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Advancing Timber for the Future Built Environment

Timber-based retrofit strategies for existing URM and RC structures: insight from ReLUIS-DPC project

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ABSTRACT: The use of timber for seismic reinforcement of existing structures is gaining significant attention, thanks to recent developments in engineered wood products such as CLT and LVL. This study, carried out within the framework of the RELUIS WP5 2022-2024 project, explores various reinforcement techniques including timber strong-backs, light timber frames sheathed with OSB panels, CLT panel coatings, endoskeletons, and exoskeletons. Each method is evaluated for its advantages, disadvantages, and applicability, with a focus on sustainability and intervention effectiveness. Results show that timber solutions offer significant improvements in the strength and deformation capacity of reinforced structures, presenting a promising option for integrated and sustainable seismic retrofitting.

KEYWORDS: Timber-Based Seismic Reinforcement, Timber Frames and Panels, Endoskeletons and Exoskeletons, Integrated Sustainable Retrofit

1 – INTRODUCTION

The use of timber for the seismic retrofitting of existing structures has recently attracted considerable attention from both the research community and the construction industry. This concept, however, is not entirely new. There are numerous examples across the world of traditional construction techniques that combine timber with other materials and have proven effective in surviving strong earthquakes, such as Himis in Turkey, Dhajji Dewari in India, Casa Baraccata in Italy, and Gaiola Pombalina in Portugal, to name a few. Building on these historical precedents and benefiting from the development and widespread adoption of new engineered wood products (e.g., laminated veneer lumber, CLT panels), a variety of timber-based solutions have been proposed in recent years for the strengthening and seismic upgrading of existing structures.

In this context, the research activities carried out within the ReLUIS-DPC project (partly in collaboration with the Joint Research Centre, JRC) have played a fundamental role. These efforts have focused on the development of retrofitting techniques that are predominantly dry-assembled, reversible, and minimally invasive. Moreover, such solutions can be effectively integrated with energy-efficiency upgrades, thereby promoting overall sustainability. From this perspective, the renewable nature of timber and the inherent prefabrication typical of timber construction have supported the development of a range of strategies, specifically targeting: i) existing timber roofs and floors, ii) masonry walls and structures, iii) reinforced concrete frames. Figure 1 provides a summary of the main techniques studied within the ReLUIS framework, with reference to points ii) and iii).

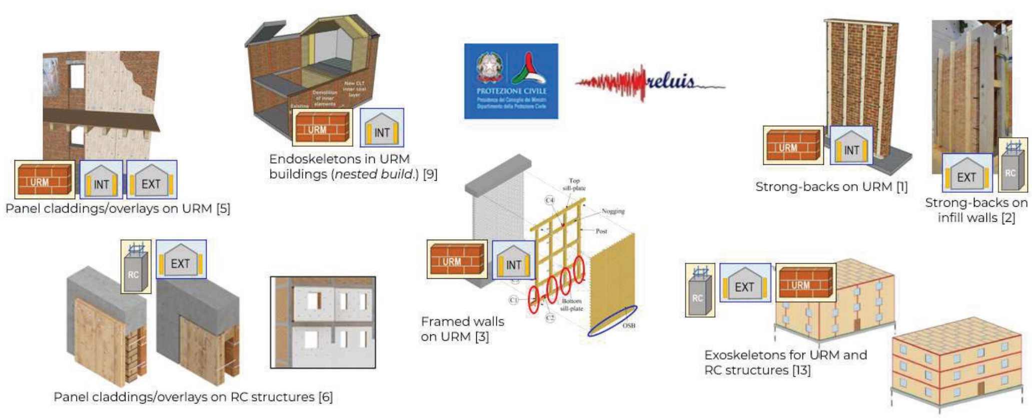

Figure 1 Synthesis of timber-based strengthening techniques for URM and RC structures studied within the ReLUIS-DPC project

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2 – DIFFERENT APPROACHES TO TIMBER-BASED STRENGTHENING

In recent years, several retrofit strategies have been developed that exploit the mechanical and technological potential of engineered timber. These strategies vary significantly depending on the typology of the structure to be strengthened (e.g., masonry vs reinforced concrete), the type and direction of the applied seismic forces (in-plane vs out-of-plane), and the construction constraints, such as reversibility, compatibility with existing elements, or integration with energy retrofit measures. The main approaches include:

Timber strong-backs

These are one-dimensional timber elements installed vertically at regular intervals on the surface of masonry [1] or infill walls [2] (Figure 2). Their main purpose is to reduce the out-of-plane vulnerability of the wall system under seismic actions. The connection between the timber members and the masonry substrate is achieved using discrete mechanical fasteners, either dry-inserted or bonded with chemical anchors, depending on the type and condition of the wall.

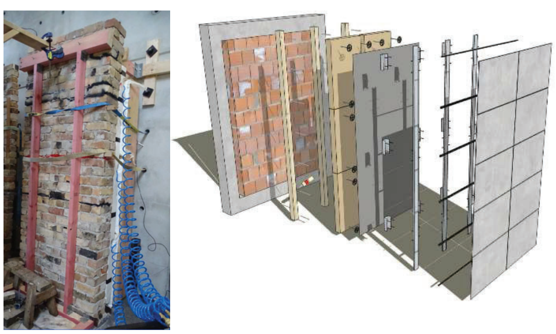

Figure 2 Timber strong-back retrofit applied to masonry walls [1] (left) and to infill walls [2] (right)

Framed wall claddings/overlays

This system consists of timber frames combined with OSB (Oriented Strand Board) panels, designed to mitigate both out-of-plane and in-plane mechanisms in masonry walls [3] (Figure 3). The vertical timber studs enhance the wall's out-of-plane bending capacity, while anchoring the timber frame to floor diaphragms improves wall-to-floor connection. Moreover, the OSB sheathing nailed to the timber frame increases the shear and flexural strength of masonry piers in their plane. The same paneling system may also be used to stiffen flexible floor diaphragms, improving the overall box behavior of the structure [4].

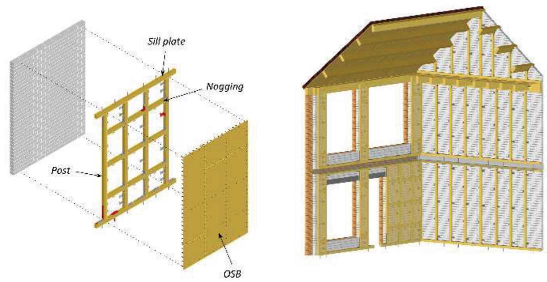

Figure 3 Retrofit with timber-framed walls: overview of the strengthening system—layout, components (left), and application to an existing masonry building (right) [3]

Panel claddings/overlays

This category includes strengthening solutions based on cross-laminated timber (CLT) or laminated veneer lumber (LVL) panels, applied for local or global retrofit of both masonry [5] and RC buildings [6]. In masonry structures, panels are connected to the substrate using a distributed layout of mechanical fasteners to create a composite timber–masonry system (Figure 4). The interaction between the panel and the existing wall is essential for increasing lateral load and deformation capacities. Panel-to-panel connections further improve the system's global behavior [7]. Hybrid configurations that combine thin solid panels with strong-backs have also been explored as a means of optimizing material use in cases of moderate in-plane strength demand.

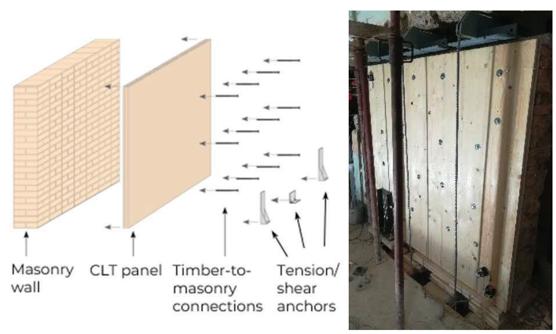

Figure 4 CLT panel retrofit of masonry buildings: components (left) and in-situ testing (right)[11]

When applied to RC buildings with masonry infill walls, panels are connected exclusively to the existing RC frame (without requiring additional foundations) using cylindrical dowel-type connectors placed along the panel edge, which transfer seismic loads from the frame to the panel. Depending on the infill type and the expected frame–infill interaction, different configurations have been developed, including solutions where the infill is preserved, partially removed (e.g., in cavity walls), or completely removed [8]. In the latter cases, the panel is connected to the RC frame through an internal timber subframe inserted within the frame bay (Figure 5).

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Figure 5 CLT panel retrofit of RC buildings: laboratory test [22] (left) and application examples (right)

Endoskeletons

The "Nested Building" concept represents an integrated retrofit solution capable of addressing multiple performance criteria simultaneously. Specifically, it enables: (i) structural strengthening and seismic upgrade, (ii) improvement of energy, thermal-hygrometric, and functional performance, and (iii) preservation of the building's external architectural identity. The system involves the installation of an internal endoskeleton composed of engineered timber elements, primarily CLT panels [9]. The new hybrid timber–masonry structure (Figure 6) strengthens the building through the addition of floor diaphragms and coupled timber–masonry shear walls. CLT floor and roof diaphragms are connected to the existing masonry walls to stabilize them against out-of-plane collapse, while also improving in-plane stiffness and strength through global diaphragm action and localized connectors [10][12].

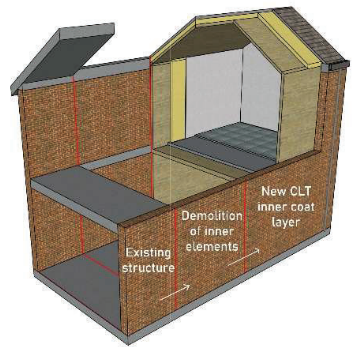

Figure 6 Application scheme of timber endoskeletons on masonry buildings (nested buildings solution) [9]

Exoskeletons

This technique involves the installation of external timber exoskeletons, composed of CLT panels, designed to work in parallel with the existing building (Figure 7). These systems increase both global stiffness and lateral resistance, reduce drift demands, and decrease seismic demands on the existing structural elements [13]. Several structural layouts have been proposed, from simple shear walls and coupled wall systems to shell-type configurations. The latter significantly reduce foundation loads while increasing energy dissipation and stiffness. Critical to performance are the connections between the timber exoskeleton and the existing building (particularly at floor levels), the connection to new foundations, and the joints between adjacent panels. Properly detailed connections can provide energy dissipation and re-centering capacity, which are fundamental for damage-control-oriented design strategies.

Figure 7 Exoskeletons. Integrated retrofit of a residential building: existing building (left); building with structural timber exoskeleton (center); building with structural–energy–architectural envelope (right) [26][27]

3 – TARGET APPLICATIONS

The choice of a timber-based retrofit strategy depends on several factors, including the structural typology, the specific vulnerabilities of the building, architectural constraints, and performance objectives. Each system offers different advantages and application domains, which are briefly described below.

Timber strong-backs

This solution is specifically designed to address out-of-plane failure mechanisms in masonry walls and infill panels. It is particularly suitable for the upper levels of buildings, where dynamic amplification effects are more pronounced. Strong-backs can be applied to the internal face of the wall (a common approach for unreinforced masonry buildings), or to the external face, for example

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when used to stabilize infills in RC frames or to support ventilated façade systems.

Framed wall claddings/overlays

This system was developed for the seismic retrofit of ordinary masonry buildings, which are often vulnerable to local mechanisms such as out-of-plane overturning of walls. These local mechanisms limit the development of global seismic behavior, significantly reducing the structure's overall capacity. Once these local vulnerabilities are mitigated, in-plane shear failure in masonry piers may become the dominant collapse mode, which can be particularly detrimental due to its limited deformation capacity.

Panel claddings/overlays

Panel-based solutions are versatile and can be applied for the integrated retrofit of both masonry buildings and reinforced concrete frames, particularly those constructed in the post-war period. In masonry buildings, the possibility to apply strengthening selectively to the most stressed elements or walls (given that the reinforcement does not alter the elastic response of the masonry) makes the system scalable and adaptable to different levels of seismic hazard and building vulnerability. Depending on whether panels are placed on the internal or external face of the wall, it is possible to optimize load transfer from the floor diaphragms (which may also be strengthened with timber systems) or to ensure panel continuity across multiple floors [14].

In RC frame buildings, timber panels may be applied to a limited number of bays, provided vertical continuity of the retrofit intervention is guaranteed down to the foundation. If necessary, additional measures should be adopted in the remaining bays to limit negative frame–infill interaction effects. To maximize durability and energy performance, the composition of non-structural layers, such as waterproof membranes and thermal insulation, must be adapted to the specific retrofit configuration [15]-[17].

Endoskeletons

The Nested Building approach assumes that interior structural elements, such as floors and partitions, can be demolished and replaced to introduce a new internal skeleton. This scenario typically applies to non-heritage buildings that have undergone previous heavy or invasive modifications (e.g., RC slab replacements or additions), which may have degraded the original seismic performance. The internal CLT skeleton is designed to ensure life safety under design-level earthquakes, even in the case of local masonry collapse. Thermal and energy performance is also improved thanks to the masonry–timber composite walls, which, when properly detailed, reduce thermal losses and increase indoor comfort [9].

Exoskeletons

Timber exoskeletons are particularly suited to the sustainable and integrated rehabilitation [18] of post-war masonry or RC buildings of low architectural value. However, their applicability may be limited by building geometry, irregularities, and size or strength constraints related to the use of CLT panels. This solution has been implemented in collaboration with industrial partners, in the integrated retrofit of a prefabricated RC gymnasium, using a hybrid steel–timber shell exoskeleton [19]-[20], [25], and in a residential building retrofitted with coupled timber wall exoskeletons [26]-[27].

4 – ADVANTAGES AND LIMITATIONS

The effectiveness of timber-based strengthening systems lies not only in their structural performance but also in their adaptability, reversibility, and low environmental impact. Each solution developed within the ReLUIS-DPC framework presents specific advantages and some limitations, as outlined below.

Timber strong-backs

This technique stands out for its very low invasiveness, cost-effectiveness, and ease of installation. Even when applied on the internal face of the wall, it can often be implemented without interrupting building use. Analytical design procedures are available for tailoring the application depending on the specific case [28]. The system is easily compatible with energy-efficiency upgrades and can be integrated with the stiffening of floor diaphragms. However, when applied externally, special attention to detailing is required to ensure adequate durability, particularly against weather exposure.

Framed wall claddings/overlays

This is a lightweight and sustainable solution characterized by short intervention times and low cost. It is primarily designed to increase the out-of-plane strength of masonry walls and to enhance wall-to-floor connections, which promotes the development of a more global seismic response. Additionally, it can increase in-plane shear and flexural capacity of masonry piers. Its effectiveness has been confirmed by experimental [3]-[4],[29] (Figure 8) and numerical studies [30], and a complete analytical design procedure is available in [31], with application examples in [32].

On the downside, the dimensions of the retrofit elements must be scaled according to the thickness and strength of the existing masonry walls, especially when aiming to improve in-plane behavior. Due to its relative flexibility compared to masonry, the system does not prevent the initial formation of cracks, though it limits their propagation and helps distribute damage more uniformly [3].

Panel claddings/overlays

When applied to masonry buildings, panel-based retrofits can lead to significant improvements in mechanical performance, which may be exploited at the panel, wall, or building scale, depending on the retrofit configuration. These systems typically activate after the onset of cracking but help control crack propagation through the action of distributed connectors and delay ultimate failure. They also contribute to out-of-plane stability, due to the bending stiffness of the CLT/LVL panels and their composite interaction with the wall via mechanical connectors. From a construction perspective, transporting and installing the panels inside the building (when required by the configuration) may pose challenges. However, this can be mitigated by shortening the panels, which does not compromise structural effectiveness.

In RC frame buildings with masonry infills, all the tested configurations can be partially prefabricated, often incorporating insulation layers to reduce installation time and cost. The least invasive configuration (retaining the infills) results in notable gains in lateral resistance without altering the initial stiffness. The more invasive configurations (partial or total removal of the infills) offer greater strength and deformation capacity, at the expense of reduced initial stiffness. These performance gains rely on transferring lateral loads from columns to beams, which must have adequate reserve capacity, a condition often found in “strong beam–weak column” configurations.

The efficacy of panel-based strengthening has been demonstrated through full-scale tests [11], [21]-[23] and application case studies [8], [24], with several design methods [33] available. Particular attention to construction detailing is required to ensure adequate durability of timber overlays, especially when the panels are placed on the exterior side of the structural frame.

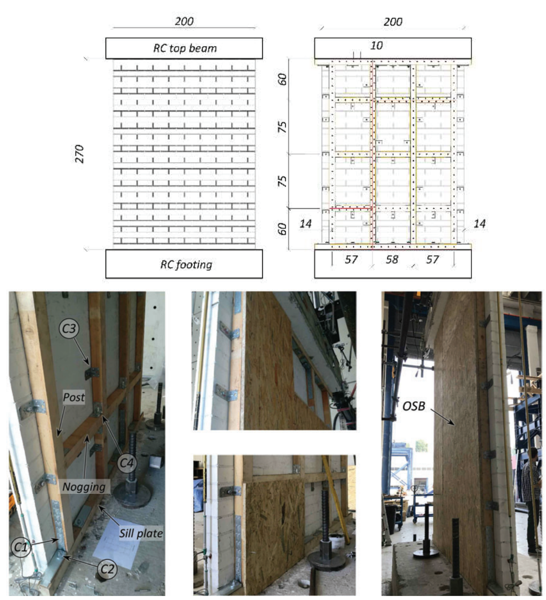

Figure 8 Retrofit with timber-framed walls: geometry and details of the strengthening system [3]

Endoskeletons

This solution supports integrated retrofitting, combining seismic upgrading with thermal and functional improvements using CLT panels. Compared to traditional materials such as reinforced concrete or steel, timber offers greater environmental sustainability [34] while satisfying key retrofit requirements: mechanical and chemical compatibility, reversibility, recognizability, speed of execution, and durability.

The dry-assembled system ensures fast installation, but it often requires demolition of internal elements (e.g., partitions or RC floors), or partial openings in load-bearing walls (e.g., near windows or doors). On the other hand, this demolition can enable new internal layouts and flexible re-use scenarios beyond the constraints of the original structural system. Since external alterations are minimal, this solution is ideal for buildings with heritage or architectural value. However, its design requires custom steel connectors and global assessment of the timber–masonry system, which may not be easily captured by standard design tools.

Exoskeletons

As an externally mounted system, the exoskeleton can often be implemented without displacing building occupants. By calibrating stiffness, strength, energy dissipation, and re-centering capacity, this system can achieve higher performance targets, reducing seismic damage to both structural and non-structural elements throughout the building’s life cycle.

The use of engineered timber materials is advantageous from a life cycle assessment (LCA) perspective (Figure 9). The CLT-based technology also favors dry, prefabricated installation, offering shorter construction times, lower site impact, and flexibility for on-site adjustments (e.g., cuts and openings). The flat surface of the panels supports the integration of insulation and finishes, and may serve as a substrate for balconies or ventilated façades.

A key limitation is the frequent need for new foundation systems, typically made of RC ring-beams and micropiles, especially impactful for systems with vertical shear walls (less so for shell-type configurations). The applicability of this solution is also constrained by geometric regularity: continuous panel placement is difficult in buildings with large openings (e.g., shops, garages, porticoes). In such cases, hybrid steel–timber solutions may be more suitable.

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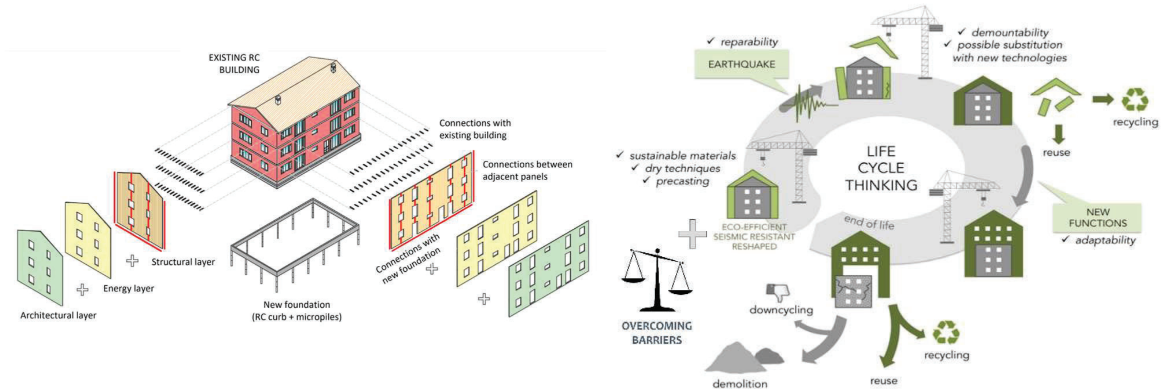

Figure 9 General concept of integrated retrofit with exoskeleton in an LCT perspective (left picture adapted from [35]; right picture from [18];

6 – CONCLUSION

This paper has presented a structured overview of various timber-based strengthening strategies developed within the ReLUIS WP5 research program for the seismic retrofit of masonry and reinforced concrete buildings. The proposed solutions, ranging from internal strong-backs to full exoskeleton systems, offer scalable, sustainable, and often reversible alternatives to conventional techniques. Their versatility allows adaptation to different structural typologies, performance requirements, and architectural constraints. While each system presents specific challenges, the growing availability of engineered wood products, combined with prefabrication and dry-assembly technologies, positions timber as a strategic material for the integrated structural and energy retrofit of existing buildings.

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