Caste of Fossa, Italy

Vitruvio
International journal of Architecture Technology and Sustainability
Volume 3 Is 2

Cultural heritage and earthquakes: a multidisciplinary approach to restoration sites

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ABSTRACT

This paper looks at a multidisciplinary approach to the restoration of sites hit by earthquakes, and illustrates how an integrated approach can successfully combine technical requirements with historical and cultural ones. The methodology presented in this study concerns the "Castello di Fossa" restoration project in central Italy, which was hit by an earthquake in 2009. Cooperation between the two teams working on the project led to the development of new ideas and the definition of an innovative role for the castle within the urban and rural landscape. The project looked at how to improve energetic and structural performance through the retrofitting of the building, whilst at the same time guaranteeing the conservation of its architectural values. Lastly, the results of this joint work undertaken by archaeologists, researchers from the National Research Centre (CNR ITC, L'Aquila) and the University of L'Aquila (DICEAA) and designers, are presented as well as the coherence of the reconstruction.

KEYWORDS

earthquake, reconstruction process, multidisciplinary approach, cultural heritage, retrofit intervention, HBIM

https://doi.org/10.4995/vitruvio-ijats.2018.10978

1. INTRODUCTION

The multidisciplinary approach described in this work is the first stage of a cultural heritage reconstruction project. The aims of the project are to achieve functional recovery as well as improvements in energy efficiency and resistance to seismic activity.
The recovery of historical architecture and its energetic and seismic retrofitting is complex, especially when its cultural value is one of the most important factors. In-depth knowledge acquired through a multi-disciplinary approach is essential and one of the first steps in the reconstruction process.
The knowledge process involves the study of the characteristics of the building, in particular, its history, its constructive materials as well as its structural aspects.
These preliminary analyses allow us to identify the features that need safeguarding as well as the state of degradation and are subsequently used in the preparation of an effective, restoration project that is coherent in method and its targets. These preliminary analyses are also used to accurately evaluate the building's energy behaviour and consequently the thermal retrofitting required (Lucchi, Pracchi 2013).
Intervening on buildings in post emergency contexts also brings problems of its own and an awareness of the construction history of the building is essential in assessing its current seismic safety and the most effective means of intervening (De Berardinis et al. 2018).
Using non-destructive diagnostic techniques during the knowledge process, has been shown to be most effective in responding to these different needs. Non-destructive techniques, if properly exploited, provide data that can shed further light on different aspects of the building with minimum damage to the building itself whilst also reducing the risks to technicians working on site.
Thermal imaging is one of the non-invasive techniques used in the work presented here and, can provide accurate and in-depth information concerning a building's structure, the degradation of the envelope, the presence of moisture or water, and voids or hidden or unexpected materials (Maierhofer et al. 2013; Proietti et al. 2013).
In this project, thermal imaging data together with data collected from an archaelogical survey of the buildings, allowed us to trace back transformations such as the sealing or opening up of different rooms, integrations, planning accretions and interventions subsequently covered up by further stratification (Balaras, Argiriou 2002). From an environmental point of view, this kind of analysis also allowed us to establish the thermal capacity of the materials which is important in the planning of the energetic retrofit.
The knowledge acquisition process provided the information necessary for the development of a HBIM (Heritage Building Information Model), which is the instrument used during the design and construction phases as an underlying support for the whole design process.
The scope of his paper is to show how restoration projects based on in-depth-knowledge of the cultural heritage can guide retrofitting solutions and ensure compatibility between interventions and the underlying aims of the building's preservation.
The information acquisition phase of the HBIM ensures that historical, archaeological, architectonic, technical and constructive analyses are all given their due weight and the overall aims of the project are achieved.

2. THE ARCHAEOLOGICAL ANALYSIS OF THE CASTLE OF FOSSA

The castle of Fossa, located in the upper part of the village of the same name, is one of the many castles throughout the territory of L'Aquila (Fig. 1). Its structure today is a result of modifications and additions over the centuries: it is composed of walls, with quadrangular towers, that enclose several residential buildings, inhabited up until the earthquake of 2009, and a circular donjon that belonged to the local town council. The first settlement dates back to the XII-XIII century, as the 1178 Bull of Pope Alexander III testifies. This document mentions the churches and castles owned by the bishop of Forcona, and this is later confirmed in the 1204 bull of Pope Innocent

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Figure 1.
Panoramic view of the Castle

III detailing the existence and ownership of these properties. It was probably in this period that the circular tower was constructed for the defence of the village and as a watch tower before several scholars believe the construction of the castle walls which date back to the XIII-XIV century (Chiarizia, Properzi 1995; Chiarizia, Latini, Properzi 2002). Unfortunately, the documentary sources relating to the castle of Fossa are few and in the absence of specific archaeological investigations this remains a hypothesis. The defensive walls on a scarp base with a slight inclination, originally had 7 towers not all of which have survived. Some were incorporated into the walls whilst others were added over a period of time

The two towers on the north-eastern wall and the one on the north wall had different functions but originally both opened inwards to facilitate defensive actions, a type of construction that is also found in fortifications nearby.

Within the walls of the castle lie the buildings that are the focus of this study: the first borders the defensive walls whilst the second, more to the interior shows traces of construction interventions over time (Fig. 2).

The different layers of cladding that cover the original

Figure 2.
Diachronic analysis of the architectural complex

buildings were identified and classified and archaeo-seismological analyses were carried out to identify anti-seismic methods used in the past.
Special attention was paid to the identification of the different stratigraphic masonry units (USM); the definition of the relationships between the stratigraphic units and to the analysis of the masonry; the latter were classified according to materials and construction techniques and included in a chronological and typological layout.
The stratigraphic interpretation of the buildings, carried out both in the field and using a digital photogrammetric model, made use of thermographic images (Ranalli and Boccabella) These images were used to investigate portions of masonry covered by layers of plaster and to shed further light on the relationship between the USMs identified thus providing useful information for structural, architectural and energetic interventions (Fig. 3).
The identified masonries were grouped into 8 types, some of which present variations that contributed to subdivision into sub-types.
Most of the masonry is a stone material of calcareous origin, irregularly rough-cut with direct percussion instruments, bound by abundant mortar and arranged in sub-horizontal lines.
The chronologically more recent types are more irregular and have fragments of bricks used as wedges to fill the empty spaces between the stones. Weak points of the walls are the modern superfetations mostly in concrete.
In brief, good quality masonry was used in the buildings studied and this together with the construction techniques used have allowed their conservation to today .
The historical and archaeological study allowed to us reconstruct the original castle layout and outline its development: initially a fortified village, then a noble residence up to the its current private residential connected and communicating with the village of Fossa. The results of the research were imported into a parametric model for those involved in the restoration project.

3. THE METHODOLOGICAL REASONS OF THE HBIM OF THE ARCHITECTURAL COMPLEX

BIM (Building Information Modeling), in its widest context is an information system managed in a three-dimensional graphic space, offering elements of great

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interest for the historical-critical process of knowledge acquisition of architectural assets and, increasingly, for the management of restoration sites, although there are still some critical aspects in its application to historical heritage (Brusaporci et al. 2018).
The acronym HBIM (Historic Building Information Modeling) was used for the first time in 2009, hypothesizing a new system for modeling historical buildings starting from a survey of the existing (Murphy et al., 2009), exploiting the advantages offered by a semantic modeling based on parametric elements (Garagnani 2015) connected to each other through a hierarchical structure of smart objects (Scianna, 2018). Following numerous experimentations that have taken place over the last few years on the historical and archaeological heritage, often with different scopes, HBIM is becoming a consolidated practice (Della Torre, 2017) to document the state of artefacts (Continenza et al. 2018); to analyze the phenomena to which they are subject; to study their constructive processes diachronically (Scandurra et al., 2017); to manage the restoration sites (Brumana et al. 2017) and, last but not least, to monitor the evolution of artefacts over time. This last use, referred to as as-built BIM has become of fundamental importance because it allows, as for new buildings, the concrete possibility of monitoring, and managing, the changes of buildings over time. The parametric models could potentially, manage information dynamically with sensors and control signals, monitoring activities (energy and structural) and, consequently, the conservation of the structure avoiding the physical exploration of the constructions (Scianna 2018).
Finally, it is worth noting that the scientific community is carrying out a thorough reflection on the level of reliability of HBIM models iwith regards to the model and reality. The debate was developed starting from the analysis of the LOD (Level of Detail) parameter, well known in BIM systems, that represents the graphic detail with which a model or an element of it, is graphically represented, to which is associated

Figure 3.
Architectural Complex 3, Est front: stratigraphical analysis of the masonries and some thermal imaging data

the Grade, the level of detail of the representation (Lo Turco, 2016). For HBIM, research groups have proposed a new parameter, the LOR (Level of Reliability), to indicate the level of correspondence between reality and the elements of the model elaborated by the operator through a critical analysis process and, consequently, the degree of knowledge of reality (Bianchini, Nicastro 2016). In this sense, a significant contribution to the scientific research was made through the identification of new parameters, such as LOG (Level of Geometry) and LOI (Level of Information) that, retracing those created for the generation of BIM models, ensure a high level of reliability of HBIM models. This research has also enriched the debate, specifically in the field of architectural restoration, on the creation of modeling protocols, guidelines, specifications and coding criteria to support HBIM management in the time following its life cycle (Brumana et al. 2018), protocols accepted at national level in the drafting of the recent UNI11337 standard (Digital Management of Construction Information Processes).

In light of the topics highlighted in this introduction, and with the aim of using the parametric model which could become the tool through which different contributions of the multidisciplinary team could be integrated, we planned the HBIM of the castle of Fossa.

The model, created starting from the Scan-to-BIM process using the 3D laser scans and the available photogrammetric models, represents the actual state of the architectural complex, in which the numerous collapses, gaps and the analysis of the degradation of the construction were modeled (Fig. 4).

The model also integrates the results of the archaeological research, namely with the insertion of the Stratigraphic Units on the external surface of the model.

The model will then be used for the structural and energetic analysis of the complex.

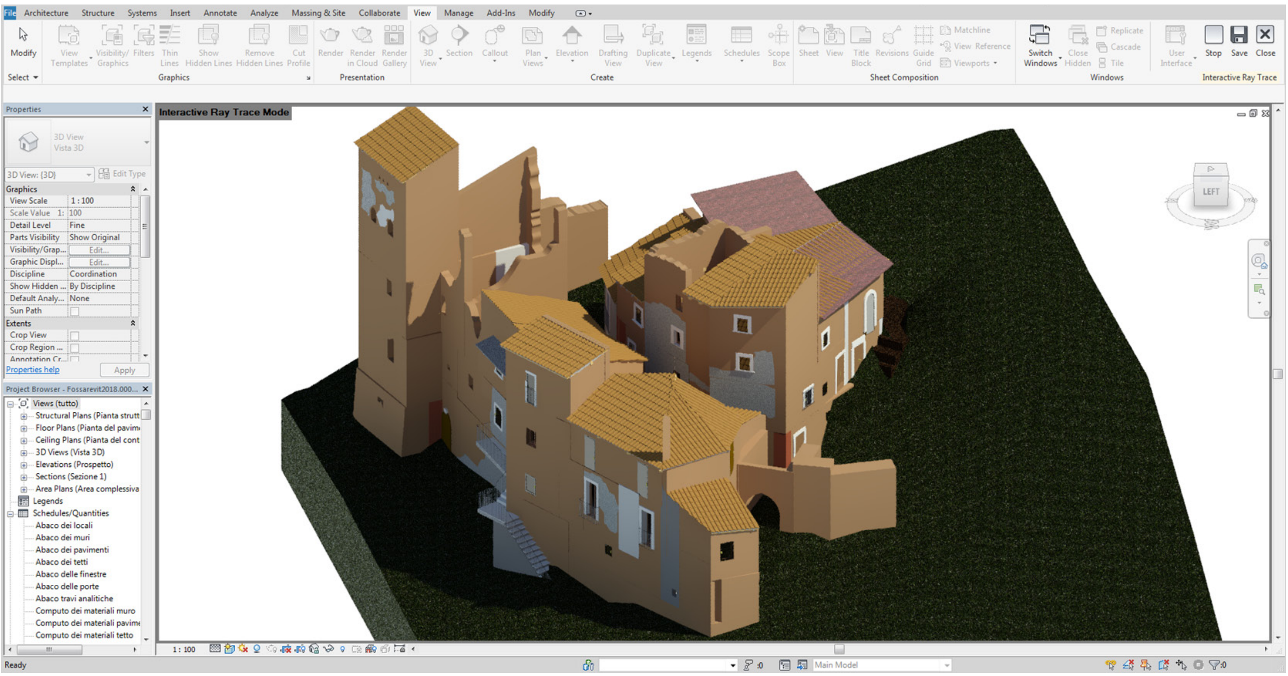

Figure 4.
Screenshot of the Revit software with the parametric model of the Castle

4 ENERGY RETROFIT OF THE HISTORICAL BUILDING: CONTACT POINTS FOR THE STRUCTURAL PROJECT IN HBIM ENVIRONMENT

In recent decades, growing concern for the energy efficiency of the building heritage has led to the definition of well-structured legislation. In parallel to this, there have also been similar developments in interest and legislation regarding seismic improvements with the provision of best procedures to follow in planning: a directive of the Council of Ministers President (February 9, 2011) on the assessment and reduction of seismic risk of cultural heritage, in reference to the technical standards for the buildings.
In practice, however, the lack of an overall scheme regarding both aspects has led to legislation alternately taking the upper hand over the another.
However, guidelines for the improvement of energy efficiency in the Cultural Heritage, published in October 2015 by MIBACT and AiCARR (MiBACT 2015) have facilitated matters. The Guidelines propose an energy diagnosis of the building aimed at defining possible improvement interventions. The guidelines can be applied to a number of fields but do not cover the specific needs of situations such as that faced by L'Aquila which is characterized by the seismic emergency. The procedure clashes with the difficulty of operating in stratified contexts, which are difficult to investigate in depth excluding the intent to intervene on the structural aspects. In the context of L'Aquila, operating according to this procedure, due to the nature and extent of the interventions carried out under post-earthquake condition, the structural and architectural status of the building can not be disregarded, while respecting the more general restoration criteria.
What remains valid and applicable to our field of study, is the application of the improvement performance criteria, despite of adaptation, according to a more flexible approach aimed at identifying the best quality that can be pursued by the building in relation to its history and its cultural and geographic context, in order to achieve current standards of safety and comfort. The Guidelines suggest, in this sense, to intervene through an interdisciplinary dialogue, approaching the project with an overall perspective, not through single and specific solutions.
The work carried out on the Castle, involves a procedure that will enable improvement in energy performance of the buildings in relation to the type of seismic improvement intervention required which is in relation to the level of damage reported by the structures and its historical-artistic values. This procedure was achieved through a continuous dialogue between the different professionals involved, in all phases of the design, from the knowledge seeking surveys to the definition of the interventions.
The multidisciplinary approach was fundamental in defining the energy improvement interventions to be adopted starting from the in-depth knowledge of the buildings, from historical and structural behavioral points of view. This approach was summarized in the HBIM, where energy retrofit solutions were modeled and verified through dynamic simulations.
As a result, we chose to intervene on the envelope in a minimal manner, reducing thermal transmittance by applying thin barriers to the heat flow exclusively on the inner surface of the masonry - using thermal insulation plaster and ultra-thin panels in order to avoid reducing the rooms' volume excessively - and focusing instead on optimizing the installations.
The combined interventions (seismic and energetic) on the envelope guarantee a significant improvement in the building's performance in terms of energy saving, as shown in Figures 5 and 6.
In fact, the energy criticalities found during the knowledge seeking process, were not related to the massive envelope, the excellent performance of which will not be affected by the seismic interventions, but rather to the heating system, which relied almost exclusively on antique fireplaces and electric heaters.
The project also envisaged the identification of a single technical room for each aggregate, where an invertible heat pump could be placed. The generator is able to support the radiant floor heating system of the various housing units, and is linked to a forced ventilation system composed of small air extraction units placed in attics unfit for habitation.
Finally, it is important to highlight how the climatic context and the envelope conformation of the Castle,

influenced the measures taken to improve energy performance through the optimization of the winter regime, identifying as effective the passive cooling in the actual state.

5 CONCLUSIONS

A restoration project aimed at conserving and valorising the Architectural Heritage cannot ignore the importance of in-depth knowledge of the buildings involved and a multidisciplinary approach to the design process of the retrofit interventions.
In emergency contexts, where valuable buildings have been damaged by natural disasters, a well-thought out planning process is essential to accurately define all the steps that will ensure effective recovery. This process presupposes surveys and analyses aimed at the acquisition of in-depth building knowledge.
The use of HBIM allow designers to follow methodological approaches in order to gain a better understanding and control all the design steps, highlighting the characteristics of the structure before intervening and representing the environment.
This study illustrates how a multidisciplinary approach to a restoration site developed in HBIM represents a best-practice method for the recovery of Cultural Heritage greatly damaged by extraordinary events such as earthquakes.

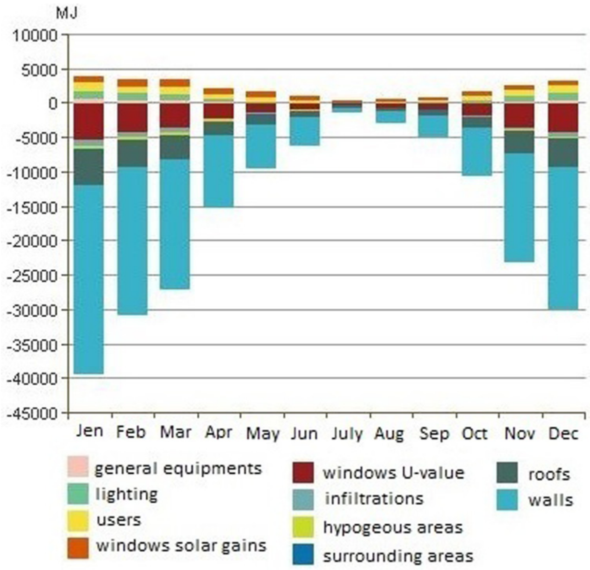

Figure 5.
Actual state. Heating loads from dynamic simulations carried out with Revit Software

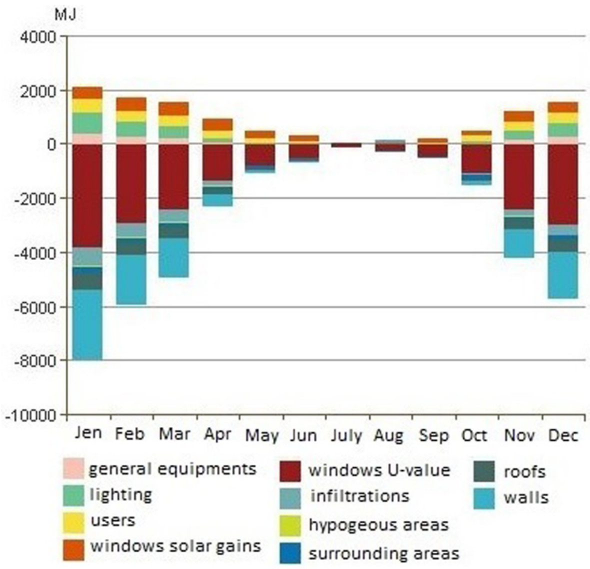

Figure 6.
Project state: combined interventions – seismic and energetic- on the envelope. Heating loads from dynamic simulations carried out with Revit Software.

NOTES

This joint research paper was written by three authors: Mariangela De Vita sections 1, 4 and 5, Francesca Savini section 2, Ilaria Trizio section 3 and Pierluigi De Berardinis supervised the research and the paper.

ACKNOWLEDGMENTS

Thanks to the architect Roberta Boccabella, the planner of the restoration project of the Fossa castle, for having made available to the team the architectural survey and the point clouds of the survey carried out with the laser scanner.
Thanks to Alessandro Giannangeli and Gabriele Petrucci of ITC-CNR for having carried out, the former the photogrammetric survey of the building and postprocessed the acquired data; and the latter for having performed, starting from the basic material, the parametric model of the castle.
Thanks to Serena Calcagni, for having carried out dynamical simulations of the buildings.

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