Sustainability in the strengthening process of the load-bearing historical structures

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Abstract. Preservation of the load-bearing historical structures represents a common research topic nowadays, as it stands a provocative and difficult task. At the same time, sustainability represents a concept of high interest in the light of recent climate change events, a concept that has become a responsibility in the past years. Safeguarding of the historical buildings with heritage value is an obligation of society to be able to pass on to future generations the historical cultural value of the buildings and the traditional construction techniques on which they were built. Nowadays, many historical buildings are consolidated with modern reversible materials and technologies, without attempting a sustainable consolidation with local traditional materials using the original building techniques and local building materials, which have already proved their effectiveness in the past. This article presents the sustainable consolidation methods proposed to consolidate the historic building of the Villa Abbatis guesthouse in the village of Apos, Sibiu County, Romania. The proposed consolidation techniques use bricks that are manufactured according to traditional method in a recently built brickworks and reuse existing building materials in the building and from abandoned buildings after the departure of ethnic Germans from Romania until 1990. The aim of this paper is to highlight the value of the traditional materials and technologies, that can bring in the retrofitting process not only the assurance of the bearing capacity, but also the preservation of the authenticity and sustainability of the entire process, in a holistic approach.

1 Introduction

Traditional architecture and technologies represent one of the most valuable asset that was inherited from the past period, offering a continuity for the tradition and identity of the local communities. The cultural value of a building or of a complex of buildings stands not only in their age, architectural style, artistic assets and others, but also in the authenticity and spirit

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of place, or in the particularity of a material or building technique that is specific to an area or a period of time.

That is also the case of Apos village, which is located in Romania, Sibiu County, on the Hartibaciului valley, in the central area of Transylvania. Apos corresponds to the area of villages with fortified churches in Transylvania, the cradle of Saxon culture in Romania, where traditionally practices and vernacular architecture are still preserved.

Nowadays, in the area that surrounds Apos village, there are several small-scale industrial activities, production workshops and nature tourism, as well as teaching workshops (Fig. 1) [2]. The main attraction of the area are the fortified churches, some of which are UNESCO World Heritage Sites, but also the production workshops based on natural and traditional building materials, such as the case of the small traditional tile factory in Apos. This small factory was founded with the support of the His Royal Highness, the Prince of Wales [3], Anglo Romanian Trust for Traditional Architecture, Global Heritage Fund and Mioritics Association and represents an important support for the local community and the preservation of the authenticity and spirit of place in Apos [1].

Fig. 1. Tiles in Apos village.

2 Sustainability in the strengthening process

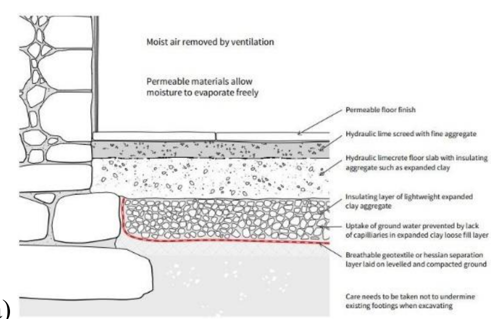
Climate emergency has been a rising issue of the world in the past decades, the built environment being accountable for approximately 40 percent of all greenhouse gas emissions. As a response, all countries are called to adopt or devise new sustainable approaches to manage the changes to the built environment. Prioritizing the retention, conservation, and refurbishment of historic buildings along with the enhancement of their energy and carbon performance will significantly increase the life span of many constructions and reduce the demand on the national energy supply system when carried out as part of a large-scale movement.

Before taking any steps towards enhancing the thermal performance of a historic building it is paramount to thoroughly evaluate its structural integrity and the makeup of its components. The attempt to improve the thermal performance of a historic building is often accompanied by risks like condensation which can give rise to mold formation, accelerate fabric decay and have a detrimental effect on the health of future occupants. The use of materials with hygroscopic proprieties represents a common practice when endeavouring to thermally upgrade but many other factors like heating regimes, orientation and exposure need to be factored in before determining the optimum solution [4].

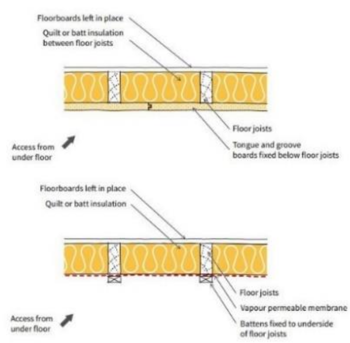
Some solutions that can be used on historical buildings are:

1. Slabs and floors - In traditional buildings solid floors were generally laid directly on the earth, permeable fills, or mortars, presenting no impervious membranes in

their build- up. Such floors have the ability to absorb the moisture and evaporate it when the humidity levels decrease, without causing any harm to other materials. When solid floors require general replacement (like ours), the integration of low-pressure heat under floor heating represents a popular practice when trying to limit the heat loss (Fig. 2a). However, such systems will increase the difference between the floor's temperature and the ground below so the integration of a permeable insulation layer below the heating system should be carried out as part of the installation. Permeability is key, so using a mix of hydraulic lime binders and insulating aggregates will have a beneficial effect since they absorb and release moisture. The integration of an underfloor heating system is not a compulsory measure [5]. Timber has been used for centuries to form intermediate floors. They generally do not require to be drought proofed or insulated if the areas above and below are heated. However, the approach changes when we are dealing with an unheated space below, the temperature contrast imposing the installation of an insulation layer. Furthermore, the lifespan of a suspended timber floor is directly influenced by the effectiveness of ventilation to the void below (Fig. 2b). Therefore, the use of air bricks and other types of vents is highly recommended. In buildings with basements or cellars the tight-fitting installation of insulation in form of batts or boards between the joists is recommended since breaks in the insulation layer will allow air movement, heat loss and promote interstitial condensation. The removal of the floorboards is not necessary in this scenario. In those places/areas where the insulation is near damp walls, the best protective measure against moisture transfer is the building paper. The integration of a continuous, low vapour resistance membrane to the underside face of the joists will also keep the insulating batts in place. Alternatively, the insulation can be held in place with tongue and grooved wood-fibre boards which will ensure a good airtight seal [6].



a)



b)

Fig. 2. Recommended solutions for slabs and floors in historical buildings: a) solid floors; b) suspended or intermediate floors.

2. Solid walls - It is important to acknowledge that moisture is not arising from a singular source. It can originate from the ground, external precipitations, or be a product of the dwellers' daily activities. Materials used to fix and maintain these walls must be selected with care to preserve their permeability. Therefore, the use of impermeable membranes, cement-based renders and plastic paints or coating, vinyl wallpapers or closed cell insulation should be avoided at all costs to prevent the exacerbation of already existing issues. Another important factor that needs to be taken into consideration when altering an external wall is building's orientation. As an example, north facing walls should be treated differently to the south-

westerly ones since they are prone to a longer exposure to damp. If a wall is subjected to prolonged damp, then a vast array of issues can occur such as deterioration of the external treatment, growth of mould on the internal face of the walls, migration of salts, tars and other chemicals which can in turn cause staining of the surface, etc. Whenever insulation is installed to an existing fabric, there is a high chance of thermal bridging occurrence around junctions like those close to windows, door reveals, eaves or floors (Fig. 3) [7].

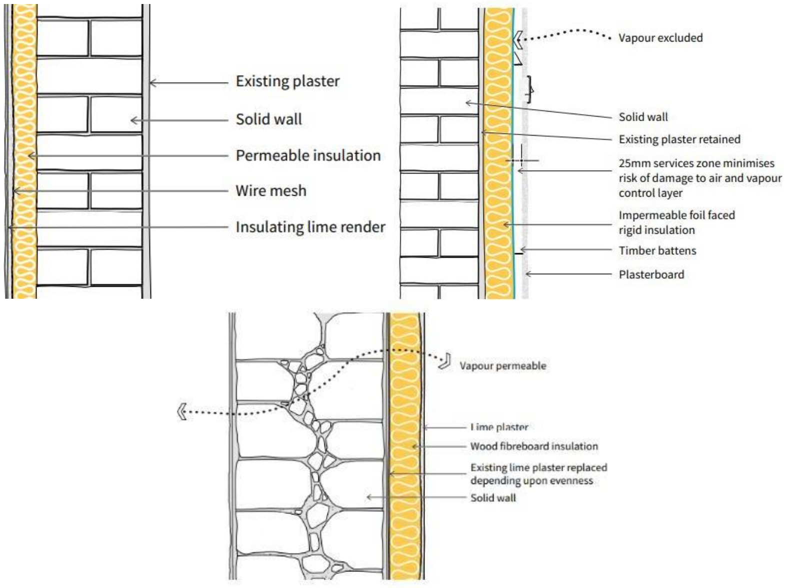


Fig. 3. Recommended solutions for walls in historical buildings.

3 Case study of the Parish House in Apos

The case study building is located in Apos village and was the Parish House of the Evangelical Church in the village. The complex of church, bell tower and parish house are considered as regional monumental site, with the code SB-II-a-B-12313 on the List of Historical Monuments of Romania.

The villages in the basin of Hirtibaciului Valley are mainly of medieval origin, with a central point which is formed by the school and the church, which are often located on higher ground and fortified with a defence wall.

The church complex is located at the north-eastern end of the settlement, strategically placed at height within the village. In the north-western part of the Evangelical Church complex of Apos was the parish house, which was a replica of the peasant house, only larger and more complex. The entire complex is illustrated in Fig. 4 [8].

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Fig. 4. Plan of the Evangelical Church Complex in Apos village: 1. Evangelical Church; 2. School; 3. Mayor's house; 4. Teacher's house; 5. Evangelical community hall; 6. Parish house.

4 Architectural and Structural Description

The parish house had eight rooms, some of which were considerably larger than the rooms of the Saxon houses, so the imposing dwelling, with a gable and tiled roof, was by far the largest residential building in the village. Its location was very favourable, in the vicinity of the school, the community hall, as well as the mayor's and the teacher's house, thus in a location that was the visual and functional centre of the settlement. Also, it was the first inhabited building made of stone and brick masonry. That is why, the size, execution and location of the parish house were an expression of the high status that the priest had in the local community [8].

It is not possible to determine exactly when the house was built, as it is the results of successive alterations and extensions. A possible stage of the development of the house is the year of 1840, when two east rooms were probably added to the oldest part of the parish house, while the south room later served as an office. An extensive renovation of the house took place in 1912, when the old wooden beam ceiling was replaced with stucco ceilings, and the floors, interior and exterior woodwork were replaced, the entire building was painted, both inside and out. In the years after the Second World War, several repairs were carried out, such as reparations of the roof, repainting of the windows and doors, replacement of the old wooden beams by vaults in the cellar, most of the work being done by voluntary involvement of the local community members, showing the importance of the parish house for them. The parish house was not only the largest residential building in the village of Apos, but also an impressive building in terms of aesthetics. Two of the facades, the one facing the main street and the one facing the church, were remarkable for their rich decorations, with cornice and frieze area heavily decorated, and also with a beltline visually delimitating the façade registers, made of stucco, between the ground floor and the basement area. Moreover, six ornamental columns were placed on the transversal façade, while on the longitudinal façade there were nine columns facing the public space, as presented in Fig. 5. The building was used as a residence for the priest and his family and as a parish office until 1988, when due to the low number of community members, the last priest of Apos left, and the parish house wasn't used anymore [9].

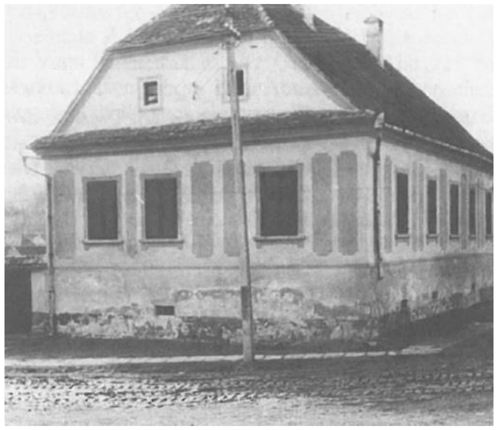
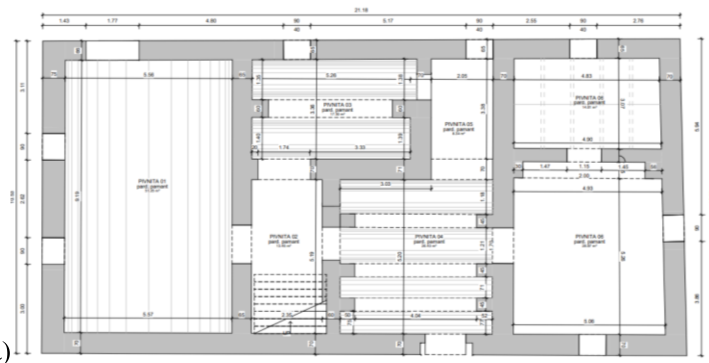


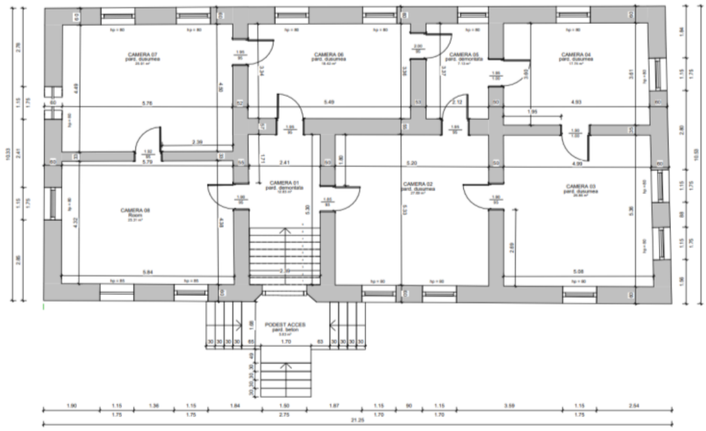
Fig. 5. Parish house – historical picture.

From a geometrical point of view, the building has a rectangular plan, with a 21 meters longitudinal dimension and 10.35 meters transversal dimension and has a basement and a ground floor. The thickness of the basement walls is 60-70 centimetres, while of the ground floor walls is 50-60 centimetres (Fig. 6). The height of the façade is 3.65 meters, while the total height of the house at the tallest point of the pitched roof is 8.97 meters (Fig. 7).

The load-bearing structure of the building is made in masonry made of brick and stone, with continuous foundations under the walls made in brick and stone masonry. The horizontal structural elements are wooden floors and brick vaults over the basement (Fig. 8a). The spatial connection between the walls is provided by metal tie rods, located also in arches (Fig. 8b), while the roof is pithed, with wooden framework (Fig. 9). The masonry arches and vaults are interventions for the consolidation of the existing building, that were made in 1955 [9].

a)





b)

Fig. 6. Parish House: a) basement plan; b) ground floor plan.

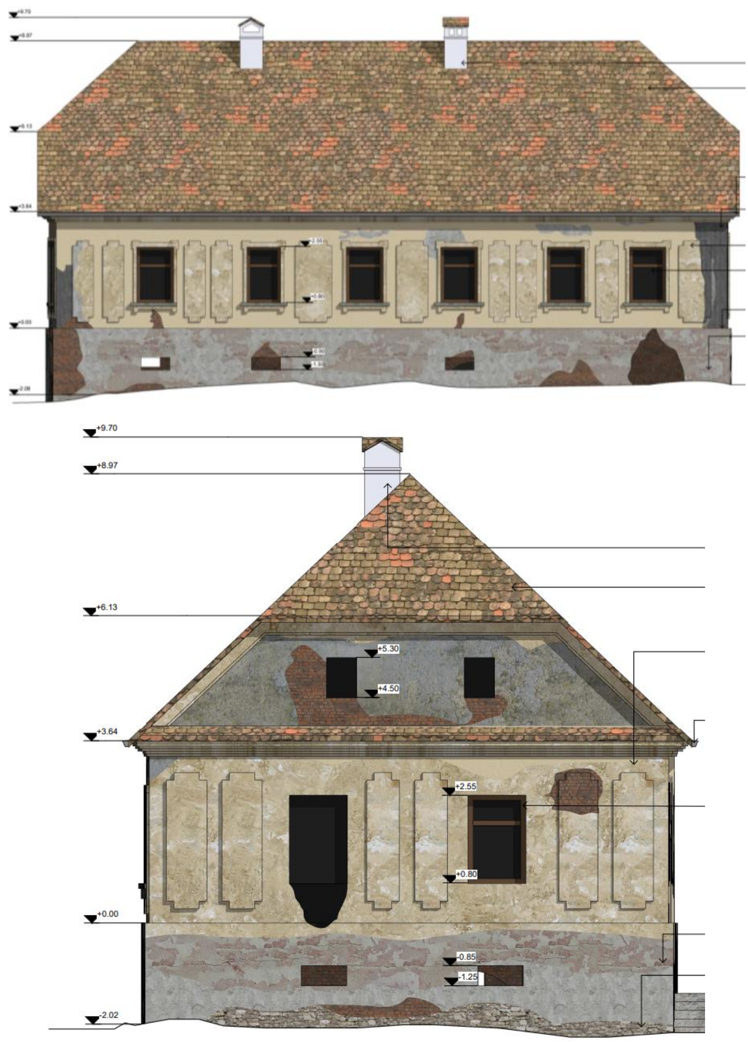


Fig. 7. Parish house – main and lateral façade.

a)  b) 

Fig. 8. Parish house: a) brick vaults over the basement; b) tie rods.

Fig. 9. Parish house – wooden framework.

5 Decay and structural damage

Although the building is located close to the Vrancea seismic zone in Romania, which is the most important seismic area in the country and is characterized by a PGA=0.20g [10], the building has recorded the most important structural damage due to the lack of maintenance over time caused by the departure of German ethnic Catholics from Romania since the 1970s.

The causes of the damages that were observed at the load-bearing structure are the following:

1. Lack of gutters and downspouts caused rainwater infiltration at the foundations, which reduced the bearing capacity of the foundation soil and caused differential settlement of the foundations (Fig. 10). This subsidence also caused damage to the brick basement arches and vaults (Fig. 11).
2. Unauthorized non-compliant interventions on the foundations. Over time, attempts were made to excavate the earth from the basement to increase the height of the basement in the area of the brick arches and vaults. Because the intervention technology was wrong, damage and subsidence occurred in the foundations, arches and vaults (Fig. 12).
3. The destruction of the tile of the roof allowed the infiltration of precipitation water, which caused physical degradation of the wood in the roof framework and wooden floor slabs. Due to the humidity, the wood rotted, reduced its cross-section, which resulted in the reduction of the load-bearing capacity of the

beams, the reduction of stiffness and the destruction of the joints. In Fig. 13a there can be seen the deformed wooden beams of the floor over the basement and in Fig. 13b the cracked wooden beams.

4. Moisture in the walls has caused rotting of the wooden beam ends in the walls and in the rafters.
5. Unauthorised break-ins and vandalism have increased the structural damage to the load-bearing masonry walls.
6. Due to differential settlement of the foundations, cracks have appeared in the joints between the walls, in the lintels and in the windows parapets.

Fig. 10. Rainwater infiltration that led to the differential settlement of the foundations.

Fig. 11. Damage to the basement masonry arches and vaults.

Fig. 12. Excavation of the earth from the basement.

a) b)

Fig. 13. Damage to the wooden elements: a) basement wooden beams; b) broken beam at the wooden floor.

6 Consolidation Proposal

The proposed strengthening solutions of the load-bearing structure are sustainable, using local materials: wood reused from the demolition of other abandoned buildings, stone and bricks reused from other demolished buildings or new bricks produced by the local kiln, local clay used for rebuilding the masonry with mortar according to local traditional recipes and metal rods reused from demolished buildings with similar characteristics. The consolidation technologies have been chosen so that they comply with the requirements for the restoration of historic buildings imposed by the Venice Charter [11]. Consolidation solutions aim to restore the original load-bearing capacity of the building and respect the principle of sustainability of the interventions, and they consist of:

1. Extension of the foundation dimensions with stone from local quarries, or stone and brick recovered from other demolished buildings (Fig. 14).
2. Restoring the continuity of masonry by removing and rebuilding load-bearing walls with locally produced brick (Fig. 14)
3. Reinforcement of the arches and vaults of the basement by restoring the compressive forces by introducing oak wood panels that are beaten from bottom to top (Fig. 15). The joints between the bricks will be filled with clay mortar according to the local recipe.
4. Tensioning the existing metal tie rods in the masonry by the traditional method of heating and beating. Other metal rods, reused from demolished houses or houses in an advanced state of decay, will be introduced.

5. Re-jointing of the wooden elements of the roof framework and slabs with nails made of local wood.
6. Removal and reinforcement of wooden lintels from doors and windows with other wooden beams, obtained from demolished houses or with wood from local production.
7. Reinforcement of the slabs by reinforcing beams with wooden beams from the demolition of other houses or wood from local production. The beams whose deformation exceeds the maximum allowed limit will be rotated on the same position by 90 degrees and will be reinforced with wooden elements fixed on both sides. Where possible, additional beams reused from other buildings will be introduced.
8. Increasing the stiffness of the slabs in the horizontal plane, by placing reused planks from other buildings, or planks of local material, fixed diagonally at an angle of 45 degrees on both sides of the beams or introducing laths resulting from demolition of the roofs in diagonal direction between the existing wooden beams.
9. Degraded areas of wooden beams from the framework shall be replaced or reinforced with local wooden materials or wood from the demolition of other beams, without discarding the entire degraded element. To increase the load-bearing capacity and stiffness, the wooden beams at the bottom of the trusses and the trusses can be reinforced with wooden joists placed on one side, on both sides or additional intermediate trusses can be introduced from reused beams or new wooden beams. The rotted ends of the rafters should be reinforced with two beams fixed by the rafters. To increase the stiffness of the roof framework, diagonal wooden braces or cables fixed to the inside face of the rafters should be inserted.
10. The masonry lateral blind walls of the building will be fixed to the rigid wooden framework by tensioning the existing tie rods and inserting additional metal rods to fix the masonry to the posts and rafters.
11. The wooden beams at the eaves will be fixed to the brickwork by plat bands resulting from the tie rods of the buildings. These pieces of metal from broken tie rods from other buildings will be inserted vertically into holes drilled in the existing masonry and fixed into the walls with hydraulic mortar. The wooden beams will be fixed by these reused metal pieces.
12. The chimneys will be rebuilt identically with new or reused bricks and clay mortar according to the traditional recipe.

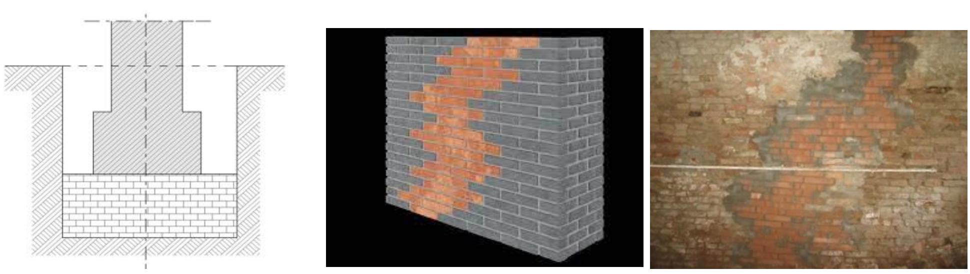


Fig. 14. Interventions at the foundations, by extending the existing dimensions.; Removing and rebuilding the masonry with *cuci e scucci* technique.

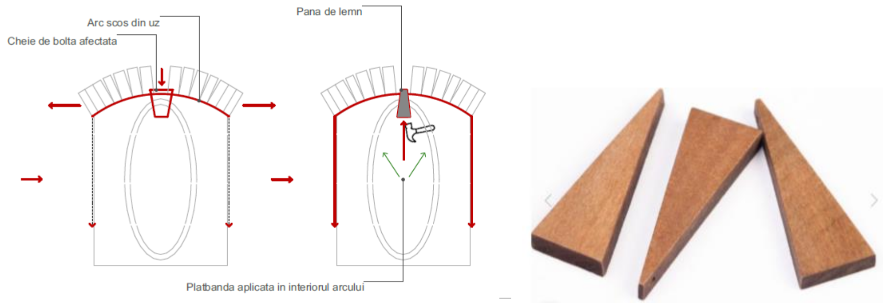


Fig. 15. Interventions at the masonry arches and vaults with wood panels beaten from bottom to top.

7 Conclusion

The paper presents solutions for restoring the load-bearing capacity of an abandoned building of historical value using traditional and sustainable strengthening methods and technologies. The case study is a good demonstration that with minimal investment in the use of local materials, the local community can reuse and save abandoned historic buildings with minimal financial efforts, while protecting the environment. The case study shows how to intervene on the Parish house building through a holistic, sustainable, prudent approach that can be used for other similar buildings in this area or in similar areas in Europe.

Acknowledgments

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