Instrumental analysis and operational protocols for the evaluation of the quality of construction

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Highlights

All research paths presented in this paper are focused on the application of new technologies toward the definition of new restoration intervention criteria in building heritage. Laser scanning and digital thermography allow acquiring large amounts of data that can be processed at a later stage after the on-site survey. The precise definition of protocols, which are presented here, allows making operations repeatable and comparable even if applied at different times and in different contexts. The aim is to overcome a deterministic approach linked to sectorial knowledge and define a new qualitative approach, expeditious, but none the less accurate.

Abstract

The paper shows three examples of research carried out at the University of Bologna which have the aim of defining the procedures for adapting the performance levels and using instrumental analysis and operational protocols according to innovative methodological criteria. Their specificity lies mainly in the attention directed toward those aspects of existing buildings that usually can not be investigated exclusively with quantitative methods. The three lines of research relate to: the expeditious assessment of the seismic vulnerability of building aggregates, the study of wide span wooden roofs in some churches of Bologna and the identification of hidden masonry textures through the use of the thermal imager.

Keywords

Qualitative operational protocols, 3d laser scanning, digital thermography, expeditious assessment

1. INTRODUCTION

The definition of operational criteria for existing buildings that are both effective and respectful of the nature of the objects on which it is intended to work requires a thorough knowledge of the characteristics of these buildings. In this field, the contribution provided by the technical culture has great importance, as long as it is considered the heritage of knowledge associated with the construction that consists of expertise, having both theoretical and applied nature, covering a broad spectrum of skills.

For these purposes it is considered necessary to investigate the construction features of existing assets trying to define quality levels and not only the quantitative parameters, or rather investigate the technical and construction solutions in their entirety, not necessarily using the predetermined interpretive...
The term “quality” refers, in addition to a synthetic vision in which blend different properties of the construction, to the definition of a value scale or to a shared interpretive framework that derives from the recognition of the efficacy, or from the compliance with certain requirements that some situations analysed previously showed becoming thus common heritage of a technical-scientific community. These investigations must be carried out through the application of analytical protocols, often aided by tools able to identify characteristics, forms, detailed solutions useful to represent the analysed objects and to understand their behaviour in certain situations. Through this method, it is possible to envisage solutions and intervention criteria that tend to ensure the achievement of certain performance or the reaching of predetermined targets.

Construction, like many social phenomena, is in fact strongly conditioned by contextual elements. A merely classificatory analysis, aimed at identifying significant features based on the recognition of a belonging to a well-defined set of already known elements, could not lead to a proper interpretation of the phenomena to which it is connected. At the same time, for those who must work on ancient buildings, being able to determine the greatest number of possible relationships between their components is an essential goal, since the purpose is to attempt a description as complete and detailed as possible in order to develop subsequently effective intervention hypothesis.

On the other hand, this does not mean that an analytical approach should avoid completely the classification criteria not allowing using the knowledge already acquired. The recognition of the qualities of a building is the activity through which the general scope can be understood or, in other words, the framework in which there are cases already analysed and studied that can provide useful information. Quantitative analysis is therefore required to understand some aspects and performance of buildings, not otherwise describable in qualitative terms only.

The giving up to a descriptive vision of reality threatens to eliminate the differences in the characterization of the objects that are usually the evidence of relationships that connect, continuously, every constructive episode to other similar and those to the reference context.

The cases discussed below show how the adherence to the will of describing a reality consisting of objects in relation to each other, although different, can offer interesting insights as long as the research tends to be inclusive of different methodological approaches. In these cases the use of rational operating
protocols, also based on the innovative use of diagnostic instrumentation and measurement tools, provides a knowledge of qualitative aspects on existing buildings that is essential for the definition of interventions aimed at updating the performance levels.

2. THE THREE RESEARCH PATHS

In the following are presented three lines of research, active inside the research group of Technical Architecture of the University of Bologna, in which the preconditions explained above put into effect through a series of investigations, even of experimental kind, aimed at understanding few important aspects of the historical architectural heritage. The exposition follows a hierarchy dictated by a development at different dimension that goes from the urban scale to that of the building ending up to the construction elements.

2.1. THE SEISMIC VULNERABILITY OF HISTORICAL BUILDING AGGREGATES

The interest in building restoration in seismic area constitutes a specific research topic in the Department of Architecture into the University of Bologna [2] [3] [4]. Within this theme, the problem of building aggregates constitutes one of the issue of greater complexity.

For some years now this topic is a necessary reference for studies involving the mitigation of seismic risk of our historic built heritage; the current national regulations in the field of construction requires that interventions on the individual structural units should be anticipated from a careful analysis of the entire construction aggregate. A shared methodology, capable to be applied effectively, does not yet exist nowadays.

There is another critical element regarding these methods of behavioural analysis of an entire aggregate; it concerns the ineffectiveness of an engineering approach, which resolves itself into a numerical modelling of the entire complex. A concrete contribution to overcoming this impasse can be represented by the development of an operational methodology towards the recognition that the possible damage modes depend on the geometrical shape, on the constructive characterization and on the historical evolution process of an aggregate.

According to Giuffrè studies, through the analysis of this data is possible to obtain useful information on probable damage scenarios because it has been recognized that the dependence of the breaking mechanisms in the wall
analizzando questi dati è possibile ricavare utili informazioni sugli scenari di danno probabili poiché è stata riconosciuta la dipendenza dei meccanismi di rottura della compagine muraria dalla qualità edilizia complessiva dell’aggregato.

La proposta avanzata, su cui si sta lavorando per affinamenti successivi, si basa sulla definizione di indici quantitativi che tendono a stimare la maggiore o minore propensione al danno e quindi utili a stilare graduatorie da estendere ad interi agglomerati, al fine di definire livelli di proprietà e consentire la gestione ed il monitoraggio degli interventi sulle singole unità.

Risulta, a tal proposito, di fondamentale importanza giungere in tempi sufficientemente ristretti alla definizione delle caratteristiche geometriche e costruttive degli edificati da sottoporre ad indagine. Allo stato attuale solo alcune amministrazioni comunali possiedono rilievi sistematici degli aggregati edilizi storici presenti nel loro territorio; per tentare di risolvere questo problema, nella metodologia studiata, oltre ad avanzare una soluzione in termini di determinazione di indici di vulnerabilità, è inserito un protocollo operativo mirato ad ottenere le informazioni necessarie alla costituzione della base geometrica di lavoro.

Quello si basa sul rilievo dei prospetti degli aggregati attraverso l’utilizzo del laser scanner 3D e sull’acquisizione di documentazione presso gli archivi degli uffici comunali e delle agenzie del territorio locali, per giungere all’ottenimento dei dati geometrici di ogni aggregato. Attraverso una serie di sperimentazioni condotte su casi reali si è potuto definire un livello di precisione della rappresentazione ottenuta tramite la strumentazione laser tale che si riesca a conteggiare la rapidità di acquisizione. Attraverso lo studio di materiale archivistico e delle bibliografie sulle vicende storiche dei contesti analizzati, si può giungere a ipotizzare la serie delle trasformazioni che, dagli impianti iniziali, portano alla situazione attuale.
analysis with the assessments on the disconnections of the walls and on the superelevation undergone by these buildings.

The constructive characterization is obtained through inspections in situ, and bibliographic researches. In the third path of research presented in this contribution a testing launched will be illustrated that aims, through instrumental analyses, to obtain additional information for the determination of masonry solutions used in historical walls covered with plaster.

At present research has allowed to analyse various aggregates in different Italian regional contexts; the study of the vulnerability of the entire historic centre of Mirandola is already complete (MO) and the analysis on all the historical aggregates of Castelfranco Emilia (MO) and San Giovanni in Persiceto are about to be finished (BO).

The study on the historical centre of Mirandola, in particular, has shown how this methodology for estimating the vulnerability finds the concrete results in a real damage scenario: in fact, after the earthquake of 2012, the damage suffered by buildings of the historic centre has been measured. Subsequently these surveys were compared with the damage scenarios obtained through the application of the proposed methodology. From this comparison
clearly emerges that it is effectively possible to forecast assessments on the vulnerability in order to plan and manage the security of the ancient built heritage.

2.2. THE INVESTIGATION ON WOODEN ROOFING IN SOME IMPORTANT CHURCHES IN BOLOGNA

Starting from the observation that some original constructive solutions of considerable extent are still present in some religious buildings of the sixteenth and seventeenth centuries, two years ago began a research that aims to understand what the technical characteristics of these construction systems are and test their state of conservation through time. The first problem to which find an answer was the complexity of a survey to be carried out in difficult conditions, working in the roofing and then having only curved surfaces to stand on (the extrados of the vaults covering interior spaces) and having to acquire a considerable amount of data because of the large dimensions of these constructions. It was thus decided to use a 3D laser scanner that allows, in a limited working time, to acquire a considerable amount of documentation, both quantitative and qualitative, retaining, at the same time, the complete traceability of the measured data, also for uses delayed in time.

The first example studied was the roofing of St. Peter’s cathedral in Bologna, an exceptional space that, excluding the presbytery, measures 25 m wide and 60 m long. All 18 wooden trusses appear to be the wider in span, if not the widest, among those existing nowadays in Italian religious buildings. The use of 3D laser scanning made it possible to capture all the data in just two working days, during which it was also conducted a photographic campaign additional to the one obtainable by default with laser instrumentation. The next post-production phase has allowed obtaining a model consisting of a point cloud of the entire roof, including, in addition to the space above the aisle, also the one above the apse. Through this data, it was possible to get a complete and detailed representation of all the wooden structures and the hardware used in the connections between all the rods of the trusses. On this basis, it was then made the interpretation of survey data that showed that the solution used has no counterpart in literature, thus constituting a case in itself, unique in its kind. It is an unusual variant of Sangallo’s truss where counter-rod, interrupted by the central king post, is transformed into two struts with minimum slope. This unique solution seems to be derived from an intuition of the manufacturer in order to allow on-site assembly of the wood tension members of this truss of unusual width.
The precise recording of the geometry of this kind of structure has allowed to understand the movements (translations, rotations and deformations) that have affected its various tension members, as well as allowing the understanding both of the assembling process of the truss and of the operations for tightening and stringing of its various parts through the stirrups. The main movements showed by all members of each truss involved the lowering of the central king post, the rotations out of and in the plane of the lateral ones, and the inflection of the tie rod. In order to be able to identify these movements it was necessary to adopt reverse engineering methods carried out through software that can compare virtual models with real objects.

Without an operating protocol already defined and without a literature that would allow to compare these hypotheses with other similar cases, the qualitative analysis was in this case a necessary first step. For this kind of approach, each case stands on its own and should be related firstly to its context before forwarding a hypothesis that has to be verified later by means of numerical procedures. In this case, the quantitative analyses were divided into two groups: local and global ones. From the first group it was obtained detailed information on the movements of each element of a single truss, while from the second one it was defined the movements of every single...
truss compared to the wall portion that constitutes the contour of the space analysed. Proposed interventions were therefore those that, in addition to meeting the criteria related to their reversibility and their compatibility, were able to solve problems and deficiencies shown by this particular construction solution. Hardly, the same information could have been obtained with other operating methods, and above all could have been recognized the uniqueness of this original solution.

Three more roofing of three churches built in the same period are being studied now: San Salvatore Maggiore, San Giovanni in Monte and San Petronio. Even in these cases, the same operating protocol is used: each of these churches presents particular roofing solutions with different degrees of complexity. In no one, the patterns deriving from manuals or literature seem to be applicable. The so-called Sangallo truss can establish at most a generic term of reference while the differences between real trusses and this model, and those between each truss with each other, make each identified solution unique. In particular San Salvatore Maggiore appears to be contemporary with the cathedral of St. Peter as edification (first half of the seventeenth century), as well as unique appears to have been the architect who designed them (Giovanni Ambrogio Mazenta). The solutions implemented appear, however, significantly different for at least two reasons: the type of truss used and the presence of brick columns that hold in some cases the trusses while, in other cases, directly the false-rafters. This truss differs from contemporary solution in St. Peter for the choice of using main rafters interrupted by lateral king posts. This reduces the hyperstatic degree of the structure, transforming the structural scheme into a pseudo-hypostatic one, with the consequent greater capacity of

Figure 4. Orthophoto extracted from the point cloud of a truss in the church of San Salvatore Maggiore in Bologna (by Claudio Demattia).
the various members to move; this is to be related to the fact that this church is located in an area of Bologna in which the consolidation of the ground under loads causes significant foundation settlements. Even in this case, as well as in the previous one, the solutions of intervention proposed are derived from the precise analysis of each truss and of each of its constituent member and are calibrated depending on the relationship between the structures and the context that contains them.

2.3. THE USE OF THE CAMERA FOR THE DEFINITION OF THE MASONRY EQUIPMENT

The great importance ascribed to masonry quality in order to achieve significant levels of performance in terms of structural safety, even against seismic actions, requires the definition of analysis criteria for its careful identification and evaluation. This becomes even more urgent in those cases in which, by this assessment, essential considerations are made in terms of estimation of seismic vulnerability of built heritage such as the method explained in the previous chapter. As further proof of the importance of the masonry quality parameter, it is emphasized how the possibility to compare and evaluate situations related to aggregates coming from different geographical contexts is found precisely in a relationship established between the different observed masonry qualities that determine, through some algorithms under improvement, specific correction factors that allow standardizing assessments. In many cases, the presence of external faces plastered hinders a proper assessment of the masonry quality; in addition to this it is believed that a significantly valid definition of this quality parameter cannot be isolated from the analysis, as well as of external walls, of those located in the inner parts of the historic building aggregates. From this need, it has arisen the will to verify the possibility of using diagnostic tools already used in the measurement of different performance parameters: mechanical strength, thermal conductivity or the presence of moisture. At first, during the bibliographic research, the use of ultrasound and the GPR has been taken into account, but both were deemed unsuitable for the intended purposes because their use requires highly specialized staff in the execution of the survey and in the interpretation of results. It was decided, therefore, to experiment the use of thermal imaging cameras inasmuch in literature there are many examples of investigations in which the use of this equipment has allowed to obtain information about the definition
of historical masonry textures beneath layers of plaster. That is why, a specific experiment has started regarding the possibility of obtaining information about the shape of the outer face of walls covered with plaster after providing heating to its surface. The thermal gradient appeared to be the key parameter to trigger a heat transfer that can be read by the instrumentation. The first goal was then the minimum energy to be provided for appreciating the visualization of differences in the surface temperature that could be put in relation with the position of the mortar joints in the brickwork below the layer of plaster.

It was designed a specimen on which carry out experimentations, constituted by a portion of two header bond, built with solid bricks, plastered only on one side with a hydraulic lime mortars. This choice was taken willing to remain strictly faithful to building solutions most frequently found in Emilia Romagna.

In constructing the specimen, a few number of constructive singularities were placed on purpose inside it trying to represent those situations that may have an influence in the behaviour of masonry walls or, in some way, may tend to lower masonry quality. A full-depth interruption simulates the typical masonry disconnection observed during the expansion processes of ancient buildings; a closed chase for implant passage; a vertical stripe made of one header bond to simulate a chimney; a partial localized discontinuity to test the ability to read even small-contained lesions that were fixed.

Figure 5. Layout of masonry specimen to be tested with thermal imager (sketched by Alice Catalini).
Defined areas of interest, the research wants to conduct a careful assessment of compatibility in order to better address the design choices. However, this does not mean The reuse of existing assets needs to update its performance requirements. It is therefore necessary to put in place intervention solutions that are, at the same time, efficient and respectful of the architectural value.

To achieve this dual goal, it is necessary to reach a level of understanding that considers various aspects that describe both the complexity of the building heritage and the different constitutive properties of its single components. In the study of the various issues raised by the assessment of structural safety, it should be emphasized that, in the past, excessively reductionist approaches have been used. The ability of the ancient structures was exclusively condensed in a few numeric-only data, merely used to implement verification procedures that were not able to describe the material reality of the analysed buildings (2). A sharp change of course has now taken place and, even if timidly, existing regulatory frameworks have a greater articulation and attention to aspects neglected until today (3).

This paper reports, through the presentation of some research topics that are being carried out, how the richness of the wide variety of design solutions present in the existing buildings should be investigated by referring to quantitative and qualitative approaches when they are efficiently combined. Specifically, the contribution that can be provided by the use of today available instruments can be very profitable if such use is combined with suitable operational protocols aimed to understand and to interpret the typological and original character. This method allows therefore to stem dogmatic or excessively generalist approaches.

3. CONCLUSIONS

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6. REFERENCES