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Green roofs for built environment recovery: technological transitions

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ABSTRACT

In 2012, the Laboratory of Recovery and Maintenance at the University of Naples Federico II starts an applied research with the Institute for Composite and Biomedical Materials – IMCB – National Research Council of Italy – CNR, of Naples. The aim is to explore the potential of a patented hybrid foam, Hypucem, as a green technology for the recovery of flat roofs in reinforced concrete buildings.

Two green extensive prototypes are developed and tested to provide an adequate response to the problem of residential buildings. The difference between them is in the mode of greening: sowing before or after the on-site assembly, with overlapping layers of green, in the first case, and their integration into special pockets formed inside the panel, in the second. Laboratory tests verify the germination and growth dynamics for a closed-cell polyurethane-concrete foam and for open-cell polyurethane-soil specimens.

Trials are carried out in a residential neighborhood realized after Second World War. During six months, the benefits to buildings' performances, in both solutions, are monitored, highlighting the importance of roofs dimensions and accessibility. With a greater ease of installation and inspection, the open-cell polyurethane foam solution, accommodating transplanted vegetation, results more suitable for a direct involvement of users in ordinary maintenance. This attitude is fundamental in order to prevent any decrease in roofs thermal resistance due to the lowering of the green layers performances.

1. Introduction

The role of atmospheric pollution in built environments has been studied for long time, because of its consequences on spaces and citizens. According to several researchers over the last forty years, greenhouse-gas emissions from buildings have been growing at a greater rate than those from other sectors. According to IPCC, atmospheric concentrations of carbon dioxide, methane and nitrous oxide are unprecedented in at least the last 800,000 years. The experts agree that European cities are experiencing severe weather conditions as a result of the fossil fuels society. Higher temperatures, extreme heat, heavy rainfalls, drought cause an uncontrolled exposure to exogenous processes with fault conditions occurring to the technical elements (Zhang et al., 2012a).

While multiple stresses threaten built environments, the development of technologies specifically devoted to vulnerability mitigation, requires today the rethinking of research perspectives and procedures for the validation of the scenarios (Brauers et al., 2013). The need to protect spaces, citizens and economies from the negative impacts of pollution and climate changes is here assumed as the basis of a technological transition (COM 614/2, 2015). Scholars define it as the long term transformation in the way the society interacts with environment (Chappin and Ligtvoet, 2014). Central issue in the review of the pathways that underlie the technological transition is to intercept the change in the behavior of the users (Geels and Schot, 2007). A product innovation is not by itself able to give place to transition; it is a response to a need matured within the society; it is supported by the consensus resulting in complex paths and trajectories (Du Plessis, 2012).

This is the cultural approach to the prototyping experience of a vegetative foam module for green roofs, here described. The systematic framework is characterized by a commitment to promote a transition towards a low carbon built environment, actively involving users in its maintenance and management (Altenburg and Pegels, 2012). Through a scientific cooperation between experts of the building recovery and materials' technologies, the project links technical requirements and recovery needs. Beyond the solutions obtained, the interest of this experience is to be found in the draft for a cultural and technological hybridization, in order to reformulate the agenda of urban settlements, under an

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"approach based on … a more holistic lens than the traditional sustainable development perspective" (Zhang et al., 2015).

Central issue in the prototyping is foreshadowing the solution life cycle, through users' involvement (Grin et al., 2010). Universities and research centers play a significant role today, linking the design to users' practices, supported by a vision that binds the actors of the building process to the technologies' durability and reliability (Zhang et al., 2011a). This experience invests on the already patented foam Hypucem, "Hybrid Polyurethane Cement" (Italian Patent N MI2006A001325, International Patent WO/2008/007187), developed by the researchers from the IMCB – CNR in 2007, to reset the technological connection between the built and the residents for a clean rebalancing of mutual impacts (Wienand, 2013).

2. Preliminary draft for sustainability transition

The greening of buildings allows to give new quality to urban often underused and degraded spaces, enhancing settlements and improving internal and external performances (Gluch et al., 2013). Many types of greening technologies have been developed and used in countries for centuries, with benefits in different climatic areas and building typologies. In recent times, vertical and horizontal surfaces have been helping to solve problems of anthropogenic congestion (Zhang et al., 2012b). According to the EU *Strategy on adaptation to climate change* (*COM (2013) 216*, 16.04.2013), their design is today recognized as a central issue in built environment recovery; its realization can reduce the energy requirements, mitigate the effects of pollution, regiment storm water runoff.

Traditionally linked to the issue of congruence between old and new, the culture for recovery, is the platform for the cooperation in prototyping between the experts of buildings' technologies, from the Laboratory LRRM University of Naples Federico II, and the materials' experts from the Institute for Composite and Biomedical Materials – IMCB – CNR Naples (Iannace et al., 2006).

Patented in 2007, Hypucem has been validated, within a one year research, as a building technology for green roofs. Obtained through the union of an inorganic substance, the cement, and an organic one, the polyurethane foam, Hypucem is characterized by high levels of mechanical strength and durability, thermal acoustic insulation or sound absorption equal to other foams commonly used in civil and industrial. With the aim of adopting the patented foam for the buildings' recovery sector, the cross – disciplinary research team defines the boundary conditions that limit and guide its adoption for green roofs, preserving the delicate identity of existing spaces.

To recover the built is "to say again, what had been once said", to leave that contemporary needs expressed by users interact with past identities. Under this perspective, the research challenge is to promote a building technology related to long term visions able to mediate the relationship between environmental and social processes. The design commitment is marked by an awareness of the impact played by technical actions on living spheres. The systemic nature of technology, the procedural dimension of the interventions on the existing built, the influence of context variables in shaping the trajectories of change, are some of the focus that motivates the design approach. The overall hypothesis is that recovery can promote controlled technological shifts that enrich the built and increase its durability and reliability (Kemp, 1994). The rules imposed by time are starting points for a vision of technologies, as opportunities for driving the realization of a desired future with the support of a creative project that reaffirms the experimental dimension of *techné*, integrating theory and science. The legitimacy of the solutions for Hypucem on roofs depends on the solution's attitude to balance the conservation/innovation contrast, with a double focus on inner identities promotion and life cycle lengthening (Matsumura, 2007).

Integrability between ancient and new is the privileged observation key in the design of the vegetative hybrid foam module (Marrazzo et al., 2007). However widespread all over the Western world, the realization of green horizontal surfaces often does not adequately take into account their limitations imposed by constructive technologies. One of the main difficulties for the implementation is to ensure the reproducibility of details in a scenario of compatibility with the existing. This research addresses the challenge of technological transition, through a design based on the selection of a wide range of contextual situations. The use of case studies is taken as an opportunity to create links between the social and technical levels involved (Zhang et al., 2014). The research develops schematic design alternatives, based on the use of Hypucem modules, pursuing a wide applicability to various urban rooftop configurations. The concept is declined in the examination of inner constraints opposed by existing technologies and users, in relation to the potential transition to a *low carbon* innovation (Edum-Fotwe and Price, 2009).

Starting point is that the built is an open system, stressed over the life cycle by several forces, which at different scales – dwellings, urban, environment – act as transition pressures. Referring to modern architectures, several social neighborhoods realized in Naples, after World War II, are assumed as architectural transition labs, to define the system of interaction and interdependence conditions, able to impact on the vegetative modules' design for green roofs (Nevens et al., 2013). Five case studies are selected (Figs. 1–5). Realized at a time strongly marked by the debate on industrialization and prefabrication, these buildings are based on traditional masonry techniques, that integrate, experimental solutions, with reinforced concrete structures. Besides the specific morphological, typological characters, these are characterized by the aggregation of different dwelling types, low-rise buildings and towers. Beyond the presence of large flat roofs, the cases have in common:

- Their localization in areas initially peripherals, today junctions with respect to the development of the city;
- The process of redemption of the property, compared to institutions manufacturers and operators, IACP and INA Casa;
- Their technological characterization, with the recurrence of constructive solutions.

These architectures are selected for the design effort and the significance and replicability of the adopted technologies. The prototyping draft focuses on constraints related to sizing and modularity of devices and elements, thickness, loads, maintenance issues. Subject of observation is, in particular, the integrability of each module within the roof context. According to a literary review, for brick - cement roofs, the constraints are traced back to (Zhang, 2014):

1. Their location, taking care of the links between the characterization of settlements, the design concepts, and performance levels;
2. Their structural coherence, to avoid that these architectures could be reduced to coated forms;
3. Their aging, to avoid the worsening of the degenerative processes.

All case studies show sophisticated constructive details. Released after second World War, they are the result of a commitment to reliability and containment of the costs and the times of the construction site. With regards to the roofs, they

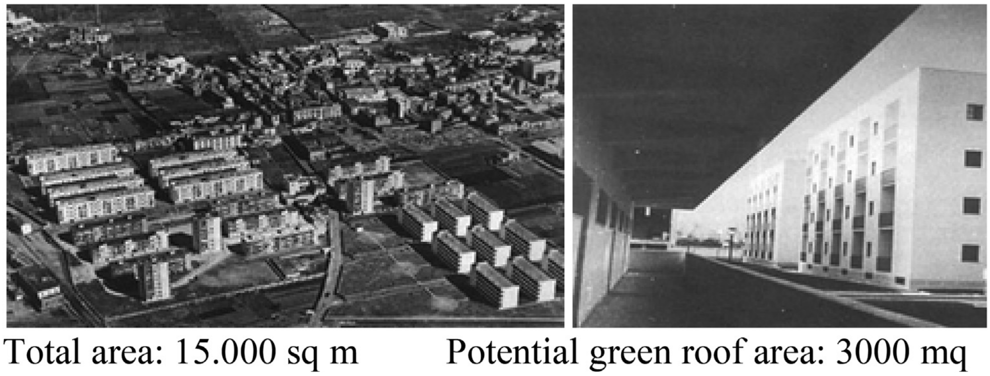


Fig. 1. Rione IACP D'Azzeglio, Barra, L. Cosenza, C. Coen, F. Della Sala, 1947–1948.

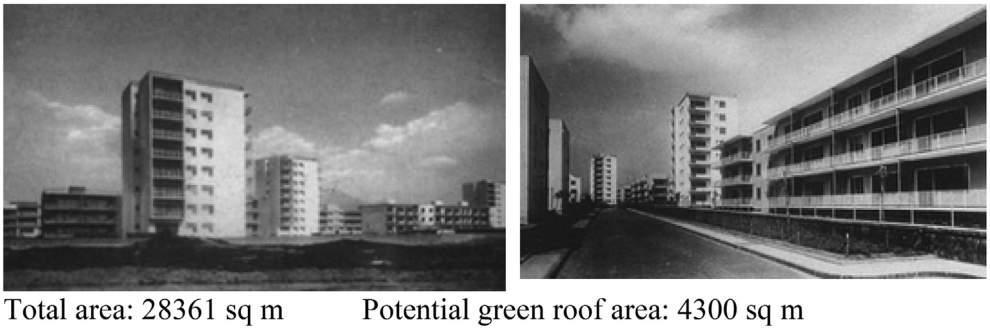


Fig. 2. INA Casa, Parco Azzurro, Barra, C. Cocchia, 1947–1954.

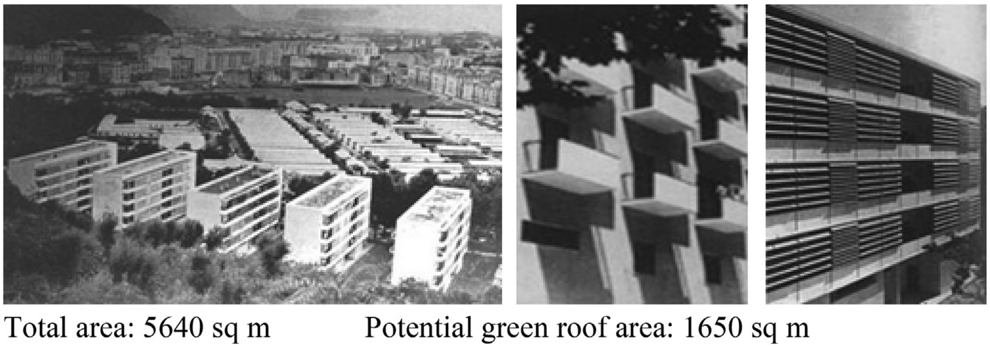


Fig. 3. Dwellings in via Consalvo, L. Cosenza, R. Salvatori, 1947–1949.

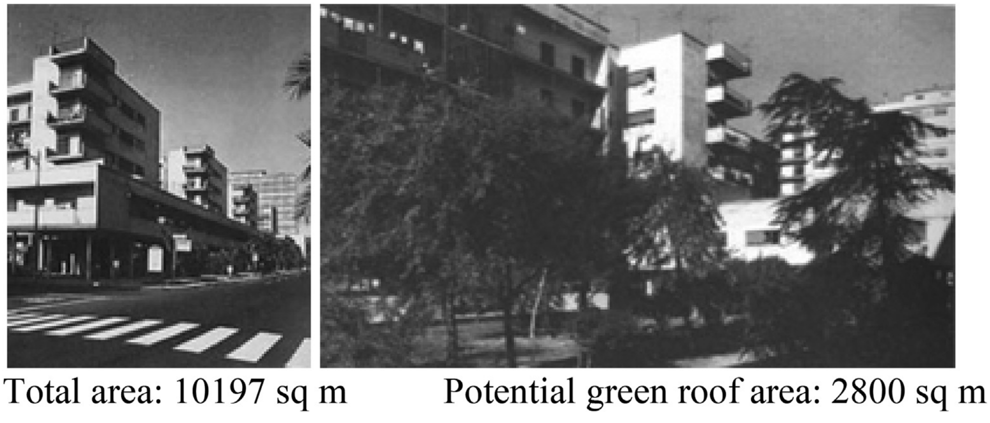


Fig. 4. Dwellings in viale Augusto, L. Cosenza, C. Coen, 1947–1951.

Number of buildings: 6 Potential green roof area: 2500 sq m

Fig. 5. Rione Luzzatti, Gianturco, L. Cosenza, C. Coen, F. Della Sala 1947–1949.

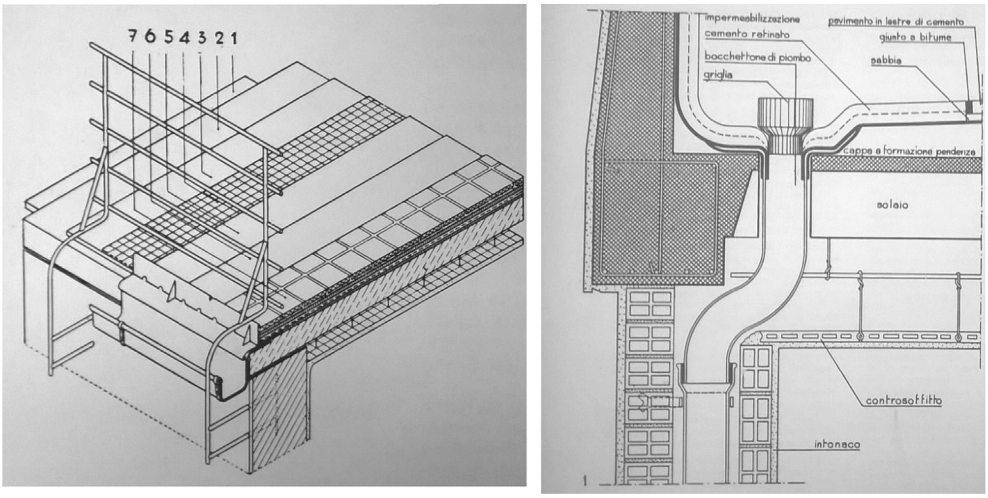
provide external surfaces in multiple layers waterproofing. This kind of detail is well described in the architectural manuals published, in Italy, few years before their realization (Fig. 6).

The reasons for their selection are in the continuity of design approaches towards innovation, assumed both in the past and now, as a slow investigation and transition. On the basis of this hypothesis, the prototyping experience comes out of a continuous process of rearrangement of previously consolidated constructive solutions. The experimental nature of these architectures is a particularly sensitive issue for their recovery. The construction market has not, to this day, materials and components specifically designed to implement their level of performance especially related to low carbon era requirements. These technologies are investigated as privileged elements through which it is possible to promote qualifying actions, mending the urban system, the building and the natural environment.

3. Executive design and prototyping hypothesis

On the basis of the outlined constraints, the team of researchers of the Laboratory LRRM prefigures a highly flexible panel, made of integrated modules, able to adapt to the needs of each modern roof and to its constructive characters. Special attention is given to the flexibility of morphologies, integration between the layers, ease of installation and inspection (Zhang et al., 2011b). A wide diversity of researchers from industrial and academic organizations enriches the discussion arena, supporting the definition of mutually reinforcing design steps and activities.

Taking up the distinction between intensive roofs – with small trees and shrubs - and extensive green, a first design choice, based on the observation of the Hypucem panel potentialities, is to deal only with thin layers. Two extensive green roof solutions are developed (Oberndorfer et al., 2007). They are characterized by a structure anchored with integrated systems that can accommodate permanently plant elements ensuring their support for static and nourishment. The modular composition of the buildings assumed as case study, orients in the determination of the dimensional constraints for the prototype. The sizing of the panel takes into account the modularity of Hypucem due to the foam production mode, starting from a prototype 20 cm by 20 cm, height 4 cm. The study of the recurrent connections between flat surface and vertical elements in roofs (as the perimeter wall)



Griffini (1931),
Rational construction of the house.

Ridolfi (1946),
Manuale dell'architetto.

Fig. 6. Roofs: constructive details.

support the definition of dimensional coordination criteria and interfaces.

The first solution is based on the overlap above the module in insulating polyurethane foam with a cultivation substrate in technical fabric. The panel is sealed to the side in contact with the casing, spaced from the latter by a frame in metal profiles - mullions and transoms - anchored with metal brackets. The second solution provides the use of the insulating foam based on polyurethane as a module container, with sculpted pockets in which to enter the soil and vegetation.

Both solutions are subjected to two series of in laboratory tests (*Test A*; *Test B*) to verify their attitude to be used in the implementation of a technological solution for roofing, with the growth of vegetation.

The aim of *Test A* (Table 1) is to detect the attitude of the hybrid panel to allow the development of vegetation both as cultivation substrate and as a support. The observation is carried out for six months (Solution 1, Solution 2) considering the development of the vegetation and its physical-dimensional modifications, taking into consideration: germination and growth in the presence different supports; changes in weight of the specimens; carbonation of the parts of the specimen placed in contact with irrigation water.

Simultaneously, a water permeability analysis supports the prototyping activity for the extensive pre-assembled modular system with *Test B* (Table 2). Object of observation is the water percolation.

4. In situ observation

An in situ validation is designed with the aim of identifying the reliability of the clean solutions with vegetative panels. Two pre-assembled prototypes are installed and monitored on top of the roof of one of the flat low – rise buildings between those of the neighborhood Casa Parco Azzurro, Barra. As part of the Neapolitan architectural scene after World War II, the social housing neighborhood located in the new expansion areas of the city, in Barra, consists of three tower blocks and nine buildings in line. Overall the neighborhood now has a potential green roof area of 4300 sq m.

For each of the prefigured hypotheses, different trials are set up, involving local users. The neighborhood is selected by virtue of the size of the horizontal surfaces and the absence of technological systems on the roofs. In low-rise buildings, the whole roof surface, easily accessible by the two stairwells, is supposed to be used for the green.

Modeling alternative solutions and relapses is the privileged approach for validating the transition dynamics. Starting point is the new commitment by researchers and technologists in fielding a systemic vision to address holistically the built recovery issues.

The potential impact of technologies with respect to climate change is defined on the basis of a dimensional prediction for those surfaces available to a technological transition. The beneficial effect of the photosynthesis process is recognized to have a significant impact, only if the greening is extended so that the vegetation can lower temperatures, reducing the amount of heat. Fundamental issue is that green roof is in good condition, otherwise the thermal performance can be seriously affected.

The in situ observations capitalize on building design, to promote community involvement, to protect, and enhance the environment and natural features. The incremental dimension of this experience is validated by verifying, in situ, the interest of users to reproduce the greening approach for other collective and private spaces, fielding mechanisms of imitation, competition, integration.

At a technological scale, the systemic character of panels informs the procedural choices on how to install the prototypes. The experimentation envisages conditions of partial green covering with vegetation, a growing medium over a waterproofing membrane. The results obtained by several scholars working on the relations between plant types and thermal insulation values, are assumed as privileged starting points, compared to the case studies' micro climatic condition.

The vegetative hybrid foam panel is conceived as a unique system which consists of the vegetation layer, the growing medium, the drainage and the membrane layers, which serve as filter and waterproofing. Climate, structural design and maintenance budgets are assumed as constraints to the choice of the vegetation.

For the realization of in situ tests, the panel Hypucem of dimension 50 × 50 cm, thickness 6 cm is cut to obtain eight modules of dimensions 25 × 12,5 cm (Fig. 7). The tests aim to observe the laying of the solution 1 with overlapping layers of green, and of solution 2 with special pockets. Special attention is given to the vegetation life cycle, during six months. Referring to the laying, a set of cross currents are studied to accommodate and support the Hypucem panels, anchoring and distancing them. The support element is resistant to permanent and variable loads and is dimensioned so that conditions of water stagnation do not occur due to variations of the inclination for adjustments.

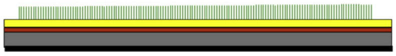
The in situ validation consists of a compatibility assessment for the plant species, taking into account data relating to: micro climatic characters, soil, seasonal growth cycle, attitudes to resist the attacks of organic vegetation, animals and micro-organisms, attitudes to resist the aggressive agents identified in fertilizers, attitudes to resist UV radiation. A mixture of many important varieties of sedum is studied, in order to cope with high temperatures. A feed system from the top with sprinkling or rain drip distribution is adopted. The soil is fed with periodic watering: the drying follows the saturation. During the observation, the solution with pre – grown vegetation demonstrates a greater aptitude to the partial replacement of the plants in the case of parasites or diseases. The modularity of the connections and the integration of the layers in the panel, make it more stable and flourishing.

Fig. 7. In situ observation, Parco Azzurro, Barra.

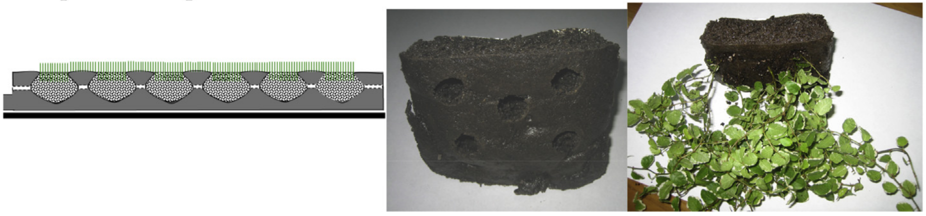
Table 1
Test A.1

Test A1

Test A1
Solution 1
Formulation: M1, Closed-cell polyurethane-concrete, foam (HYPUCEM);
Specimen: S1, Horizontal support to cultivation substratum hybrid material, cultivation substrate felt, vegetation;
Sowing: Ocimum basilicum.



…
Test A12
Solution 2
Formulation: M3, Open-cell polyurethane-soil, foam (50%-50%);
Specimen: S6, Horizontal support with a cavity: hybrid material, cultivation substrate soil, vegetation;
Transplant: Ficus pumila.



…
Test A15
Solution 2
Formulation: M4, Open-cell polyurethane-soil - fertilizer, foam (50%-45%-5%);
Specimen: S7, Vertical support with cavities: hybrid material, cultivation substrate soil, vegetation;
Transplant: Scindapsus aureus.
Make multiple cavities at an angle through the manual removal of material.
Inserting the roots of the plants in the cavities.
Inserting and compaction of soil cavities.
Final weight (g): 157.

Final Results Test A

The germination timing of the solution 1 with the cultivation substrate felt is longer, compared with the traditional sowing in pots. The specimens show few traces of carbonation of the parts placed in contact with irrigation water.

In solution 2, specimens are grafted with pre – grown vegetation. Several changes in weight are detected besides carbonation.

Regarding the hypothesis of an integrated system Hypucem – waterproofing product, two technological alternatives are tested: mono component waterproof membrane and bituminous membrane. The presence below the panels of a sealing element with waterproofing products contributes to the increase of thermal insulation performances by avoiding any water infiltration in case of damages in the watering system. After two months, both products show adequate adhesion to the support Hypucem.

The systemic perspective adopted in promoting and validating the innovation processes enables to manage the complexity of

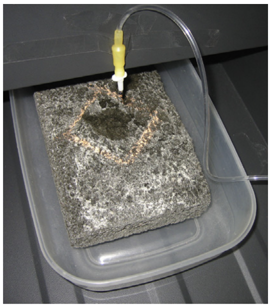
Table 2
Test B.

Test B1

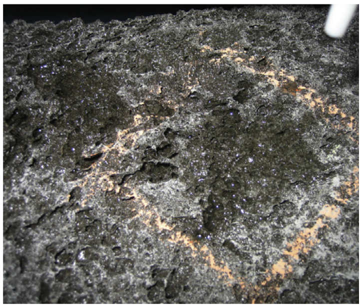
Physical-dimensional characters of the test specimens. Weight (g): 297; length (cm): 19.4; width (cm): 12.5; thickness (cm): 3.5; irregular porosity of the material (horizontal and vertical channels).

Dripping mode. Quantity of water (ml): 100; water dosing time (min.): 120; distance between the dispenser and the specimen (cm): 5.5

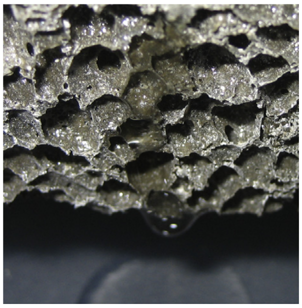
Surveys during Test B1



Specimen 3 min after the dripping.



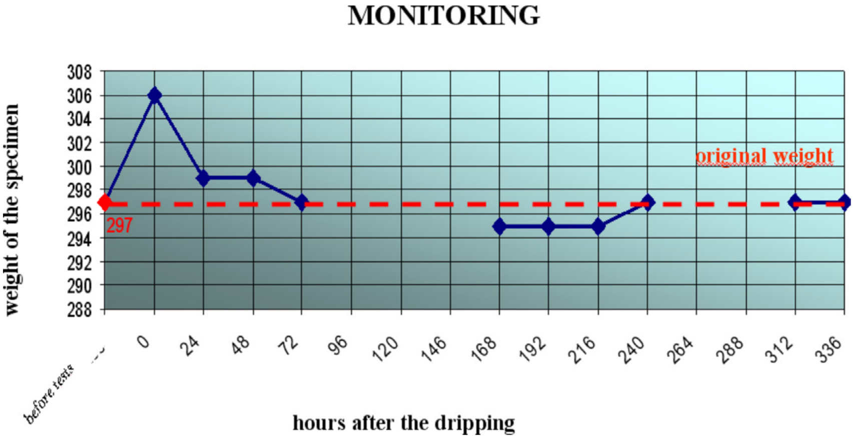
Specimen after 6 min after the dripping: formation of an area of stagnation outside of the panel.



Specimen 20 min after the dripping: leakage of water from an edge of the lower face.

Final Results Test B

After the dripping, it is possible to observe: the 90% water percolation; the leakage of water from an edge of the specimen lower face; the absence of water on the upper face of the specimen. In terms of physical-dimensional changes in the specimen: there is an evident process of increase, reduction and re-acquisition of the original weight over a period of 336 h - 14 days. There is also stationarity in the other physico-dimensional characters, and a negligible loss of matter in the form of granules.



technical change phenomena, giving priority to the technical, scientific, economic, social context.

Moving the focus of research on technological solutions to reduce the anthropogenic impact within these sites re-establishes a past cultural continuity between spaces' vocations and technological performances. Clean foam panels offer solutions not only to local problems. They return a possible element for rebalancing the environmental foundations of the built. The neighborhoods chosen for the validation, have always been places of innovation. Sixty years after their construction, designing overbalancing solutions is a strategy that connects *knowing with doing*. In a long time perspective, the architectural technology witnesses a profound change in the channels of research and dissemination for the built. University laboratories act as new engines for the development and promotion spread of a new thought for settlement systems. Green roof help lower temperatures inside the building and thus reduce the demand for the use of air-conditioning systems. Adopting cleaner transition technologies for buildings' recovery, helps to increase the quality of dwellings in terms of usability and enhance their overall image. Testable benefits fall within the sphere of environmental sustainability, being the adopted solutions able to intercept pollutants and combustion residues, retain dust, transform carbon dioxide into oxygen in part, counter climate change through the improvement of the water cycle and water systems management. In a long term perspective, the improvements to be measured after the experimentation are attributable to a property value increase: the greening solutions support housing developers in achieving a reduction in recovery costs, obtaining a green brand reputation.

5. Conclusion

Promoting the stewardship of built environment transition towards the mitigation of climate impacts, through the design of devoted technologies is the input key of this study. The Hybrid Polyurethane Cement foam, patented in 2007, is successfully assayed to increase the performance levels for architectures. Two extensive pre-assembled systems integrated with vegetative panels are developed for green roofs, taking into account its modularity and dimensioning. Different for the mode of greening, with overlapping layers, in the first case, and integrated pockets, in the second, the solutions are prototyped and tested in laboratory, assessing their attitude to meet the needs of reducing the environmental footprint of the built environment. For each solution, several trials are set up in the neighborhood Casa Parco Azzurro, Barra (Naples). Here, taking as input data the results of the laboratory experimentation, the replicability of the installation and vegetation maintainability are validated. Underlying result obtained through the experiment is the convenience for large surfaces with green solutions. Referring to the modularity of the connections and the integrability of the green layers, the second solution, with pockets inside the Hypucem panel, results more effective and durable.

Among the research lines undertaken, rather than outlining a final technological solution, the work contributes to design a procedural approach for low carbon buildings' transition. Forty years after the first debates on buildings' recovery, the scientific community recognizes in the existing project, the set of operations aimed not only at protecting but also promoting, the resources management. The emergence of new needs, variety and variability of demand, flexibility and multiplicity of uses, requires a profound rethinking of the principles that underpin the move towards technologies. Under this perspective, roofs emerge as an ideal case for designing and testing cleaner solutions, integrated with the existing systems. Underlying result of the study is to improve users' attitude to make the best use of them. In designing architectural transition, the research traces new pathways linking the level of the technical choices with social awareness. In this way, the process of technological innovation is designed as an holistic transition, slow variation, selection and retention able to intercept and drive changes, in places and users.

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