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Evaluation of the efficacy of traditional recovery interventions in historical buildings. A new selection methodology

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Abstract

The traditional Mediterranean architecture shows the balance between nature and human activities, whose conservation has to consider the local characters and the low recovery technologies and lead to the recovery design, by favoring the criterion of minimum intervention.

The research has found a complete systematization from the identification of housing types representative of the historical construction materials (calcareous sandstone and stone block) present in Puglia and Basilicata regions. Consequently you can assess the energy and static vulnerability of the pre-consolidation state and identify qualitatively and verify quantitatively the traditional recovery solutions, exportable on similar constructive units present in other environments.

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Keywords: energy rehabilitation; vernacular architecture; environmental monitoring; nonlinear analysis, seismic vulnerability, index of elastic-seismic improvement.

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1. Introduction

The interaction and the links between resource materials, energy and cultural of the site, and between the functional, structural and linguistic organization of the architecture are the basis of the concept of "environmental culture". In the vernacular architecture with this term we mean the combination of knowledge and techniques that constitute the symbiosis between architecture and nature, capable of guaranteeing the conditions of comfort and building safety, to counter vulnerabilities resulting from Geo-environmental adversity falling on the building organizations.

The traditional Mediterranean architecture in this way becomes a system in which forms, morphologies, constructional techniques are melt and are recomposed into an original unit, fruit of the balance between nature and human activities [1]. Any energy, functional and structural intervention cannot ignore the understanding of the building as a whole, which is indispensable for a correct design and construction "process" in any renovation interventions in architectural heritage, even if it's a minor construction. In this way the intervention that emerges is certainly appropriate because it isn't a distortion of the "own logic" (formal-spatial-material) of the pre-existent and it is in continuity with the "modal logic" (IE procedural) that it requires. You want to try to give shape to what can only be carried out in full compliance with the historical nature on which one works and excluding the rest.

Specific simulations experimental energy, based on traditional techniques of passive cooling systems have been activated in particular environments, in the Basilicata Region, in particular in the Sassi of Matera, just for the purposes of exploitation and the adaptation plant engineering and technology for a living comfort and environmental "sustainable". The non-linear dynamic analysis, carried out in the historical centers of Trani and Molfetta in Puglia, have finally shown that a combination of traditional interventions, based on their own solutions of the rules of the local art, they are able to ensure improvements in terms of static vulnerability of 31.65 % in the state ex-post if compared to techniques of modern recovery and strong invasiveness, for which there is a value of 3.70 %. It's interventions selected qualitatively in order to ensure reversibility, reduced invasiveness and the integrity of the construction, respecting its structural design and the transformations that took place in the course of history.

In the panorama of the current common effort in order to reduce the environmental impact of the contemporary activities and of the future ones, the reuse of existing heritage and the reduction of the final consumptions of energy are two priority ways for a balanced coexistence between man and nature, between present and future.

2. The energy aspects of the Lucan regional context. The "Sassi" of Matera [2]

The deep knowledge of the environmental and energy features of Mediterranean architecture is critical to reaffirm the balance between nature and built environment, even in the specific strategies of air conditioning based on the use of natural resources. The Lucan hinterland is characterized by the presence of a Mediterranean climate with temperate winters and hot and humid summers and with a wide availability of local materials (calcareous sandstone, calcareous stone, unfired clay), which has given different housing types and aesthetic and functional solutions. On the basis of local technical-construction knowledge, particular attention was paid to the settlement context of "Sassi" of Matera (since 1993 in the UNESCO World Heritage List) that represents an emblematic case of how the construction activity, over the centuries, has directly affected on the territory through the changes made by the men and the exploitation of the present natural resources. In the ancient times the tormented morphology, rich of valleys, ravines, terraces, a time covered with forests and raging rivers, provided the ideal place for the first spontaneous settlements made by hypogea and built environments, modelled entirely in the calcareous sandstone (commonly called "tufa").

2.1. The stationary method: the Mc4 software

The recent National Legislation on Energy Efficiency in Buildings (UNI/TS 11300-1) [3] establishes the definition of methods for the energy certification that minimize the charges for the users, in order to promote the culture of energy certification. In this context, it appears the strategic role of the calculation codes for the energy evaluation of the buildings, which have to be at the same time simple and reliable.

In the present work, it is shown the result obtained by a calculation code of the stationary type, that is in accordance with the recent guidelines for National Energy Certification. The MC4 is one of the rare software that you can use for the energy diagnosis of historic buildings, but with some strong limitations due to the fact that was created on the basis of programs dedicated to the sizing of the air-conditioning systems [4].

In fact, it has been demonstrated by the literature [5], that between the stationary and dynamic method, there are appreciable deviations in the consumption estimation if you refers, in a specific way, to the summer season, while there is a better convergence of the two methods in the winter period. In fact in the winter period it is possible to approximate the temperature to a daily average value and to obtain a relatively trusted result; in the summer period, on the other hand, the temperature is characterized by greater deviations between maximum and minimum values: in this way there is the heating of the envelope in certain hours of the day, also due to the contribution of the solar contributions to the windows and the cooling of it in other hours. Instead, in the stationary method, the climate data are approximated to monthly average values, so it is evident that the calculation of the cooling is not trusted as for the heating.

The main simplification assumptions of the calculation in the stationary method are:

- the stationary aspect of the thermal exchanges within the period of calculation: this hypothesis allows you to assume constant values of the temperatures (the average values in the period) and to take into account the effects of the internal energy changes of the masses in a simplified way;
- the monodimensionality of the thermal flows through the elements of the building envelope, with a consequent simplified treatment of thermal bridges, which are not assessable in the cases of buildings with irregular and curved floors;
- the assumption of seasonal or monthly average values of climate data;
- the simplified evaluation of the contributions of the internal heat gains and of the solar ones.

The structural and architectural buildings complexity, the constructive uncertainty and the difficult graphic representation imply a critical reading of the results and a scrupulous validation phase.

2.1.1. The global energy performance index

The buildings, or rather the building-plant systems shall be classified according to an index of global energy performance EP_{gl} [kWh/(m^2·year)], which is defined, in the case of residential buildings with continuous occupation, as the ratio between the annual demand for primary energy and the floor area of the building [6]:

$$EP_{gl} = EP_i + EP_{acs} + EP_e + EP_{ill}$$

Where:
EP_i = energy performance index for winter heating;
EP_e = energy performance index for the summer cooling heating;
EP_{acs} = energy performance index for the production of domestic hot water;
EP_{ill} = energy performance index for the artificial lighting.

In this way are defined the different classes in which this index may fall, each one identified by a letter from A to G. The class of a building should be included in a special energy performance certificate.

2.2. The cases of study and the energy evaluation

The energy evaluation focused on two cases, an excavated architecture and a built one, and show the big differences between these two kinds of buildings, that are made by the same material and that are rich of bioclimatic traditional strategies. On one hand you have the irregular spaces excavated in the calcareous sandstone and on the other one the built architectures that is characterized by vaulted spaces, called *"lamioni"* (Fig.1 (a),(b)). A previous energy audit has determined that the typical calcareous sandstone of Matera has the following average characteristics: surface mass of 825 kg/m^2, conductivity of 0.72 W/mK and specific heat of 1.1 kJ/kgK [7].

The first case, totally excavated never reaches a temperature greater than 23°C with an energy requirement for the cooling of the envelope Q_c /U_p that is equal to 0. During the summer season you have small solar gains (4.22 kWh/m^2) and quite small internal gains (20.95 kWh/m^2), while in the winter season you don't have solar gains (-1.50 kWh/m^2) , but big internal gains (51.98 kWh/m^2), due to the high thermal inertia. The value of the energy requirement for the heating Q_h/S_u is low, but it is really important to take in mind that these values are very uncertain because there isn't a determined trasmittance in similar cases. The great thicknesses of the excavated architectures seem to place the studied environments in an energy winter class D if they are analysed with a stationary calculation method (Fig.2). However, these results are indicative since the uncertainty of the calculation in the excavated environments is not negligible. It is impossible to know exactly the thicknesses of the earth surrounding them and for this reason you can consider a maximum ideal thickness of 1 m for the equivalent wall in contact with the ground that consists of calcareous sandstone, insulation and lime plaster [7].

The second case, made by different floors above ground, during the summer season shows big solar gains (59.91 kWh/m^2) and quite small internal gains (28.95 kWh/m^2), while in the winter season you don't have solar gains (-14.22 kWh/m^2) , but you have big transmission gains (100.3 kWh/m^2). So the built architectures, characterized by thicknesses ranging from 0.4 m up to 0.9 m, are included in the winter energy class E (Fig.3). Therefore, it is evident that these environments have a good level of energy comfort and that the greatest problem is represented by the humidity rates that compromise the habitability of the excavated architectures and that concern those built in a lesser extent.

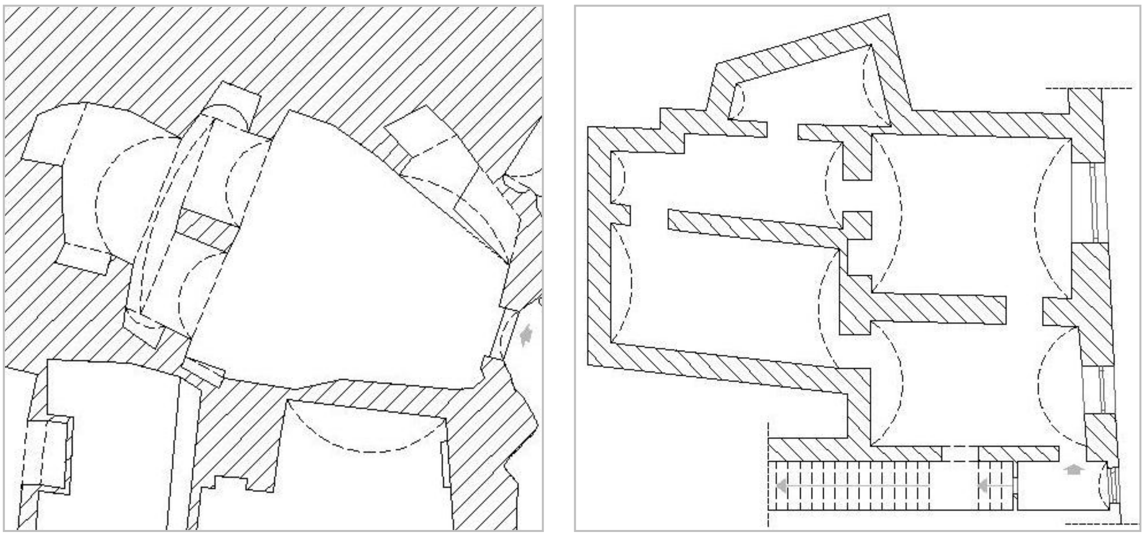

Fig. 1. (a) the excavated architecture; (b) the built architecture

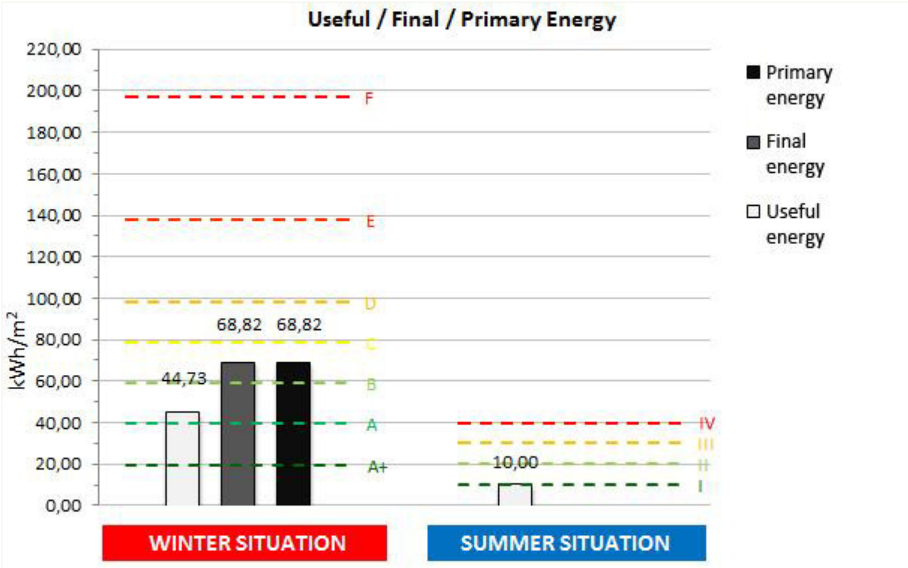

Fig. 2. The energy stationary calculation for the excavated architecture

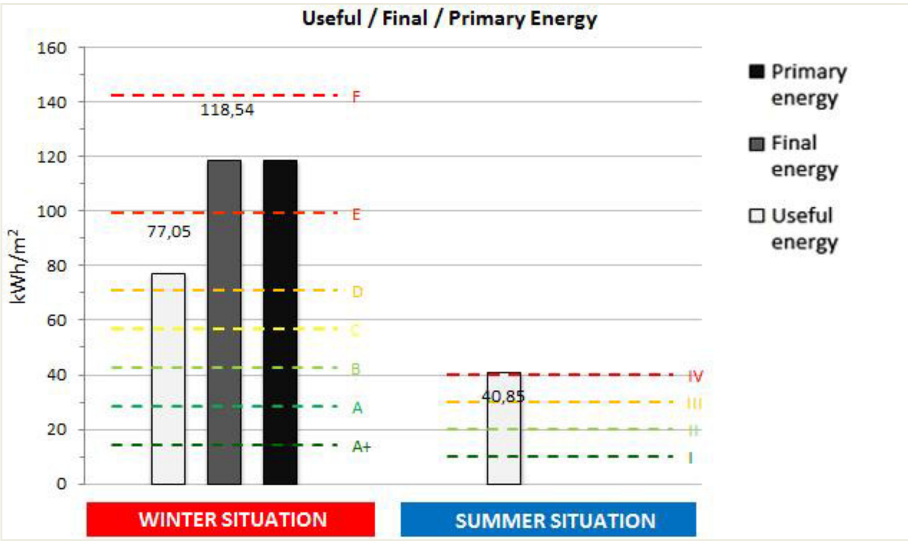

Fig. 3. The energy stationary calculation for the built architecture

The ratio between glass and floor area don't exceed the 5% and it is even equal to zero in the case of the excavated architecture. For this reason the reduced supply of the solar energy and the excellent thermal inertia makes useless the replacement of the frames, which is very expensive [8]. In the excavated environments, it is impossible to install some kind of insulation (for example aerogel panels) due to the high irregularity of the surfaces, so the only way to reduce the energy consumptions is to use with active solutions based on using renewable energy (e.g. biomass, heat pumps, solar thermal and photovoltaic systems and so on), but you need to manage the humidity rate of the air. This can be reduced with the increase in ventilation that however implies an increase in the heating energy.

3. Sustainability of seismic recovery interventions in historical Mediterranean buildings [9]

The concept of environmental sustainability buys a further importance in the act of preservation of historical buildings from disasters, such as seismic. Many countries, especially in the south of Europe, are heavily exposed to seismic risk, which is the cause of destruction or damage of the cultural heritage. The recent Italian experience of seismic events (Umbria and Marche 1997, Puglia and Molise 2002, Abruzzo 2009) has sanctioned considerable information about the intrinsic vulnerability of monumental buildings. The historical buildings are usually characterized by an inherent vulnerability to seismic action, being the masonry, not very resistant to tensile strain, especially along the horizontal planes of the joints normally compressed [10, 11]. On the occasion of an earthquake, the horizontal action involved in fact might exceed the weak resistance of the material for the states of tangential stress and tension, causing injury to slide or detachment of the elements. In addition, the modifications and the addition extensions determine the presence of many facilities within the same building, whose behavior is strongly influenced by the action that strikes them [12, 13]. In the case of an earthquake, the inertial horizontal forces are capable of causing the loss of balance of these elements especially if they are slim or not properly connected to the rest of the building. This intrinsic vulnerability is extremely enhanced in some cases, by the lack of effectiveness assessment of some new construction techniques; solutions such as the remake of a reinforced concrete roof, the inclusion of too rigid curbs at the top of the walls, the use of armed seams as an alternative to traditional metal tie rods, have caused in many cases damages higher than those that the original structure would probably have presented. It should be added the impact in terms of energy expenditure that such solutions can cause on the environment both in the production phase of the same, both in the course of their lifetime on the structure in which they are implemented.

The safeguard of these historical and monumental buildings from earthquakes would preserve people from a serious hazard to their own safety, but also would protect unique art and architecture masterpieces from severe damage or even from destruction, by controlling exceedingly the environmental sustainability of recovery interventions in terms of life cycle assessment. In this way, the choice of adopting antiseismic traditional recovery interventions, marked by a reversibility and reduced invasiveness is certainly appropriate, because it poses as not a distortion of the "logic" (formal and spatial-material) of the pre-existent and in continuity with the "modal logic" (procedural) that it approves.

The "knowledge", or better qualification of the traditional buildings, understood as the set of information in order to fully define the historical-material-constructive characters as well as the state of preservation and performance capabilities residual, assumes in this case a decisive role for an appropriate assessment of static and environmental sustainability. The definition of reliable models and methods for seismic risk assessment of historical constructions is thus a very interesting topic

3.1. Case of study: Structural and historic framework

The Augustinians monastic complex, figure 4, located in the town of Trani, (Italy), is a complex structure, developed in different time between the XVI and XVIII century. It presents heterogeneous characteristics. The continuous aggregations to the original building, dating back to 1530, certainly allowed its conversions from a simple elegant palace to a monastic structure and finally to hospital and school. This has encouraged its choice in the field of inquiry, having the opportunity to relate to more than an urban aggregate evolved over time. Each block, although equipped with a regularity of external patterns in the perimeter walls, is characterized internally by a subdivision due to different transformations that have characterized the building in time. The presence of plans in different positions, both on the ground and first floors, cause altimetry irregularities that certainly cannot be neglected in mechanical modeling of individual building blocks.

Fig. 4. Augustinian Monastery in Trani

3.2. Knowledge of the historical building

In order to get more detailed information about the masonry typologies of the building a set of non destructive diagnostic technologies was applied to some representative walls. It is worth mention that such an investigation approach is paramount for historic structures, where the acquisition of missing data about materials and techniques by non invasive methods enables the comprehensive qualification of all the building elements - which might be very different due to construction characteristics and/or modifications over the time - as well as the preservation of their integrity and stability. Nevertheless, the selection of the most suitable diagnostic technologies should take into account all the data from the preliminary qualification of the building - through historical research, geometrical surveys, photographic documentation, mapping of materials and construction techniques, decay pattern surveys - in order to address the time and cost effective achievement of significant and reliable results [14]. The information, acquired through measurements and investigations in situ in monastic complex, referred have been systematized in appropriate schedule graphs forms.

3.3. Seismic vulnerability and Life Cycle assessment

In this work a micro-modeling approach has been adopted. After being updated and refined on the basis of the modal force tuning, the model was implemented in COMSOL© multiphysic software (nonlinear structural materials module) for the seismic assessment. The compression behavior of the masonry was introduced through the model of Drucker Prager. The parameters of cohesion c and friction ø were derived from the compression media strength, obtaining the values c = 0.48MPa and ø=13°. The tensile behavior was instead played through a smearing crack model, with a tensile strength of 0.1 MPa, constant cut-off criteria and linear softening up to a value of maximum deformation assumed equal to the 1 ‰. In this way, the crack is simulated through a diffuse band of lesions and it is modeled through a modification of the materic properties. The model was initially subjected to non-linear static analysis for gravity loads. After the pushover analysis, a series of non linear dynamic incremental analyses[15] were carried out by applying at the base of the building ten artificial earthquakes to safety life state for the city of Trani. A curve displacement -shear was constructed for each set analysed. In this way, it was possible to define an "IDA mean" curve (Fig.5), subjected to the methodology N2 [16], in order to obtain the request of displacement for the city of Trani in SLV.

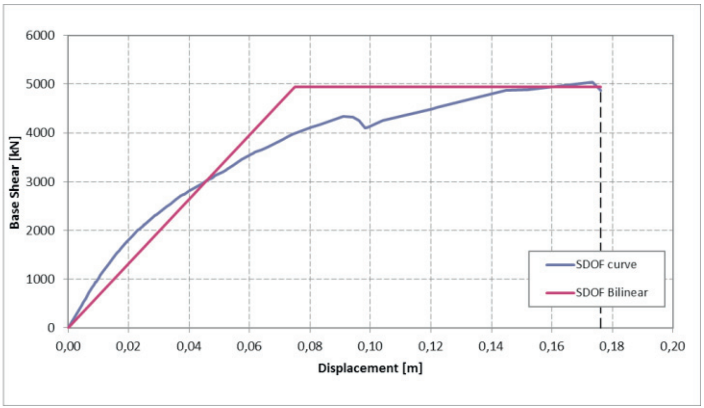

Fig. 5. "IDA mean” curve in the pre-consolidated state.

The incremental dynamic analysis has shown a low cracking strength for buckling and in plane folding mechanisms in masonry walls present on the ground floor. The failure strength of the individual elements has led to the qualitative definition of two combinations of interventions: traditional and modern interventions.

The combination of "traditional" interventions of earthquake recovery (Fig.6) was selected qualitatively in order to ensure a reversibility and reduced invasiveness for its wholeness, respecting its structural design and the transformations that took place in the course of history. This has been achieved through the choice of the following types of intervention, suitably introduced in the model:

Fig. 6. The combination of "traditional" recovery interventions

- metal tie rods with normal steel galvanized, in the direction of maximum action of seismic stress;
- hydraulic lime injections within the solution walls affected by cracking mechanisms to buckling in the plane;
- reinforcement to introduce of the barrel vault, in correspondence of the overlying masonry in false present at the second level;
- masonry structures in contrast of the oscillation of the gable top of façade.

The traditional interventions have been compared to a combination of "modern" recovery interventions (Fig.7) of strong invasiveness, daily used for recovery on historical buildings.

Fig. 7. The combination of "modern" recovery interventions

So we have:

- top and intermediate beam with reinforced concrete;
- armed plasters on masonry, affected by cracking mechanisms to buckling in the plan in the phase of pre-consolidation;
- dressings in FRP (Fiber Reinforced Polymer) to the extrados of the tunnel and cross vaults;
- columns made of reinforced concrete, inserted in order to ensure an effective contrast of the oscillation of the gable top of façade.

For each combination of intervention, they have been carried out dynamic analysis incremental, in order to identify the curves of average capacity by means of which perform a comparison between seismic demand and capacity. Verified the satisfaction of seismic request, it was possible to estimate the effectiveness of intervention by a ratio of elastic stiffness in the state consolidated and not, obtained through a bilinear interpolation of the curves. In this way it was possible to obtain:

- for +X and –X directions, the combination of traditional antiseismic recovery interventions manifests a minimal increase in stiffness of the 144% as compared to a combination of modern interventions, with a ratio of elastic stiffness between the state consolidated and not of the 2.4923 compared to 1.1747 . This is equivalent to admitting a reduction of the period of vibration of the building and a reduced displacement, in other words a reduced vulnerability or. propensity to suffer damage;
- for +Y and –Y directions, the combination of traditional antiseismic recovery interventions manifests a minimal increase in stiffness of the 74% as compared to a combination of modern interventions, with a ratio of elastic stiffness between the state consolidated and not of the 1,829 compared to 1.0506.

The combinations of intervention were evaluated in terms of environmental sustainability (Life Cycle Assessment) in SimaPro© software, examining the parameter GER, Gross Energy Requirement, required for the production of the product, and the GWP parameter, Global Warming Potential. It was thus possible to achieve reduced values of GWP (KgCO2eq) of 69.23 % and GER (MJ) of 72.92 % in the combination of traditional antiseismic recovery compared to modern techniques. This confirmed the achievement of a structural and environmental sustainability through the use of traditional recovery techniques.

4. Conclusions

It is indispensable to deepen the theme of sustainability in terms of low technologies and to look for solutions with low cost and low environmental impact. This operating philosophy clashes with the compatibility of the destinations of use, with the historic nature, with the structural body, with the distribution-functional quality of the building both if it has a monumental character and both if it belongs to urban complexes of historical interest such as the historical centers, a current trial of harmonization of the constructions with the typical context of the place. The approach to the restoration/recovery must involve the use of methodologies and technologies to integrate the traditional and the innovative aspects. You must consider design approaches which consider as predominant element the environmental factor, very crucial in the development of the historic architecture.

Thanks to these studies, once identified weaknesses and peculiarities of the envelope, it is possible to design the intervention strategies and to reinterpret the local traditional architecture by preserving the current needs in terms of energy efficiency and historical-material suitability of the proposed intervention.

The study has extremely offered the opportunity to establish a combined methodology of assessment that looks at the same time structural efficiency and environmental sustainability.

Although this presupposes an integrated system of data acquisition and management of information and knowledge, however, it will be able to permeate the concept of structural safety of the historic buildings with all the aspects that are unlikely to be integrated within a mechanical model, even if it is refined.

References

[1] Braudel F. *Il Mediterraneo, lo spazio, la storia, gli uomini, le tradizioni.* Milano: Bompiani; 2002.

[2] The text of the paragraph 2 was edited by Tiziana Cardinale and Nicola Cardinale.

[3] Norma UNI TS 11300 – Parte 1:2008. *Prestazioni energetiche degli edifici. Determinazione del fabbisogno di energia termica per la climatizzazione estiva e invernale*. 2008 + EC1/2010.

[4] Software Mc4Suite 2012, Mc4 Software.

[5] Filippi M., Fabrizio E. *Introduzione alla simulazione termoenergetica dinamica degli edifici.* Milano: Editore Delfino; 2012.

[6] Decreto ministeriale 26/06/2009, n.158. *Linee guida nazionali per la certificazione energetica degli edifici*. Roma: Ministero dello Sviluppo Economico, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ministero delle Infrastrutture e dei Trasporti.

[7] Cardinale N., Rospi G., Stazi A. Energy and microclimatic performance of restored hypogeus building in south Italy: the "Sassi" district of Matera. *Building and Environment* 2010; **37(4)**: 94-106.

[8] Guida A.G.M.I.R. et al. *Energy efficiency improvement and suitability interventions on vernacular Geocluster (Basilicata).* Milano: 39th IAHS World Congress on Housing Science – Changing needs, adaptive bulidings, smart cities; Semptember 17-20, 2013.

[9] The text of the paragraph 3 was edited by Domenico Colapietro and Fabio Fatiguso.

[10] D'Ayala D. *Seismic Vulnerability and Risk Assessment of Cultural Heritage Buildings in Istanbul, Turkey*. In: Proceedings of the 14th world conference on earthquake engineering, Beijing, 2008.

[11] D'Ayala D., E. Speranza E.. *Definition of collapse mechanisms and seismic vulnerability of historic masonry buildings*. Earth Spectra 19(3): 479–509, 2003.

[12] De Sortis A., Antonacci E., Vestroni F. *Dynamic identification of a masonry building us-ing forced vibration tests*, Engineering Structures, 27, 155-165, 2005.

[13] De Fino M., De Tommasi G., Fatiguso F., *Experimental studies to normalize the sonic test on masonry walls, Proceedings of REHABEND 2009* "International workshop about re-habilitation and NDT", 29-30 October 2009, Bilbao, Spain. ISBN 978-84-8873-404-4 2009.

[14] McCann D.M., Forde M.C. *Review of NDT methods in the assessment of concrete and masonry structures*, NDT & E International, **34(2)**, 71-84, 2001.

[15] Vamvatsikos D., Cornell CA., *Incremental dynamic analysis*. *Earthquake Engineering and Structural Dynamics*, **31(3)**:491_514, 2002.