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Article

Valuation of Ecological Retrofitting Technology in Existing Buildings: A Real-World Case Study

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Abstract: The world's existing buildings are aged, in a state of deterioration and in need of interventions. When selecting the type of possible intervention to be applied, the choice falls between two alternatives: simple unsustainable ordinary maintenance versus ecological retrofitting i.e., an increase in the quality of the indoor environment and building energy saving using local bio-natural materials and products. The present research seeks to respond to the requests of recent comprehensive reviews which ask for the retrofitting of the world's huge existing building stocks and portfolios by proposing an approach and testing it in a specific case study (at the unit, building and urban block level) which can then be carried out and repeated in the future on a larger urban scale. The real-world experimentation in the provided case study achieved the important outcome and goal of a Green Building strategy and post-carbon city framework i.e., the significant enhancement of the thermal performance of the buildings as a result of a few targeted key external works and the consequent saving of energy in those already existing (but not preserved and not included in the state national register or record of monuments) Liberty-style constructions. All the above show that these important existing buildings can be ecologically retrofitted at an affordable cost, although initially slightly more expensive than the cost of ordinary unsustainable maintenance. However, this difference is offset by the favorable pay-back period, which is fast, acceptable and of short duration. The tried and tested approach, the positive proposed case study and the experimental database-GIS joint platform (the details of which can be found in an additional supplementary research which is currently being carried out) are the bases on which a future decision support system will be proposed. This support system can be carried out as a tailor- made solution for the ecological retrofitting of the enormous existing building stocks and portfolios which must be considered on a larger scale i.e., at ward, quartier, city, regional and country level.

Keywords: appraisal; valuation; valuation of green building; valuation of post-carbon city strategy; valuation of building energy; energy performance simulation programs (EPSPs); building portfolios and stocks; data base management system; DBMS; GIS

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1. Introduction. Framework of Green Building and Post Carbon City Strategies and Their Benefits

Recent comprehensive reviews [1] ask for general and scientific actions to mitigate global warming. Humankind, and the entire planet, are in increasingly greater danger due to climate change, global warming and its destructive side effects [2–8].

Among such effects are higher atmospheric temperatures notably at the poles and in Greenland, the melting of the poles, permafrost, glaciers and snowfields, and the consequential rise of ocean levels and saltwater surface warming. They also include more frequent extreme hurricanes in the Atlantic, typhoons in the Pacific and cyclones in the

Indian Ocean. These often cause huge floods, droughts due to the lack of regular rainfall and the scarcity of fresh water. The increase in atmospheric temperatures has also impacted on global crop yields reducing harvests of wheat by 6%, rice by 3.2%, maize by 7.4% and soybean by 3.1%. These drops in yields may result in global food shortages, leading to famines and emigration from the affected areas.

It has to be especially noted that among the important causes of climate change is the huge overconsumption of energy in the world. In the latest 2017 UN estimate expressed in million tons of oil equivalent (= 11.63 Tera Watt hour, TWh) the world's annual total consumption is 13,970 TWh with China using 3063, USA 2155, Europe 1828, India 882, Africa 812, the Middle East 750, Russia 732, Italy 125. This energy is largely derived from fossil fuels, including coal, gas, oil and biomass. The burning of these fuels leads to greenhouse gas emissions. The atmosphere is being polluted at all levels, and this causes climate change as well as impacting seriously on human health.

It is crucial to recognize that the building or civil sector consumes over 40% of the world's total energy consumption from fossil sources for construction processes, and for thermal management of residential as well as nonresidential units. This percentage is even higher in densely populated urban areas, especially the world's megalopolises, which, from 2015 UN estimates, include the North East Boston to Washington, USA (52 million = m), the Great Lakes, USA (59 m), Mexico City (28 m), Rio de Janeiro and South East Brazil (51 m), the Bogota Triangle (29 m), Tokyo (38 m), Seoul (25 m), Manila (50 m), Pearl, PRC (55 m), Yangtze, PRC (88 m), Bohai, PRC (66 m), Kolkata (65 m), Delhi (46 m), Mumbai (80 m), only EU Blue Banana (90 m) and total Europe Blue Banana (120 m).

Thus, the civil sector is the main user of fossil energy and, consequently, the greatest polluter and the biggest cause of planet climate change.

Reducing fossil energy consumption by retrofitting in this sector is an exceptional opportunity and one of the most effective steps in reducing world greenhouse gas emissions. It is also a smart investment for families, users and building owners, given the immediate multiple and positive impacts which will result from retrofitting, because it is a capital investment with immediate effects. Fossil fuel energy consumption must be dramatically cut to ensure the planet's survival by the bioecological enhancement of the construction's energy efficiency. This is a feasible strategy which must be enforced starting at the building stocks/portfolios level within the green building and post-carbon city theoretical framework, then by implementing green urban districts and wards / quartiers / neighborhoods, cities and regions, and finally countrywide ecological transitions.

Regrettably this strategy is often seen as an additional cost in new constructions, as well as in the retrofitting of existing buildings. Therefore, a scientific economic valuation must be performed and completed in order to explain to people and allow them to understand and appreciate that the reduction of fossil energy consumption in buildings is of structural and permanent benefit regarding income and efficiency, and not just a passive cost loss. Prototype tests as well as case studies are of great help in demonstrating the opportunity, the feasibility and the profitability of a retrofitting strategy. This is the aim of the present and future research.

2. Background. Multiple Immediate Benefits Derived from Ecological Retrofitting of Existing Building

2.1. Theoretical Framework: Taxonomy of Benefits Deriving from Ecological Retrofitting

As soon as a building or an elementary unit is retrofitted and made energy-efficient, the owner and the users have a healthier construction and they start to save permanently on significant expenses related to indoor microclimate management and operating costs.

Therefore, the owners and the users of a bioecologically retrofitted unit or building benefit immediately in terms of lower energy consumption, economically in terms of higher productivity, in wellbeing with a healthier indoor environment, and ecologically in terms of lower outdoor CO_2 emissions, as well as a much-improved atmosphere.

Valuation and economic scientific research notices, addresses and appraises some of the benefits stemming from energy efficiency derived from ecological retrofitting.

In fact, the research shows clearly that tenants, owners, the indoor milieu, the environment and society in general immediately enjoy the multiple positive benefits of ecological retrofitting and energy enhancement performance as a result of even a small number of targeted retrofitting works, with little or no inconvenience to the occupants [9–18]

The strategy's effectiveness and worth can be seen in the immediate financial and ecological benefits which the tenants or owners enjoy. This empirical evidence demonstrates the existence of ecological retrofitting multiple benefits, such as:

- Energy benefits: a permanent structural and perceptible cut in kWh consumption.
- Economic benefits: a consequent permanent structural saving in expenses ("energy bill") earmarked and assigned for building energy management.
- Ecological benefits: a cut in CO_2 emissions [19–35] proportional to the cut in kWh consumption.
- Environmental benefits: a consequent permanent structural saving in collective social costs of carbon or CO_2 [36–43] and the reduction of damage caused by pollution and CO_2 emission and its monetary equivalent.
- Health benefits: a general improvement in indoor wellbeing due to the natural materials used and the resulting improved indoor and outdoor environment.
- Financial real estate benefits: pioneer research has proved that ecological retrofitting increases the building and individual unit selling price in the local real estate market because sustainability positively affects a building's market value, even in small towns and poor local economies such as the one proposed in the case study [44–52].
- Ecological transition benefits: the transition to a near Zero Carbon World, (nZCW) is the main priority of all European states, regions, provinces and urban governments and the same applies to the private sector.

2.2. Theoretical Framework: Answers from Empirical Evidence

The background described above, embodied in the case study, gives empirical answers to issues raised in the theoretical framework concerning the users and producers of new strategies such as Green Building and Post Carbon City. Such issues are as follows:

- The investigation of the individual's behavior and reaction to innovative processes and new ecological products, adopting the Innovation Diffusion Theory, IDT, ([53,54] (Rogers, 1995, 2003)) from the user's point of view.
- Investigation of the dynamics and forces which influence producers of innovative processes and the suppliers of new ecological products, employing the Theory of Planned Behavior, TPB, ([55] (Ajzen, 1985)).

Empirical evidence of the case study solves the issues raised in the theoretical framework. There are no objective reasons to obstruct the Green Building and Post Carbon City Strategies. Barriers or obstacles might be the inadequate perception of users and the insufficient awareness or the social responsibility of suppliers. These must be neutralized by a clear valuation and appraisal of the drivers (the immediate and multiple benefits stemming from ecological retrofitting) and of the stimulus (the measures and incentives for the World Ecological Transition).

3. Aims of the Research. Methodological Steps

3.1. Aims of the Research

"Passivation" is the enhancement of an existing edifice (by ecological retrofitting) towards "near Zero Energy Buildings" (nZEBs) before taking into consideration energy production from renewable source systems and HVAC implants.

The aim of the research is to test in a proposed case study if ecological retrofitting, as a result of a few targeted external key works for passivation, produces the passive significant enhancement of the thermal performance of existing buildings (not preserved and not included in the national registry of monuments) and a significant saving of energy.

The research also aims to assess and verify if the additional differential initial cost (compared with ordinary unsustainable maintenance costs) has a pay-back ("counting the numbers of years it takes to recover the amount invested") of that differential in an acceptable, short-term period, and if its amount is reasonable and affordable.

3.2. Methodological Steps

The methodological steps of the research case study are as follows.

(a) An existing building ecological retrofit implementation approach, by adopting natural, bio ecological, historical, recyclable/renewable and local/regional materials and products in the framework of the circular economy, focusing more on passivation (gearing towards EU nearly zero energy buildings, nZEBs) before taking into consideration energy production from renewable alternative sources and HVAC implants.
(b) An experimental preview test of the approach and of the targeted retrofit works in the simplest prototype small construction with the purpose of preventive verification of the proposed methodology.
(c) A Data Base Management System and a spatial information system (joint platform) based upon state-of-the-art PostgreSQL DBMS and GIS at the unit and building level. This constitutes a first crucial step in the formulation of an imminent proposition (in future research) of a decision support system, which will then be carried out at larger scales i.e., at ward, quartier, city, regional and country level, but only if the cited DBMS-GIS joint platform is available. Given the limited space available this part of the research will be detailed in a supplementary separate report.
(d) Real-world testing in a case study of simulated ecological retrofitting in the challenging area of existing buildings with architectural importance (but not preserved and not included in the national list of monuments or historic landmarks, the latter managed by so called "Soprintendenze" i.e., government office) such as those in the case study on the main street of the rebuilt post-earthquake city of Reggio Calabria;
(e) An assessment (ecological as well as financial) of energy saving and emissions mitigation.
(f) Estimation of the differential costs involved in ecological retrofitting works compared to ordinary maintenance without energy enhancement.
(g) Estimation of the pay-back period adopting scientific analytical techniques instead of just heuristic or empirical cost assessments.

3.3. Method, Steps and Key Work of Nature-Based Ecological Retrofitting

Unavoidable and urgent ordinary maintenance, mandatory by building regulation safety laws, provides the opportunity to transform compulsory BAS ordinary work into an ecological retrofitting intervention, which is the key event in the life cycle of a building as well as a significant partial solution to global warming. Works are external to avoid inconvenience and stress to the occupants.

The structure of the proposed research, in paragraphs (Par.), is as follows.

Par. 04. Test materials, scenarios and a manageable Program for Building Energy Performance Simulation (BEPSP) [56–62] on a reference prototype small building; research selects the EPSP by simulation and valuation.

Par. 05. The real-world case study, urban block #102, its buildings and units are presented.

Par. 06. Units and buildings EPSP simulation outcomes; energy (kWh) consumption and CO_2 emission in alternative common and sustainable scenarios. The research valuates the energy consumption in units, the difference between the two scenarios in terms of energy saving, and avoided emissions and pollution.

Par. 07. Cost estimation and pay-back over time; the years needed to pay-back the additional costs for the ecological materials (compared with the usual) and the use of special plaster and cork panels which are outstanding bio ecological insulators.

Par. 08. First results and conclusion.

3.4. Astonishing Low Thermal Conductivity of Bio Produtcs

As stated above, the present research aims to compare, verify and assess the effectiveness of the ecological retrofitting strategy on existing buildings, namely the possible positive impacts of bio ecological "passivation". This involves natural-based thermal external insulation of buildings using products manufactured from renewable and/or recyclable and oil-free raw materials (Figure 1) which are to be found in the same region, or the Mediterranean area, in a circular and green economy framework.

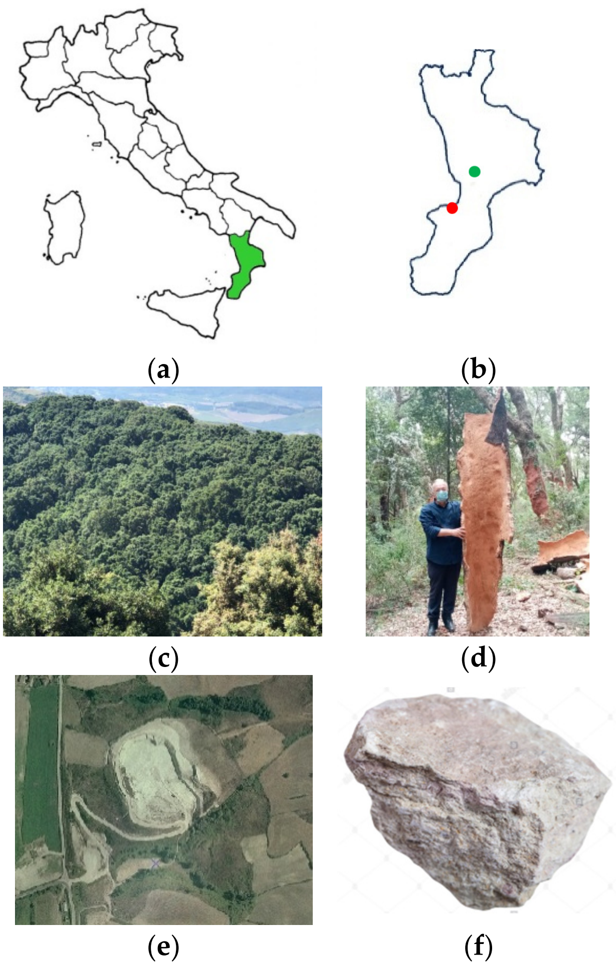


Figure 1. (**a**) Italy and Calabria region (green). (**b**) Municipalities in Calabria region, Italy. Lamezia Terme, location of oak cork forests (green point). Stefanaconi, location of marlstone quarry (red point). (**c**) Lamezia municipality: oak cork forest (terrain photo, 2021). (**d**) Lamezia Terme oak cork forest: debarked big cork plank. (**e**) Stefanaconi municipality: marlstone quarry (air-balloon photo, 2014). (**f**) Stefanaconi marlstone quarry: rock sample. Source: Authors.

Cork [63–67] and marlstone [68] are two key raw materials which can be used to manufacture products such as panels and plaster for external thermal insulation, respectively, of: flat/sloping roofs, loose stone foundation and vertical walls.

Sustainable forests and increased forest cover help in capturing CO_2 [69–81].

Key element of products are their high insulating power and their astonishingly low thermal conductivity:

- cork panel: 0.040 W/m^{2}K;
- natural hydraulic lime base plaster: 0.066 W/m^{2}K;
- natural hydraulic lime base super plaster: 0.029 W/m^{2}K.

These low thermal conductivities can make the big difference (Figure 2) as will be demonstrated in the following "reference building" experimentation.

(**a**) (**b**)

Figure 2. (**a**) Multilayer external insulating super plaster named "volcalite". Source: Authors. (**b**) Real-world ecological retrofitting of buildings at Mediterranea University of Reggio Calabria (Italy), Department of Architecture. Flat roof/terrace "passivation"/insulation with insulating/ventilated bio natural cork panel named "genius". Covered by insulating "vermiculite screed", waterproof bituminous membrane and ventilated raised adjustable floor tiles. Source: Authors.

4. Test for Materials, Scenarios and a Manageable EPSP on Reference Building

4.1. Ecological Retrofitting Strategy: Alternative Scenarios

The preventive assessment of an Ecological Retrofitting Strategy was performed before its implementation in the case study, on a small building (Figure 3); the so-called: prototype, reference or sample building.

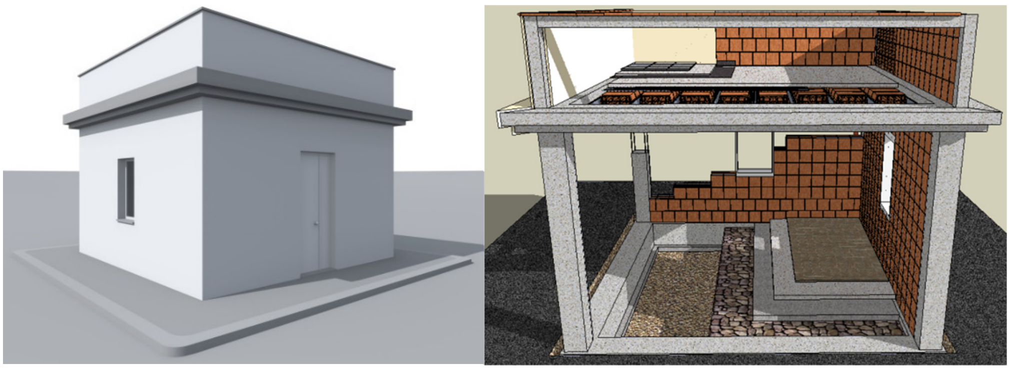


Figure 3. Prototype/reference/sample building. Source: Authors.

The reference building can be easily assessed in its energy performances, under alternative scenarios, because it is small (5 × 5 × 4 meters), with extremely simplified architectural characteristics, i.e., one-story or single-story cubes. It consists of a common punctiform structure in reinforced concrete (base beam, pillars, flat roof slab) and the usual buffering in common bricks. Research includes comparative tests on the reference building without (Common Scenario) versus with (Sustainable Scenario) its envelope thermal external insulation, or coating of foundation, crawl space, walls and flat roof.

In the Common Scenario (Business as Usual = BAS) the building is finished with popular commonly-used (external) plasters in cement-based mortar, or in industrial hydrated lime plus cement-based mortar.

This plaster is made up of four to five layers including a bridge of adhesion, plaster (rustic), shaving (finishing) and putty or smooth finishing with an American metallic spatula, and with a synthetic color.

In the alternative Sustainable Scenario, the innovative external plaster is based on bio-ecological natural hydraulic lime, derived from local marlstone and mixed with expanded vermiculite (or perlite) for better insulation. It is made up of four layers: bridge of adhesion ("*aderenza*"), plaster = rustic ("*intonaco*"), civil = shaving ("*rasatura*") and final colored finishing ("*arenino colorato*").

There is, therefore, the addition of horizontal bio natural cork panels, derived from local cork oak forests, with a thickness of 6 cm both above the floor or attic and under the crawl space.

It is useful to recall the astonishing low thermal conductivity (W/m^{2}K) of these products:

-cork panel (0.040),
-ime-base plaster (0.066)
-and lime-base super plaster (0.029).

In the Sustainable Scenario there are also ecological windows possessing optimum thermal efficiency, involving structures based on natural wood or chloride or PVC with low emission stratified double glazing.

4.2. Comparative Building Energy Performance Simulation Programs (BEPSPs)

Additionally, it has been performed a comparative test of Building Energy Performance Simulation Programs (BEPSPs) through the valuation of energy consumption in kWh and CO_2 emission in kilos in the two cited different scenarios (Common versus Sustainable-Ecological) by means of three very different tools described below.

- Energy Plus® (Version 8.3.0) together with Design Builder (Version 4.5.0.178) is one of the best-known energy simulation software tools. It is complex software for energy diagnosis and thermal simulation in dynamic building arrangements. It has external graphical interfaces that facilitate the creation of the thermal model of the building and the inclusion of its characteristics, like Design Builder and others BIMs. Energy Plus is adopted to perform this first simple experiment on the elementary prototype edifice or reference building.
- Blumatica Energy® (Version 6.1) is user-friendly and relatively cheap software that allows the planner to design the thermal insulation of buildings as well as the management of their energy certification. It is interesting to compare its performance with that of more complex Energy Plus and more popular Termus.
- Termus® (Version 30.001) is one of the most popular Italian software platforms used for the assessment of energy performance of buildings. Energy certification (APE-AQE), calculation of transmittance and drafting Protocol Ithaca are some of the outputs of this software. It is the best-known standard software in Italy. It is reliable as well as friendly enough to be advised for local professionals and adopted for the present complex Case Study in this first valuation. In future research, a more complex modeling of thermal and wet transmission will be adopted to better understand and reduce the need of improvements.

4.3. Energy Performances and Pay Back Estimate

The software provides (Table 1) the following:

- total (area x kW/m^2 year)
- Global Primary Energy (EPgl) which demonstrates the general efficiency of the building, of the envelope and of the systems;
- total CO_2 (area x CO_2 kg/m^2 y) that the building and the systems release in the environment, as direct consequences of fossil material burning.

Estimate of energy consumption were carried out on two scenarios (Common versus Sustainable) using the EPSPs cited above, each having its own characteristics. The output is given below and is convergent to a surprising degree.

The output of the three Energy Performance Simulation Programs (Table 2) was also well convergent in the percentage (%) of energy saving and sufficiently convergent in the percentage (%) of pollution mitigation of two distinct scenarios.

Table 1. Comparison of output concerning energy consumption and emission, from three Building Energy Performance Simulation Programs (BEPSPs): Termus, Blumatica Energy, Energy Plus.

	Termus		Blumatica Energy		Energy Plus	
Scenarios	**EPgl kW/m² y**	**CO_2 kg/m² y**	**EPgl kW/m² y**	**CO_2 kg/m² y**	**EPgl kW/m² y**	**CO_2 kg/m² y**
01. Common (BAS)	114	24	116	11	129	15
02. Sustainable	69	15	71	8	73	9
Δ	−45	−9	−45	−3	−56	−6

Table 2. Percentage differential (kWh/m^2/year consumption; kg/m^2/year emissions) between Common BAS and Sustainable Bio Eco Scenarios.

	Termus Δ (%)	**Blumatica Energy Δ (%)**	**Energy Plus Δ (%)**
EPgl kWh/m^2 y	−40%	−39%	−44%
CO_2 kg/m^2 y	−36%	−26%	−43%

The valuation compares total energy consumption (kWh) and CO_2 emissions (kg) assessed by adopting the most conservative tool, Energy Plus, to test the worst scenario.

Considering just the annual saving in consumed less energy (−1400 kWh) and the statistical cost of energy for small users (€\kWh 0.42), the monetary annual saving equals: kWh1.400 × €\kWh 0.42 = € 590 (Table 3).

Table 3. Total energy consumption (kWh) and CO_2 emissions (kg) in 01 and 02 Scenarios per year (adopting the tool resulted most conservative, Energy Plus tool).

Scenarios	**Area m²**	**EPgl kW/m² y**	**Total Annual EPgl: kWh**	**CO_2 kg/m² y**	**Total Annual CO_2: kg**
01. Common (BAS)	25.50	129	3313	15	382
02. Sustainable	26.21	73	1913	9	235
Δ = differential (saving; mitigation)			−1400		−147

Based on analytical and detailed estimates, this research forecast (Table 4) the financial costs involved in the construction of the two alternative scenarios.

Table 4. Comparison of the investment construction costs of the two prototypes. Cost differential (=Δ) of sustainability.

Prototype	**Common**	**Sustainable**	**Δ = Differential**	**%**
Tot €	37,156	40,378	+3221	8.66
Tot €\m^2	1456	1540	+83	
Tot €\m^3	364	385	+20	

The difference (in both monetary amount and percentage) is small (+3221 € = 8.66%).

Given a very conservative interest rate of 4% (highly prudential) the light initial extra cost for bio ecological sustainable passivation of the building in second scenario would be paid back in a few years (Table 5).

Subsequent savings, following the cost differential pay-back, represent positive added value.

Passivation using biomaterials (cork panels; marlstone-based plaster) have an acceptable pay-back time of seven years.

Table 5. Pay Back (€3541), in just seven years, of Differential Cost (€3221).

Year	Annual Saving	Anticipation Coeficient	Financial Amount	Saving Net Value
n.	€	$1/q^n$	€	€
1	590	0.96	567	567
2	590	0.92	545	1112
3	590	0.89	524	1637
4	590	0.85	504	2141
5	590	0.82	484	2626
6	590	0.79	466	3092
7	590	0.76	448	3541

4.4. Taxonomy of Multiple Contextual Benefits. Healthiness, Salubrity and Other Impact Benefits

In conclusion, the comparison of two alternative scenarios in the reference building allows for a quantitative valuation of their different energy consumption in terms of kWh, as well as CO_2 emissions, due to the above-cited low thermal conductivity of bio insulating products. The two most immediate and visible results are the lower ecological emissions and lower energy consumption. The positive impact of the use of bio ecological insulation in buildings is evident when compared to its non-adoption, not only from the energy and economic point of view. Also, healthiness and geo-strategic independence from oil are also the final goals of the strategy. All the above possess relevant economic and ecological value. In fact, future research will evaluate in multidimensional terms additional "fundamental benefits" i.e., healthier indoor and outdoor environments due to mitigated emissions as well as geostrategic independence from oil due to radical savings, which is the key geostrategy of import substitution. This research ascertained above the coherence, convergence and similar outcomes of three very different Building Energy Performance Software Programs (BEPSPs) namely EnergyPlus, Termus and Blumatica.

All the above is implemented in the following real-world case study adopting the reliable, popular and friendly Termus platform, just above tested.

Furtherly, research detected that bio ecological green buildings have higher selling prices compared to other buildings [44–52].

The Green Building strategy at the urban level initiates Post Carbon Historic Centers, Universities and Cities.

5. The Real-World Case Study

The aim of the research is to test if ecological retrofitting produces the enhancement of thermal performance of existing buildings (not preserved and not included in the national registry of monuments) and consequent energy saving, and to verify if the differential initial cost of investment has a pay-back in an acceptable short-term period.

5.1. Liberty Style City. Rebuilt after 1908-Earthquake

The case study of Reggio Calabria (Calabria, the Southernmost region of Italy, Figure 1a), a settlement (Figure 4) which was rebuilt (in Liberty style) innovatively as total anti-seismic city after the destructive earthquake and subsequent tsunami of 1908, in the Messina-Sicily and Reggio-Calabria Strait.

The reconstruction of Reggio Calabria after the earthquake of 1908 stands out because of the high quality of its urban planning which can be seen in its European urban pattern where streets and avenues converge in public squares and shape the key elements of the newly rebuilt city: The Urban Blocks. The main and peculiar characteristic of the new city of Reggio Calabria is the very small size of its Urban Blocks (about 50 × 50 m) or "blocks", and, therefore, the average small footprint is around 2500 square meter (Figure 5). This factor has created many positive effects, such as the large number of streets, the European urban character, wide tree-lined avenues, free street parking, many safe sidewalks, extended street shop-fronts, urban tree plantation, small manageable courtyards and the outstanding waterfront ("the most beautiful Italian mile").

Figure 4. City of Reggio Calabria (Calabria region, Italy). Close-up: Mediterranea University of Reggio Calabria and its four white ivory towers: - Architecture, - Engineering, - Agriculture and Forests, - Economics, Law and Human Sciences. Middle: Sea Strait of Messina-Sicily and Reggio-Calabria. Background: Etna Volcano. Source: Authors. 2020.

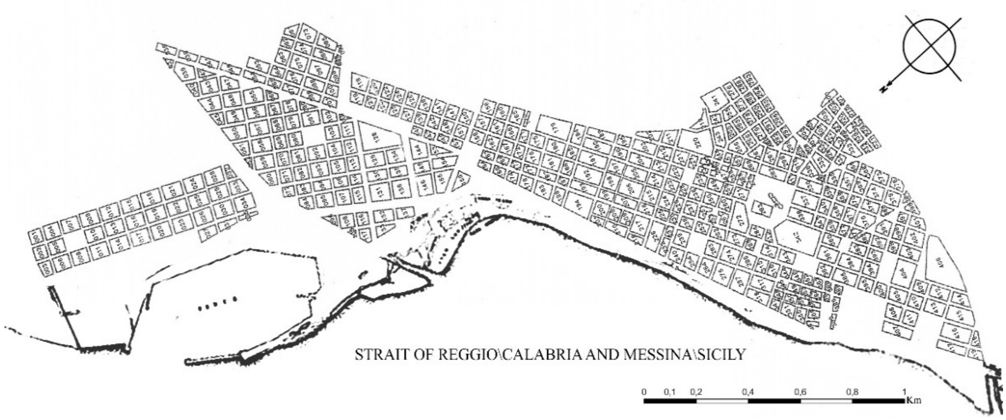


Figure 5. City of Reggio Calabria (Calabria region, Italy). Digitalization of New City Plan drawn up by Eng. Pietro De Nava, approved on March 5, 1911 and on May 14, 1914, with subdivision of the urban area into Urban Blocks numbered from #1 (North) to #419 (South), and four quartiers (from left to right: South; Center; North/Latin/University; Port/St. Catherine). Source: Authors.

5.2. Quartiers

The Liberty style post-1908-earthquake rebuilt new city is subdivided into four quartiers / districts / zones: Station/South; Center; North; St. Catherine/Port. The North zone (Figure 6) lying between the Center and St. Catherine/Port, is named the "Latin Quartier" (i.e., University Quartier) because it is very close to the Campus of Mediterranea University of Reggio Calabria. It was chosen as the area for the experimental Case Study.

Figure 6. City of Reggio Calabria (Calabria region, Italy). "Latin Quartier". From south (bottom) to north (up) on Garibaldi main street: Riace Bronzes Archaeological National Museum (bottom); experimental Urban Block # 102 (middle); Mediterranea University of Reggio Calabria, Architecture Campus (up) one of the largest of Italy and Europe. Source: Google Maps. 2001.

5.3. Green Quartier and Ecological Retrofitting of Historic Buildings

The "Latin Quartier" or University Quartier was chosen as the area for the Case Study with the aim of designing a potential Sustainable Neighborhood, Green Quartier or Energy District. In order to plan ahead and carry out the ecological retrofitting of the whole quarter, GIS (detailed in a further parallel in progress research at urban level) assessed that over 400,000 m^2 of fronts need to be eco-insulated and about 180,000 m^2 of "black flat roofs" need to be aerated-ventilated and eco-insulated. It is difficult to perform ecological retrofitting because the edifices have architectural relevance and interest, although they aren't preserved under cultural regulations or included in the monument register or heritage list, and the Liberty decorations must be restored and not destroyed.

Appropriate and compatible sustainable interventions were planned and designed for the real-world Case Study (especially eco-insulation with natural materials) and evaluated regarding their environmental and energy impacts.

Natural insulation and transpiration dramatically reduce kWh of energy consumption for winter heating, as well as for the more energy demanding summer air conditioning. The research quantified the amount of avoided mass of CO_2.

The approach might be applied to different contexts in many cities in the world.

5.4. Urban Block #102 Experimentation

Specific experimentation was implemented on Urban Block #102, an interesting Liberty architecture, on the Northern final stretch of main street (Corso Garibaldi) of the rebuilt city of Reggio Calabria. The post-earthquake reconstruction of Reggio Calabria did not include three-story buildings, due to the anti-seismic law issued after the 1908 earthquake, which prohibited buildings over two-story. On 13 March 1927, the construction of three-story buildings began to be accepted. Urban Block #102 is the first three-story construction after the 1908 earthquake, representing a unique formal and technical character among all the buildings in that period. It is located on a trapezoidal area, owned by the post-earthquake Reconstruction Authority (the so called: "Ente Edilizio") free from shacks, steeply sloping, surrounded by the Garibaldi main street (today Amendola Boulevard, East), Salazar (South), Minniti (West), Mattia Preti (North) Streets.

5.5. Urban Block #102. Two Buildings. Four Bodies

Block #102 can be classified among the European "blocks with open court" (Figure 7) category, a common type of settlement in the Reggio Calabria reconstruction.

Figure 7. "Latin Quartier" Urban Block #102. Sources: Google Maps, 2018. Vision from South (Salazar Street), bottom, to North (Preti Street), top. East: Amendola Boulevard. West: Minniti Street.

It is composed of two buildings divided by an internal courtyard (open on the streets for faster escape during potential earthquakes), covering 1565 m^2, 74% of the entire block of 2130 m^2. Each building is composed by two structural bodies, side by side. Both buildings have Liberty decorative elements in the upper part and, in the one (Minniti Street), below an ashlar. They have coloured decorations and a beautiful, coffered wood under the pitched roof, with a two-tone and decoration, typical of the Art Nouveau style.

5.6. Urban Block #102 2D Direct Survey

A direct manual geometric survey was performed using a metric roll, laser meter and plumb line, scaled and laid out in Vector 2D, geo referenced and interconnected in an urban map. Measurements of Urban Block #102 are shown below (Tables 6–8).

Table 6. Reggio Calabria. Survey measures of the Urban Block #102. Cadastral Parcel # 236.

Built Area	Built Perimeter	Roofing Area	Flat Roofing Area	Average Height	Total Built Volume	External Façade Area	Internal Courtyard Area
(mq)	(m)	(mq)	(mq)	(m)	(mc)	(mq)	(mq)
815	154	309	498	14	10,568	2018	501

Table 7. Reggio Calabria. Survey measures of the Urban Block #102. Cadastral Parcel # 144.

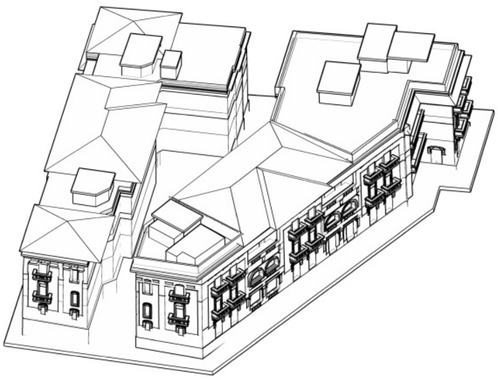
Built Area	Built Perimeter	Roofing Area	Flat Roofing Area	Average Height	Total Built Volume	External Façade Area	Internal Courtyard Area
(mq)	(m)	(mq)	(mq)	(m)	(mc)	(mq)	(mq)
738	152	382	296	12	9175	1783	501

Table 8. Reggio Calabria. Survey measures of the Urban Block #102. Total Block #102.

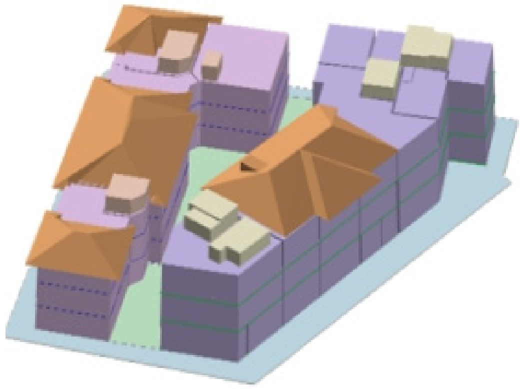
Built Area	Built Perimeter	Roofing Area	Flat Roofing Area	Average Height	Total Built Volume	External Façade Area	Internal Courtyard Area
(mq)	(m)	(mq)	(mq)	media(m)	(mc)	(mq)	(mq)
1553	307	691	794	13	19,743	3800	501

5.7. Urban Block #102 3D Direct Survey

The research created a survey from scratch. Vector 3D Urban Building System, geo referenced, was used to coordinate 3D photo assets of Google Maps and Bing Maps (centroid GPS coordinates WGS84: 38°07′05.2″ N; 15°39′19.7″) with Vector 3D direct metric surveys of specific buildings, in a city and regional framework and strategy. Accordingly, Urban Block #102 Vector 3D survey, created with the AutoCad® software (edu 2019) (Figure 8a), have been compared with 3D models created with Gis ArcMap®-ArcScene® software (10.3.1.) (Figure 8b) and overlapped with Google Maps 3D photo/images (Figure 9).



(**a**)



(**b**)

Figure 8. Urban Block #102. Comparison of direct survey drawing in: (**a**) AutoCad® 3D; (**b**) drawn in ArcMap®–ArcScene® 3D. Source: Authors.

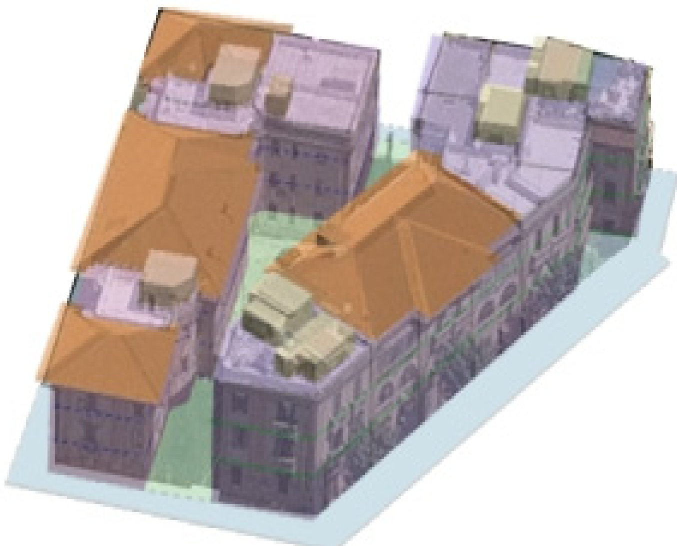


Figure 9. Urban Block #102. Survey. Overlapping of AutoCad® 3D direct survey (also drawn in ArcMap®-AscScene®) and 3D Google Maps Image, 2018. Source: Authors.

5.8. Block #102 Indirect Façade Metric Orthophotographic Survey

An indirect photographic survey was carried out and the derived metric orthophotographs of the façade/fronts were carried out (Figures 10–15), scaled and coordinated with Cadastre Systems of:

- Urban Buildings (parcels).
- Urban Real Estate Units ("Subalterni Catastali").

This coordination of both (parcels+units) is a new state-of-the-art service.

5.9. Block #102. Cadastral Systems and Data

Data from Cadastral Systems concerning urban buildings (parcels) as well as urban real estate units ("Subalterni Catastali") were collected, and uploaded to the Geo Data Base (detailed in a further parallel in progress research), and gave the following structure of buildings and units in the specific Case Study. The buildings have a total of n. 45 apartments, all horizontal, with an average of 15 apartments per floor:

- 5 apartments with 4 rooms, with kitchen, bathroom and accessories.
- 21 apartments with 3 rooms, with kitchen, bathroom and accessories.
- 11 apartments with 2 rooms, with kitchen, bathroom and accessories.
- 8 apartments with 1 room, with kitchen, bathroom and accessories.

5.10. Historical Technical Archive of City Reconstruction

The university and Town Hall saved from destruction the "Historical Technical Archive of City Reconstruction" (HiTACiR), which is source of unique, extraordinary and precious information concerning the entirely re-built total anti-seismic new city.

A giant effort to scan and computerize thousands and thousands of documents has been undertaken by the GeVaUL, Geomatic Valuation University Laboratory, of Patrimony Architecture Urbanism (PAU) Department, at Mediterranea University of Reggio Calabria, Italy. The HiTACiR Archives, organized by GeVaUL University Laboratory in a spatial DBMS engine with PostgreSQL and GIS, provides the documents of Block #102. Relevant documents are below enlisted. Documents from the archives are of utmost importance for Ecological Retrofitting of existing buildings having architectural relevance.

A few, of the many, archive documents of Urban Block #102 are listed below.

They have been reproduced, computerized and used for retrofit diagnosis, design and appraisal.

1. General planimetry. Scale 1: 500.
2. Roof plan. Scale 1: 500.
3. Ground floor plan. Scale 1: 500.
4. First floor plan. Scale 1: 500.
5. Second floor plan. Scale 1: 500.
6. Front on Garibaldi Main Street. Part A. Scale 1: 500.
7. Front on Garibaldi Main Street. Part B. Scale 1: 500.
8. Front on Mattia Preti Street. Scale 1: 500.
9. Front on Rosevelt Street. Scale 1: 500.

5.11. Urban Block #102 Needs Urgent Repair: Maintenance versus Eco Retrofitting. Over Lapping among Direct Survey and Archive Documents

Finally, a triple overlapping helped to diagnostic the repair needs of Urban Block #102 by vector direct survey; façade\front ortho photographs and documents from the archive.

All of these documents helped to ascertain the decay, degradation, deterioration and danger of plaster collapse of Urban Block #102 buildings, the need of urgent repair and the choice between two alternative Scenarios: simple maintenance versus Ecological Retrofitting with bio ecological new insulating lime-based plaster and cork panels.

The comparative valuations in the following Case Study provide empirical evidence for choosing among alternative scenarios.

5.12. Urban Block #102: Coordination among Direct Survey, Ortophoto Survey and Cadastre: Units ("Subalterni Catastali)" on Fronts\Facades

Coordination among the direct survey, orthophoto survey and Cadastral Systems made possible a new service for Ecological Retrofitting and financial management: "Subalterni Catastali" or Real Estate Units on Fronts\Facades, as reported below.

Amendola Boulevard street front (Figure 10). Alterations:

- Small alterations to East Front\Elevation; due to unauthorized elements on shop front of real estate commercial units (so called: "Subalterni Catastali").
- Relevant and invasive alterations to East Front\Elevation; due to unauthorized elements on front of residential units.

Figure 10. Reggio Calabria. Urban Block #102. Cadastral parcel n. 236. Real estate urban units (subalterni catastali) from Urban Building Cadastre. Garibaldi main street (today: Amendola boulevard) front/façade. Orthophotography. Scale 1: 500. Source: authors' survey.

Relevant alterations to roof; due to new volume on the roof, not included in original design (Archive documents).

Mattia Preti Street front (Figure 11). Degradations and alterations to the elevation Florentine-type ashlar and related moldings: rising damp; vandal stains; graffiti; dirt.

Figure 11. Reggio Calabria. Urban Block #102. Cadastral parcels: (**left**) n. 236, (**right**) n. 144. Real estate urban units (subalterni catastali) from Urban Building Cadastre. Mattia Preti Street front. Orthphotography. Scale 1: 500. Source: authors' survey.

Salazar Street front (Figure 12). Degradations and alterations to the elevations\fronts:

- first floor: new window frames\fixtures, different from the previous as well as from the original design reproduced and attached in the appendix;
- second floor: new window frames and shutters, addition of new volumes not included in the original design, reproduced and attached in the appendix;
- third floor: new window frames and shutters, addition of new volumes not included in the original design in the archive documents.

Figure 12. Reggio Calabria. Urban Block #102. Cadastral parcels (**left**) n. 144, (**right**) n. 236. Real estate urban units (subalterni catastali) from Urban Building Cadastre. Salazar Street front. Orthophotography. Scale 1: 500. Source: author's survey.

Courtyard Amendola/East side front (Figure 13). Degradations and alterations side, elevations\fronts: new window frames\fixtures, different from previous as well as those of the original design in the archive documents.

Figure 13. Reggio Calabria. Urban Block #102. Cadastral parcel n. 236. Real estate urban units (subalterni catastali) from Urban Building Cadastre. Courtyard east side front (Amendola side). Orthophotography. Scale 1: 500. Source: author's survey.

Minniti Street front (Figure 14). Degradations and alterations to the elevations\fronts: new window frames\fixtures, different from previous as well as those of the original design in the archive documents.

Figure 14. Reggio Calabria. Urban Block #102. Cadastral parcel n. 144. Real estate urban units (subalterni catastali) from Urban Building Cadastre. Minniti Street front. Orthophotography. Scale 1: 500. Source: authors' survey. Minniti Street elevation\front.

Courtyard Minniti/West side front (Figure 15). Degradations and alterations to the elevations\fronts: new window frames\fixtures, different from previous as well as those from the original design in the archive documents.

Figure 15. Reggio Calabria. Cadastral parcel n. 144. Real estate urban units (subaltern catastali). from Urban Building Cadastre. Courtyard side Front. Orthophotography. Scale 1: 500. Source: authors' survey. Courtyard side elevation\front.

6. Units and Building Energy Performances Simulation Outcomes: kWh Consumption and CO_2 Emission in Alterative Common and Sustainable Scenarios

6.1. Foreword. Taxonomy of Back Bone External Works

The present research performed thermal and energy assessments of Urban Block #102 consisting of two distinct buildings (Figures 7–9) made up of various units: one facing Minniti Street and the one facing Amendola Boulevard/Street (city main street).

An important goal pursued in the Green Building and Post Carbon City Strategies is the strong enhancement of thermal building performance, and consequential significant energy saving, with affordable additional costs with respect to ordinary maintenance without energy enhancement. The key external works listed below are the backbone of the Ecological Retrofit approach:

- new insulating plaster (on the vertical walls) based on natural mineral Marlstone and on derived natural hydraulic lime, NHL (so called: "*calce romana*");
- new insulation for a flat roof, a terrace or a pitched roof, based on natural vegetal cork panels derived from local (Circular Economy) and Mediterranean cork oak forests, and on an additional new slope layer based on natural mineral expanded (insulating) pearly-stone;
- new insulation for the crawl space on slab intrados based on natural vegetal cork derived from local and Mediterranean cork oak forests;
- efficient new windows possessing optimum thermal efficiency involving window-structures based on natural wood or chloride or PVC, and low-emission stratified double/triple glazing.

6.2. Energy Performance of Each of 54 Real Estate Units of Block #102

Quantitative Energy Performances Simulations (EPS) were carried out for both the Common (CS) and Sustainable Scenario (SS) interventions adopting the EPSP friendly software TerMus tested and selected in previous research section. Each unit of each building of Urban Block #102 (total of 54) have been evaluated in its energy performance, comparing the Common (CS) and the Sustainable Scenario (SS) with respect to annual total energy consumption in kWh and total carbon dioxide emission in CO_2 kg; annual unitary energy consumption in kWh/m^2 per year, and unitary emission in CO_2/m^2 per year. A total of 216 EPS.

The EPSP software provided the following outputs regarding:

- Envelope index (EPi, inv), i.e., the energy dispersed by the building itself.
- Global primary energy index (EPgl), which demonstrates the efficiency of both the building-plant system on heating and the domestic hot water production and distribution system.
- CO_2, i.e., the Kg of Carbon Dioxide that the building and heating system emits into the environment.

The energy consumption and CO_2 emission values of the Common (SC) and Sustainable (SS) Scenarios and differential (Δ) are shown in the Table 9 below.

Table 9. Reggio Calabria. Block #102. Summary table about energy consumption and pollution.

Energy Assessment per Year		Consumption	CO_2 Assessment per Year		
Common Scenario	(kWh)	379,753	CO_2 Common Scenario	(kWh)	74,393
Sustainable Scenario	(kWh)	199,443	CO_2 Sust.Scenario	(kWh)	32,374
Energy Saving Δ	(kWh)	180,310	CO_2 Avoided Emission Δ	(kWh)	42,017
Energy Saving	(%)	47%	CO_2 Saving Pollution	(%)	57%

The quantification of energy savings makes it possible to establish whether the proposed intervention is part of the National and European Strategies of the Ecological Transition. The clear approach of Ecological Retrofitting (based on bio-ecological, natural and oil-free materials) reached the goal of a strong enhancement of thermal building performance, and of significant energy saving because of key interventions listed above.

Successful enhancement of thermal building performance was quantified by Building Energy Performance Simulation using the Termus tool.

There was remarkable energy significant saving of around 47% (kWh:379,752–199,443 = 224,438), and a CO_2 emission huge mitigation of 57% (kg: 74,393–32,374 = 42,016).

The next step was to estimate of investment cost differential between the Common Scenario intervention and the Sustainable Scenario intervention and the years needed for the pay-back of this differential investment cost, to understand if the success in energy saving (even in a cultural relevant historic building) is bearable in financial terms.

It is important to determine if after the additional and differential initial cost is paid back, the permanent energy saving in the building will create continuing added value. This must be considered at both the unit and building level, as well as at the larger cumulative ward, quartier, city, region and country level.

7. Cost Estimation and Pay-Back over Time

7.1. Ecological Retrofit Strategy and Circular Economy

The present research attempted to respond to the Ecological Retrofitting review call by approaching the retrofitting of historic buildings using natural, bioecological, historical, renewable/recyclable and local/regional raw materials in the framework of the Circular Economy. In the proposed Ecological Retrofitting strategy, the key raw materials for bio sustainable insulation in creating a Green Building are natural cork and marlstone. Both of them come from the region, and their use and enhancement help the Circular Economy of the region as well as the Strategy for the Post Carbon City and Green Region.

7.2. Cost Engineering: Bridging Quantity Estimation

The few targeted works were specifically for two alternative Scenarios (Common/Maintenance versus Sustainable/Eco-Retrofitting), subdivided and detailed into simpler and necessary indivisible operations ("*Lavorazioni*") and the specific measures which to be implemented in a real world "chantier" or construction site. The required number of necessary indivisible operations ("*Lavorazioni*") were estimated by using highly detailed surveys (directly in-the-field as well as ortho photographic) and documents from the historical archives, which were collected in the early stages of the case study. In this research, the "*Lavorazioni*", or the number of necessary indivisible operations, are reported in English as well as in the original language of the *chantier* or construction site.

7.3. Cost Estimation

A detailed assessment to obtain the cost estimation was made using Elementary Factor Analysis (EFA). The aim was to obtain an analytical evaluation (not just a rough estimate, neither heuristic-intuitive) of the resources needed for the actual implementation of the intervention on the two buildings of block #102.

To achieve this purpose, an information module was developed with:

- the necessary processes for the passivation intervention;
- related microeconomic analyses of the elementary factors used i.e., economic production function;
- estimates of the market prices of the factors.

Subsequently, microeconomic analyses of elementary factors were compared with information available in local markets on price lists and tariff rates.

The final result is the estimate of the costs of the two chosen intervention scenarios which are realistically applicable in an energy requalification intervention i.e., comparing the intervention known as Business as Usual or BAS, in the Common Scenario, and that of Sustainable and Ecological innovation, in the Sustainable Scenario. Insulating the building with natural hydraulic lime mortar determines the climactic and energy effects, the return from which is calculated and financially analyzed in the pay-back.

The sum of all the processes, estimated here with Elementary Factor Analysis (EFA), provides the Estimative Metric Calculation (EMC) of the entire work.

The following are the "*Lavorazioni*" quantities in the EMC framework for each of the two identified and compared scenarios.

7.3.1. Retrofitting Cost Report. Metric Calculation. Scenario #1: Common Scenario

The operation quantities in Common Scenario #1 for simply maintenance of two buildings are estimated in the following Table 10.

Table 10. Reggio Calabria (Italy). Block #102. Cadastral Parcel #236. Building: Via Amendola. Cadastral Parcel #144. Building: Via Via Minniti. Metric Calculation. Scenario 1: Common Scenario.

No	Cod	Parcel#236, Indivisible Operations/Processing ("Lavorazioni")	U.M.	Quantity
		PROSPETTI. FRONTS\ELEVATIONS		
01	L1	Ponteggi prefabbricati Prefabricated scaffolding	mq	2335.23
02	L2	Rimozione pluviali e canali di gronda Removal of roof rainwater gutters and downspout pipes	ml	218.49
03	L3	Pluviali e canali di gronda nuovi New roof rainwater gutters and downspout pipes	ml	218.49
04	L4	Rimozione unità esterne condizionatori e parabole Removal of external air conditioning Condenser units and satellite dishes	cad	25.00
05	L5	Condizionatori Olimpia Splendid. Boiler Unico New special (single unit) Air Conditioner "Olimpia Splendid"	cad	22. 00
06	L6	Demolizione intonaco (tranne tutti i decori) Existing plaster demolition	mq	1135.43
07	L7	Trasporto macerie presso discarica autorizzata The transport of rubble, and its disposal in authorized landfills	mc	45.43
08	L8	Pulitura superfici con acqua a bassa pressione Low pressure wall washing	mq	1703.87
		BAS, Business As Usual. INTONACO COMUNE. BAS PLASTER		
09	L10	Completo ponte di aderenza. Plaster: bridge of adhesion; render; primer; basecoat (layer 01)	mq	1135.43
10	L11	Completo spiano Plaster floating coat (layer 02)	mq	1135.43

Table 10. *Cont.*

No	Cod	Parcel#236, Indivisible Operations/Processing ("Lavorazioni")	U.M.	Quantity
11	L12	Completa rasatura Plaster setting (layer 03)	mq	1135.43
12	L14	Completa finitura Plaster finishing (layer 04)	mq	1135.43
13	L16	Completo fissativo Plaster: prepaint; paint primer (layer 05)	mq	1135.43
18	L18	Completa tinteggiatura Plaster paint (layer 06)	mq	1135.43
		INFISSI [#236. Mq 296.06]. FIXTURES		
19	L19	Smontaggio infissi lignei e di alluminio Removal of existing wooden and metal fixtures	mq	296.06
21	L21	Infissi in alluminio taglio freddo. Vetro camera 4-12-4 Aluminum fixtures. No insulating. Double glazing	mq	296.06
		ELEMENTI. ELEMENTS		
22	L22	Scartavetratura, verniciatura e protettivo su metallo Metal sanding (sandpaper), polishing, restoration and painting	mq	57.72
23	L23	Scartavetratura, stuccatura e vernice su legno Wood sanding (sandpaper), polishing, restoration and painting	mq	47.80
		DECORI. DECORATIONS		
24	L24	Pulitura manuale con spazzola di saggina (decori) Cleaning of decorations with broomcorn brush	mq	568.84
25	L25	Integrazione di parti mancanti nei decori Integration of the gap in decorations	mq	5.90
		RIMOZIONI. DEMOLITIONS		
26	L26	Rimozione parti non conformi Demolition of unauthorized elements and parts	mq	85.39
27	L27	Rimozione superfetazioni Demolition of unauthorized constructions	mc	72.19
		STRUTTURE. STRUCTURES		
28	L28	Trattamento antiruggine acciaio strutturale FE b 38K Rust-proof treatment of structural steel	ml	1468.10
30	L30	Completa malta rinforzata TCA-MI per lesione Special reinforced structural mortar for structural damage repair	ml	9.28
		COPERTURE, TERRAZZI. ROOFS FLAT ROOFS\TERRACES		
31	L31	Demolizione pavimentazione Demolition of flat roof pavement	mq	423.98
32	L32	Rimozione guaina Removal of existing deteriorate waterproofing asphalt	mq	423.98
33	L33	Demolizione massetto Demolition of screed	mc	42.39
34	L34	Massetto delle pendenze Sloping floor screed	mq	423.98
35	L35	Completa nuova guaina bituminosa New waterproofing bituminous membrane	mq	423.98
36	L36	Nuova pavimentazione in piastrelle di gres New gres tile pavement	mq	423.98
#236				

Table 10. *Cont.*

No	Cod	Parcel#144, Indivisible Operations/Processing ("Lavorazioni")	U.M.	Quantity
		PROSPETTI. FRONTS\ELEVATIONS		
01	L1	Ponteggi prefabbricati Prebabricated scaffolding	mq	1819.13
02	L2	Rimozione pluviali e canali di gronda Removal of roof rainwater gutters and downspout pipes	ml	188.52
03	L3	Pluviali e canali di gronda nuovi New roof rainwater gutters and downspout pipes	ml	188.52
04	L4	Rimozione unità esterne condizionatori e parabole Removal of external air conditioning Condenser units and satellite dishes	cad	10.00
05	L5	Condizionatori Olimpia Splendid. Boiler Unico New special (single unit) Air Conditioner "Olimpia Splendid"	cad	10.00
06	L6	Demolizione intonaco (tranne tutti i decori) Existing plaster demolition	mq	1246.40
07	L7	Trasporto macerie presso discarica autorizzata The transport of rubble, and its disposal in authorized landfills	mc	62.88
08	L8	Pulitura superfici con acqua a bassa pressione Low pressure wall washing	mq	1246.40
		BAS, Business as Usual. INTONACO COMUNE. BAS PLASTER		
10	L10	Completo ponte di aderenza Plaster: bridge of adhesion; render; primer; basecoat (layer 01)	mq	1246.40
11	L11	Completo spiano Plaster floating coat (layer 02)	mq	1246.40
12	L12	Completa rasatura Plaster setting (layer 03)	mq	1246.40
14	L14	Completa finitura Plaster finishing (layer 04)	mq	1246.40
16	L16	Completo fissativo Plaster: prepaint; paint primer (layer 05)	mq	1246.40
18	L18	Completa tinteggiatura Plaster paint (layer 06)	mq	1246.40
		INFISSI [mq in #144 parcel. 106.05 + 131.77 = 237.82]. FIXTURES		
19	L19	Smontaggio infissi lignei Removal of existing metal fixtures	mq	106.05
20	L20	Smontaggio infissi in metallo Removal of existing metal fixtures	mq	131.77
21	L21	Infissi in alluminio taglio freddo. Vetro camera 4-12-4 Aluminum fixtures. Uninsulated. Double glazing	mq	237.82
		ELEMENTI. ELEMENTS		
22	L22	Scartavetratura, verniciatura e protettivo su metallo Metal sanding (sandpaper), polishing, restoration and painting	mq	37.72
23	L23	Scartavetratura, stuccatura e vernice su legno Wood sanding (sandpaper), polishing, restoration and painting	mq	91.81
		DECORI. DECORATIONS		
24	L24	Pulitura manuale con spazzola di saggina (decori) Cleaning of decorations with broomcorn brush	mq	259.55
25	L25	Integrazione di parti mancanti nei decori in eps Integration of the gap in decorations	mq	1.06

Table 10. *Cont.*

No	Cod	Parcel#144, Indivisible Operations/Processing ("Lavorazioni")	U.M.	Quantity
		RIMOZIONI. DEMOLITIONS		
26	L26	Rimozione parti non conformi Demolition of unauthorized elements and parts	mq	42.58
27	L27	Rimozione superfetazioni Demolition of unauthorized constructions	mc	16.76
		STRUTTURE. STRUCTURES		
28	L28	Trattamento antiruggine acciaio strutturale FE b 38 K Rust-proof treatment of structural steel	ml	220.07
30	L30	Completa malta rinforzata TCA-MI per lesione Special reinforced structural mortar for structural damage repair	ml	1.00
		COPERTURE, TERRAZZI. ROOFS, FLAT ROOFS\TERRACES		
31	L31	Demolizione pavimentazione Demolition of flat roof pavement	mq	218.73
32	L32	Rimozione guainaRemoval of existing deteriorate waterproofing asphalt	mq	218. 73
33	L33	Demolizione massetto Demolition of screed	mc	17.50
34	L34	Massetto delle pendenze Sloping floor screed	mq	218.73
35	L35	Completa nuova guaina bituminosa New waterproofing bituminous membrane	mq	218.73
36	L36	Nuova pavimentazione in piastrelle di gres New gres tile pavement	mq	218.73
#144				

7.3.2. Retrofitting Cost Report. Metric Calculation. Scenario 2: Sustainable Scenario

The operation quantities in Sustainable Scenario #2 for Ecological Retrofitting of two buildings are estimated in the following Table 11.

Table 11. Reggio Calabria (Italy). Block #102. Cadastral Parcel #236. Building: Via Amendola. Cadastral Parcel #144. Building: Via Minniti. Metric Calculation. Scenario 2: Sustainable Scenario.

No	Cod	Parcel#236, Indivisible Operations/Processing	U.M.	Quantity
		PROSPETTI. FRONTS\ELEVATIONS		
01	L1	Ponteggi prefabbricati Prefabricated scaffolding	mq	2335.23
02	L2	Rimozione pluviali e canali di gronda Removal of roof rainwater gutters and downspout pipes	ml	218.49
03	L3	Pluviali e canali di gronda nuovi New roof rainwater gutters and downspout pipes	ml	218.49
04	L4	Rimozione unità esterne condizionatori e parabole Removal of external air conditioning Condenser units and satellite dishes	cad	25.00
05	L5	Condizionatori Olimpia Splendid. Boiler Unico New special (single unit) Air Conditioner "Olimpia Splendid"	cad	22.00
06	L6	Demolizione intonaco (tranne tutti i decori) Existing plaster demolition	mq	1135.43
07	L7	Trasporto macerie presso discarica autorizzata The transport of rubble, and its disposal in authorized landfills	mc	45.42

Table 11. *Cont.*

No	Cod	Parcel#236, Indivisible Operations/Processing	U.M.	Quantity
08	L8	Pulitura superfici muri con acqua a bassa pressione Low pressure wall washing	mq	1703.87
10	L10	Completo ponte di aderenza Plaster: bridge of adhesion; render; primer; basecoat (layer 01)	mq	232.98
11	L11	Completo spiano Plaster floating coat (layer 02)	mq	239.98
12	L12	Completa rasatura Plaster setting (layer 03)	mq	232.98
14	L14	Completa finitura Plaster finishing (layer 04)	mq	232.98
16	L16	Completo fissativo Plaster pre-paint (layer 05)	mq	232.98
18	L18	Completa tinteggiatura Plaster paint (layer 06)	mq	232.98
		INFISSI. FIXTURES		
19	L19	Smontaggio infissi lignei e di alluminio Removal of existing wooden and metal fixtures	mq	296.06
21	L21	Infissi a taglio termico Insulating fixture. Triple glazing	mq	296.06
		ELEMENTI. ELEMENTS		
22	L22	Scartavetratura, verniciatura e protettivo sui metalli Metal sanding (sandpaper), polishing, restoration and painting	mq	57.72
23	L23	Scartavetratura, stuccatura e vernice su legno Wood sanding (sandpaper), polishing, restoration and painting	mq	47.80
		DECORI. DECORATIONS		
24	L24	Pulitura manuale con spazzola di saggina (decori) Cleaning of decorations with broomcorn brush	mq	568.84
25	L25	Integrazione di parti mancanti nei decori Integration of the gap in decorations	mq	5.90
		RIMOZIONI. DEMOLITIONS		
26	L26	Rimozione parti non conformi Demolition of unauthorized elements and parts	mq	85.39
27	L27	Rimozione superfetazioni Demolition of unauthorized constructions	mc	72.19
		STRUTTURE. STRUCTURES		
28	L28	Trattamento antiruggine acciaio strutturale FE b 38K Rust-proof treatment of structural steel	ml	1430.86
30	L30	Completa malta rinforzata TCA-MI per lesione Special reinforced structural mortar for structural damage repair	mq	9.28
		COPERTURE, TERRAZZI. ROOFS, FLAT ROOFS\TERRACES		
31	L31	Demolizione pavimentazione Demolition of flat roof pavement	mq	423. 98
32	L32	Rimozione guaina Removal of existing deteriorate waterproofing asphalt	mq	423.98
33	L33	Demolizione massetto Demolition of screed	mc	423.39

Table 11. *Cont.*

No	Cod	Parcel#236, Indivisible Operations/Processing	U.M.	Quantity
37	L37	Pannello in sughero Slim 4 cm Eco bio insulating cork panel 4 cm	mq	423.98
38	L38	Pannello in sughero Genius (3 + 2.5) cm Eco bio insulating cork panel 5.5 cm	mq	423.98
39	L39	Posa in opera tavelloni 100 × 25 cm Hollow flat brick blocks	mq	423.98
34	L34	Massetto delle pendenze Sloping floor insulating screed	mq	423.98
40	L40	Guaina traspirante Tyvek Eco wicking\breathable waterproof fabric	mq	423.98
41	L41	Pavimento flottante gres Floating gres tile pavement	mq	423.98
		INTONACO BIO ECO SOSTENIBILE ISOLANTE. BIO ECO SUSTAINABLE INSULATING PLASTER		
44	L44	Completo ponte di aderenza Hd System Td13pa Bio natural lime-based basecoat\bridge of adhesion (layer 01)	mq	903.34
46	L46	Completo intonaco termocoibente Hd System Volcalite Bio natural lime-based floating coat (layer 02)	mq	903.34
48	L48	Completa rasatura Hd System Td13p1 Bio natural lime-based setting (layer 03)	mq	903.34
50	L50	Completa finitura colorata Hd System Arenino Ar20 Bio natural lime-based colored finishing (layer 04)	mq	903.34
#236				
No	Cod	Parcel#144. Indivisible Operations/Processing	U.M.	Quantity
		PROSPETTI. FRONTS\ELEVATIONS		
1	L1	Ponteggi prefabbricati Prefabricated scaffolding	mq	1819.13
2	L2	Rimozione pluviali e canali di gronda Removal of roof rainwater gutters and downspout pipes	ml	188.52
3	L3	Pluviali e canali di gronda–First plast New roof rainwater gutters and downspout pipes	ml	188.52
4	L4	Rimozione unità esterne condizionatori e parabole Removal of external air conditioning Condenser units and satellite dishes	cad	10.00
5	L5	Condizionatori Olimpia Splendid–Boiler Unico New special (single unit) Air Conditioner "Olimpia Splendid"	cad	10.00
6	L6	Demolizione intonaco (tranne tutti i decori) Existing plaster demolition	mq	1246.40
7	L7	Trasporto macerie presso discarica autorizzata The transport of rubble, and its disposal in authorized landfills	mc	62.88
8	L8	Pulitura con acqua a bassa pressione Low pressure wall washing	mq	1246.40
		INFISSI [mq in #144 parcel:. 106.05 + 131.77 = 237.82]. FIXTURES		
19	L19	Smontaggio infissi lignei Removal of existing wooden fixtures	mq	106.05
20	L20	Smontaggio infissi metallici Removal of existing metal fixtures	mq	131.77
21	L21	Infissi a taglio termico Insulating fixtures. Triple glazing	mq	237.82

Table 11. *Cont.*

No	Cod	Parcel#144. Indivisible Operations/Processing	U.M.	Quantity
		ELEMENTI. ELEMENTS	E	
22	L22	Scartavetratura, verniciatura e applicazione protettivo su metalli Metal sanding (sandpaper), polishing, restoration and painting	mq	37.72
23	L23	Scartavetratura, stuccatura e applicazione vernice su legno Wood sanding (sandpaper), polishing, restoration and painting	mq	91.81
		DECORI. DECORATIONS		
24	L24	Pulitura manuale con spazzola di saggina Cleaning of decorations with broomcorn brush	mq	259.55
25	L25	Protettivo ad emulsioni art shield1 Art shield protective emulsions	mq	1.06
		RIMOZIONI. DEMOLITIONS		
26	L26	Rimozione parti non conformi Demolition of unauthorized elements and parts	mq	42.58
27	L27	Rimozione superfetazioni Demolition of unauthorized constructions	mc	16.76
		STRUTTURE. STRUCTURES		
29	L28	Trattamento antiruggine acciaio strutturale FE b 38K Rust-proof treatment of structural steel	ml	220.07
30	L30	Completa malta rinforzata TCA-MI per lesione Special reinforced structural mortar for structural damage repair	mq	1.00
		COPERTURE, TERRAZZI. ROOFS, FLAT ROOFS\TERRACES		
31	L31	Demolizione pavimentazione Demolition of flat roof pavement	mq	218.73
32	L32	Rimozione guaina Removal of existing deteriorate waterproofing asphalt	mq	218.73
33	L33	Demolizione massetto Demolition of screed	mc	21.87
37	L37	Pannello in bio sughero Slim 4 cm Eco bio insulating cork panel 4 cm	mq	218.73
38	L38	Pannello in bio sughero Genius (3 + 2.5) cm Eco bio insulating cork panel (3 + 2.5) cm	mq	218.73
39	L39	Posa in opera tavelloni 100 × 25 cm Hollow flat brick blocks	mq	218.73
34	L34	Massetto delle pendenze Sloping floor insulating screed	mq	218.73
40	L40	Nuova guaina traspirante Tyvek Ecological wicking waterproof fabric	mq	218.73
41	L41	Pavimento flottante in gres Floating gres tile pavement	mq	218.73

Table 11. *Cont.*

No	Cod	Parcel#144. Indivisible Operations/Processing	U.M.	Quantity
		INTONACO BIO ECO SOSTENIBILE ISOLANTE BIO ECO SUSTAINABLE INSULATING PLASTER		
44	L44	Completo ponte di aderenza Hd System Td13pa Bio natural lime-based basecoat\bridge of adhesion (layer 01)	mq	1246.40
46	L46	Completo intonaco termocoibente Hd System Volcalite Bio natural lime-based floating coat (layer 02)	mq	1246.40
48	L48	Completa rasatura Hd System Td13p1 Bio natural lime-based setting (layer 03)	mq	1246.40
50	L50	Completa finitura colorata Hd System Arenino Ar20 Bio natural lime-based colored finishing (layer 04)	mq	1246.40
#144				

7.4. Necessary Indivisible Operation Cost Estimation

The present research provides an information and estimation module with:

- the technologies used in the necessary indivisible operations;
- the consequent production functions, compared with information commonly known and available in local markets;
- microeconomic analysis of the necessary indivisible operations and their Elementary Factors (so called: "Elementary Factor Analysis, EFA");
- estimates of the market prices of the factors.

The above detailed estimate was performed with Elementary Factor Analysis (EFA) obtaining the detailed analytical (non-heuristic) cost estimation of the two alternative interventions:

- Business As Usual, in the Common Scenario;
- Ecological Retrofitting, in the Sustainable Scenario.

The sum up of all the necessary indivisible operation ("Lavorazioni") costs are estimated here (Table 12) with Elementary Factor Analysis (EFA) and provides the Estimated Metric Cost (EMC) of the whole work for each of the two compared scenarios.

Table 12. Reggio Calabria. Block #102. Monetary Estimated Metric Calculation (mEMC) in €.

#236		Total Amount. Common Scenario	€	283,670
#144		Total Amount. Common Scenario	€	249,943
block	#102	Total Amount. Common Scenario	€	533,614
#236		Total Amount. Sustainable Scenario	€	337,225
#144		Total Amount. Sustainable Scenario	€	281,797
block	#102	Total Amount. Sustainable Scenario	€	619,023

7.5. Estimate of Energy Management Costs and CO_2 Emissions

The information/valuation and the decision-making system provided data on the remarkable savings produced by Ecological Retrofitting, or passivation, both in terms of energy and CO_2 emissions. Extensive and complex market research provides advice and figures regarding the energy and pollution costs, at least at the first and preliminary stage of technical costs (not the changeable market price to final consumers that will be calculated in the second stage of the research) which seem to be as follows:

- Energy (€/kWh): 0.35; (statistical technical cost for the average user);
- CO_2 (€/kg): 0.25; (equivalent environmental cost [36–43]).

The information/valuation and decision-making system results (Table 13) show that by passivating, the annual energy consumption of block #102 in the Common Scenario is 379,752 kWh per year which, after Ecological Retrofitting or passivation, remarkably drops to 199,443 kWh per year. Ecological Retrofitting or passivation also affects CO_2 emissions, which in the Common Scenario are 74,393 kg of CO_2, per year, which after Ecological Retrofitting or passivation remarkably drop to just 32,374 kg.

Table 13. Reggio Calabria. Block #102. Energy and CO_2 Management Costs.

Termus (Acca)	Energy Consumption	Energy U.C.	Energy Management Cost	CO_2 Emissions	CO_2 E.C.	CO_2 Annual Cost
Scenarios	kWh	€/kWh	€	kg	€/kg	€
Common	379,753	0.35	132,913	74,393	0.25	18,598
Sustainable	199,443	0.35	69,805	32,374	0.25	8094
Δ	−180,310		−63,108	42,019		−10,505

The information/valuation and decision-making system provides the results (Table 14) of the Total Estimated Metric Cost (EMC) for the Common and Sustainable Scenario of Block #102, sum of the two Cadastral Parcels #236 and #144, and are as follows:

Table 14. Reggio Calabria. Block #102. Cadastral Parcels #236 and #144. Total Cost Estimated Metric Calculation (EMC) for Common and Sustainable Scenario and differential (Δ).

Total Amount. Common Scenario	€	533,614
Total Amount. Sustainable Scenario	€	619,023
Common Scenario/Sustainable Scenario Differential	Δ	85,409
% Increase in the cost of implementation	%	16%

By only considering the annual saving in energy expenses from the analysis of the annual savings table, the time of return (Pay-Back Period) of the differential (higher initial cost of Ecological Retrofitting) is obtained (Table 15).

Table 15. Pay-back period of the differential of the technical intervention cost. Conservative interest rate: 4%. Progressive sum of saving = Total Saving/Sum Up.

	Monetary Annual Saving	Anticipation Coefficient	Annual Present Value	Sum Up
	€	**$1/q^n$**	**€**	**€**
1	63,108	0.96	60,584	60,584
2	**63,108**	**0.92**	**58,060**	**118,643**
3	63,108	0.89	56,166	174,810
4	63,108	0.85	53,642	228,452
5	63,108	0.82	51,749	280,200
6	63,108	0.79	49,855	330,056
7	63,108	0.76	47,962	378,018
8	63,108	0.73	46,069	424,087
9	63,108	0.70	44,176	468,263
10	63,108	0.68	42,914	511,177
11	63,108	0.65	41,020	552,197
12	63,108	0.62	39,127	591,324
13	63,108	0.60	37,865	629,189
14	63,108	0.58	36,603	665,792
15	63,108	0.56	35,341	701,132
16	63,108	0.53	33,447	734,580
17	63,108	0.51	32,185	766,765
18	63,108	0.49	30,923	797,688
19	63,108	0.47	29,661	827,349
20	63,108	0.46	29,030	856,378

Note: Pay back of initial investment cost differential in just two years. The additional saving after two year pay back is further added value of the project/intervention.

8. First Results and Conclusions

Recent comprehensive reviews [1] concerning global warming, a Green Building exit strategy from the planet's ecological crisis and Building Energy Performance Simulation Programs encourage researchers to provide help and advice to asset users, holders, contractors and all interested parties in building energy retrofitting who have attempted to:

- adopt natural, bio-ecological, historical, renewable/recyclable and local/regional raw materials in the framework of the Circular Economy;
- include in the energy retrofit strategy the challenging aim of conserving and restoring existing buildings of architectural relevance;
- enhance the energy performance of such existing buildings;
- estimate the energy enhancement of such constructions as a result of few targeted external works (=Lavorazioni), examining, in particular, the initial investment costs and the longer-term multiple benefits stemming from structural energy saving as well as permanent CO_2 emission mitigation.

The present research addresses the reviews [1] by contributing:

- an existing building retrofit implementation approach by adopting natural, bio-ecological, historical, recyclable/renewable and local/regional materials in the framework of the Circular Economy;
- a real-world test in a case study of bio-ecological retrofitting in the challenging area of existing buildings of architectural importance (although not preserved and not included in the heritage list and record of monuments) such as those in the case study carried out on the main street (Amendola boulevard; previous Garibaldi corso) of the rebuilt post-1908-earthquake, total anti-seismic, innovative new city of Reggio Calabria;
- an assessment (ecological as well as financial) of energy saving and CO_2 emission mitigation;
- an assessment of the initial investment costs involved in ecological retrofitting works (versus ordinary maintenance without energy enhancement) adopting a valuation based on scientific analytical techniques (with the estimate of the micro-economic production functions of indivisible works = "Lavorazioni") instead of just heuristic or empirical cost intuition;
- a forecast of the pay-back period of the additional differential initial cost of sustainable interventions compared with Business as Usual (BAS) ordinary upkeep works.

The valuation and appraisal scientific discipline contribute to this strategy [82–139] which can be tested in further case studies.

The real-world experimentation in the provided case study achieved the important goal of the Green Building and Post Carbon City strategies i.e. the significant enhancement of building thermal performance resulting from a few targeted keys works (="*Lavorazioni*") and the consequent permanent structural saving of energy in those existing constructions.

Indeed, the case study data obtained with the help of the geo data base engineered by PostgreSQL and GIS (which will be presented in detail in future research) is very encouraging because when ecological retrofitting (Sustainable Scenario) is compared with ordinary mandatory usual simply maintenance (Common Scenario, or Business as Usual upkeep, BAS) the following observations can be made:

- energy saving amounts to 47%;
- related monetary annual saving is € 63,108;
- avoided CO_2 pollution is 57%,
- the related monetary annual equivalent estimate of avoided ecological damage is € 10,505;
- the additional initial cost of sustainable works is a mere 16% extra where this extra cost is calculated compared to the common scenario;
- the pay-back period of the additional differential cost of sustainable interventions is just two years.

All of the above show that these existing buildings can be bio-ecologically retrofitted at a reasonably affordable additional initial investment cost and the cost differential pay-back is fast, acceptable and over a short period of time.

As mentioned above, the present research does not address spatial information because further parallel research is developing a joint system based upon state of the art PostgreSQL rsDBMS and GIS at a unit and building level. This constitutes a first crucial step in the formulation of an imminent future proposal concerning decision support systems to be implemented at the wider level. Furthermore, future research will attempt to address the retrofitting of huge existing building stocks/portfolios on a larger scale i.e., at the ward, quartier, city, region and country level.

For other buildings included in the heritage lists and in the record of monuments, relevant research, such as [140–142], among others, are greatly helpful

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