Valuation of Seismic, Energy, Architectural. The Role of GIS

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Riassunto
Obiettivo della ricerca è di prefigurare una strategia sia di riqualificazione urbana che di prevenzione sismica per l'edificato storico che sintetizzi contestualmente tre diversi importanti aspetti: manutenzione ordinaria e straordinaria dei caratteri costruttivi-estetici-storico-artistici; interventi di sostenibilità energetica per rafforzare le originarie già efficienti caratteristiche climatiche dell'architettura storica; verifica e miglioramento sismico. La ricerca ha permesso di: conoscere a fondo l'originale quartiere "antisismico" ricostruito dopo eventi tellurici devastanti in modo da resistere ai sismi futuri; acquisire informazioni e svolgere confortanti verifiche sismiche sull'edificio prototipale interno al Quartiere; derivare indicazioni d'intervento generalizzato all'intero quartiere del Caso di Studio e dei relativi costi limitatamente alla conservazione.

1. Background

States and international organizations are aware of Earth environmental emergency, as well as of urban ecological and energy crisis. One causal factor among several is the disinvestment of existing settlements and the migration of high percentage of rural population to megalopolis where consequent is the urbanization of all available rural land surrounding original built areas and the increase of energy consumption. Communities and territories are addressed to treasure and re-use the consolidated settlements, not to abandon them, and therefore to save the open and arable land surrounding metropolis and megalopolis, by means of: revitalization of economy in historic towns and villages; physical rehabilitation following their economic revamping; restoration and retrofitting interventions, characterized by ecological and cultural sustainability, over the wide heritage; energy rehabilitation of buildings; adoption of renewable energy sources for decentralized energy production that make local communities energy independent and, as much as possible, self-sufficient.

2. General objective of the research

General objective of the research is to design and assess the potential relationship between urban rehabilitation strategies, energy efficiency and seismic retrofitting within a Green Building framework and to introduce Sustainable Conservation at urban level. This is by setting-up design of strategies alternative to present inefficient *status quo* in city energy management and innovative <Green Urban Conservation> good practices along with structural dynamic reinforcing at large scale, supported by geographic information systems.

Furthermore, research aims to set-up a general methodological and valuation framework that might be employed in different contexts, places and situations.
Research deals with New Sustainable Urbanism, specifically faces and confronts the emergency of the growing energy consumption in human settlements, particularly in urban areas.
Research investigates the possible global solution to the inefficient thermal behavior of buildings as well as to the excessive civil energy consumption, caused in particular by the growing use of devastating summer air-conditioning units in hot climate countries.
Research has built-up a connection between urban rehabilitation strategies and building energy efficiency by integrating several elements within a GIS framework: 3D city modeling; design for a Green City; cost estimate for Green City investments; valuation of energy yearly demanded; comparison with the *status quo* scenario; economic analysis over time of operating costs of alternative scenarios; comparative ecological impact analysis of alternative scenarios.

3. Alternative scenarios of intervention: sustainable *versus* un-sustainable

As introduced above, research highlights the possibility to intervene on the same kind of decay with alternative approaches (comparative scenarios technique).
Present state scenario: *Status quo*, do-nothing.
Sustainable scenario: Conservative and high energy efficient, designs and adopts ecological materials to reduce heat dispersion toward the outdoor as well as to cut fossil fuels consumption for heating and conditioning and consequently to lower down CO_2 emissions.
Un-sustainable scenario: Designs and employs popular materials commonly used in ordinary construction yards, characterized by poor thermal behavior and insulating characteristics that sometimes make worse and worse the energy dispersion compared to the *status quo ante*.

4. Operational research methodology

The global system framework has been set-up, tested in the Case Study and articulated in some main activities such as:

- <Geodatabase> activity *i.e.* design of a dedicated geographic information system;
- <Physical Analysis> activity *i.e.* geometrical modeling and urban 3D information system: 3D; typologization;
- <Valuation> activity *i.e.* behavioral modeling and integrated energy-economic-ecological analysis: sampling; parameterization; generalization.

The intersection of the outputs derived from the different activities make it possible to achieve one of the goal of the research *i.e.* to calculate seismic and energy rehabilitation costs at single building level, and to generalize the results at the uncommon valuation level of neighborhood and entire urban areas. Strategy implementation aims to redirect the ordinary maintenance works toward building passivation with specific interventions involving external plaster and roof renovation, natural ventilation and insulation in an original way that allow the works to be done only in the exterior avoiding any resident moving, structural dynamic strengthening.

5. Real world "sustainable neighborhood" design and estimate

New wider eco-urban approach as well as GIS strategic support have been deployed and employed in a real world design and social experimentation, constituting the Case Study, concerning the fostering-up of an <Ecological Safe Urban District> in an already existing urban area.
Case Study is localized in Reggio Calabria (Italy), in the Northern part of its Liberty reconstruction re-built after the earthquake and subsequent tsunami of 1908.
At present time this area or neighborhood is largely inhabited by university students of four University Schools (Architecture; Engineering; Agriculture; Law) and it has been named "Latin Quarter" *i.e.* "neighborhood surrounding University location". It has been chosen as area of Case Study finalized to design a potential <sustainable neighborhood>. The neighborhood has been usefully mapped into GIS giving the impressive and sensible extension of: 480.000 m^2 of surface;

125 urban blocks; 840 buildings distributed covering a built surface of 208.000 m^2 with 2.500.000 m^3 of built area; over 400.000 m^2 of fronts to be insulated; about 180.000 m^2 of <black flat roofs> to be aerated-ventilated and insulated; a population of 6.400 residents, plus thousands of University Students living there as non-resident renting rooms and flats privately and unofficially during the academic year.
Urban Sustainability interventions for the real world Case Study (especially insulation with natural materials) have been designed and valuated in their environmental and energy impacts. Natural insulation and ventilation reduce dramatically the needs and energy consumption for winter heating as well as for more demanding summer air conditioning. Impressive is also the amount of avoided kg and costs of CO_2.
The approach might be applied to different contexts in many cities in the world.

6. Building prototype: example from real world

The real world plan at neighborhood scale has been implemented in a prototype building through a real world construction yard, doing a real "passivation" work and seismic retrofitting.
The reconstruction of Reggio Calabria after the earthquake of 1908 is characterized by high and great urban qualities, among which the most important is represented by its urban pattern with streets and avenues converging in public squares.
Main and peculiar characteristic of Reggio Calabria is the small dimension of its Urban Blocks (about 50x50 meters), and therefore the average footprint is around 2.500 square meters. Among the positive effects of this exemplar pattern there is a richness in articulation of urban spaces and a consequent high street density. After over seventy years, the most prominent guru and reviews of Architecture re-discovered the quality of the above pattern and this framework is now one pillar of the New Urbanism international movement.
The building prototype Urban Block #128 named Palazzo De Mojà after its designer, includes four main buildings and is located inside the Latin Quarter on the continuation of the Corso Garibaldi. It was built between 1935 and 1939, and stylistically belongs to the Italian Rationalist architectures. Today this building is the seat of the Regional Court of Administrative Law Judges.
A Global Maintenance Program for Urban Block #128 according to the principles of New Urbanism has been designed. It consisted in: ecological insulation and aeration of the pitched roof by adopting lis natural cork; *restitutio ad integrum* of interiors according to the original identity (loyalty to the original drawings and materials) and spatiality of the project; adoption of bio-ecological materials to improve the healthiness of the building; reinforcement of the roof.
It followed a huge energy saving, and the yearly annual energy consumption (*i.e.* the Primary Energy Need) is reduced by over 50% only with this intervention: from 91,14 kWh/m^2 to only 42,50 kWh/m^2, just for winter heating. Not considering the great saving due to more expensive summer air-conditioning. The first positive effect is a considerable reduction of the energy management costs. Now the building is monitored by temperature data loggers to control the effect of insulation ventilation upon internal temperature constantly compared to external temperature.

7. First results on energy side

Strategy implementation aims to redirect the ordinary maintenance works toward building passivation with specific interventions consisting in external plaster and roof renovation including winter insulation as well as summer natural ventilation.
By operating a generalization in the Case Study area, it is at first considered the passivation of vertical surfaces of 400 buildings (50% of existing), with thermal-insulating plaster made of mortar composed by natural hydraulic lime and inert and optimal insulators such as pumice, perlite and expanded vermiculite. It can be foreseen a cycle of only six or eight years for the completion of a program of 400.000 m^2, 1.000 m^2 per building and an average of 82 m of perimeter and 12 m of height. By considering the thermal-insulation and ventilation of roofs it is estimated a work of 180.000 m^2.

The hypothesis of front passivation for 400.000 m^2, for a maximum cost of €\ m^2 80 determines a potential minimum investment of € 50.000 per building and of € 32.000.000 for the entire neighborhood. By hypothesizing the insulation and ventilation of roofs for 180.000 m^2 with aerating natural cork for a cost of €\ m^2 60 it is possible to quantify the total investment of € 10.800.000.
It follows that the **total cost of passivation for the 50% neighborhood is € 42.800.000**.
These expenses are shortly recovered by the owners of single housing with annual installments constituted by the substantial saving on energy bill, before described and quantified.
The existing total built volumes, assessed by means of the built geographic information system, are 2.500.000 m^3. By considering an average height per unit of 3 m, it is possible to give a first estimate of the built unit surface in the entire neighborhood of about 830.000 m^2 to be managed on energy side.
Sample analyses performed on the different building typologies have shown with reference to the present state an average theoretical energy need per m^2 during one year (the so-called FEP) of 100 kWh\ m^2. By multiplying this parametric data for the total m^2 of all buildings it can be obtained a first rough result of the **total energy need for the entire neighborhood** of about **83.000.000 of kWh per year**. Considering an average cost of energy of 0,15 €\kWh it can be obtained a **total expenses of energy management of about € 12.450.000 per year**.
Research, field work, yard observations, as well as specific experimentations performed on the sample prototypal buildings, assuming an intervention of sustainable energy rehabilitation, have highlighted an average reduction of 40% of the theoretical amount of energy need. Considering the average cost of 0,15€/kWh it can be obtained a smaller total expense per year for energy management of about € 7.500.000. The energy need of the sustainable scenario is likely to be reduced to 50.000.000 kWh every year *i.e.* 50.000 MWh. The total physical differential is therefore equal to 33.000.000 kWh (*i.e.* 33.000 MWh) not consumed and the consequent monetary amount of **year energy saving** is of **€ 4.950.000 (33.000.000 kWh x 0,15 €\kWh)**.
Considering a total saving of passivation equal to € 4.950.000 per year, the correspondent **payback** can be assessed in about **10-11 years**, at steady rate of 4% .
Last but not least, the production of a MWh of energy by burning oil releases into the atmosphere about 255 kg\MWh of CO_2. An intervention at neighborhood level, besides a monetary saving of € 5.000.000 per year, with 33.000.000 kWh less every year, produces an ecological benefit of **CO_2 yearly not released in the atmosphere equal to 8.415.000 Kg (8.415 ton) of CO_2 per year**. The economic values of this "avoided damage" can be compared to the cost of international Carbon Capture Storage (CSS) of the same CO_2 amount summed-up to realize saving, expressed by the "avoided energy expenses". To this preliminary valuation will be added the extraordinary saving achievable by the summer air-conditioning, which results will be edited in the next-near future.

8. Seismic retrofitting for innovation in urban treasuring. Effective integration among: asset conservation, energy efficiency and seismic safety

Strategy above defined pursues the social and economic effectiveness coordinating in synchronicity:
- the conservation of buildings in the architectural (so called "aesthetic") elements;
- with their thermal-energy amelioration.

This efficiency action might be defined as: "one construction yard, two or more goals", that means the start-up of just one construction work site to get several goals.
Many specific actions and works are in common (such as fences and scaffolding) and burdens are splits for the two or more goals. It reduce the general and overhead costs in construction or initial stage, improving and shortening the pay-back perspective, as well as time consumption for operating work and organizational resources.

8.1. New innovation: integration with seismic retrofitting

An important further innovation is the enlargement of coordination to a third important goal that is the seismic retrofitting of existing buildings. In so doing three objectives are pursued at a time for each building:

-architectural conservation (significance; aesthetic);
-thermal enhancement (energy);
-seismic retrofitting (safety).
It is of paramount importance to harmonize architectural aesthetic and seismic safety.
In fact reinforcing a historic building to comply with newly chartered requirements or rules, as requested by many building codes, can damage and erase much of a historic building's integrity, authenticity, significance, appearance. It is because most existing and today-known approaches of building reinforcing try to impose new structural members and different materials compared to original architecture. Impact is often intrusive, sometime quite overwhelming.
To avoid this intrusiveness, broad sustainability in urban conservation includes the respect of authenticity, then restoration theory has split retrofitting in:
- seismic reinforcing for contemporary constructions;
- seismic amelioration specific for historic buildings.
Latter is more sensitive to original structures, with respect to the historic character of buildings, even when the reinforcement output itself is visible.
Safety upgrading in seismic retrofitting is often permanent, rarely reversible, than international conservation theory detailed the general recommendation as follows.
"-*Historic materials should be preserved and retained to the greatest extent possible and not replaced wholesale in the process of seismic strengthening."*
"-*New seismic retrofit systems, whether hidden or exposed, should respect the character and integrity of the historic building and be visually compatible with it in design."*
-Seismic work should be "reversible" to the greatest extent possible to allow removal for future use of improved systems and traditional repair of remaining historic materials."

8.2. Research strategy: team
Architectural conservation (historic preservation) goal is the permanence of historic buildings over time without intrusive restoration.
Seismic retrofitting goals are primarily the safety for human life through the conditional goal that is the structural protection of building during earthquake.
Anti-seismic codes are put together mainly for new construction, and there is little experience in dynamic enhancement of old structures and experts are needed to be skilled and to be:
- sensitive to historic materials and the building's historic characters;
- experienced in specific seismic requirements for historic preservation.

All this requires pioneer and prototypal first experimentation of:
- innovative team, for historic building seismic enhancement, composed by architect, structural engineer, contractor, conservationist, able to conceive non intrusive solutions;
- innovative approach knowledgeable about historic buildings and about meeting structural needs by using alternative, but seismically equivalent, solutions.

The way of implementing is a real world work yard for experimentation of prototypal seismic enhancement of an effective building with manifold objective:
- architectural conservation (significance; aesthetic);
- thermal enhancement (energy);
- seismic retrofitting (safety);
- cost registration.

Costs have a great deal of importance in choice process and selection of the most appropriate seismic retrofit approaches, measures, works, and, specially, timing. . To estimate cost of damage prevention it is advisable to observe real interventions implemented in real world work yard.
Regarding timing, it is advisable and always preferable to start-up the works before an earthquake occurs, when options are available for strengthening existing members. Once that damage is done, the cost will be substantially higher and it will be more difficult to find engineers, architects, contractors and conservationists available to do the work on a constricted schedule

Prevention is an ethical must because saves human lives, and is much more economical. It should be performed at urban scale working-up urban planning for seismic retrofitting, generalizing at neighbourhood level the building experience through typologization process, and, so doing, contribute in answering the questions: where in the city and how much in the building?
The integrity and significance of the historic building, compared with the cost and benefit of seismic upgrading, need to be weighed in seismic defence urban planning. Buildings with strongest structure may need little or no further bracing or tying. Buildings with weakest structure, however, may need more extensive interventions. Following options are available for the level of seismic retrofit depending on the expected seismic activity and the expected progressive level of performance.
- Basic Life Safety.
- Enhanced Life Safety.
- Enhanced Damage Control.

8.3. Real world case action and cost signals
Consequent to the above analysis, the Case Study has been set-up, containing, a completed the plan for a Sustainable Quarter around University with an integrative program for contextual and synchronic seismic retrofit interventions and energy efficiency (by building insulation) able to:
- prevent probably damage from the next expected future earthquake
- save energy for 30 million of kWh each year, thanks to insulation as demonstrated.

The financial pay-back of the economic investment for energy efficiency is in just 6-8 years. After the pay-back, the saving is all a total benefit lasting for all the life cycle of the intervention.
Within the Case Study, a Case Action has been the opportunity to realize a sample implementation of the urban plan in a relevant building of the Rationalistic Architecture, where the Regional Court is located. The work yard (*chantier*) completed the interventions, costs have been monitored and estimated, and real thermal impact on building behaviour is now being monitored by remote data logger. The instrumental empirical evidence show the first (conservation) and second (energy efficiency) "mission is accomplished": 40% reduction of thermal dispersion by roof and walls. Construction materials are natural and bio-ecological, and made in Mediterranean regions helping the inter-sectoral linkages between local industries. The analytical evidence through structural mathematical model shows the third mission accomplished *i.e.* the good performance of reinforced structures during simulation of heavy earthquake.

9. Conclusions
The experimented research strategy allows to set-up a large scale plan to enforce Urban Sustainability policy and to achieve the goals of energy saving programs and seismic safety.
The operational methodology allows to: precisely quantify and estimate the general urban plan for energy saving; reduce the necessary times of investigations; provide guidelines to households, Society and to local Governments on the possible results achievable by large urban scale interventions; derive keystone prototype data.
In fact, in the specific research here presented the articulation of buildings per typologies has allowed, by surveying and studying carefully a limited number of paradigmatic prototype and sample buildings, to obtain reliable results in a reasonable time, to employ less activity, to reduce the costs for the analyses, estimate, assessment and design.
At the end, besides the most relevant outcomes above cited, research has achieved the possibility to: sort out parametric costs for seismic rehabilitation and energy data; develop subsequent cross-analysis thanks to the build-up of a Geodatabase within a geographic information system; deepen the assessment for entire urban areas. All the created data, collected information, performed analyses, are crystallized safely in a stable, querying, flexible and open system. A real world yard in a prototype real world building tested the methodology, and confirmed the previous performed valuation.