Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.
Copyright © 2019 ISEC Press
ISBN: 978-0-9960437-6-2

GREEN ROOFS TO IMPROVE THE ENERGY RENOVATION RESILIENCE OF HISTORIC BUILDINGS

GIOVANNI SANTI[1] and SARA BATTINI[2]

[1]*Dept of Energy, Systems, Territory, and Constructions Engineering (D.E.S.T.e.C.), University of Pisa, Pisa, Italy*
[2]*Dept of Civil and Industrial Engineering (DICI), University of Pisa, Pisa, Italy*

The introduction of vegetation in urban areas, through both green roofs and green walls, is a sustainable strategy for improving the environment and the quality of life, as well as crucial for urban biodiversity since the moment it is able to create new habitats for plant and animal species. The design and realization of green roof systems abroad is promoted and stimulated while in Italy, this subject, is still an innovation not supported by many real implementations. The application of this technological green system has a great importance for the redevelopment of existing building heritage, especially for historic buildings, to improve their energy-performance qualities, with respect for their architectural value. The aim of this study is to identify the technical issues for the realization of green roofs in urbanized contexts by focusing on the implementation of a green roof on a building of Leghorn following intervention guidelines developed. This research shows that not only does this system allow higher energy saving, but it also brings a decrease of load bearing on the structure.

Keywords: Greenery integrated system, Retrofits, Benefits, Energy saving, Costs, Components, Structural assessment.

1 INTRODUCTION

The application of green roofs in architecture and in the green technology field can be found more often in new constructions, but sometimes, they are considered as retrofit instruments for existing buildings. Green roofs, in particular the extensive ones, are a technology that was originally promoted in Europe several decades ago and are increasingly realized in cities, because they are an important strategy that addresses some key urban environmental issues, allowing the achievement of different benefits (Tabares-Velasco *et al.* 2012, European Commission 2013). Since the first studies in this field, it has been possible to appreciate the positive effects of green roofing at urban scales and on single building, such as the storm water management, the retention of polluting substances, the energy conservation, the mitigation of the urban heat island effect (UHI), the increased longevity of rooftop membranes, the absorption of the particulates and the noxious substance in the air, the oxygen production and the relative absorption of CO_2, in addition to the protection against the erosion due to atmospheric agents and climatic phenomena (Berardi *et al*. 2014, Galbrun and Scerri 2017). Green environments improve air quality and have proven economic health benefits such as stress reduction, lower blood pressure and muscle tension, and increased positive feelings (Coutts and Hahn 2015). In this context green roofs, in cities, can magnify these effects for business people and city residents, and extensive green roofs are a modern modification of the roof-garden concept because they have shallower substrates, require less maintenance, and are more strictly functional in purpose than intensive living roofs or roof gardens. Several study cases show the environmental, thermal and acoustic benefits of horizontal green roof systems, particularly in the case of retrofitting existing buildings. Nevertheless, it is also important to understand the relationships between these systems in architectural terms, therefore linked to both the urban context and the single building. Currently, commercially tested systems, assessed by various studios, are limited to find better technology solutions that optimize stratigraphy to be deployed or technology solutions with detail points to significant parts, but which can enter into crisis, for example, in building cases with particular architectural and historical features. Since we are taking into consideration an intervention on a pre-existent building, it is necessary to check that:

1. The increase of loads can be supported by the existing structure of the building.
2. Enough space can be found for the increased thickness of roofs and facades.
3. The new envelope may assure the expected performance.
4. Construction elements which can obstruct the implementation of the system be removed or mitigated.
5. Implementation in the pre-existent building of the irrigation plant of the greenery system can be possible.
6. Plant species should integrate with the context, so that they must be chosen carefully.

There are several studies which analyze the energetic performance of these systems according to the localization, the plant species implemented, planting substrates and ecological relevance (Francis and Lorimer 2011) but only few studies analyze the relation between the identity of the building, from an architectural and technical viewpoint, and the features of this kind of system. In this context, the reversibility of the retrofitting interventions is very important to preserve the structural and architectural features of the building (Maahsen-Milan and Fabbri 2013). The aim of this study is to focus on the architectural and executive aspects of the implementation of extensive green roofs so that they can be perfectly integrated with the existing building, and to quantify the possible energy benefits obtained. At present, the reference legislation in Italy is represented by UNI 11235:2015 (Guidelines for the design, execution, control and maintenance of green roofing) that defines the rules in relation to particular situations of use, climatic and building context.

2 METHODS

Speaking about retrofitting of existing buildings can appear easy since it is characterized by construction interventions based on dry assembly of several technological elements, but a careful evaluation of possible limitations to plan the strategies which permit to overcome them is needed. In this condition it is of considerable importance to define the field of action on the existing building heritage according to the construction period (in relation to both stylistic-architectural and technical-constructive canons) and to the presence of possible conservative limitations (the field of restoration for buildings with historical/landscape implies further verifications to check whether interventions are allowed). It is therefore necessary to confront ourselves with current, local and national laws and rules, i.e. binding legislation (laws) and voluntary rules (technical standards), in order to verify the legitimacy and the feasibility of retrofitting works; in this regard intervention guidelines were developed after the analysis of some implementations (Table 1).

3 THE CASE STUDY

This work describes the implementation made at the Frangerini Impresa S.r.l in Leghorn, illustrating the various phases of the installation and providing a cost estimation of that.

On June 2018, a green roof was implemented on building located in the industrial area of Leghorn. The building consists of two blocks: one destined to stock which develops completely on the ground floor and the other one characterized by two levels: the ground floor used as stock and the upper floor for offices. The area of the installation is the walkable terrace which is located on the first block adjacent to the office plan having dimensions 24.7m x 3m. The structure is made by prefabricated reinforced concrete and, in particular, the slab below the terrace consists of pre-fabricated Y concrete beams and concrete cast with electrowelded wire mesh; then there is an insulating panel in XPS, a waterproofing sheath and a floating floor.

Table 1. Logical frameworks of the problems inherent to retrofitting interventions on existing buildings.

Problems	Intervention strategies	Purposes
Higher costs for the recovery intervention	According to the level of complexity of the building that is going to be recovered, especially for those with a high historical-architectural value, the costs of the intervention may increase. A precise economic evaluation is necessary, even resorting to the Value Analysis, in order to determine the cost-benefit ratio of the intervention.	Economic sustainability of the intervention with value verification of the necessary categories of works.
Evaluation of the conservative importance of the historical elements that characterize the building.	Retrofitting interventions can involve both a single building and groups of buildings, but also any single intervention, if set in a historical context, conditions and is conditioned by the context. In-depth archival research is necessary to trace the evolutionary genesis of the settlement and geometric surveying campaigns in order to know the places and the building itself.	Verifying if the project interventions are integrated both at an architectural and technological level with the pre-existent building.
Verification of the presence of any regulatory protection limitations.	Checking the presence of any historical, artistic, archaeological, landscape limitations that could affect the area and the single building in the rules that regulate the construction activity in the area involved.	Consistency of the intervention with the regulations in force.
Verification of the technical feasibility of the intervention.	The retrofitting intervention must be verified during the design phase so that the achievement of the expected results in terms of energy, environmental and economic sustainability can be demonstrated. It is necessary to carry out analyses of the climatic and environmental context, of the evolutionary history of the building and of the context in which it rises, of the building type and of the specific bioclimatic properties, of the materials and construction techniques used, of the thermal performance and of the static system that connotes the building.	Verifying the correspondence of the expected performance of the intervention with the project requirements.
Poor knowledge of the results obtained.	The state of the art inherent to the retrofitting interventions both with direct interventions and with numerous case studies and simulations, illustrates the immediate and expected results, the durability and the problems that could arise between pre-existent buildings and new intervention. Given the relative recent field of application, they cannot be clearly determined, especially if we think about GSI. In the building dossier it will be appropriate to highlight the need to sample the efficiency of the intervention with pre-established deadlines according to its nature.	Durability of the intervention over time and sustainability of future maintenance interventions.

The intervention is characterized by the subdivision of the surface into two areas (5.6m x 6.56m): in the first one gray leaf species were planted (Lavandula angustifolia and Senecio, light green in Figure 1) and in the other one there are green leaf species (Rosmarinus officinalis prostratus and Thymus vulgaris, green in Figure 1). The existing floating floor was removed for a surface of 5.76m^2. Then this surface was cleaned, in order to obtain a surface suitable for laying the successive layers. Subsequently a perimeter border of 30 cm height was created for containing the whole system and in particular the substrate consisting of loose material; with the laying of this edge, the surface is reduced to 4.76m^2 due to the presence of flooring support systems.

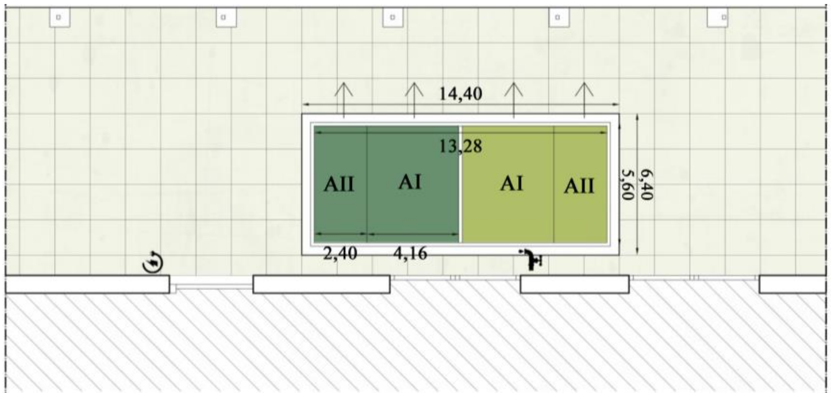

Figure 1. Installation diagram showing the position of the drains, the types of connections to water and electricity.

Figure 2. View of the main phases of the green roof implementation.

Then, a transparent polyethylene sheet was laid, taking care to create some openings in correspondence with the four types of green roof in order to convey the water in the collection tanks. Above the polyethylene, the insulating panels in expanded polystyrene foam were positioned at the edges of the surface and even the non-woven geotextile in polypropylene was laid there, whose function is to retain the substrate so that it is possible to avoid a leaching of the latter and a contamination of the waste water. Before laying the substrate, it was necessary to wet the non-woven geotextile for both having a damp surface in contact with the substrate and preventing dust formation. A separation panel was then placed, and the volcanic lapillus was positioned with an average thickness of about 6cm that works, as well as part of the substrate, as a loose mineral drainage too. The mix of pumice and compost was then placed above the lapillo and surmounted by a last pumice layer. The substrate was composed as follows by reference proportions of the Daku ROOF SOIL2, which provides a 60% of pumice and 40% of lapilli with addition of 20% of the total volume of compost. At this point it was possible to plant the plant species, previously in vase, subdividing them into gray-green leaf species and green leaf. Finally, the implementation was completed with the irrigation necessary for the system to start up.

4 FINDINGS

Table 2 shows the calculations concerning the loads acting on the coverage deriving from the installation of the green roof and those existing before the removal of the floating floor and the related supports.

Table 2. Comparison of the loads before and after the implementation of the green roof.

	ρ [kg/m³]	**Spessore [mm]**	**Carico [kg/m²]**
non-woven geotextile	200	2	0,4
insulating panels in XPS	30	40	1,2
Lapillo	900	30	27
Pumice	600	100	60
Compost	450	30	13,5
	[kg/pianta]	[piante/m²]	
Plants	1	10	10
Additional loads	-	-	**112,1**
	[kg]	**[quantità/m²]**	
Flooring	15	7,6	113,5
	[kg/supporto]	**[supporti/m²]**	
Floor supports	0,555	5	2,775
Removed loads	-	-	116,23
Resulting additional load	-	-	- 4,13

The metric estimate of the implemented system is shown in the Table 3. The cost per quantity and the cost per square meter, multiplied by the surface, provides the total cost of the complete installation to which the costs for labor, planning and annual maintenance are added up.

Table 3. Cost estimation of the green roof realized at Frangerini Impresa S.r.l.

	quantity	**€/quantity**	**€/m²**	**m²**	**€**
Plants in vase Φ 14 cm	10 plants/m²	2 €/plant	20	4,76	100
Lapillo	1 m²	7,90 €/35l	13,3	4,76	63,3
Pumice	1 m²	180 €/m³	18	4,76	85,7
Compost	1 m²	2,80 €/45l	2,5	4,76	11,9
non-woven geotextile	1 m²	49,50 €/100m²	0,5	4,76	2,4
insulating panels in XPS	1 m²	9,16 €/m²	9,2	1,5	13,8
polyethylene sheet	1 m²	5 €/20m²	0,25	5,5	1,4
Costs of stratigraphy	-	-	63,75	-	278,5
Specialized labor	3 workers (2hours)	30 €/h worker	-	-	180
Architectural project	-	600 €	-	-	600
Permission to build	-	900 €	-	-	900

Table 3 (contd). Cost estimation of the green roof realized at Frangerini Impresa S.r.l.

Maintenance	-	-	0,64	-	2,79
Total	-	-	64,39	-	1961,3
Tax relief	60% (65% with design costs)	-	- 38,2	-	1274,8
Total with tax relief	-	-	25,55	-	686,5

5 CONCLUSIONS

The simulation was conducted in Leghorn and involved four types of stratigraphy:

- TYPE AI, with rock wool insulation panel of 8 cm height;
- TYPE AII, with rock wool insulation panel of 8 cm height and XPS insulating panel of 4 cm height;
- TYPE BI, without any insulation panel;
- TYPOLOGY BII, with insulation panel in XPS of 4 cm height.

The comparison of these types shows that the one that guarantees the greater reduction of the annual primary energy requirement is the BII type (57% - 66%), followed by the AII with reductions ranging between 12% and 18%, then by BI (4% - 10%) and, finally, by the AI which increases the needs of 11% - 19%. From the point of view of the loads acting on the roof, an estimate was made of those currently present due to the pavement and those that were added with the implementation of the new stratigraphy: it was determined that, by removing the flooring and installing the green package, the loads on the floor are reduced by 0,04 kN/m^2 for this reason interventions on the structure to increase the load capacity are not necessary. In order to study the economic feasibility of the intervention, a cost analysis was conducted to identify the investment return period. Also, from the economic point of view the best type is BII with reductions of the costs for air conditioning between 53% and 56% and the best species, again, the Rosmarinus officinalis prostratus with a saving of 0,38 €/m^2 for the AII system and 3,97 €/m^2 for the BII system. Unfortunately, the AII typology does not allow to have an economic return because the costs to be incurred for maintenance over the years exceed the economic savings on energy.

References

Berardi, U., GhaffarianHoseini, A. H., and GhaffarianHoseini, A., State-of-the-Art Analysis of the Environmental Benefits of Green Roofs, *Applied Energy*, 115, 411–428, 2014.

Coutts, C., and Hahn, M., Green Infrastructure, Ecosystem Services, and Human Health., *International Journal of Environmental. Research and Public Health*, 12, 9768-9798, 2015.

European Commission**,** Green Infrastructure (GI), Enhancing Europe’s Natural Capital, Bruxelles, 2013.

Francis, R. A., and Lorimer J., Urban Reconciliation Ecology: The Potential of Living Roofs and Walls, *Journal of Environmental Management*, 92, 1429-1437, 2011.

Galbrun, L., and Scerri, L., Sound Insulation of Lightweight Extensive Green Roofs, *Building and Environment*, 116, 130-139, 2017.

Maahsen-Milan, A., and Fabbri, K., Energy Restoration and Retrofitting. Rethinking Restoration Projects by Means of Reversibility/Sustainability Assessment, *Journal of Cultural Heritage*, 14, 41–44, 2013.

Tabares-Velasco, P. C., Zhao, M., Peterson, N., Srebric, J., and Berghage, R., Validation of Predictive Heat and Mass Transfer Green Roof Model with Extensive Green Roof Field Data, *Ecological Engineering*, 47, 165-173, 2012.