07118-3_13/FIGURES/6

Di Gennaro, L., Damiano, E., De Cristofaro, M., Netti, N., Olivares, L., Zona, R., Iavazzo, L., Coscetta, A., Mirabile, M., Giarrusso, G. A., D’Ettore, A., & Minutolo, V. (2022). An innovative geotechnical and structural monitoring system based on the use of NSHT. *Smart Materials and Structures*, *31*(6), 065022. https://doi.org/10.1088/1361-665X/ac5fc6

Di Gennaro, L., Frunzio, G., & Loreto, G. (2023). The Restoration of Santa Maria delle Grazie: The New Life of an Ancient Church. *Building Technology Educators’ Society 2023(1)*, 163–171. https://doi.org/https://doi.org/10.7275/btes.1949

Di Gennaro, L., Guadagnuolo, M., & Monaco, M. (2023). Rocking Analysis of Towers Subjected to Horizontal Forces. *Buildings*, *13*(3), 762. https://doi.org/10.3390/buildings13030762

Di Giulio, R. (2010). Sustainable roof-top extension: a pilot project in Florence. . *Portugal Sb10 Sustainable Building Affordable to All Low Cost Sustainable Solutions.*

D.M. 03 ottobre. (1978). *Criteri generali per la verifica di sicurezza delle costruzioni e dei carichi e sovraccarichi.*

Faella, G., Giordano, A., & Guadagnuolo, M. (2010). *UNSYMMETRIC-PLAN MASONRY BUILDINGS: PUSHOVER VS NONLINEAR DYNAMIC ANALYSIS*.

Faggiano, B., Sandoli, A., Iovane, G., Fragiacomo, M., Bedon, C., Gubana, A., Ceraldi, C., Follesa, M., Gattesco, N., Giubileo, C., Pio Lauriola, M., Podestà, S., & Calderoni, B. (2022). The Italian instructions for the design, execution and control of timber constructions (CNR-DT 206 R1/2018). *Engineering Structures*, *253*, 113753. https://doi.org/10.1016/j.engstruct.2021.113753

Frunzio, G., De Simone, M., Loreto, G., Di Gennaro, L., & Massaro, L. (2023). The use of wood betters the relationship between people and places. *BTES 2023 - Building Technology Educators' Society Conference*, 130–133. https://doi.org/https://doi.org/10.7275/btes.1944

Frunzio, G., & Di Gennaro, L. (2018). Seismic structural upgrade of historical buildings through wooden deckings strengthening: the case of study of Palazzo Ducale in Parete, Italy. *Procedia Structural Integrity*, *11*, 153–160. https://doi.org/10.1016/j.prostr.2018.11.021

Frunzio, G., & Di Gennaro, L. (2019). *Wood in the structural restoration of masonry buildings. In C. Gambardella (Ed.), Le Vie dei mercanti XVII International Forum - World Heritage and Legacy.* . *ISBN 978-88-492-3752-8*, 934–942. http://hdl.handle.net/11591/411583

Frunzio, G., & Di Gennaro, L. (2021). The out of plane behaviour of masonry infilled frames. *Journal of Physics: Conference Series*, *2090*(1), 012148. https://doi.org/10.1088/1742-6596/2090/1/012148

Frunzio, G., Di Gennaro, L., & Guadagnuolo, M. (2019). Palazzo Ducale in Parete: remarks on code provisions. *International Journal of Masonry Research and Innovation*, *4*(1/2), 159. https://doi.org/10.1504/IJMRI.2019.096826

Frunzio, G., Di Gennaro, L., Massaro, L., & D'Angelo, F. (2021). THE CLT PANELS IN STRUCTURAL RESTORATION: CHARACTERISTICS AND TECHNICAL REGULATIONS. *12th International Conference on Structural Analysis of Historical Constructions - SAHC 2020*, 2718–2728. https://doi.org/10.23967/sahc.2021.281

Frunzio, G., Rinaldi, S., Guadagnuolo, M., Massaro, L., & Di Gennaro, L. (2022). Use of engineered wood for the retrofitting of existing structures. *9th International Conference on Harmonisation between Architecture and Nature - Eco-Architecture 2022*, 225–236. https://doi.org/10.2495/ARC220191

Ganey, R., Berman, J., Yao, L., Daniel Dolan, J., Akbas, T., Loftus, S., Sause, R., Ricles, J., Pei, S., Van De Lindt, J., & Blomgren, H. E. (2017). Experimental Investigation of Self-Centering Cross-Laminated Timber Walls. *Journal of Structural Engineering*, *143*(10), 04017135. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001877

Gelfi, P. (2021, November 30). *Civil Engineering Free Software - VcaSlu - Verifica Cemento Armato Stato Limite Ultimo*. Https://Gelfi.Unibs.It/Software/Programmi_studenti.Html.

Granello, G., Palermo, A., Pampanin, S., Pei, S., & Lindt, J. van de. (2020). Pres-Lam Buildings: State-of-the-Art. *Journal of Structural Engineering*, *146*(6), 04020085. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002603

Guadagnuolo, M., Di Gennaro, L., Basile, A., & De Matteis, G. (2023). Simplified methods for the evaluation of mechanical properties of tuff masonry walls in Campania (Italy). *Procedia Structural Integrity*, *44*, 878–885. https://doi.org/10.1016/j.prostr.2023.01.114

Guadagnuolo, M., & Faella, G. (2020). Simplified Design of Masonry Ring-Beams Reinforced by Flax Fibers for Existing Buildings Retrofitting. *Buildings*, *10*, 12. https://doi.org/10.3390/buildings10010012

Hashemi, A., & Quenneville, P. (2020). Seismic performance of timber structures using rocking walls with low damage hold-down connectors. *Structures*, *27*, 274–284. https://doi.org/10.1016/J.ISTRUC.2020.05.050

Iovane, G., Sandoli, A., Marranzini, D., Landolfo, R., Prota, A., & Faggiano, B. (2023). Timber based systems for the seismic and energetic retrofit of existing structures. *Procedia Structural Integrity*, *44*, 1870–1876. https://doi.org/10.1016/j.prostr.2023.01.239

Izzi, M., Casagrande, D., Bezzi, S., Pasca, D., Follesa, M., & Tomasi, R. (2018). Seismic behaviour of Cross-Laminated Timber structures: A state-of-the-art review. *Engineering Structures*, *170*, 42–52. https://doi.org/10.1016/J.ENGSTRUCT.2018.05.060

Khalfi, O. (2019). *Rooftop architecture: a sustainable alternative for urban expansion. Temple University.*

Legambiente. (2023). *Ecosistema scuola. XXII Rapporto nazionale sulla qualità degli edifici e dei servizi scolastici.*

Longarini, N., Crespi, P., & Zucca, M. (2018). *DISSIPATIVE CROSS LAM ROOF STRUCTURE FOR SEISMIC RESTORATION OF HISTORICAL CHURCHES*.

Margani, G., Evola, G., Tardo, C., & Marino, E. M. (2020). Energy, Seismic, and Architectural Renovation of RC Framed Buildings with Prefabricated Timber Panels. *Sustainability*, *12*(12), 4845. https://doi.org/10.3390/su12124845

Massaro, L., Di Gennaro, L., Frunzio, G., Sallicandro, E., & Serpieri, R. (2024). Understanding past rules of the art in columna-capreoli wood trusses. *Developments in the Built Environment*, *19*. https://doi.org/10.1016/j.dibe.2024.100472

Massaro, L., Serpieri, R., Frunzio, G., & Di Gennaro, L. (2023). TIMBER CARPENTRY WITHOUT STEEL CONNECTORS. *COMPDYN Proceedings*, 3203–3212. https://doi.org/10.7712/120123.10633.20422

Minutolo, V., Cerri, E., Coscetta, A., Damiano, E., De Cristofaro, M., Di Gennaro, L., Esposito, L., Ferla, P., Mirabile, M., Olivares, L., & Zona, R. (2020). NSHT: New Smart Hybrid Transducer for Structural and Geotechnical Applications. *Applied Sciences*, *10*(13), 4498. https://doi.org/10.3390/app10134498

Monaco, M., Iannuzzo, A., Tafuro, A., & Gesualdo, A. (2020). *DYNAMIC ANALYSIS OF A POMPEIAN DOMUS*. 4922–4929. https://doi.org/10.47964/1120.9399.19876

Munden, J. P., Graziotti, F., Magenes, G., & Tomasi, R. (2023). STIFFNESS OF WOODEN FLOORS FOR SEISMIC EVALUATION OF EXISTING MASONRY STRUCTURES IN NORWAY. *World Conference on Timber Engineering (WCTE 2023)*, 2510–2516. https://doi.org/10.52202/069179-0330

Palermo, A., Pampanin, S., Buchanan, A. H., & Newcombe, M. P. (2005). *Seismic Design of multi-storey buildings using laminated veneer lumber (LVL)*.

Pilon, D. S., Palermo, A., Sarti, F., & Salenikovich, A. (2019). Benefits of multiple rocking segments for CLT and LVL Pres-Lam wall systems. *Soil Dynamics and Earthquake Engineering*, *117*, 234–244. https://doi.org/10.1016/j.soildyn.2018.11.026

Riccadonna, D., Giongo, I., Schiro, G., Rizzi, E., & Parisi, M. A. (2019). Experimental shear testing of timber-masonry dry connections for the seismic retrofit of unreinforced masonry shear walls. *Construction and Building Materials*, *211*, 52–72. https://doi.org/10.1016/j.conbuildmat.2019.03.145

Sandoli, A., & Calderoni, B. (2020). The Rolling Shear Influence on the Out-of-Plane Behavior of CLT Panels: A Comparative Analysis. *Buildings*, *10*(3), 42. https://doi.org/10.3390/buildings10030042

Sandoli, A., D'Ambra, C., Ceraldi, C., Calderoni, B., & Prota, A. (2021). Sustainable Cross-Laminated Timber Structures in a Seismic Area: Overview and Future Trends. *Applied Sciences*, *11*(5), 2078. https://doi.org/10.3390/app11052078

Scandone, P. et al. (1970). *Carta della pericolosità sismica d'Italia.*

Smiroldo, F., Bartolotti, A., Colombo, M., & Giongo, I. (2023, October). *Timber-based seismic retrofit of a 5-storey RC structure built in 1955*.

Smiroldo, F., Giongo, I., & Piazza, M. (2021). Use of timber panels to reduce the seismic vulnerability of concrete frame structures. *Engineering Structures*, *244*, 112797. https://doi.org/10.1016/j.engstruct.2021.112797

Smiroldo, F., Paviani, I., Giongo, I., Zanon, S., Albatici, R., & Piazza, M. (2021). An Integrated Approach to Improve Seismic and Energetic Behaviour of RC Framed Buildings Using Timber Panels. *Sustainability*, *13*(20), 11304. https://doi.org/10.3390/su132011304

Sun, X., He, M., & Li, Z. (2020). Novel engineered wood and bamboo composites for structural applications: State-of-art of manufacturing technology and mechanical performance evaluation. In *Construction and Building Materials* (Vol. 249). Elsevier Ltd. https://doi.org/10.1016/j.conbuildmat.2020.118751

Valluzzi, M. R., Saler, E., Vignato, A., Salvalaggio, M., Croatto, G., Dorigatti, G., & Turrini, U. (2021). Nested Buildings: An Innovative Strategy for the Integrated Seismic and Energy Retrofit of Existing Masonry Buildings with CLT Panels. *Sustainability*, *13*(3), 1188. https://doi.org/10.3390/su13031188