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Environmental sustainability of the retrofitting of a vernacular dwelling in the Liguria seaside

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Abstract. In the Genova hinterland, a traditional rural dwelling has been completely restored with the addition of new buildings respecting the landscape and the relationship with the existing vernacular construction. The project, in compliance with all the bio-architecture criteria of intervention associates traditional natural materials such as stone and lime with cutting-edge materials and techniques such as raw earth and hempcrete.
Both the recovery and the new buildings have been the subject of meticulous bio-design in terms of material choices and diversification of construction techniques according to the area of intervention and of the local material culture. The original stone walls have been preserved and consolidated with fibre-reinforced lime mortar applied directly on the stone wall after removing the old mortar. Timber beams and wooden floors have been almost completely renovated, but preserving and consolidating wherever possible the original structures. External walls have been re-plastered with thermo-plaster based on lime and diatomite. On the interior, a hemp lime mortar has been used.
Environmental sustainability of the whole retrofitting has been assessed by using the Life Cycle Assessment (LCA) methodology in compliance with the international ISO standards 14040 and 14044. The scenario is from cradle to construction, i.e. A1-A5 in terms of European directive EN 15804. The study is fully compliant with this directive in terms of impact indicators and additional benefits.

1. Introduction

Saving raw materials and natural resources as well as recycling materials, in compliance with one of the paradigms of circular economy, is certainly one of the most effective strategies to sustainable buildings and architecture [1]. In the same perspective, retrofitting of vernacular dwellings instead of demolition and reconstruction represents an effective way to implement sustainable policies in the building sector [2]. In addition, if the materials used in the retrofitting are low impact the beneficial effects are even higher, and Life Cycle Assessment (LCA) is the suitable tool to evaluate environmental performances [3]. Indeed, it is a standardized methodology [4] [5], worldwide accepted in the building and construction sector, as demonstrated by EN standards that regulate its application in this specific field [6] [7].

Recently, in the scientific literature LCA studies of natural building materials have appeared [8] [9] and of recycled materials used in rammed earth [10]. However, environmental assessments of building retrofitting based on natural materials are still very scarce in the present literature [11].

The case study hereafter illustrated is just the application of the above mentioned good sustainable practices: (1) retrofitting of a rural house, recovering wherever possible the old building structures; (2) use of natural and local materials in the respect of the cultural heritage and local vernacular tradition [12].

Environmental sustainability of the whole retrofitting has been assessed by using the Life Cycle Assessment (LCA) methodology in compliance with the international ISO standards 14040 and 14044 [4] [5]. The scenario is from cradle to construction, i.e. A1-A5 in terms of European directive EN 15978 [6]. The study is fully compliant with this directive in terms of impact indicators and additional benefits.

2. Case study: “Villa degli Ulivi” [12]

2.1. Green design strategies

“Villa degli Ulivi” is a traditional rural dwelling located in the Genova hinterland, near the seaside. The building was not inhabited since long time and in very poor conditions before starting the retrofitting. The original building was partially preserved, and a new body was erected (Figure 1).

Both the recovery and the new buildings have been the subject of meticulous planning as for the choice of green materials as well as for diversification of construction techniques, according to the area of intervention and the local material culture. The existing building has favoured the maintenance of the stone wall mass with interventions of consolidation in fibre-reinforced hydraulic lime mortar applied directly on the stone masonry equipment, after old plaster removal.

The wooden floors were subject to different interventions through the replacement of beams starting from the ones recovered, flanking of new joists or total reconstruction of wooden floors if necessary. All the inter-floor slabs were subject to consolidation. The roof was completely redone in the respect of the traditional local material culture in the choice of the wooden structures and the slate roof covering (Figure 2).

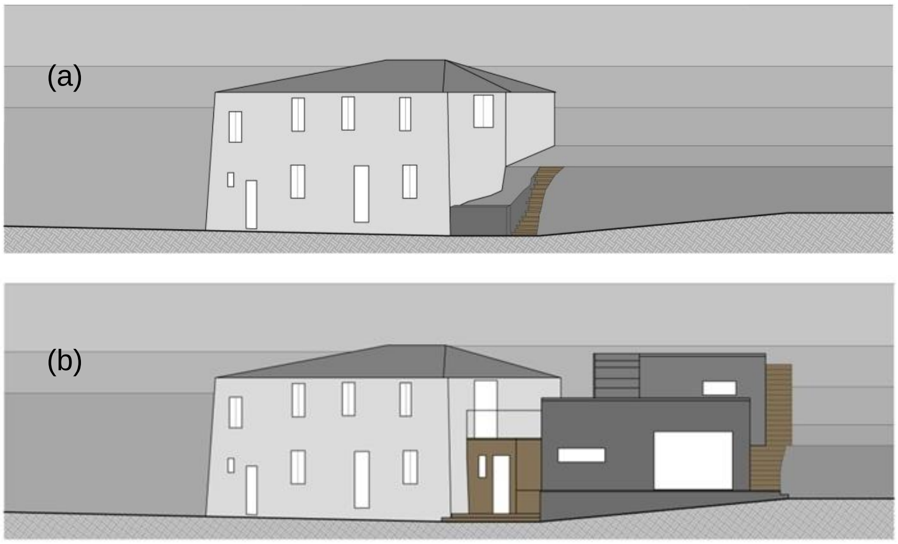

Figure 1. Schematic view of “Villa degli Ulivi” before (a) and after (b) the retrofitting.

The renovation of the roofing (Figure 2) allowed the insertion of the necessary thermal insulation realized through hemp fibre mats, the juxtaposition of water-repellent membranes to improve water tightness and a detachment of the roof covering, to improve summer conditions. The entire casing has been re-plastered with thermo lime-based plasters and diatonite on the outer part of the exterior walls and thermally enhanced plasters on the inner side, exploiting fine hemp fibres. The façade, instead of being white painted, has the natural white lime colour with chromatic nuances suggested by the colour of the sands the finishing mortars are made of. In this way it is the material itself that dialogues with the context and not a veil of paint that masks it (Figure 3).

Figure 2. Detail of the roof with slate tiles.

Figure 3. Part of the external façade with natural white lime mortar.

2.2. Earthen materials

In the coverings of the bathrooms on the first floor the combination of lime and *cocciopesto* is repeated; final wax treatments and Moroccan black soaps guarantee the water repellence of the walls.

The ceilings of the rooms used for services and the ceiling of the kitchen-living room of the new body are made with dough and innovative raw earth materials to accentuate the hygrometric regulation of these environments that generate water vapour. The indoor micro-environment in some rooms is controlled through clay-based body plasters with earth-plaster finishing painted with lime; in other cases the body plaster and the brown earth finishes follow the waving shape of the ceiling of a bathroom obtained through ribs and mats of marsh reeds.

2.3. New building

The new body of the dwelling has been integrated into the terracing of the landscape by creating a façade with the local slate (Figure 4). This exterior covering is only the last layer of an articulated stratigraphy that proposes a clad insulation in cork panels, then facade protection panels anchored directly to the masonry. The inner side of the masonry is completed with plaster and raw earth finishes that wrap all the rooms following linear shapes in the rooms or organic forms like those in the living room.

Figure 4. New body of "Villa degli ulivi" with external façade in local stones.

The thick earth plaster on the one hand guarantees the necessary thermal inertia and the specific hygrometric regulation, but at the same time it has also a symbolic function, which reminds the excavations scratched in the mother earth to obtain the appropriate spaces for the new volumes. The geology of these terraces presents, in fact, an alternation of clayey lands and slate veins, all covered with vegetable soil, that vegetable soil which in suitable mixtures is re-proposed for garden roofs.

In the new body the raw earth is chosen in its lightest ochre colours to offer brightness and contrasting with the red of the handmade terracotta tiles of the floors that also in this case give continuity to the various rooms through rounded shapes in the curved staircase and, in smaller sizes, in other smaller rooms.

The red-pink colour of the hazelnut terracotta flooring is also proposed in the *cocciopesto* coverings. The critical points of the few walls against the ground in the living quarters, the counter-rock crawl spaces and the ground connections of the natural insulators are solved with waterproof cellular glass materials properly installed and sealed.

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3. LCA methodology

3.1. Goal and Scope

The aim of this study was to assess from an environmental perspective the retrofitting of a vernacular house using traditional materials typical of the rural region where the building is located, to be eventually compared with other retrofitting interventions conducted in a more traditional approach.

Consistently, the environmental burden of the retrofitting has been analysed with the LCA methodology, as defined by the ISO standards 14040 [4] and 14044 [5]. Moreover, at the building level the reference standard EN 15978 [6] specifies the stages to be considered in the assessment. In the present work, only the product (A1-A3) and construction stages are included, and to be precise of the construction stage only the A5 phase has been considered, while the transports to the construction site in this preliminary analysis have been discarded.

The functional unit was the renovated "Villa degli Ulivi". The house has a gross floor area of 250 m^2: 156 m^2 (old building) and 94 m^2 (new building).

The impact assessment methodology adopted is based on the CML methodology as requested by the standard [6]. In particular the impact categories here presented are:

- Global warming measured in kg CO2 eq. (GWP);
- Depletion of the stratospheric ozone layer measured in kg CFC11 eq. (ODP);
- Formation of tropospheric ozone photochemical oxidants measured in kg ethylene eq. (POCP);
- Acidification of land and water measured in kg SO2 eq. (AP);
- Eutrophication measured in kg PO43- eq. (EP);
- Abiotic depletion for non-fossil resources measured in kg Sb eq. (ADP);
- Abiotic depletion for fossil resources measured in MJ (ADP, Fossil fuel).

Moreover, whenever available, Environmental Product Declarations (EPDs) of specific materials were used as data source for the LCA; the remaining data were taken from the Ecoinvent 3.4 database. The LCA calculations were performed with the software SimaPro 8.5. For rammed earth and hempcrete, instead, data developed by the authors in previous works were adopted [8] [9].

3.2. Life Cycle Inventory

The data collection was classified per building element as detailed in Tables 1 and 2, for new and restoration interventions, respectively. Details about surface areas and weight of the new building materials used in the interventions are reported in the tables. Source of data was the executive design, then the study can be considered at the design stage. However, the effective use of materials during the construction has been checked. Apart from some stealing (copper elements) that required material replacement (and that it is not accounted for in the present analysis), there were no substantial discrepancies between the executive plan and the final bill check.

Electrical energy and water consumption during the construction phase are primary data taken from bills kindly supplied by the construction company. Building machines use and diesel consumption have been neglected as well as transports of materials from producers to construction site. Consistently, the stage A4 [6,7] is not included in the present study; as for the stage A5, the contribution from the building machines can worsen a bit the outcomes, but a preliminary estimation indicates only minor effects on the overall environmental performances.

For convenience, building elements are grouped in sub-systems as detailed in Table 3.

4. Life Cycle Impact Assessment (LCIA)

Results of the LCIA are reported in Table 4, where detailed account of the product stage (A1-A3) and construction stage (A5) are given separately. As expected, the product stage amounts for more than 95% of the impacts in any category.

A more clear idea of the role of different interventions can be deduced from the Figures 5 to 11, where for each impact category the contributions of the product stage A1-A3 are decoupled into the three subsystems: roofing, floors, and masonry, encompassing new/old interventions. For completeness, in these figures are also reported tap water and electricity consumptions of stage A5.

Table 1. Newly built interventions.

	Component	Tot. surface (m^2)	Tot. weight (kg)
1a	New foundation floor	39.2	12,997
1b	Foundation floor – Hempcrete insulation	10.8	3,941.9
3h	Entrance perimeter wall bearing blocks	8.9	2,445
3d	Air-space's retaining wall	20.8	16,056
3c	Hallway retaining wall	21.1	17,851
3i	Bearing block perimeter wall	33.8	35,632
4b	Concrete stairs roofing	26.3	14,838
4d	Reinforced concrete and hallow tiles mixed green roofing	58.0	28,917
6a	New partition wall	12.32	1,321
6b	New noise-absorbing partition wall	14.0	1,447
	Total	245.22	135,446

Table 2. Restoration interventions.

	Component	Tot. surface (m^2)	Tot. weight (kg)
1e	Foundation floor (room 5a)	10.22	3,407
1f	Foundation floor (room 4)	11.42	2,998
3g	Foundation floor (room 1-2)	12.32	3,021
2a	Existing wall + thermal plaster	114.8	11,256
2b	Existing retaining wall	20.2	883
4a	Existing roofing	111	12,710
5a	Rustic wooden floor	24.5	2,980
5b	Rustic wooden floor above the cellar	11.06	1,474
5c	Rustic wooden floor (room 9)	11.9	1,377
	Total	327.42	40,106

Table 3. Classification of building elements in sub-systems.

Sub-System	Roofing	Floors	Masonry
Components	4a	1a	2a
	4b	1b	2b
	4d	1e	3c
		1f	3d
		3g	3h
		5a	3i
		5b	6a
		5c	6b
Total amount of materials (kg)	56,465	32,195.9	86,891
	32.2%	18.3%	49.5%

In six out of seven impact categories roofing is the most impacting sub-system; this result is not unexpected considering that roofing has been entirely renovated, even though the largest amount of new building materials for retrofitting is found in the masonry sub-system (see Table 3). Indeed, in the abiotic depletion category masonry is by far the most impacting category.

Table 4. Impact assessment of the whole retrofitting of "Villa degli ulivi" (referred to the total net gross floor area, i.e. 250 m^2).

Impact Category	Unit	Total	A1-A3	%	A5	%
AP	kgSO_2eq	415.39	397.65	95.73%	17.74	4.27%
EP	kg PO_4 eq	130	125.48	96.82%	4.12	3.18%
GWP	kg CO_2 eq	125,131	122,349	97.78%	2,781.55	2.22%
POCP	kg C_2H_4 eq	25.47	24.90	97.77%	0.57	2.23%
ODP	kg CFC-11 eq	0.0066	0.0063	95.09%	0.0003	4.91%
ADP	kg Sb eq	3.10	3.10	99.97%	0.0008	0.03%
ADP, Fossil Fuel	MJ	898,826	863,673	96.09%	35,153	3.91%

For the sake of future comparisons LCIA results are also reported per m^2 of total gross floor area (250 m^2) in Table 5. As a very preliminary analysis, in a recent review [13] two average values of the GWP for residential buildings are reported: 483.22 and 18.44 kg CO_2eq/m^2 for product and construction stage, respectively. These values compare well with our present findings, i.e. 500.52 and 11.13 kg CO_2eq/m^2, respectively.

Table 5. Impact assessment of the whole retrofitting per unit gross floor area.

Impact Category	Unit	Total	A1-A3	A5
AP	kgSO_2eq/ m^2	1.66	1.59	0.07
EP	kg PO_4 eq/ m^2	0.52	0.50	0.02
GWP	kg CO_2 eq/ m^2	500.52	489.40	11.13
POCP	kg C_2H_4 eq/ m^2	0.10	0.100	0.002
ODP	kg CFC-11 eq/ m^2	2.64E-05	2.52E-05	1.20E-06
ADP	kg Sb eq/ m^2	1.24E-02	1.24E-02	3.20E-06
ADP, Fossil Fuel	MJ/ m^2	3595.30	3454.69	140.61

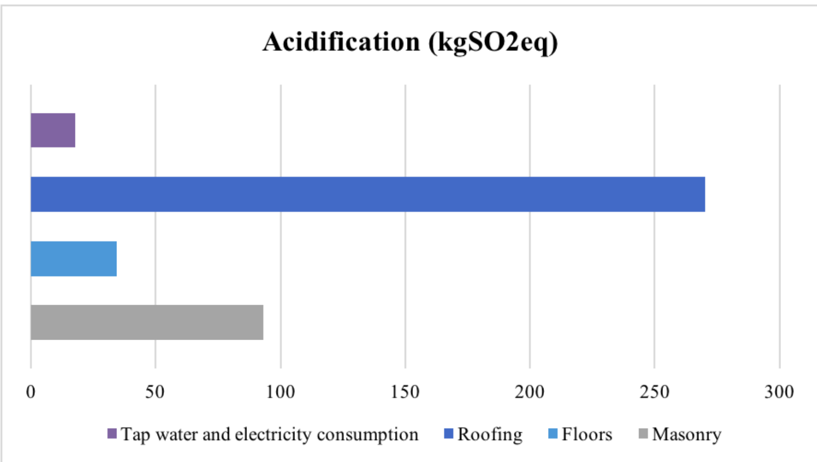

Figure 5. Acidification kgSO_2eq per sub-system.

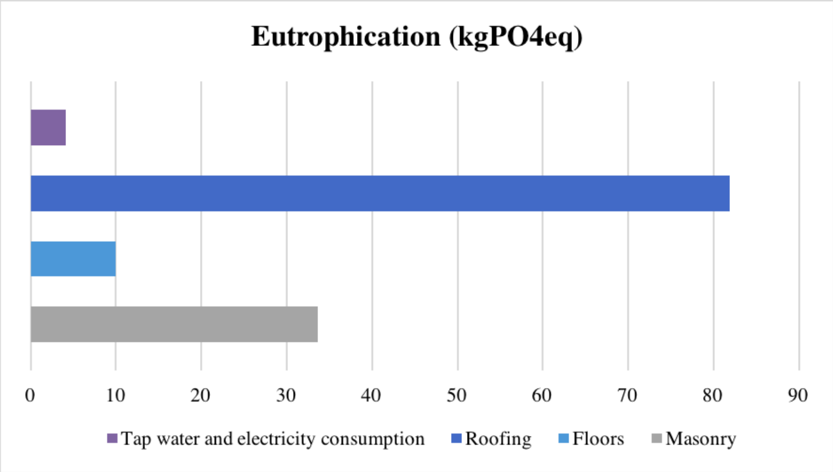

Figure 6. $kgPO_4eq$ per sub-system.

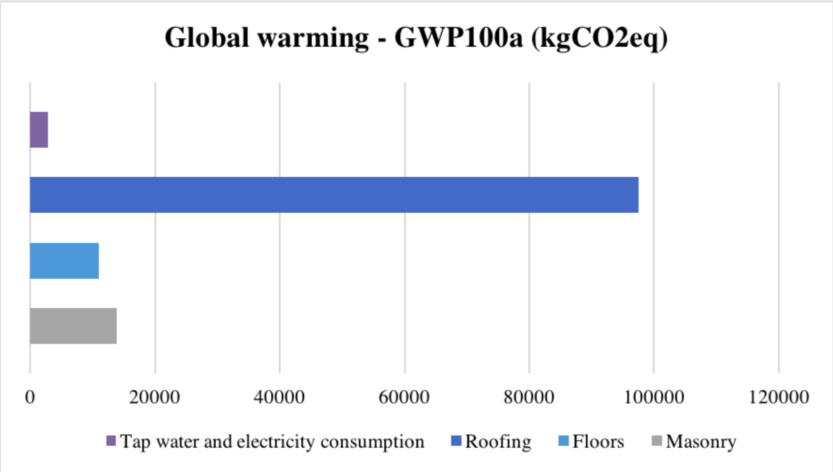

Figure 7. $kgCO_2eq$ per sub-system.

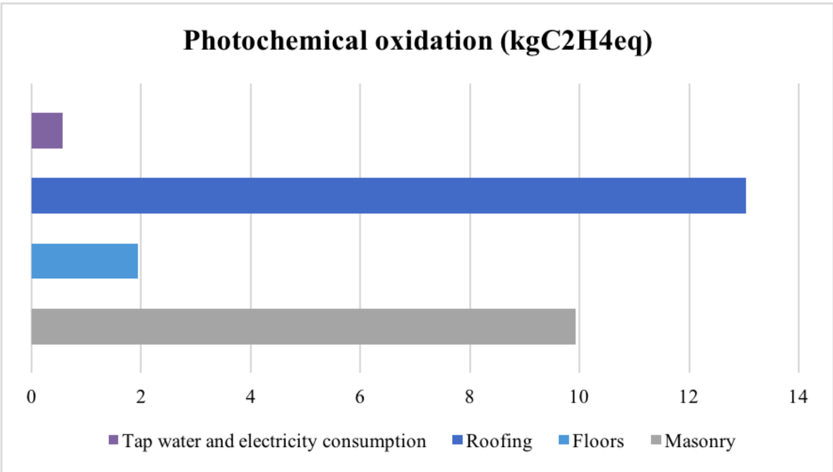

Figure 8. kgC_2H_4eq per sub-system.

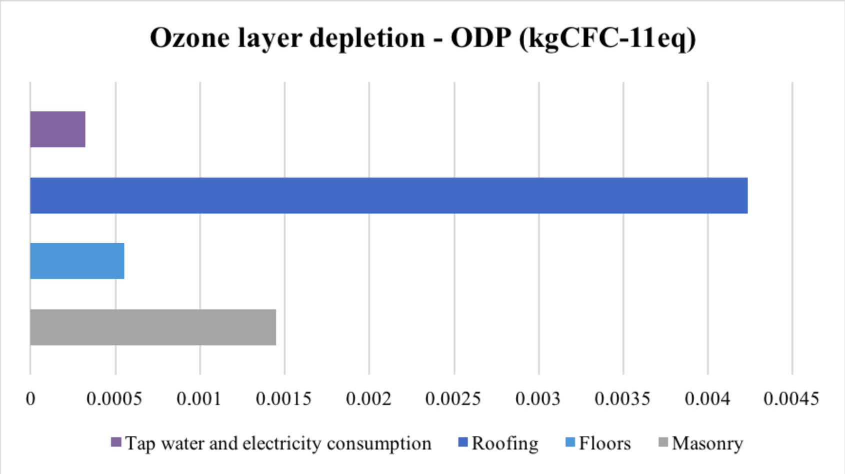

Figure 9. kgCFC-11eq per sub-system.

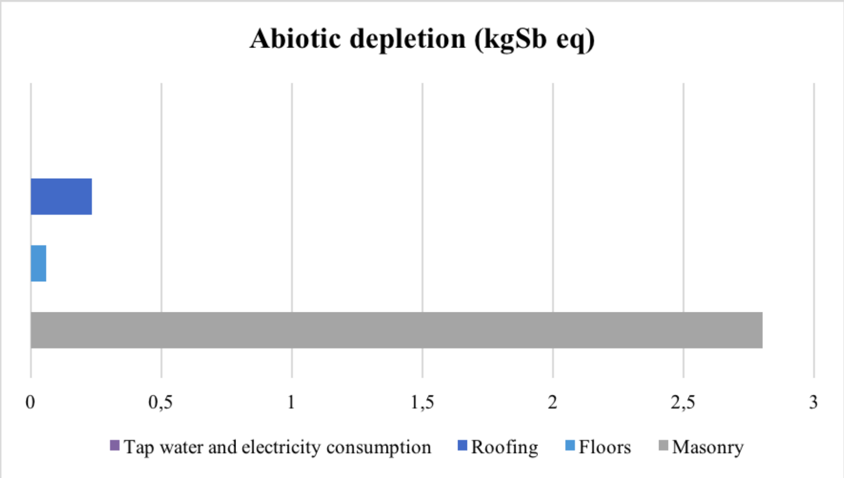

Figure 10. kgSb eq per sub-system.

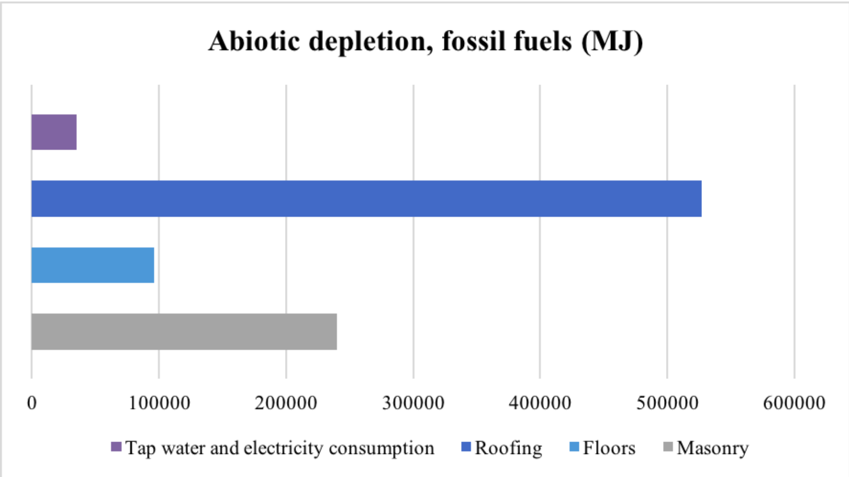

Figure 11. MJ per sub-system.

5. Conclusions

In the present work, a rural dwelling situated in the Liguria seaside has been completely renovated respecting as much as possible the materials traditionally used in that region [12]. Special attention was also given to the materials selection for the interior design, with a marked preference for natural materials: earth-based materials, hempcrete, local stones among others.

Starting from the retrofitting executive design, a materials inventory was compiled and used as a basis to perform the LCA analysis from cradle-to-gate, i.e. including materials production (A1-A3) and construction stages (A5) [6] [7]. The retrofitted house has been used as functional unit; however, for the sake of future comparisons impacts are also reported per m^2 of gross floor area. A preliminary comparison with literature data [13] seems to indicate that the carbon footprint at the product and construction stage is in line with literature data. A recent study has produced a benchmark of environmental impacts applied to 24 statistically-based dwelling archetypes, representative of the EU housing stock in 2010 [14]. The environmental impacts are related to housing per person per year in EU and this makes difficult any direct comparison because in the present work the house service life has not been evaluated. However, in further works these aspects deserve certainly to be taken into account in order to compare on a sound basis different technological solutions as well is the basic choice of retrofitting vs. reconstruction.

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