USE OF ENGINEERED WOOD FOR THE RETROFITTING OF EXISTING STRUCTURES

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ABSTRACT

Densely populated cities characterize urbanized territories, and most public buildings fail to meet many of the new demands imposed by the pandemic and the modern lifestyle. The need to expand spaces has become imperative, although, at the same time, it is necessary to reduce land consumption and preserve green spaces. If we consider the existing heritage a resource, these problems could represent an opportunity to improve existing structures both from a technological and structural point of view. It is possible to effort a holistic approach by improving the energy impact of new buildings and the heritage seismic behaviour facing the problem in a multidisciplinary way. Starting from the "building on the built" philosophy, this paper presents a possible use of engineered wood, such as cross-laminated timber (CLT), to pursue this strategy. The proposal is the realization of volumetric additions to existing buildings without further land consumption. This type of intervention, mentioned as "parasitic architecture", positively impacts urban regeneration strategies. The use of prefabricated timber components (CLT) endorses the speed of realization, reducing the interferences with the surroundings and improving the healthiness and safety of the environment.
Keywords: parasite architecture, sustainable architecture, structural analysis, cross laminated timber, CLT, engineered wood, pres-lam, life cycle assessment, LCA, footprint.

1 INTRODUCTION

Today the need to expand anthropized spaces is a reality with which is necessary to interact. At the same time, the reduction of soil consumption appears fundamental to preserve green spaces. Within the scenery of possible solutions to the problem, the intervention on existing buildings can represents an opportunity. It could be an occasion both to adequate the seismic response of existing buildings according to current rules (NTC 2018) both to improve their energy impact [1]. The presence of volumetric additions to existing buildings could play the role of renewing the formal, structural, and technological aspects. The loads increasing on the structures requires a deep knowledge of the buildings to better evaluate the new static condition moreover [2]. Even if, for existing building, local reinforcements represent the better solution [3]. It is possible to effort a holistic approach by:

- improving the energy impact of new buildings;
- improving the heritage seismic behaviour;
- saving green space;
- reducing consumption of land;
- facing the problems in a multidisciplinary way [4].

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Starting from the "building on the built" philosophy, there are three types of intervention:

- Parasitical architecture (Fig. 1). New volumes are added onto existing buildings but distinct from the host one both formally and spatially but linked to.
- Rooftop architecture (Fig. 2). Roofs are used as new soils to create a local expansion or to design a complex urban system [5].
- Exoskeleton systems. It can be superimposed on the facades by creating an independent structure on its foundations. It can accommodate new spaces and support possible elevations [6].

Figure 1: Two view of Rucksack House arch. Stefan Eberstadt, 2004.

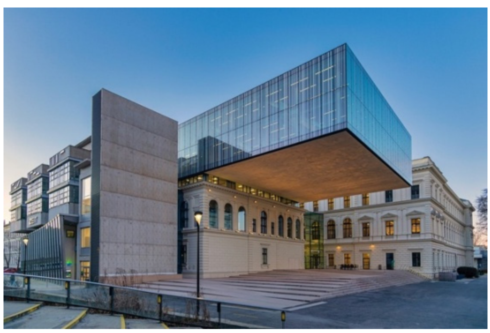

Figure 2: Enlargement of the University of Graz, Atelier Thomas Pucher, 2019.

The proposal of this paper is to investigate all the aspects involved the volumetric additions to existing buildings providing a possible solution to expansion without further land consumption. The most important aspect, according to our point of view, is the challenge of the building material choice which deeply influences both structural and functional aspects of the intervention [3], [7]. From this perspective, the use of wood or its technological evolutions as engineered wood, could be a real way to pursue the holistic approach. The main features of the engineered wood are:

- respect high structural and architectural standards;
- increase energy efficiency;
- increase environmental sustainability;

- speed of installation;
- dry processing.

A brief overview of the authors proposal, is presented in the following section.

2 PARASITE ARCHITECTURE TECHNOLOGIES

"Parasitical Architecture" can represent "building on the built" philosophy for a sustainable urban regeneration. The new added volumes can be realized according to the following schemes (Fig. 3).

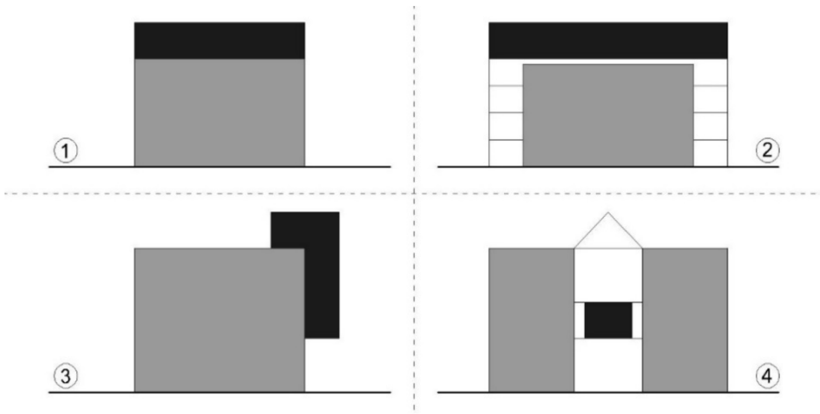

Figure 3: Schemes of parasitic volumes.

The first three schemes represent additions to the existing building while the last one provides a new volume within the space that elapses between two separate structures.. So, without consumption of land, each one creates social and common areas.

In the first scheme the new volume is placed on the roof top and is entirely supported by the existing structures. It is realized with the same characteristics and technologies of the underlying building reproducing its configuration without variations of materials and shape except for the extra height.

In the second scheme, the new volume often named exoskeleton, is completely separated from the original building with independent foundation (Fig. 4). It a self-supporting structure and any load increase is not transferred to the main building.

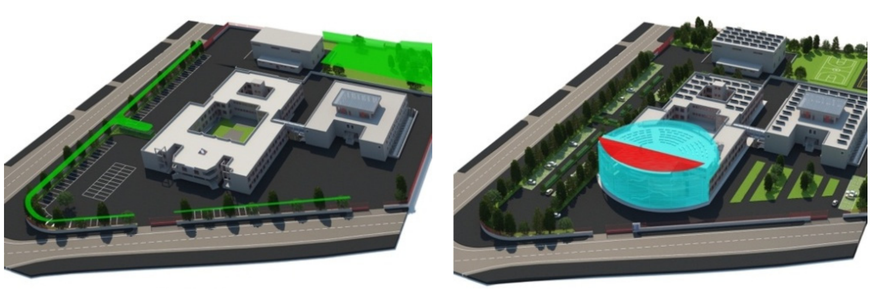

Figure 4: Addition with exoskeleton for A. Volta Institute of Aversa (CE) Italy: Actual state and rendering of the project state [8].

The third scheme best fits the idea of "parasite architecture". It is an addition that can be supported by the facades, the roof tops or both (Figs 5 and 6).

Figure 5: Parasitic volumetric additions in the district "le fornaci" in S. Maria Capua Vetere (CE) Italy: State of fact [9].

Figure 6: Parasitic volumetric additions in the district "le fornaci" in S. Maria Capua Vetere (CE) Italy: Rendering of the project state [9].

They are usually designed as expansions of housing units or to create new common independent areas vertical connected with the original structure.

The last scheme is an "aerial" volume located in the free courts. It provides aero-illuminating ratios without using free areas usable for outdoor activities. It could be a good solution for school buildings with large courtyards. With this solution, schools earn new areas keeping the spaces for outdoor activities unchanged.

Large span beams connected to the internal perimeter walls support the new volumes giving the structural elements of the walkway the role of horizontal links.

The main difficulties that this typological approach could produce are synthetically listed as follow:

- the connection between the new volumes and the existing one;
- the architectural, environmental, social impact of the new volumes on the urban context;
- the evaluation of the real improvement in terms of accessibility, energy efficiency, safety, new services, etc.;
- the addition of new loads on the load-bearing structure could create problems to its foundation system.

It has to be highlighted that if the basic structure is constituted of masonry, some further consideration must be made especially for the scheme 3 and 4. This problem is better exposed in the following paragraph.

3 PARASITE ARCHITECTURE: STRUCTURAL ASPECTS

It is not possible to have complete knowledge of the existing structure only through the determinations of all mechanical parameters that manage it, especially for masonry buildings [10]–[13]. These parameters should be considered together with other information like technologies used at the construction time, structural schemes, and design choices. Any volumetric addition imposes an interaction between new and old. As shown, the new addition can be connected or not to the original building. So, the possible scheme depends on the type of addendum. Schemes 1 and 3 best represent the parasitic dependence of the “host” structure. The new configuration of the building, according to the Italian standard NTC 2018 [14], is subject to global verification mainly due to the load increase on the original structure [15], [16]. The increase in masses, the “new” centre of gravity and of stiffnesses and the “new” shape ratios impose a modification of the seismic behaviour, however. So, the increasing of load-bearing sections for scheme 1 and the eccentric added mass in scheme 3 determine a reasonable modification of the static schemes. The last case requires in-depth assessments of the torsional behaviour of the building, moreover [17], [18]. An example of eccentric volumetric addition, or simply scheme 3, is shown in Figs 7 and 8. This new volume is built off-site and added by tie rods and bolts to the R/C base structure. If the base structure is a masonry one, it must be reinforced at the contact points [19], [20]. In any case, a local verification is required for the anchors. Fig. 9 shows the two possible solutions:

- on the two facades of a linear building;
- on the facades of an internal courtyard.

Scheme 2 (exoskeleton) is an independent structure from the existing one. Even if the new addition could share the foundation of the old structure. It is also important to consider the soil–structure interaction (SSI) [21], [22]. This case has similar structural problems of schemes 1 and 3, even if the addendum does not completely depend on the base structure. This problem could represent a possibility to reinforce the existing building (Fig. 9) by acting as an active element in the structural retrofit strategy [23]. The adaptive exoskeleton system [24] is an example of this intervention strategy (Fig. 10). It can be viewed as a device that improves the structure’s initial characteristics.

When the addendum is completely independent from the original building, the real challenge is keeping independence unchanged over time. The distance between the

Figure 7: Render of a parasitic volumetric additions of type 3.

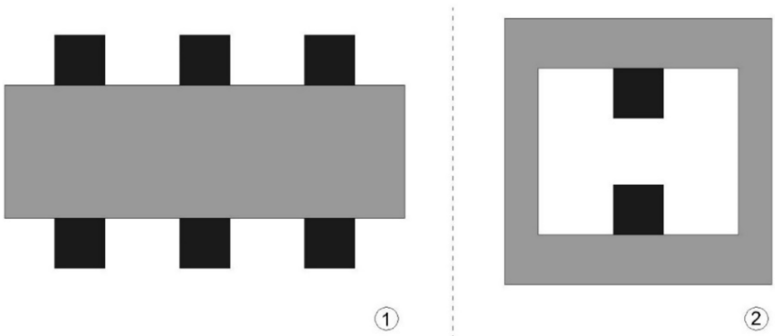

Figure 8: Parasitic volumetric additions of scheme 3: possible layout in plan (1) linear building, (2) courtyard building.

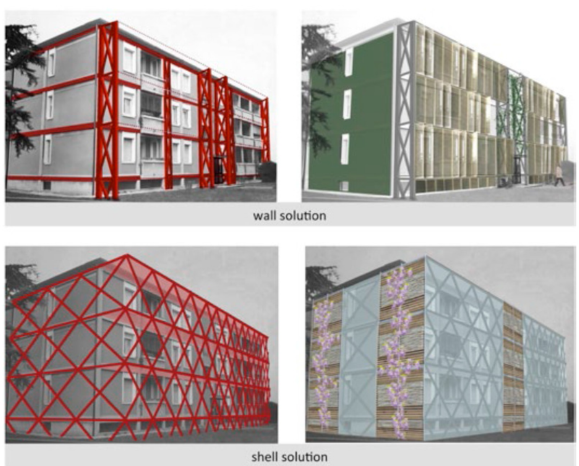

Figure 9: Two retrofit solutions with adaptive exoskeleton [23].

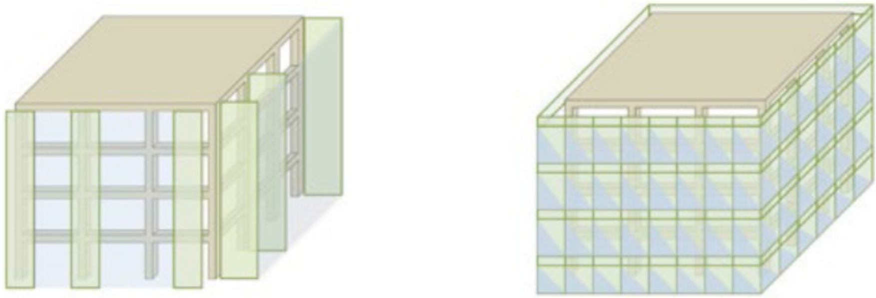

Figure 10: Two retrofit solutions with added seismic-resistant elements [24].

foundations of the two structures must be adequate to avoid that the structures interact during an earthquake. The design of the seismic joints is a mandatory [25]. The construction of suitable structures to climb over the original one meets some difficulties. The new structure has to guarantee compliance with the requirements and their maintenance over time.

Large decks impose the improvement of stiffness of the floors. Adequate qualities of translating bi-directional stiffness and resistance as well as torsional stiffness qualities could be achieved by the best plan position of concentric bracing [26].

One other problem is represented by pillars that weigh on the beams of the over structures. So, the "floating column" behaviour imposes an in-depth analysis that considers:

- the effects of the vertical component of the seismic action;
- the punching problem;
- the torsional effects additional.

Villa Fiorita Clinic located in Aversa [27] is an example of addendum with an independent structure (Figs 11 and 12). There is no interaction between the new and old which is completely covered and incorporated by the new. In case of earthquake the interactions between the buildings is reduced by dissipation devices which allows to limit the displacement of the addendum. The concentric bracing with active diagonals allows to have an earthquake-resistant structure and the perform the dissipative function (Figs 13 and 14).

Figure 11: Villa Fiorita Clinic: State of fact [27].

Figure 12: Villa Fiorita Clinic: Project state [27].

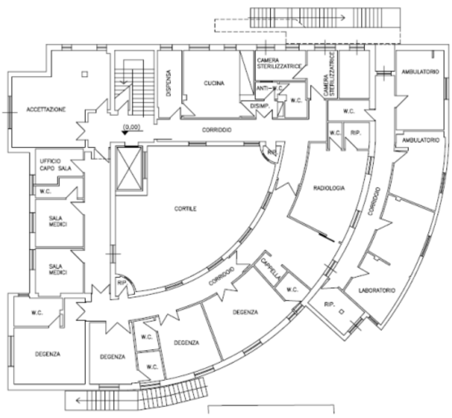

Figure 13: Villa Fiorita Clinic: Original plan view [27].

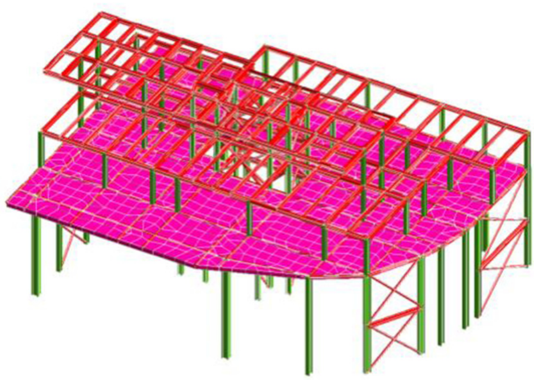

Figure 14: Villa Fiorita Clinic: Structural model of the added structure [27].

Scheme 4, the last one, is the most complex scheme due to the difficulties to establish the new connections to the existing structure. Moreover, the structural elements, which impose horizontal actions, need major attention.

This concise overview reveals that schemes 2 and 4 can be used to improve the structural performances and to increase the seismic capacity of the building. To significantly reduce post-event repair costs [28], or simply to apply the "low-damage" strategies, the schemes proposed use dissipative elements and systems which let obtain the increasing of the seismic capacity and limit post-event damage. A way to achieve the goals proposed is the use of wood [29], [30]. The problems related to the anisotropy of raw material has been overcame by technological innovations that give birth to the engineered wood that can fully be used as a valid alternative of the most commonly structural materials [11], [31]–[33]. The use of wood could create smart and sustainable buildings with the volumetric additions without soil consumption.

Another possible solution is the pres-lam system [34] created for seismic-resilient and sustainable structures [35]. This patented technology is based on the use of, glulam and/or CLT (cross-laminated timber) that are prestressing by a post-tensioning system on-site using sliding cables and tensioning equipment.

The dissipative characteristics of these structures made with this technology are investigated by several authors [36]–[38]. Also, the dissipative effects due to the insertion of rocking elements inside existing structures [39]–[43], or the presence of metal connections for reinforcement interventions in its plane with CLT panels [44] or off-plan [45] are investigated. There is a common trend in the in field research groups that investigate the possible use of this elements for exoskeletons or endoskeletons on existing masonry buildings [46], [47].

The use of engineered wood, like, CLT panels, allows a holistic approach for the Eco Architectural Renovation, not only in energy and seismic terms but also as a low impact during the construction phases. The use of these elements, substantially executed off-site, allows:

- faster installation;
- the precisely establishment of the times;
- the clear identification of the areas involved in the construction and assembly phases;
- above all, the original building could keep its activities without interruption.

Moreover, the use of wood let to strongly reduce the production of CO_2, using wood as building material imposes the management of forest that encourage the growth of new trees. The wood used to realize the CLT panels keep storing di CO_2. To this amount we can add the amount saved choosing wood rather than another building material. The life cycle assessment related to wood allows to achieve low CO_2 footprint intervention according to eco-architecture and same goals proposed in agenda 2030.

4 CONCLUSIONS

The use of engineered wood like CLT and pres-lam, assembled with innovative "off-site" technologies, let the realization of volumetric addition without further free soil consumption. Moreover, prefabricated elements allow rapid interventions even in densely populated urban areas. This reduces the interference with the surrounding as a safety advantage. The parasite architecture concept fits the "resilient thinking" transforming the need to expand the spaces as an opportunity to improve the energy impact and structural performance of the existing heritage, with a great multidisciplinary approach and with low CO_2 footprint. Two ways are identified:

- the advantage of a lower regulatory burden adopting the added independent of the base building;
- the improvement of seismic characteristics of the base building where additions become one with it.

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