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TIMBER AS BRIDGE BETWEEN PAST AND FUTURE: STRUCTURAL UPGRADING AND CONSERVATION OF THE ANCIENT TIMBER AND MASONRY VENETIAN SAWMILL OF VALLARO (BRESCIA, ITALY)

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ABSTRACT: This work presents an extensive static and seismic retrofitting intervention performed on a relevant historic case-study building, the Venetian sawmill of Vallaro (Brescia, Italy). This heritage construction from the end of the 19th century features three building portions, two realized in timber and one consisting of a masonry structure with timber floors and roofs. The building had been neglected for decades and was in a poor state of conservation, despite representing a valuable example of the typical historic architectures of the mountainy area in the Province of Brescia. With the support of the local municipality, a complete restoration of the sawmill has started, with the objective of transforming it into a territorial museum. To this end, a series of reversible and compatible timber-based interventions were planned in consultation with the local superintendence for architectural heritage. The structural design aimed at preserving the historic value of the sawmill, especially in its original timber components, such as trusses, braced columns, and diaphragms. The present case study enables to showcase the advantages of the applied strengthening methods in such a complex architectural restoration and the importance of tailored structural detailing, combining the improvement in static and seismic performance with the protection and preservation of ancient timber members.

KEYWORDS: Structural Upgrading, Architectural Restoration, Timber, Masonry, Historic Buildings

1 – INTRODUCTION

The historic building stock belonging to the architectural heritage of several countries, often features masonry walls as vertical loadbearing structural components, and timber floors or roofs as horizontal elements. With reference to the Italian context, these building typologies are very frequent, and have highlighted significant vulnerabilities from the seismic point of view, as proved by several local or global collapses observed after recent earthquakes [1–3]. These structural failures have been caused by the poor characteristics of masonry walls, the lack of adequate connections among vertical and horizontal structural components, as well as the flexibility and insufficient capability of timber floors to transfer and redistribute seismic loads. Hence, improving these characteristics is essential for preserving monumental constructions and the architectural heritage in general, by limiting as much as possible the structural damage induced by earthquakes. However, when designing static and seismic retrofitting methods for such buildings, their historic value has to be taken into account as well. The selected interventions have thus to be reversible, not invasive, and enable the architectural conservation of these structures [4–6]. In this context, timber-based techniques constitute a promising, effective opportunity for reversible seismic strengthening and restoration of existing buildings [7–26]: with regard to the improvement of the response to earthquakes of timber floors, research studies on wood-based retrofits such as the overlay of cross-laminated timber [7, 12, 23], oriented strand board [11, 13], or plywood panels [8–11, 14–22, 26], demonstrated the excellent performance and great potential of these strengthening methods.

As a result of a fruitful synergy between academic research and professional engineering, this work presents a relevant recent example of application of reversible timber-based strengthening interventions for the restoration of an ancient sawmill with a mixed timber-masonry structure, located in the province of Brescia, Italy (Fig. 1). The timber-based solutions were for this case integrated with light steel elements as well, in order to preserve as much as possible the original appearance of the existing wooden structural components, and thus minimize the impact of newly added elements. After a brief description of the case-study building (Section 2), the design (Section 3) and implementation (Section 4) of the main retrofit solutions adopted is discussed, followed by the conclusions of this work (Section 5).

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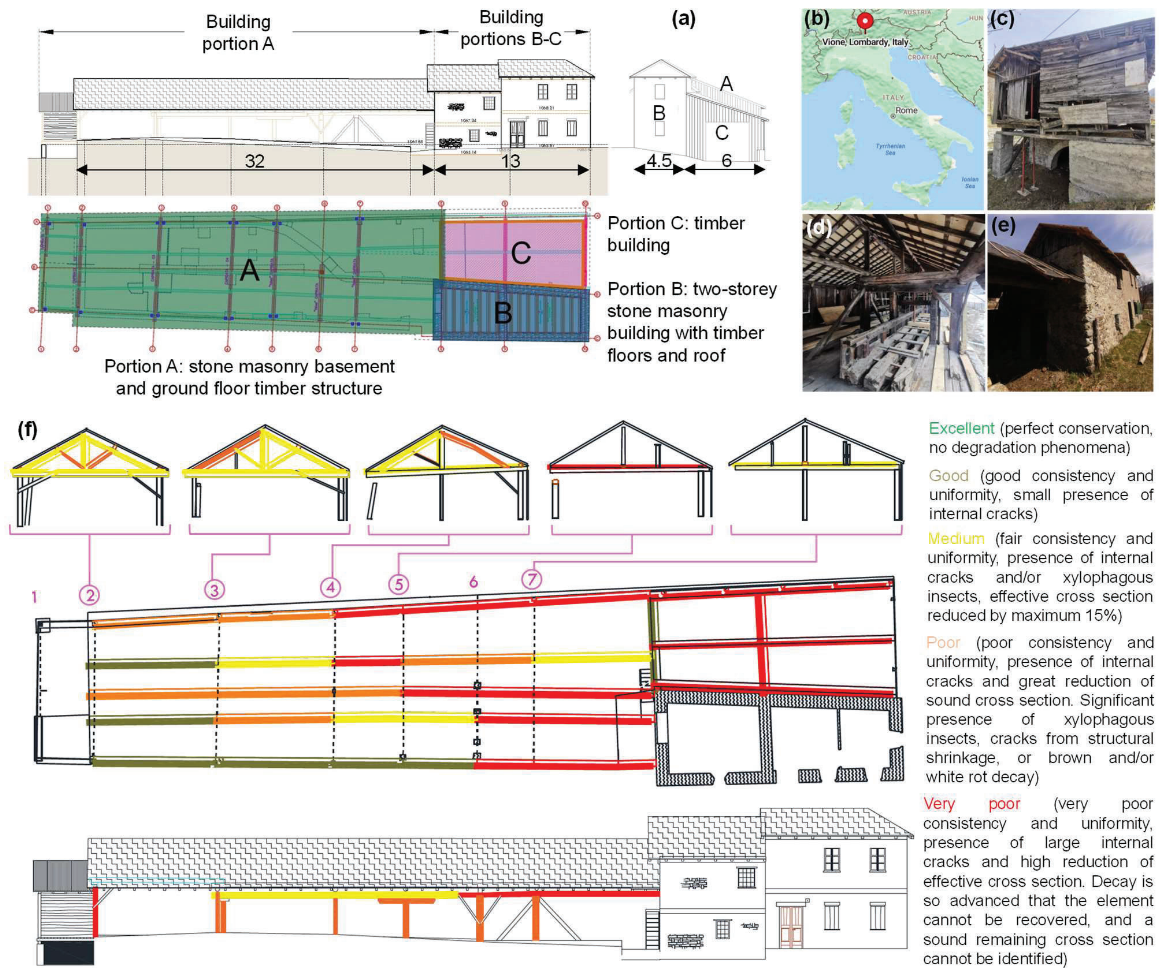

Figure 1. Plan and prospects of the case-study sawmill (a) and its location in Northern Italy (b); external (c) and internal (d) views of portion A of the sawmill before retrofitting; view of portion B (e); results of the assessment of the conservation of timber structural elements based on micro-drilling measurements (f), with classification of the conservation state following Italian standard UNI 11119:2004 [27], kindly provided by Ph.D. Eng. Dario P. Benedetti [28].

2 – CASE-STUDY BUILDING

The Venetian sawmill of Vallaro, located in the municipality of Vione (Province of Brescia, Italy, Fig. 1b) and built in the late 19th century, has selected for a full restoration plan by the local community, in order to transform it in a territorial museum. The building features three independent portions A, B, and C (Fig. 1a):

- Portion A (280 m^2, Fig. 1c-d) consists of a single-storey timber structure featuring seven silver fir (*Abies alba Mill.*) and larch (*Larix spp.*) trusses, resting on a stone masonry basement with 50-60 cm thick walls;
- Portion B (50 m^2, Fig. 1e) is a two-storey stone masonry structure with 50-60 cm thick walls and silver fir (*Abies alba Mill.*) timber floors and roof;
- Portion C (80 m^2) consists of a prolongation of the roof structure of portion A, made entirely of silver fir (*Abies alba Mill.*).

The existing structure was the result of a series of interventions carried out over time, causing overlapping between original members and later included elements, often poorly implemented with incompatible or low-quality materials. These factors, along with the past neglect of the building in the last decades, have contributed to the apparent poor conditions of the sawmill from the conservation point of view (Fig. 1), with extended degradation phenomena caused by water infiltrations from the roof. In light of the visually observed poor state of the sawmill, several investigations were conducted to assess the conditions of the existing structural elements. In particular, detailed on-site inspections on the stone masonry in 10 different locations were undertaken, and micro-drilling measurements were carried out on the timber members in 41 locations to assess their state, by means of an IML-RESI Power Drill 400 having a 3-mm needle. This comprehensive on-site assessment allowed to reconstruct the conservation state of the main timber structural elements (Fig. 1f), following the classification of Italian standard UNI

11119:2004 [27]. The wooden roof structure of portion A, including the trusses and timber columns, was found in an overall poor state of conservation after the past neglect of the building; the ground timber floor featured some sounder elements, but part of it was strengthened in the past with an incompatible 20-mm-thick concrete slab. In portion B and C, the evident signs of decay in the timber elements were confirmed by the outcomes of the micro-drilling measurements, based on which a very poor state of conservation was assigned to these structural members.

Based on the on-site performed investigations, several main vulnerabilities were found in relation to the future use of the building as a museum. Portion A presented insufficient load-carrying capacity of the wooden columns, with the existing structures able to sustain static actions only because of provisional works. The wooden members in the floors and the roof were decayed and very undersized for the future increased design loads. Furthermore, the past interventions consisted of incompatible reinforced concrete structural elements that were also found in poor state of conservation. Local cracks were detected in masonry walls of building portions A and B as well. Finally, all horizontal structural elements were not able to create an effective diaphragmatic and dissipative action against seismic loads, and adequate joints between floors and walls were absent.

3 – DESIGN OF THE RETROFITS

The sawmill of Vallaro required extensive strengthening interventions because of the overall poor conditions of the building, combined with the prospective design loads following the Italian Building Code [29]. In particular, the prescribed crowd live load in museums would be 4.0 to 5.0 kN/m^2 [29], an unrealistic target for an existing building with floors in such conservation state, where the strengthening measures have not to be invasive, and preserve as much as possible the original appearance and historic value of the construction. Hence, in consultation with the local municipality and Superintendence for Architectural Heritage, it was first decided to limit the number of visitors present in the museum at the same time, in order to design the structural upgrading of the floor diaphragms for a target crowd live load of 2.0 kN/m^2. However, the other site-related live loads are also quite large, given the building's location in the mountainy area of the Province of Brescia, at an altitude of approximately 1100 m above mean sea level: the snow load is 3.5 kN/m^2, the wind load is 0.7 kN/m^2, and the peak ground acceleration for earthquake loading is 0.1g [29]. Thus, measures to radically improve the static and seismic behaviour of the sawmill were designed, having as main goal the conservation of the existing timber members and the use of wood-based solutions (Fig. 2).

For portion A (Fig. 2a), given the low residual load-carrying capacity of the decayed timber columns, newly integrated slender steel elements were designed, along with a new steel frame connected to the strengthened masonry foundations. In this way, both the static and seismic response of the structure could be improved. In consultation with the local Superintendence for Architectural Heritage, a wood-based solution was not adopted for this case, because it would have required very massive structural elements, which could have partly hidden the original appearance of the existing building. Instead, a timber-based strengthening was designed to preserve the wooden roof and enhance its structural response: 12-cm-thick C24 cross-laminated timber (CLT) slabs, along with additional steel strands, were adopted to improve the static behaviour of the roof, and enable its diaphragmatic action against lateral loads, while contemporarily preserving the existing wooden trusses. These were strengthened with particular care in minimizing the impact of newly added elements, and following the principles of similar successful past conservation interventions [5, 30]. Thus, through a combination of timber chocks, and steel ties, struts, and strands, the structural response of wooden trusses could be enhanced without the need for invasive interventions (Fig. 2b). Additionally, to guarantee sufficient ventilation around these existing ancient timber members, the steel angles around them were not in direct contact with the trusses, but slightly separated by means of neoprene spacers (Fig. 2a). Besides, also the ground timber floor was strengthened with 30-mm-thick plywood panels and additional wooden beams placed alongside the existing ones to improve the flexural and seismic response. All diaphragms were effectively connected to the masonry walls, by means of S275 or S355 steel angles and M14 or M20 threaded bars. All incompatible past interventions involving reinforced concrete elements, were demolished and integrated with new wooden or steel members, while the interior was restored and set up for the future museum activities (Section 4).

For portion B (Fig. 2c), flexural strengthening of the timber floors and roofs was necessary. This was realized by means of new timber beams of the same wood species, placed alongside the existing ones, and a 20-mm-thick plywood panels overlay fastened on them with 6×120 mm screws at 300 mm spacing. Besides, effective connections between horizontal and vertical structural elements were designed, including also new steel ties for an improved confinement of the stone masonry. In portion C, these measures were integrated with an entirely new prefabricated CLT structure, hosting the prospective location of the shop and café of the museum (Fig. 2c). The CLT module enables to support the existing wooden elements, which showed severe decay and excessive lack of load-carrying capacity. The designed solutions allowed to preserve as much as possible the original appearance and features of the sawmill, in spite of its poor conditions, while ensuring a safer, renovated environment for hosting a museum in this relevant, historic location.

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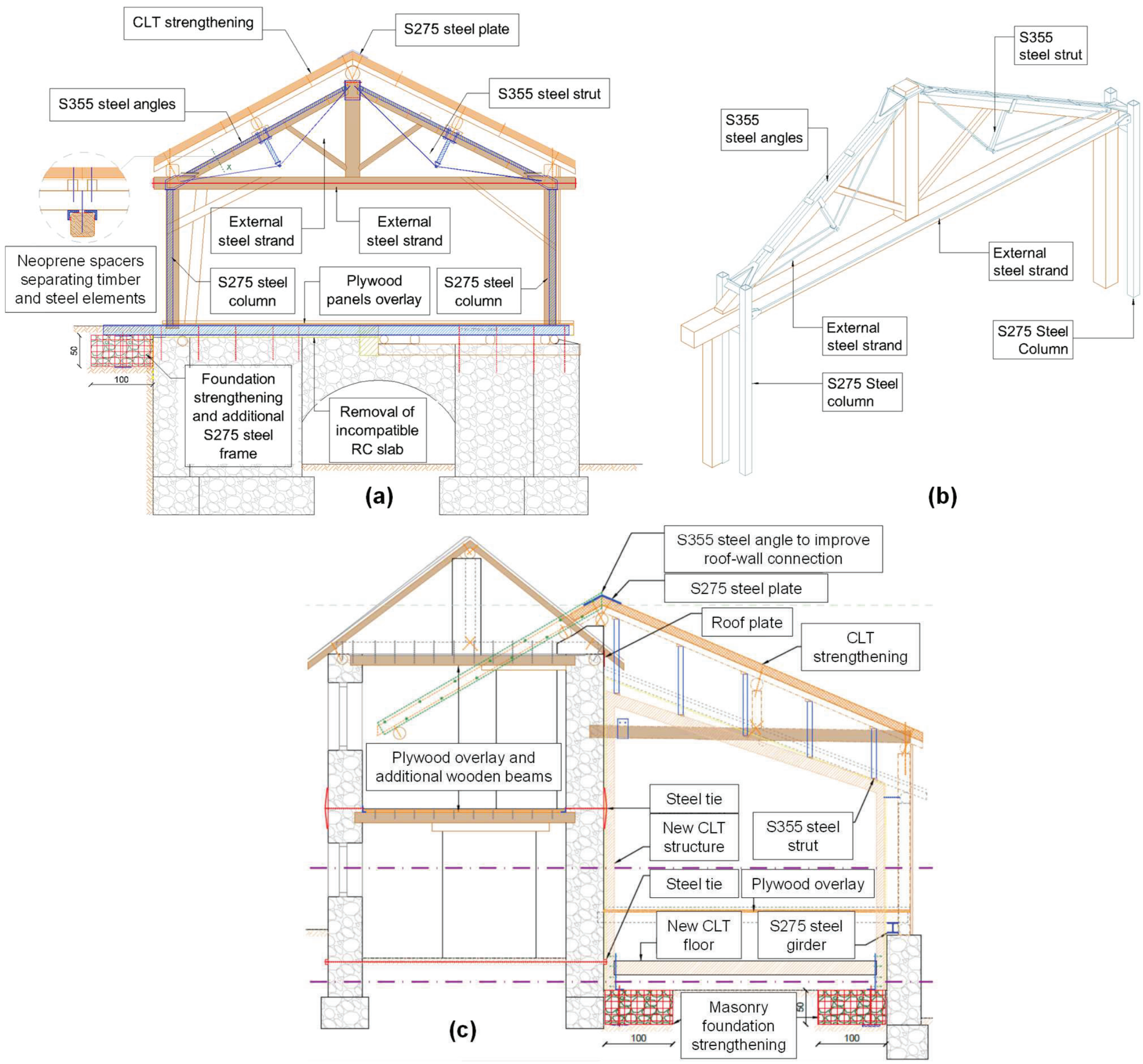

Figure 2. Representative overview of the designed integrated timber- and steel-based retrofits for the structural upgrading of the sawmill: interventions applied to portion A (a), including the principles adopted for strengthening the existing timber trusses (b), and to portion B (c) of the building.

4 – EXECUTION OF THE RETROFITS

The designed retrofitting solutions were implemented in the building in the attempt to minimize their impact on the ancient sawmill during renovation, and to mitigate the appearance of the strengthening measures after their installation. For instance, the light steel elements employed for recovering the trusses of portion A of the building, were painted with a grey colour resembling the shadows created by the natural light inside the construction (Fig. 3a-e). This system, cooperating with the CLT overlay for the roof's static and seismic upgrading (Fig. 3f, g), is sufficient to withstand the expected serviceability limit state loads, with the existing trusses only being activated in the resisting mechanism at ultimate limit state. Furthermore, the plywood panels overlay installed for the static and seismic strengthening of all timber floors in portions A and B (Fig. 3h-k), was then covered with the existing, restored, 100-year-old planks, to maintain the original appearance of the sawmill, as shown in Fig. 3a-b. After retrofitting, the preparations to transform the interior of the sawmill into the planned territorial museum also started, with the installation of timber-based devices (Fig. 3l). Finally, the integration of the new prefabricated CLT module in portion C of the existing construction was successfully achieved (Fig. 3m-o), with the creation of a comfortable interior space and a minimal impact on the more ancient building portions, from both a structural and visual perspective (Fig. 3o).

Figure 3. Implementation of the designed retrofitting solutions in the sawmill: renovated interior of portion A with recovered timber elements, strengthened trusses, and light steel frames (a, b); details of the designed timber-steel retrofits for the wooden trusses in portion A (c, d, e); static and seismic upgrading of the roof diaphragm of portion A with cross-laminated timber panels (f, g); installation of the plywood panels overlay for static and seismic strengthening of the existing timber floors in portions A (h, i) and B (j, k) of the sawmill, including timber-masonry connections with steel angles; preparations of the interior of the building to host the territorial museum (l); installation of the prefabricated cross-laminated timber module in portion C of the sawmill (m, n); view of the renovated building from outside (o), merging ancient and new timber elements and featuring new steel ties for the masonry walls.

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5 – CONCLUSIONS

This work has presented the application of integrated timber- and steel-based strengthening techniques on the Venetian sawmill of Vallaro in Vione (Brescia, Italy). The designed solutions were particularly appreciated by the Superintendence for Architectural Heritage, as the historical and architectural value of the buildings was preserved. The reasonably low impact on the construction, linked to a large improvement in structural response, is surely a first point of strength of wood- and steel-based techniques in this case-study building. Furthermore, the large use of timber allowed to realize interventions that were cost-effective, efficiently installable, reversible and compatible with the existing structural members, while contemporarily strengthening and protecting them. All floors and roofs can now withstand the expected static loads and act as diaphragms against wind and seismic actions. The use of CLT- and plywood-based solutions, in combination with light steel elements, allowed an efficient retrofitting process of the building, including the installation of tailored structural detailing, the full conservation of all existing wooden members, and the restoration of the seven ancient silver fir trusses.

The present case study contributes to further highlight the benefits of timber-based retrofitting techniques, and to support the research framework and engineering practice promoting their use for the preservation and the structural as well as seismic upgrading of architectural heritage.

6 – ACKNOWLEDGEMENTS

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7 – REFERENCES

[1] S. Lagomarsino. “Damage assessment of churches after L’Aquila earthquake”. In: Bulletin of Earthquake Engineering 10 (2012), pp. 73–92.

[2] M. Indirli, G. Marghella, A. Marzo. “Damage and collapse mechanisms in churches during the Pianura Padana Emiliana earthquake”. In: Energia, Ambiente e Innovazione 4-5 (2012).

[3] A. Penna, C. Calderini, L. Sorrentino, C.F. Carocci, E. Cescatti, R. Sisti, A. Borri, C. Modena, A. Prota. “Damage to churches in the 2016 central Italy earthquakes”. In: Bulletin of Earthquake Engineering, 17 (2019), pp. 5763–5790.

[4] A. Gubana. “State-of-the-Art Report on high reversible timber to timber strengthening interventions on wooden floors”. In: Construction and Building Materials 97 (2015), pp. 25–33.

[5] M.A. Parisi, M. Piazza. “Restoration and strengthening of timber structures: principles, criteria, and examples”. In: Practice Periodical on Structural Design and Construction 12(4) (2007).

[6] N. Gattesco, L. Macorini. “High reversibility technique for in-plane stiffening of wooden floors”. In: Proceedings of the 6th International Conference on Structural Analysis of Historic Construction (2008), Bath, United Kingdom.

[7] J.M. Branco, M. Kekeliak, P.B. Lourenço. “In-Plane Stiffness of Timber Floors Strengthened with CLT”. In: European Journal of Wood and Wood Products 73 (2015), pp. 313–323.

[8] A. Brignola, S. Pampanin, S. Podestà. “Experimental Evaluation of the In-Plane Stiffness of Timber Diaphragms”. In: Earthquake Spectra 28(4) (2012), pp. 1–23.

[9] I. Giongo, D. Dizhur, R. Tomasi, J. Ingham. “In-plane assessment of existing timber diaphragms in URM buildings via quasi-static and dynamic in-situ tests”. In: Advanced Materials Research 778 (2013), pp. 495–502.

[10] E. Giuriani, A. Marini. “Wooden roof box structure for the anti-seismic strengthening of historic buildings”. In: International Journal of Architectural Heritage 2 (2008), pp. 226–246.

[11] A. Gubana, M. Melotto. “Experimental tests on wood-based in-plane strengthening solutions for the seismic retrofit of traditional timber floors”. In: Construction and Building Materials 191 (2018), pp. 290–299.

[12] N. Longarini, P. Crespi, M. Zucca. “The influence of the geometrical features on the seismic response of historical churches reinforced by different cross lam roof-solutions”. In: Bulletin of Earthquake Engineering 20 (2022), pp. 6813–6852.

[13] M. Miglietta, N. Damiani, G. Guerrini, F. Graziotti. “Full-scale shake-table tests on two unreinforced masonry cavity-wall buildings: effect of an innovative timber retrofit”. In: Bulletin of Earthquake Engineering 19 (2021), pp. 2561–2596.

[14] M. Mirra. "A set of calculation tools supporting the design, modelling and application of plywood-based seismic retrofitting interventions on timber floors in existing buildings". In: Structures 63 (2024), 106378. https://doi.org/10.1016/j.istruc.2024.106378.

[15] M. Mirra, A. Gerardini, S. Ghirardelli, G. Ravenshorst, J.W. van de Kuilen. "Combining architectural conservation and seismic strengthening in the wood-based retrofitting of a monumental timber roof: the case study of St. Andrew's Church in Ceto, Brescia, Italy". In: International Journal of Architectural Heritage 18(5) (2023), pp. 750–770. https://doi.org/10.1080/15583058.2023.2187726.

[16] M. Mirra, G. Ravenshorst. "Optimizing Seismic Capacity of Existing Masonry Buildings by Retrofitting Timber Floors: Wood-Based Solutions as a Dissipative Alternative to Rigid Concrete Diaphragms". In: Buildings 11(12) (2021), 604. https://doi.org/10.3390/buildings11120604.

[17] M. Mirra, G. Ravenshorst, P. de Vries, F. Messali. "Experimental characterisation of as-built and retrofitted timber-masonry connections under monotonic, cyclic and dynamic loading". In: Construction and Building Materials 358 (2022), 129446. https://doi.org/10.1016/j.conbuildmat.2022.129446.

[18] M. Mirra, G. Ravenshorst, J.W. van de Kuilen. "Experimental and analytical evaluation of the in-plane behaviour of as-built and strengthened traditional wooden floors". In: Engineering Structures 211 (2020), 110432. https://doi.org/10.1016/j.engstruct.2020.110432.

[19] M. Mirra, G. Ravenshorst, J.W. van de Kuilen. "An analytical model describing the in-plane behaviour of timber diaphragms strengthened with plywood panels". In: Engineering Structures 235 (2021), 112128. https://doi.org/10.1016/j.engstruct.2021.112128.

[20] M. Mirra, G. Ravenshorst, J.W. van de Kuilen. "Comparing in-plane equivalent shear stiffness of timber diaphragms retrofitted with light and reversible wood-based techniques". In: Practice Periodical on Structural Design and Construction 26(4) (2021). https://doi.org/10.1061/(ASCE)SC.1943-5576.0000602.

[21] E. Ongaretto, L. Pozza, M. Savoia. "Wood-based solutions to improve quality and safety against seismic events in conservation of historical buildings". In: International Journal for Quality Research 10(1) (2016), pp. 17–46.

[22] D.F. Peralta, M.J. Bracci, M.B.D. Hueste. "Seismic Behavior of Wood Diaphragms in Pre-1950s Unreinforced Masonry Buildings". In: Journal of Structural Engineering 130(12) (2004).

[23] E. Rizzi, M. Capovilla, M. Piazza, I. Giongo. "In-plane behaviour of timber diaphragms retrofitted with CLT panels". In: Aguilar R et al. (eds.) Structural Analysis of Historical Constructions, RILEM Bookseries 18 (2019), pp.1613–1622.

[24] A. Wilson, P. Quenneville, J. Ingham. "In-plane orthotropic behavior of timber floor diaphragms in unreinforced masonry buildings". Journal of Structural Engineering 140(1) (2014).

[25] M. Mirra. "An integrated approach for seismic design and modelling of plywood-retrofitted timber floors". In: Procedia Structural Integrity 64 (2024), pp. 869-876. https://doi.org/10.1016/j.prostr.2024.09.361.

[26] M. Mirra, A. Gerardini. "Design and modelling tools for timber-based seismic retrofitting: from research to practice". In: Procedia Structural Integrity 64 (2024), pp. 877-884. https://doi.org/10.1016/j.prostr.2024.09.362.

[27] UNI 11119:2004. "Cultural heritage - Wooden artefacts - Load-bearing structures - On site inspections for the diagnosis of timber members" (in Italian). Rome, Italy (2004), Italian Standard Body (UNI).

[28] D.P. Benedetti. "Relazione tecnica sulle indagini diagnostiche eseguite sulla struttura della copertura - Segheria Veneziana - Vione (BS)" ("Technical report on the diagnostic investigations coducted on the roof structure – Venetian Sawmill – Vione, Brescia". In Italian). START Apps S.r.l.u., May 2021, Brescia, Italy.

[29] NTC 2018. "Italian Building Code", in Italian. Rome, Italy (2018), Ministry for Infrastructures and Transports.

[30] L. Jurina. "Numerical model and consolidation interventions of Palazzo della Ragione in Milan". In: Procedia Structural Integrity 11 (2018), pp. 410–417.

 https://doi.org/10.52202/080513-0331