Non-destructive methods applied for in situ mechanical diagnosis: Florentine historical buildings in Pietra Serena

Teresa Salvatici[1], Irene Centauro[1*], Sara Calandra[1,2], Eugenio Segabinazzi[1], Emanuele Intrieri[1] and Carlo Alberto Garzonio[1]

Abstract

Uniaxial Compressive Strength (UCS) is a key indicator of the mechanical properties of a rock, particularly in the diagnostic and restoration phases when stones are employed as construction material. In historical buildings, it is important to determine UCS values without utilizing tests that involve destructive rock sampling. To estimate UCS, non-destructive techniques, such as ultrasonic pulse velocity (Vp) and Schmidt hammer tests (R), can be combined to provide a useful tool. However, for architectural elements with complex morphology, it is sometimes impossible to perform both ultrasonic and sclerometric test. Three different UCS predictive models, one using R only, one using Vp and one using both, have been developed through regression techniques on a dataset comprising 45 Pietra Serena sandstone samples with varying levels of decay. The models were tested for their performance through Cross-Validation techniques and were then applied to a dataset of Vp and R values measured in situ on Pietra Serena corbels of balconies belonging to historical buildings in Florence (Italy). The specific predictive models were applied to real case studies, and the UCS of the rocks used in historical buildings was calculated, enabling the definition of the mechanical characteristics of building elements belonging to an important cultural context, Florentine historical architecture, without using destructive testing.

Keywords Ultrasonic pulse velocity, Schmidt hammer test, Uniaxial compressive strength, Pietra Serena sandstone, Historical buildings

Introduction

Diagnostic investigations are fundamental procedures for the conservation and safeguarding of buildings that belong to the historical-artistic heritage. These surveys can be conducted in laboratory or through in situ measurements. Non-destructive techniques (NDT) are preferred over laboratory tests, and in the case of historic and architectural structures, they are often the only possible solution to assess material properties. This is because they provide information on the mechanical properties of materials, their level of damage, the presence of defects, cracks, weathering effects, etc., without requiring sampling. Additionally, NDT tests are easier and less expensive than destructive tests.

The decrease in the mechanical properties of stone materials is closely linked to the deterioration phenomena that impact building materials. The most common effects of degradation include swellings, cracks and fractures, and in severe cases, complete detachment [1]. These are affected by: (i) internal parameters, such as porosity, mineralogical composition, and structure, which are specific to the material itself, and (ii) external

*Correspondence:
Irene Centauro
irene.centauro@unifi.it
[1] Department of Earth Sciences, University of Florence, Via A. la Pira 4, 50121 Florence, Italy
[2] Department of Chemistry Ugo Schiff, University of Florence, Via della Lastruccia, 13, 50019 Sesto Fiorentino, Italy

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parameters, such as temperature, pressure, relative humidity or exposure to atmospheric agents.

The deterioration processes that affect the preservation of cultural heritage structures frequently involve non-structural stonework, which is prevalent in the historical buildings of urban centers such as Florence. The specific characteristic of these elements, including corbels, cornices, capitals, coat of arms, etc. is their overhang relative to the facade plane, which exposes them to the risk of detachment and falling. Furthermore, there are other potentially critical factors that may contribute to the risk of collapse, such as increased susceptibility to weathering due to their morphology and frequent replacement over the centuries. Therefore, the loss of mechanical properties of these elements not only poses a potential threat to the integrity and cultural identity of the buildings but also to the safety of people.

In this work, ultrasonic pulse velocity and Schmidt hammer were selected as simple, cost-effective and straightforward methods to estimate the mechanical properties of building stones. These NDT were chosen because they enable continuous monitoring, which is useful in assessing the evolution of the state of conservation of the materials [1, 2]. Many studies have investigated the possibility of estimating the Uniaxial Compressive Strength (UCS) of rocks based on parameters derived from NDT techniques such as rebound index (R) obtained from the Schmidt hammer, and P-wave velocity (Vp) obtained from the ultrasonic pulse velocity test, either separately or together [3–6]. These techniques have also been used to determine the rock weathering degree [7–9].

Ultrasonic velocity tests are widely used to identify the mechanical properties of various materials, including stones and concrete. The Vp value is dependent on both the physical properties (density, elasticity, porosity, etc.) and on the conservation state of the stone. Vp has a strong correlation with UCS, to the extent that researchers have used the ultrasonic pulse velocity to predict the strength of different types of stones [10–13].

The Schmidt hammer test is a minimally invasive method that allows for the determination of superficial hardness of construction elements. The R values, which represent the amount of elastic energy returned by the material during the test, are used to estimate UCS of the material through conversion tables or literature equations and relationships [14].

The combined use of both techniques improves the accuracy of estimating the compressive strength of both natural and artificial stone materials [15, 16]. However, further experimental data are required to confirm the reliability of the method for stones used in historical and architectural manufacts.

This study evaluates the potential of these techniques on Florentine Pietra Serena sandstone. Three predictive models of UCS were developed based on laboratory measurements and later applied to 4 case studies located in Florence.

By comparing the results of various diagnostic tests conducted on protruding stone elements such as balcony corbels, we established a precise correlation to assess the mechanical properties of Florentine building materials. This analysis also provided an initial understanding of the level of decay of the stones [17, 18].

Data set

A corbel is a structural or decorative piece that projects from a wall and provides support for a balcony or cornice. These elements can be found in historic palaces, churches, and other architectural structures, adding both functional and aesthetic value to the building. Corbels come in a wide range of shapes and sizes, often showcasing intricate craftsmanship and detailing. They can be simple and straight, resembling a protruding ledge, or they can take on more elaborate forms, such as animal or human figures, floral motifs, or abstract designs. Regarding width or projection, corbels typically extend horizontally from the wall anywhere from a few centimeters to a meter or more.

136 corbels of balconies from historical buildings and churches in Florence, Italy (including the Corsini al Prato Palace, Pucci Sansedoni Palace, Ginori Conti Palace, and Santa Croce Basilica) were examined in situ using ultrasonic and Schmidt hammer tests (Fig. 1). Over 500-point measurements were carried out [17–19]. The corbels, which can have variable depths and thicknesses, were investigated in the portion corresponding to the protruding part from the façade. This part also has variable dimensions, but in the analysed cases, the average thicknesses investigated were 30 cm.

The Pietra Serena corbels exhibited various types of degradation phenomena, including material loss and scales detachment, as well as cracking, granular disintegration, powdering, discoloration, and biological growth deposits. Figure 1 shows five different corbels with varying degrees of deterioration: (a) cracking and deposits; (b) fracture, delamination, disintegration, erosion, discoloration, efflorescence, deposit, and presence of a rusty metal bracket; (c) good condition with erosion; (d) deposits, powdering, blistering, delamination, and erosion; (e) good superficial condition.

Pietra Serena

Pietra Serena sandstone is an important part of Florence's architectural and urban appearance, with its use dating back to the Renaissance, and contributed to the

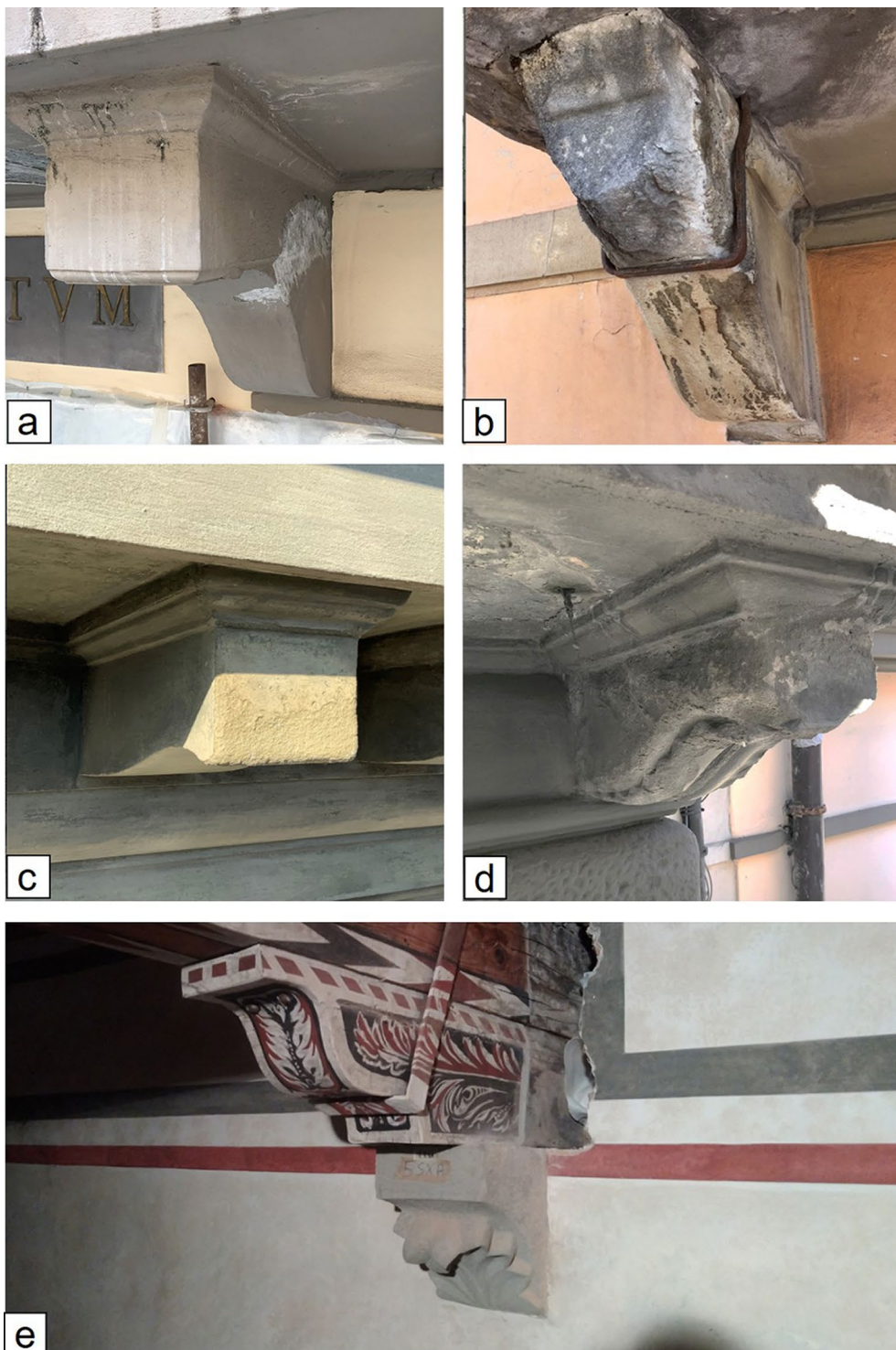Salvatici *et al. Heritage Science*   (2023) 11:116

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Fig. 1 Stone corbels of balconies of some historical buildings of Florence, **a** Ginori Conti Palace; **b** Corsini al Prato Palace; **c** Pucci Sansedoni Palace corbel under eaves and **d** Pucci Sansedoni Palace balcony corbel; **e** Santa Croce Basilica

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development of a new architectural style [20, 21]. Its morphological features add to the artistic image of the city center, which was named a World Heritage Site by UNESCO in 1982.

The denomination Pietra Serena is the commercial/artistic name of a sandstone found in the Macigno and Monte Modino turbiditic Formations cropping out in the Northern Apennines, dating back to the late Oligocene-Early Miocene. These formations have typical Bauma sedimentary features and reach a maximum thickness of about 3 km [22]. Its petrographic characteristics are discussed in specific bibliographic sources [21, 23].

Pietra Serena was mainly sourced from outcrops near Florence, which kept transportation costs low [24, 25]. The first mining activities were in the hills around the right Arno riverbank, at the hills of Fiesole, Settignano, Vincigliata and in Mugnone valley (belonging to the Monte Modino Formation). Later, further quarries were exploited, located along the left Arno riverbank at Gonfolina locality, Chianti Mountains and Tavarnuzze town and are referred to different levels of Macigno Formation.

As demand for Pietra Serena increased over time, Pietra Bigia, a similar sandstone with a light brown colour, was also used, along with the particularly durable stone known as Pietra del Fossato [21, 25].

Today, the quarries of Pietra Serena around Florence are depleted [22]. The replacement stone used for construction and restoration of the stone elements is Firenzuola sandstone, which has similar macroscopic properties to Pietra Serena but is geologically different. Firenzuola sandstone consists of silicoclastic turbidites of Marnoso–Arenacea Formation and has different mechanical properties with an average UCS value of 115 MPa [26]. The mechanical properties of different sandstones can vary depending on the outcropping area [27, 28]. UCS values of Pietra Serena range from 70 to 100 MPa (determined perpendicularly to the bedding), but values around 50 MPa are also reported [21]. These values reflect the state of preservation too.

Methodology
Numerous statistical approaches and regression analyses have been used by various authors [6, 29] to estimate UCS through NDTs in laboratory studies, on different types of materials. However, not all these relations are suitable for Pietra Serena, which is used as both ornamental and building material for the main Florentine monuments. This study uses two traditional NDTs, the Schmidt hammer and the ultrasonic pulse velocity tests, to assess in situ mechanical characteristics related to different types of decay phenomena observed

in historical Pietra Serena corbels. However, to obtain a reliable correlation between Pietra Serena UCS and the NDT measurements, specific equations needed to be obtained through statistical regression between NDT values and UCS values directly measured in laboratory.

As the studied elements are not available for sampling, the UCS values have been estimated through a range of supplementary laboratory analyses performed on various Pietra Serena samples coming from detached elements from other buildings. The specimens were under different conservation conditions, which was helpful to provide a wide range of possible results. Cross validated [30, 31] regression techniques were used to obtain correlations between the NDT results and the UCS values. These correlations were then applied to the NDT results obtained in situ. The aim is to establish an effective methodology for assessing the degree of mechanical decay in historical building stone elements by comparing the results of these techniques between laboratory and in situ testing. This methodology will serve as a baseline for future studies, condition monitoring, and implementation of preservation measures.

Ultrasonic velocity test
Ultrasonic velocity testing is a non-destructive method for measuring the dynamic properties of rocks, which can be conducted both in situ and in the laboratory. This technique calculates Vp by measuring the travel time and distance between transmitter and receiver, and it varies according to mechanical properties such as density and elastic modulus. These properties are linked to characteristics like porosity, micro-cracks, and rock type, which are also correlated to uniaxial compressive strength [6, 10]. These characteristics are also correlated to uniaxial compressive strength and so many authors found relations between UCS and Vp [1, 12, 32–38]. Ultrasonic velocity measurements are useful for detecting low deterioration and a slight decrease in the mechanical strength, even though the material appears to have no visible decay effects [13].

The soundwaves frequency normally used in ultrasonic testing is between 20 and 150 kHz [UNI EN 14579]. Currently, all ultrasonic detector instruments are made up of two parts: the generator that sends the signal into the material to be examined, and the detector that receives, amplifies, filters and displays the signals that return to the probe after propagation through the material.

The investigations presented in this paper were conducted with two instruments: TICO equipment from Proceq with two piezoelectric transducers with a diameter of 50 mm of natural resonance frequency of 54 kHz and IMG 5200 CSD, which uses two low

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frequency antennas of 50 kHz, with a diameter of 50 mm. To perform the test, the transducers are kept on the surface under examination, until the oscilloscope curve is stable, when it is thus possible to read the wave travel time to the receiving probe. The measurements were carried out with direct transmission test: the transmitter/receiver transducers pairs are placed on two opposite faces of the sample, a method that proves particularly useful also for detecting internal lesions. Furthermore, direct transmission test is the one that offers results of a certain reliability (accuracy of ± 1%). The choice to conduct UPV tests in direct mode is aimed at highlighting inhomogeneities within the stone matrix that can give rise to detachments of large portions of material. The accuracy of the test is affected by the sample morphology, particularly the presence of flat and parallel surfaces, which improves test performance [39]. Testing becomes more challenging when uneven surfaces partially obstruct ultrasound transmission or create interference. A thin film of water-based coupling gel was used for all measurements, both laboratory and in situ ones. This gel ensures treatment reversibility and compatibility with the stone substrate, which are essential requirements for working on architectural heritage. For in situ measurements of corbels, two or three points with a direct transmission line were tested depending on their specific morphology and dimension. The resulting velocity for each corbel is the average of all its measurements point.

Schmidt hammer test

The Schmidt hammer, or rebound hammer, is one of the oldest tools for non-destructive in situ testing of concrete and rock mechanical characteristics. This method, originally designed for testing the hardness of concrete, has been used on many different rock types in many parts of the world [40], and in several studies R has been tested to estimate the UCS and the Young modulus (E) of stone materials [4, 34, 41–50]. This method consists of a device which measures the distance travelled by a spring-loaded mass that is released against a plunger when the hammer is pressed onto a hard surface. The plunger impacts the surface and the mass recoils. The distance travelled by the piston after rebound is called the rebound value (R). Hammer rebound readings are considered consistent and reproducible [44] and depend on the hardness of the surface against which its mass strikes. However, the R values are significantly influenced by many other factors such as the hammer type, the absolute orientation of the hammer and its inclination with respect to the surface, the specimen dimensions, the surface smoothness, weathering and moisture content [51].

The standard method for the test is described in [52, 53]. The type of hammer for testing rocks is the L-hammer, which generate 0.735 Nm of impact energy. The International Society for Rock Mechanics (ISRM) recommends the use of an L-type hammer on rocks with UCS ranging from 20 to 150 MPa. The American Society for Testing and Materials (ASTM) does not specify any hammer type and recommends applying at least 10 impacts for rocks with UCS ranging from 1 to 100 MPa. Indeed, an extensive literature review reveals that both types have been employed to estimate the strength of various rock types [49].

In this paper, the L-type Geostone from Novatest was utilized, wich has a percussion energy of 0.705 Nm and a range of 10–200 MPa. At least 10 impacts were made on the measured surface, keeping the hammer perpendicular, to obtain averaged R values and reduce the effect of measurements taken under non-standard conditions due to difficult operating circumstances, such as limited site accessibility.

Laboratory analyses

Laboratory analyses were carried out on different types of Pietra Serena cave samples and portions of architectural elements to determine their Vp, R, and UCS values. The samples, which were around $6 \times 6 \times 6$ cm in size, were cut from larger stone slabs, resulting in a total of 45 samples. These laboratory samples were subjected to natural aging and exhibited varying degrees of conservation, allowing for comparison with the different degradation phenomena observed on the on-site elements (Table 1).

The ultrasonic tests on all cubic samples were carried out considering 3 different probe positions along the opposite faces, and the Vp result is the average value. The Schmidt hammer tests were conducted on the cubic samples according ISRM 1978 [14, 52]. Finally, UCS value was obtained, breaking the samples with a 60 kN loading cell hydraulic press INSTRON MODEL 5592. Tests were performed in displacement control by imposing a load constant stress rate of 1 ± 0.5 MPa/s, to obtain a uniaxial compressive strength (UCS).

The results of Vp, R and UCS obtained on laboratory samples were used to derive 3 correlations, namely UCS-Vp, UCS-R and UCS-R-Vp (Figs. 2 and 3; Table 2).

Various statistical metrics were employed to assess the accuracy of the regression models [54]: R^2, Root Mean Square Error of Cross-Validation (RMSECV) and Mean Absolute Percentage Error of Cross-Validation (MAPECV).

To obtain accurate and statistically significant results, the chosen performance metrics were calculated using the K-Fold Cross-Validation technique using R programming language. K-Fold Cross-Validation divides the data

Table 1 List of laboratory samples and their dimensions, average, standard deviation values of Vp (m/s), R (—), UCS (MPa) measured and description of degradation phenomena

| Name of slabs	N. of samples	Vp (m/s)	R (-)	UCS (Mpa)	Description
P01	4	2420±130	37±3	52±10	Compact stone in good condition
P02	4	2420±110	32±6	44±5	Partial disintegration and exfoliation
P03	4	2870±510	34±2	41±6	Partial delamination and presence of lichens
P04	3	1630±250	23±9	8±0	Strong delamination, erosion, cracks, biological colonization
P05	5	2640±80	28±4	35±2	Partial delamination, deposit
P06	4	2730±130	34±2	56±5	Partial exfoliation, deposit, disintegration
P07	4	2720±160	33±3	53±7	Delamination, erosion
P08	3	3130±60	35±1	71±13	Compact stone in good condition
P09	8	3410±110	40±4	116±19	Compact stone in good condition
P10	6	500±140	22±2	12±2	Strong erosion, cracks
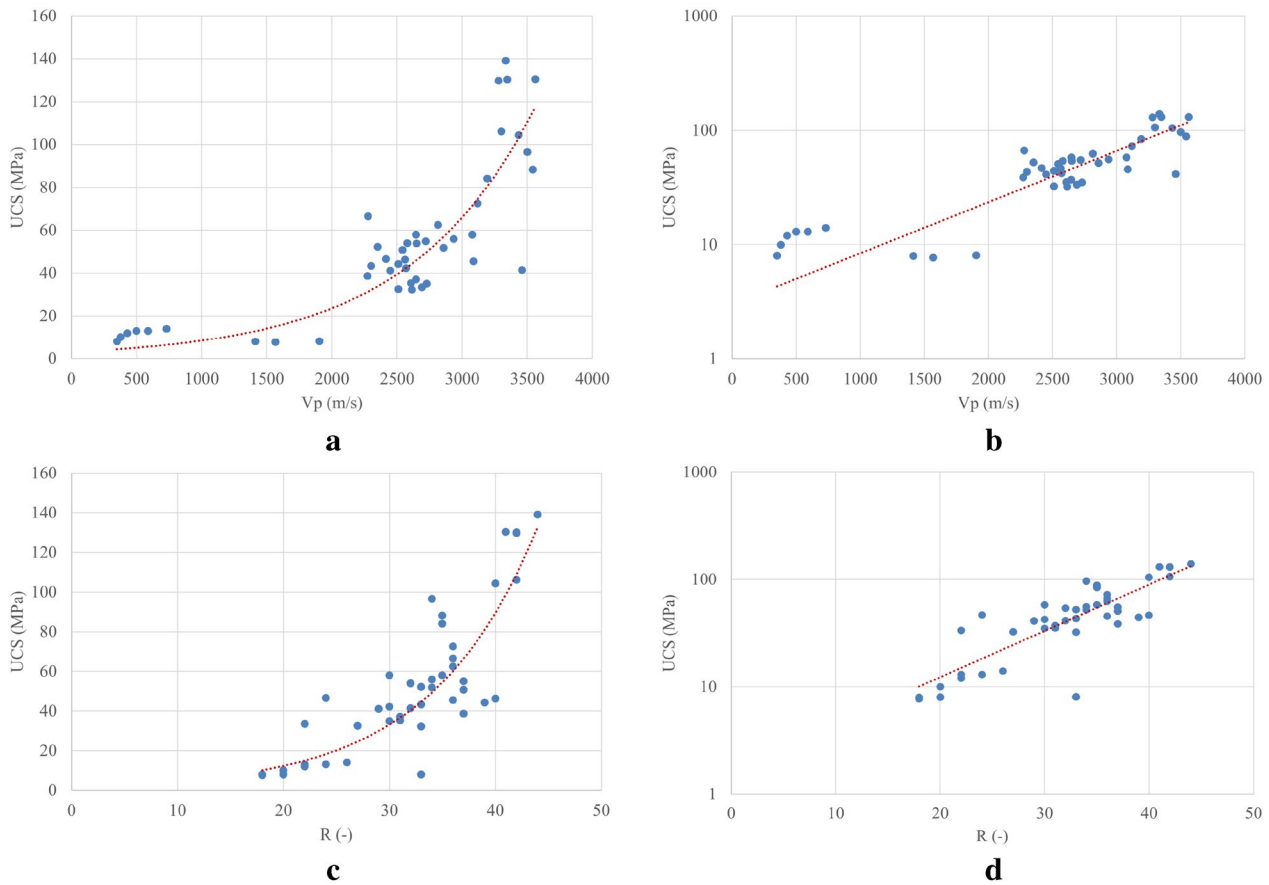
Fig. 2 Exponential correlation between **a** Vp and UCS in linear and **b** logarithmic scale and **c** R and UCS in linear and **d** logarithmic scale obtained on laboratory data set

into K subsets (folds) of almost equal size. Iteratively, one subset is used as a validation set and the remaining ones are used to generate the model. This ensures that the MAPECV and RMSECV are calculated on data the forecast model has not previously trained on.

In this study, 10-fold Cross-Validation was used, where the dataset was randomly divided into 10 folds. The model was trained on 9 folds and tested on the remaining fold. This process was repeated 10 times, with each fold used as the test set once. In order to ensure that each
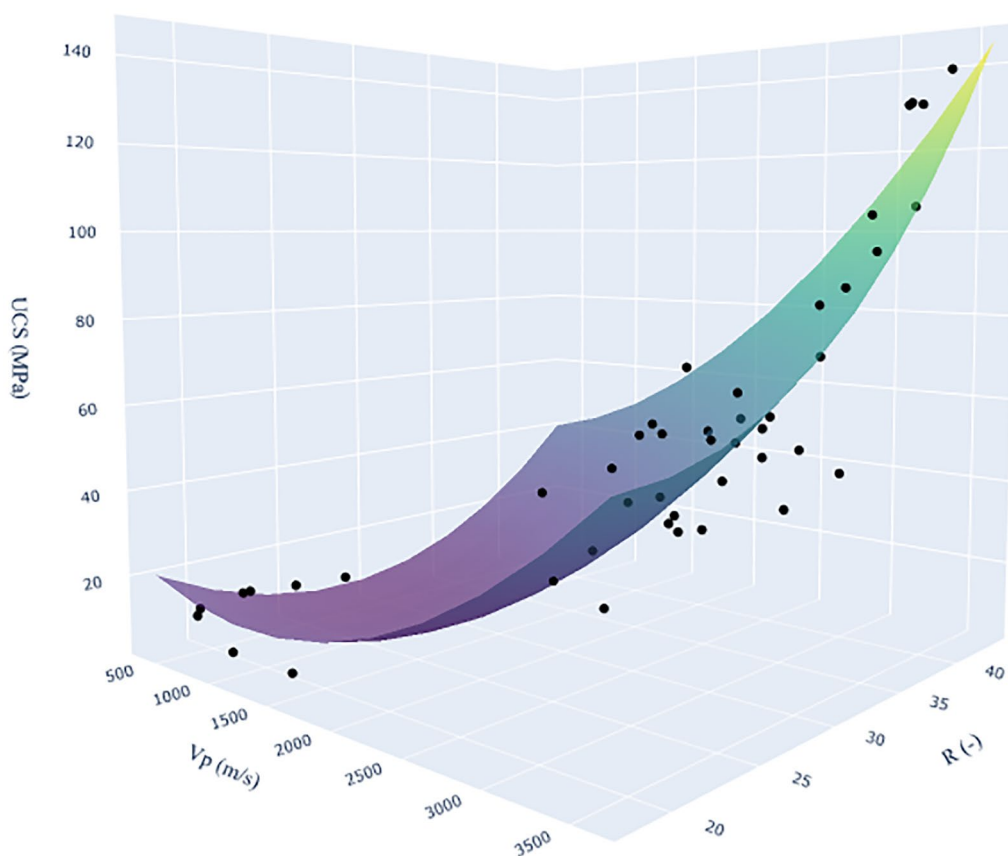
Fig. 3 Non-linear correlation between the Vp, R and the UCS on laboratory data set

Table 2 Statistical metrics of UCS-Vp, UCS-R and UCS-R-Vp, exponential models and non linear model, respectively

Model	R^2	RMSECV (% RMSECV)	MAPECV (%)
UCS $= 4.5004 *$ $e^{0.000905Vp}$	0.72	16.32 (28)	35
UCS $= 2.11 * e^{0.0944*R}$	0.73	13.81 (23)	37
UCS $= 1.105^R + 1.001^{Vp}$ $- 2.51$	0.86	9.95 (17)	24

training iteration had a complete set of strength, velocity, and rebound values for every class, samples were randomly selected from different replicates in each iteration of the cross-validation process. This process was performed for all 3 correlations presented in this paper.

RMSECV, which is the standard deviation of the residuals calculated across all the Cross-Validation iterations, was used to compare forecasting errors of the trained models on our dataset. If its value is close to zero, the predicted data are similar to the measured ones (1).

$$RMSECV = \sqrt{\frac{\sum_{i=1}^{N}(A_i - F_i)^2}{N}} \quad (1)$$

where N is the total number of observations, A_i the actual values of UCS and F_i the forecasted values of UCS.

The MAPECV is the most common measure to assess forecasting errors and the prediction accuracy of a forecasting method. The MAPECV expresses the error as a percentage, and a smaller MAPECV indicates a better forecast (2).

$$MAPECV = \frac{\sum_{i=1}^{N}\left|\frac{A_i - F_i}{A_i}\right|}{N} * 100 \quad (2)$$

For each Cross-Validation iteration, the RMSECV and MAPECV were calculated for the test set. The mean MAPECV and RMSECV were then computed from the results of each iteration, which are presented for each model (Table 2).

Both linear and non-linear models were tested to obtain the UCS-Vp and UCS-R correlations. The exponential model was found to provide the best fit and was

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therefore chosen to create the forecast model (Table 2). Figure 2a shows the scatter plot of the laboratory dataset comparing Vp and UCS and the regression line of the exponential model. The correlation coefficient (R^2) between the UCS and Vp for the exponential regression model is 0.72. In Fig. 2b, scatter plot of laboratory dataset comparing R and UCS, along with the regression line of the exponential model is shown. The correlation coefficient (R^2) between the UCS and R for the exponential regression model is 0.73.

Both the UCS-Vp and UCS-R models exhibit similar performances, confirming that both techniques can provide good predictions of rock strength values. This is particularly relevant because, in diagnostic investigation in situ, practical constraints often do not allow for both measurements to be carried out.

To achieve the best possible predictive performance, a model that correlates all 3 measured values (Vp, R, UCS) has been created. The best fit was obtained using a nonlinear model in the form (3):

$$UCS = a^R + b^{V_P} + c \qquad (3)$$

Figure 3 shows the scatter plot of our dataset comparing Vp, R and UCS and the surface of the nonlinear model. The correlation coefficient (R^2) between the UCS, R and Vp for this regression model is 0.86, a significant improvement over the single Vp and R models. This is

also true for the MAPECV and RMSECV metrics, which show a much better performance in predicting the UCS value when both Vp and R are calculated.

In Table 2 are shown the correlation equations and performance metrics of the UCS-Vp, UCS-R and UCS-R-Vp models, obtained from laboratory analysis. One factor that can contribute to the remaining errors in correlation analysis is surface degradation, which can alter the physical properties of a stone and affect the results of different tests in various ways.

Results and discussion

The obtained model was applied to predict the UCS values of the Pietra Serena corbles in Florentine monuments, starting from the measured in situ values of R and Vp. The bubble chart in Fig. 4 shows the relationship among the three parameters: R and Vp (measured) and UCS predicted (namely, UCSp). There is a linear distribution of values and a direct correlation between Vp and R, as previously assessed in other studies based on the integrated application of mineralogical petrographic, chemical, and physical analysis with ultrasonic and Schmidt hammer tests [17].

In Fig. 4, the size of the data points corresponds to the values of UCSp. By observing the distribution trend of these values, it is possible to confirm a direct correlation between Vp-R measured in situ and UCSp. These
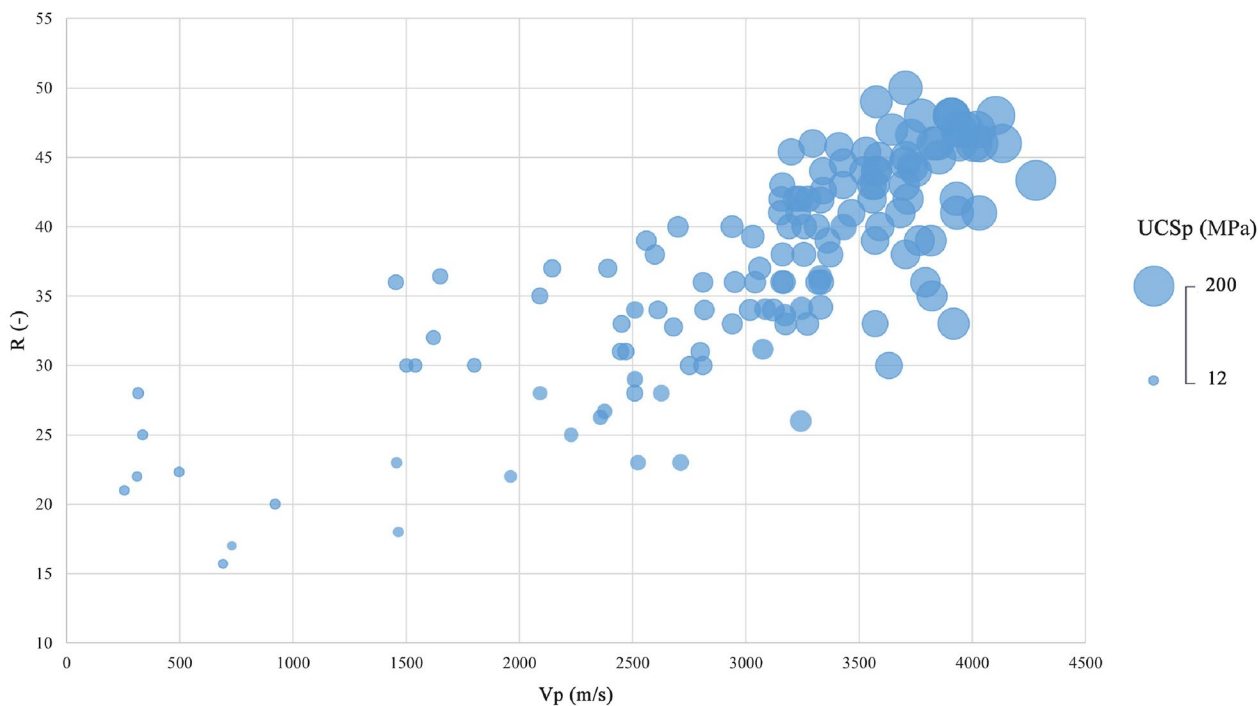

Fig. 4 Relationship among the three parameters: Vp and R (measured) and UCSp

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parameters reflect the level of decay of the corbels, in terms of the mechanical characteristics defined by the macroscopic description.

Stone elements located in the area with Vp values lower than 2500 m/s, R values lower than 30 and UCSp values lower than 26 MPa are in the poorest condition, displaying several forms of degradation. This area encompasses several corbels belonging to Corsini al Prato Palace and Pucci Sansedoni Palace (Fig. 1b and d). These values are consistent with the significant level of deterioration observed through the macroscopic description. At an intermediate level, corbels display generally good surface conditions, although with some detachments and fractures in the stone matrix, (Fig. 1a, e). These cases fall within an area with Vp values between 2500 and 3500 m/s, R values between 30 and 40 and UCSp values between 26 and 65 MPa. Lastly, corbels in good condition are represented by elements with Vp values exceeding 3500 m/s, R values over 35, and UCSp values higher than 65 MPa (Fig. 1c).

As previously mentioned, it is not always feasible to acquire both NDT parameters in the field of architectural heritage. Therefore, two single predictor models based on R and Vp were calculated. The performance of these models was then compared in two case studies described in Sect. "Introduction", which involved two stone corbels exhibiting different levels of degradation: one with advanced decay (Fig. 1b) and one in good condition (Fig. 1c). It can be noted (Table 3) that the UCSp values provided by the models based on R and Vp alone are all similar to those of the two-predictor model. In fact, considering the standard deviation (σ) obtained from the laboratory UCS measurements (Table 3), which is 7 MPa, all predictions are distributed in a range of one σ from the two-predictor model.

This confirms the possibility of using single-predictor models in those cases where it is not possible to use the multivariate model, which nevertheless remains the most reliable model.

Conclusion

In this paper, ultrasonic pulse velocity and Schmidt hammer tests have been used to predict the UCS of constructive elements like Pietra Serena sandstone corbels of balconies. These methods are portable, easy to use, and require almost no sample preparation (except for possible surface cleaning) so they can be easily employed in the field. Being able to reliably measure the UCS of stone materials without damaging or altering the materials themselves is essential to ensure the preservation of cultural heritage sites.

In the laboratory, the measured UCS and Vp showed a good exponential correlation, with a correlation coefficient of 0.72, also the UCS and R showed a similar correlation with a coefficient of 0.73. These models, cross validated with a K-Fold Cross-Validation, were then used to obtain UCS predicted values. The performance of the model has been validated with the RMSECV and MAPECV metrics, showing a good predicting ability. Then, a multiple regression analysis was carried out considering Vp and R as independent variables, and UCS as the dependent variable. A significant non-linear correlation exists in a multivariate regression between R, Vp and UCS with correlation coefficient of 0.86. Higher reliability and accuracy are achievable with the combined method because the use of two techniques together reduces the influence of the factors affecting the measurements, that can produce a bias on the results.

The model obtained from laboratory tests was then applied to Vp and R values measured in situ on the Pietra Serena corbels, in order to obtain UCSp values. The UCSp values are consistent with the level of decay of the corbels. The results are also in good agreements with the reference work of Salvatici et al. [17]. The method to allow, with good approximation, the estimation of UCS value of Florentine Pietra Serena sandstone in all cases of historic and architectural structures where the NDT are preferred over destructive techniques, suggesting a workflow consisting of both Schmidt hammer and ultrasonic velocity tests wherever possible, but enabling the use of only one of them if necessary.

Several other variables can impact the physical-mechanical properties of the stone, such as the salt content and the presence of water. For this research, we decided to maintain the natural environmental conditions, even in laboratory samples (neither dried nor wet). This method may have limitations, but it is preferable for an efficient, non-invasive, and quick solution for evaluating the mechanical properties of the elements under study. This is particularly useful when sampling is not feasible, such as in the case of UCS direct testing.

The validity of the proposed methodology is limited by the data range and sample types which were used to derive the equation, but this study shows the effectiveness and potential of NDTs, especially when working on a building of historical and cultural importance and provide a reference point for further investigations carried

Table 3 Result and comparison of the models UCS-Vp, UCS-R and UCS-R-Vp, UCSp on two corbels

	Vp (m/s)	R (−)	UCSp (Vp-R)	UCSp (Vp)	UCSp (R)
Corsini al Prato Palace	920	20	13	10	14
Pucci Sansedoni Palace, corbel under eaves	3470	41	98	104	101

out on an important construction stone such as Pietra Serena, widely used in the UNESCO site of Florence. Future discussions can be conducted taking into account possible degradation factors and how R and Vp measurements change according to the case studies.

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