Architecture, Structures and Construction
https://doi.org/10.1007/s44150-023-00106-8

ORIGINAL PAPER

The use of numerical models within the BIM environment, for the issue of Cultural heritage restoration. Buildings designed until 1940 in Albania

Nikolla Vesho[1] · Merita Guri[1] · Arjola Sava[1]

Received: 15 March 2023 / Accepted: 29 October 2023

Abstract
The study is related to the historical and architectural heritage of the city of Tirana, based on the period of Italian influence until 1940. The stock of these buildings represents an interesting case, in terms of research, since they are close to the 100th anniversary after the construction and have great values for the city, as well as architectural heritage. The lifespan of these objects depends on interventions over the years, conservation, updating with digital monitoring technology and the inclusion of BIM and h-BIM tools in the treatment process. It is important to mention that the building does not only need facade maintenance and refinishing, but by getting to know its fragile parts we can have a seismic retrofit strategy ready. Specifically, this research focuses on several digitization processes, 3D models, simulation and intervention proposals. One of the main aspects is the communication between computer models, dealing with the FEM numerical model and the architectural model inside and outside the BIM environment, reducing the gap between them and without major data loss. After analyzing the collapse scenarios, it is intended to increase the accuracy of seismic retrofit interventions, with the sensitivity that belongs to a cultural heritage object. The application of numerical models for legacy objects presents a challenge since the complexity of handling an old building, the parameters of materials, calibrations and approaching the real response of the building in a seismic situation is known. Applications through BIM tools and files with numerous numerical data tend to make a contribution to the field of seismic engineering and heritage restoration in Albania. Variants with proposals on seismic retrofit strategies for protected buildings will be given at the end of this study.

Keywords Cultural heritage · Survey · Seismic retrofit · Numerical models · Nonlinear analysis · BIM tools · Revit · Dynamo · Interoperability

Introduction

The research will start with a short presentation of the cultural heritage buildings of Tirana, Albania during the Italian influence until the end of 1940s, archival research on the details of the projects and technical interpretations on the solutions given in that early period [1, 2]. Aspects on the architecture of the buildings and the related architectural solutions will also be addressed [1–3]. These are symbolic buildings that lay the foundations of a city like Tirana. On the contours of these buildings along the two main boulevards of the city, urbanism continues to be conceived and updated for the future (Fig. 1) [3]. Through these objects, symbols of heritage, today Tirana of skyscrapers continues to be intertwined in a silent harmony.

In the history of architectural design, a group of designers from Florence proposed and designed the monumental structures in Tirana, which possess precious architectural and cultural elements that must be preserved and promoted, taking them into the future as a value for the nation. In this study, a building that is significant for the city and its inhabitants will be treated in particular. The research will address the case, highlighting the architectural qualities of

✉ Nikolla Vesho
nikolla.vesho@unife.it;
nikolla_vesho@universitetipolis.edu.al

Merita Guri
merita_guri@universitetipolis.edu.al

Arjola Sava
arjola_sava@universitetipolis.edu.al

1 Department of Architecture and Civil Engineering, Polis University, Rruga Bylis 12, SH2, 1051 Tiranë, Albania

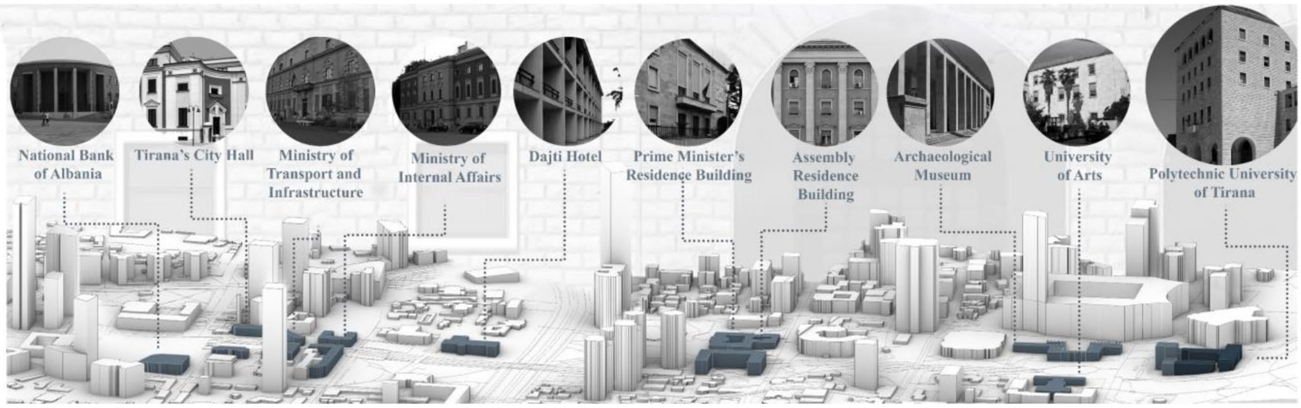


Fig. 1 Axonometric representation of the central boulevard, showing the interweaving of skyscrapers with cultural heritage buildings [4]

the building through analysis, architectural modeling and numerical simulations working in BIM environments. It is intended to explain and recognize design morphology, materials, architectural surveying, data collection and numerical modeling working through BIM. The data of this study will serve for restoration, adaptation and consolidation interventions in the future.

The protected heritage buildings, being positioned in the central axis called "martyrs of the nation avenue", are considered assets of the city, their facades have always been preserved in terms of aesthetics (Fig. 1) [2, 3]. But, there has been no in-depth researches regarding their structural performance as well as genuine repair interventions. There are also many unknowns regarding their current seismic capacity and performance. This concern is related to the engineering opinion, numerical models and matrices with data for simulations of possible scenarios of the structural aspect. Today's dilemmas related to numerical models for old structures is the prevalence of non-coherent data related to the real object and its performance. But the numerical model f.e.m[1] and the inclusion of BIM helps engineers and architects take effective measures for the building [4]. Seismic retrofitting for cultural heritage buildings often causes damage to the originality, style and aesthetics of the architecture and theoretically should be done, only if the stability of the structure is in real danger [5, 6]. An efficient "surgical-intervention" can only be realized if numerical models are created within BIM, to enable simulations, possible collapse scenarios and theoretical interpretations on the respective strategies.

The purpose of this research is to present and partially apply a detailed methodology to address the problems of cultural heritage restoration, the survey process, the creation of a database with different numerical data for the this objects, simulations and theoretical analysis on the possible scenarios of collapse according to unfavorable situations, giving proposals with relevant solutions. Listed below are a set of key objectives:

(a) The objective of this study is the optimization of cultural heritage restoration and increasing the efficiency of this field in Albania, Through BIM tools, numerical models & F.E.M modelling, controlled by several algorithms to reduce the gap between architects, engineers and other experts in the field of restoration [4]; (b) Through this research, the announced target was to find GAPs and limitations of retrofitting interventions in cultural heritage buildings; (c) Including seismic simulations within the architectural restoration process, as well as the study of collapse mechanism scenarios, before an intervention; (d) Long-term objective, Continuous monitoring of buildings and equipping buildings with automated sensors, focusing on seismic performance and operation of technological networks inside the building, controlled through BIM tools and MEP models.[2]

The study aims to evaluate the performance of these buildings, as well as to evaluate and compare their seismic performance in today's condition also according to the requirements of the Eurocodes, considering all the conditions of the time when they were built.

Theoretical framework

Numerical model

Axonometric representation of building structure can be considered as a complex problem and for solution of this kind of problem is often obtained by using finite element

[1] The finite element method (FEM) for numerically solving differential equations arising in engineering and mathematical modeling.

[2] MEP stands for "mechanical, electrical and plumbing." MEP engineering is the science and art of planning, designing and managing the MEP systems of a building.

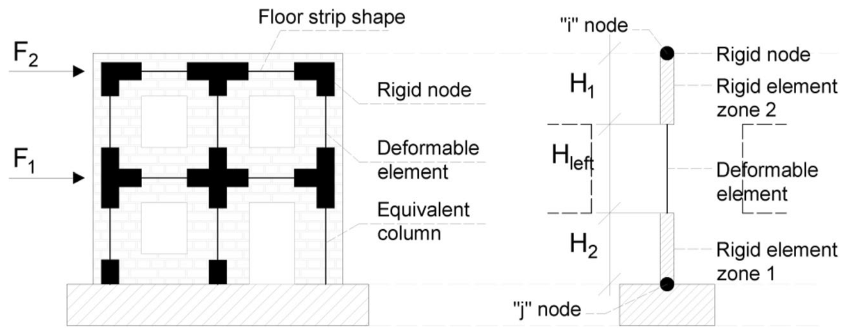


Fig. 2 Equivalent frame model with its elements, proposed for simulations [4]

method [7]. The computational or numerical model, which uses classical finite elements, incorporates substantial disadvantages as a result of high time-consuming computations and algorithms "*high number of degrees of freedom in terms of statics*" and extended data processing [8–10].

The 3-muri calculation model is the numerical parameterization of the global behavior of the structure, respecting the constitutive bond and cooperation of the material parameters or data (Fig. 2). The most frequent cause of errors in structural design is the difficulty to identify calculation models that are effectively representative of structure real behavior. The 3Muri model and concept, always starting from the basic concept of equivalent frame model (Fig. 2), rigorously addresses the bending mechanism considering the effective redistribution of the compressions to the discretization of the section, also to the achievement of the maximum compressive strength of the panel, while describing the "shear mechanism" according to the bond effect [11, 12]. Structural masses and stiffnesses are distributed over all 3-dimensional model of degrees of freedom. The connection nodes and joints, belonging to a single wall panel, maintain their "degrees of freedom" in the local reference plane, while the nodes belonging to several walls connected in axonometric projection, must necessarily have the "degrees of freedom" in the global reference of the structure, considered "three-dimensional nodes" [7, 13, 14].

BIM tools and h-BIM levels concept

Building Information Modelling (BIM), which is said to be most likely a technology-led change to deliver the highest impact to the construction sector.[3] BIM means different processes related to different professions. BIM can be considered as a process for design and creating information database on buildings. BIM applications have a comprehensive approach to all the steps of design, construction and maintenance of a building, making the process more optimal and efficient [15–18].

According to [15], "*A modelling technology and associated set of processes to produce, communicate and analyze building models; A new approach to being able to describe and display the information required for the design, construction and operation of constructed facilities*".

Currently there are many definitions with different points of view related to BIM, however there is a common denominator that BIM is a process for combining and storing information, numerical data and digital technology to create an automated process on a project [17, 19]. It integrates data from many sources and fields, at the same time it is updated in parallel with the real project along a set time frame in a parameterized way, including the design phase, construction management and operational information needed for these processes [20].

The research first examined the logic of BIM and the multi-disciplinary context of BIM. Then the focus is given to the latest methodologies related to h-BIM processes, which can be useful for restorers and professionals in the preservation of historical heritage buildings [18, 21, 22]. The h-BIM will be used beyond the classical framework, using up to 3-levels of BIM for this target. The research uses the anticipated potential of HBIM to support the treatment of historical heritage, documentation, digital libraries, simulations and information exchange for professionals and experts involved in this process [23, 24]. HBIM tools produce in a parameterized and automatic way all architectural and engineering project drawings, 3D axonometric models of buildings, plans and all 2-d sections, implementation details and technical specifications [25, 26]. These digital models are very suitable for introducing the culture of handling this issue, to enable professionals to interact with files and model database of architectural heritage in order to continuously improve the process.

According to [27], there are 3-levels of h-BIM as follows: "*h-BIM Level 0: Unmanaged CAD, probably 2D, with paper as the most likely data exchange mechanism; h-BIM Level 1: Managed CAD in 2D or 3D format with a collaboration tool providing a common data environment, possibly some*

[3] [referred to "World Economic Forum WEF, Shaping the Future of Construction, 2016" http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_Inspiring_Innovators_redefine_the_industry_2017.pdf].

standard data structures and formats; h-BIM Level 2: Managed 3D environment held in separate BIM(M)[4] *tools with attached data. The approach may utilize 4D programme data and 5D cost elements; h-BIM Level 3: Fully open process and data integration. Managed by a collaborative model server. Could be regarded as iBIM*[5] *or integrated BIM(M) potentially employing concurrent engineering processes*".

Connection between the architectural model with numerical model f.e.m.

As one of the basic interconnections of BIM modeling, a finite element treatment "F.E.M. method", would be valuable, also desirable, with which to schematize each individual brick unit, local wall panels, discretized frames and the reciprocal constraints. However this operation including 4D BIM[6] modeling would involve an enormous computational burden and extremely random relationships [4, 9, 22, 26, 28]. By adopting 3-dimensional finite elements models it's possible to obtain an exhaustive modeling for any type of existing construction and in particular, for those made entirely of unreinforced masonry with simple rigid ribbed slab. In particular, technical-application aspects are further elaborated in (Chapter 3) [8, 10].

Non-linear analysis for seismic analysis

The nonlinear analysis Pushover, methodology is able to define capacity curves with performance point, the shear resistance and collapse mechanisms. It is able to combine different mechanisms for global seismic performance analyses of buildings with sufficient regularity and limited height, and take into account the type of connection among the structural elements [29].

The assessment of seismic performance of URM buildings[7] requires the identification of the collapse mechanisms and masonry local damages step by step activated by the synthetic earthquake (elastic demand spectrum).[8] Referring the current practice in our region has been taken into account only three first modes of failure, by studying the capacity curves of certain structural typologies to get the right strategy for strengthening and updating the structure.

The most important step is transformation and conversion of panels in piers and spandrels labeling.[9] The vertical panels working in compression are converted in the Piers (frame elements that work in compression), while the horizontal panels under the openings below are converted to the spandrels that means "beams in bending" [30]. The parameters for the seismic analysis will be considered according to Eurocode recommendations, since this analysis will be based on this evaluation method [31].

The state of seismicity in Albania

The territory of Albania is familiar with the seismic events generated by the fusion of the Alpine-Mediterranean seismic plates, which derives from the collision of the Euro-Asian plate with the African plate and accounts about 15% of the total energy released by earthquakes worldwide [32]. Throughout history, many seismic events have shaken the area from ancient times to the present days. The Earthquake of November 26, 2019 (moderated event) (Fig. 3C) should be mentioned, which was the strongest seismic event that was recorded in Albania for a period of 40 years (the last one that should be mentioned again, the Ulqini-Shkoder earthquake of 1979), the map showed in (Fig. 3A) [32, 33]. The 2019 earthquake was a significant event, despite the fact that the maximum ground acceleration was only 0.195g in the Durrës region and 0.12g in the Tirana region. The second map shows the update of the old map considering the recent seismic events with a focus on the earthquakes of 2019 (Fig. 3B) [33].

Above in (Fig. 4A, B), the seismic acceleration of the events of 2019 is presented, accompanied by other recorded components. Related to (Fig. 4C), a numerical processing of the recorded data was done to generate the elastic design spectrum, which is widely used in seismic analysis, as well as the comparison of the 2-accelerations of the September and November 2019 earthquakes [34]. After the events of November 26, 2019 in Durres region (Fig. 4A, B, C), the focus and underlining of the destructive power of the earthquake was returned, where, in addition to the victims, it caused a significant impact on the country's economy, through a broad campaign called the "reconstruction fund" [34]. It is clear that these circumstances expose the high seismic vulnerability in the Albanian territory and therefore the need to incorporate reliable, efficient and affordable anti-seismic solutions. To continue with the special care and complicated solutions for the "cultural heritage" buildings and their structures.

4 BIM(M) refers to management of "collection and exploitation of information across a project".

5 iBIM stands for "Integrated Building Information Modelling" and it is a BIM model that includes "concurrent engineering processes".

6 4D-BIM dimension is commonly known as "modelling scheduling information to model construction and retrofitting sequences".

7 Unreinforced masonry building typology, without reinforced concrete frames.

8 Merging a number of strong short-period ground motions and long-period ground motions. From the merging of these accelerograms, an elastic specter is deduced.

9 pier is equal to column; spandrel is equal to beam. Both piers and spandrels are equivalent panels constructed of shell elements, showing the element way of work according the static concept.

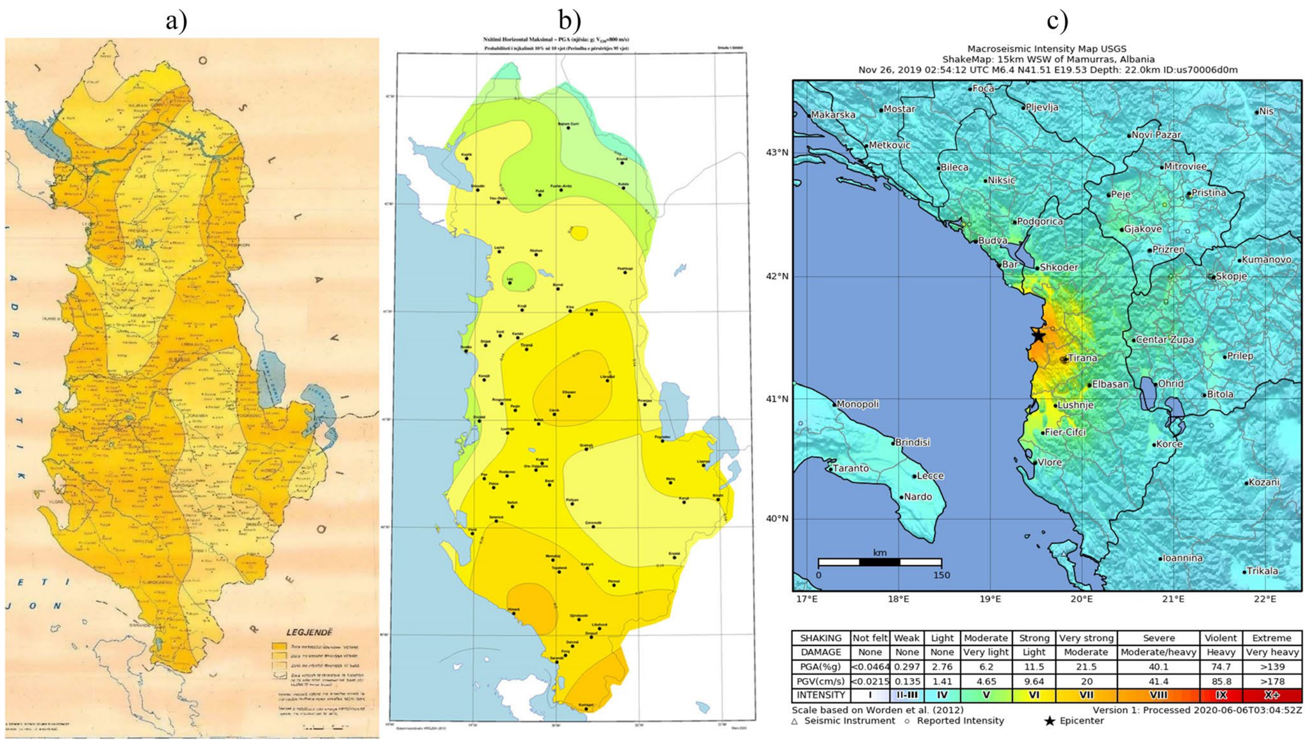


Fig. 3 **a** Map of the current design code for seismic zoning of Albania, year 1979 [33]; **b** New seismic map, related to peak ground acceleration PGA recurrence period 95 years, return period 95 years, probability of exceeding 10%, Summarized and re-worked [33]; **c** November 2019 Earthquake M6.4 affected area (Source: usgs.gov) [4]

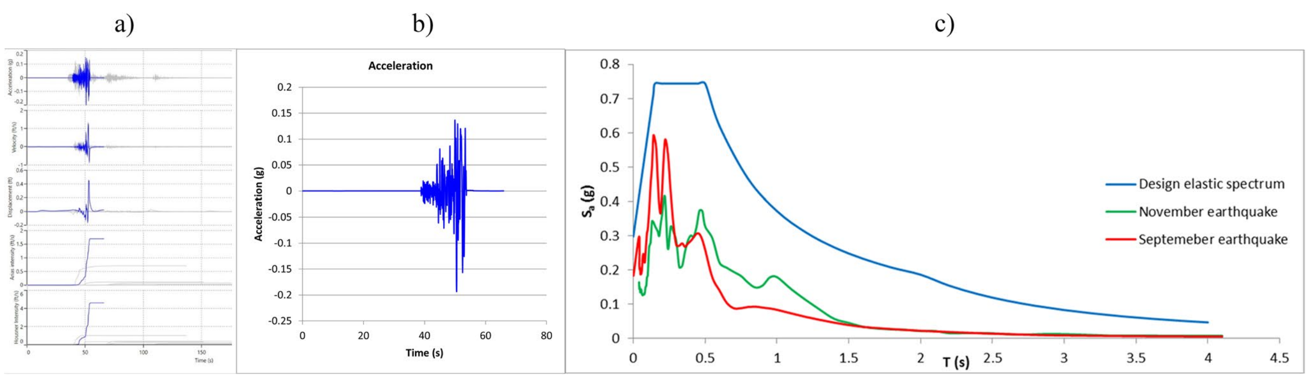


Fig. 4 **a** Summary diagram developed by the institute of seismology, after the seismic events of September & November 2019 [33]; **b** Data related to M.6.4 Durres earthquake acceleration recorded [33]; **c** Two response spectra from Tirana re-worked and compared to the current design code elastic spectrum [34]

Proposed methodology

A summary explanation on the steps of the proposed method: The developed h-BIM model has the ability to provide the geometric information and numerical data of the structure (a) from the architectural survey and (b) digitization of the archival project, accompanied by its attributes such as: (i) mechanical parameters of materials, (ii) introduction to seismic structural analysis. The results of such analyzes are also stored as attributes within the h-BIM base model, providing a usable integrated platform for building management [4]. Phase A—Problem formulation, on-site investigation process and database creation; Phase B—Architectural 3D Model Design, h-BIM model with 3 in-depth levels and analysis; Phase C and D—(a) Familiarity with the BIM Environment and recommended platforms; (b) Multidisciplinary simulations with f.e.m. model and (c) inclusion of non-linear seismic analysis, outside the BIM environment,

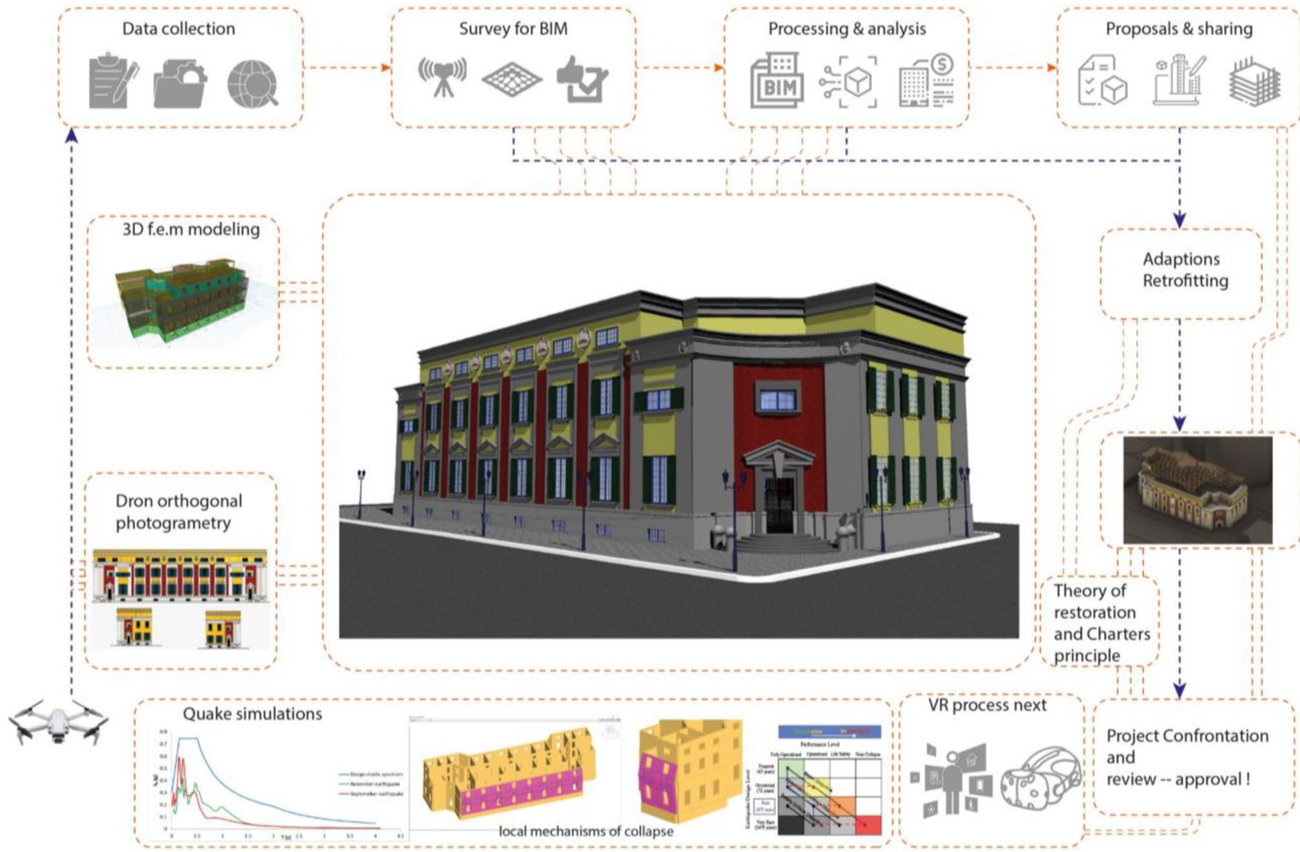


Fig. 5 Proposed methodology main scheme, reworked [4]

ensuring an efficient connection; Phase E—Assessments on efficient variants and design of "seismic retrofitting projects"; Phase F – Results and proposals. The principle of the method is the interoperability between numerical models and data [4, 23, 28].

An illustrated scheme, to show the applicability of the proposed method, based on the [4], shown in (Fig. 5) where several cycles are summarized: (a) collection of numerical data, survey method; (b) the basic 3D model of the building assisted by BIM tools and communication with satellite models, Inside and outside the Autodesk environment; (c) parameterization and connection between models; (d) relevant seismic analyzes and other possible simulations, especially the focus in this study was the inclusion of non-linear static analyses, interpretations on possible collapse scenarios; (e) intervention proposals and project drafting, which aim to optimize the interventions for this category of buildings and minimize the damage to the cultural heritage image, continuing with the control and monitoring of the building's performance for a long time [15, 20, 26, 28].

In the process of modeling with the help of BIM tools, we can optimize this process by including Dynamo scripts, in Revit within the Autodesk environment. So, another level of efficiency is achieved in the process of digitization of cultural heritage buildings, parameterization of restoration processes and libraries with numerical data exportable in excel (Fig. 6) [35]. By creating these bases with accurate geometric data, we can follow the process of further analysis and simulations inside and outside the Autodesk environment [23, 26, 28, 35]. This algorithmic model is used in the selected case study for seismic simulations and possible collapse scenarios.

To provide more details on the applicability of the method, based on the principles explained above, in (Figs. 7 and 8) are shown some specific stages of application of Dynamo scripts to optimize and parameterize processes such as the creation of technical files with numerical and geometric data for certain elements of the Building. Also, the transfer of data in an excel file where an architect or engineer can perform parametric intervention through this programming language, powered by Dynamo. Scripts have the advantage that they can be used for other buildings as well [22, 23, 35].

While a theoretical diagram related to the process of computational design, the diagnosis of a failed step and the cyclic

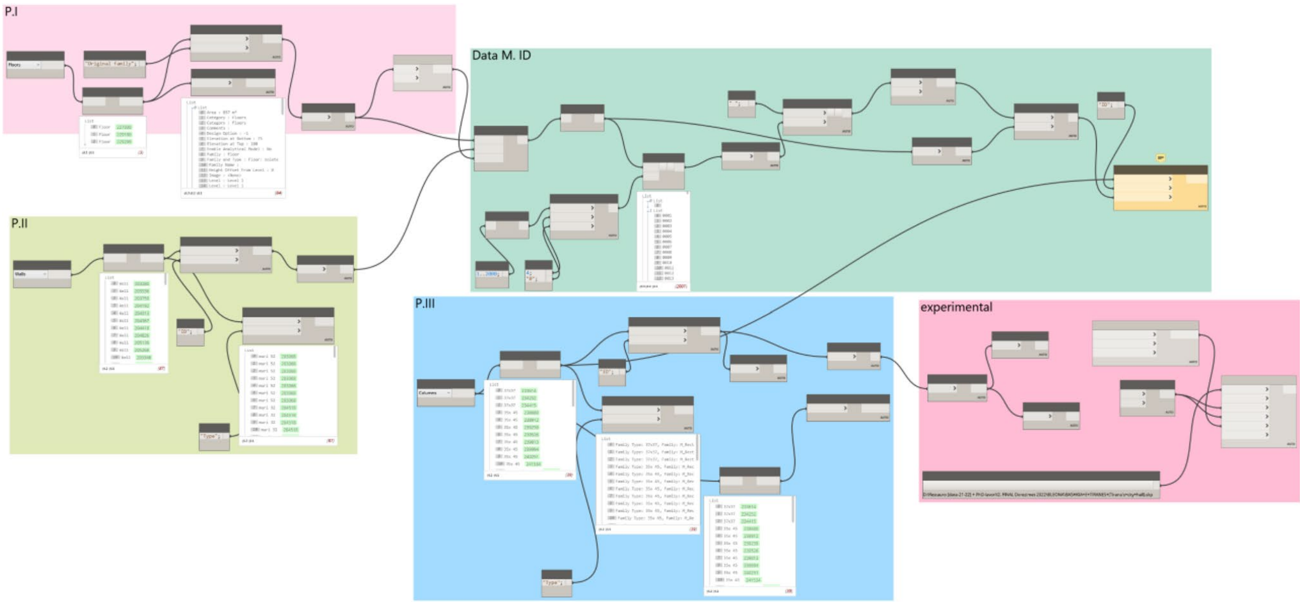


Fig. 6 Graphics files of a basic script included in the methodology, with the help of Dynamo algorithms within the Autodesk Revit environment

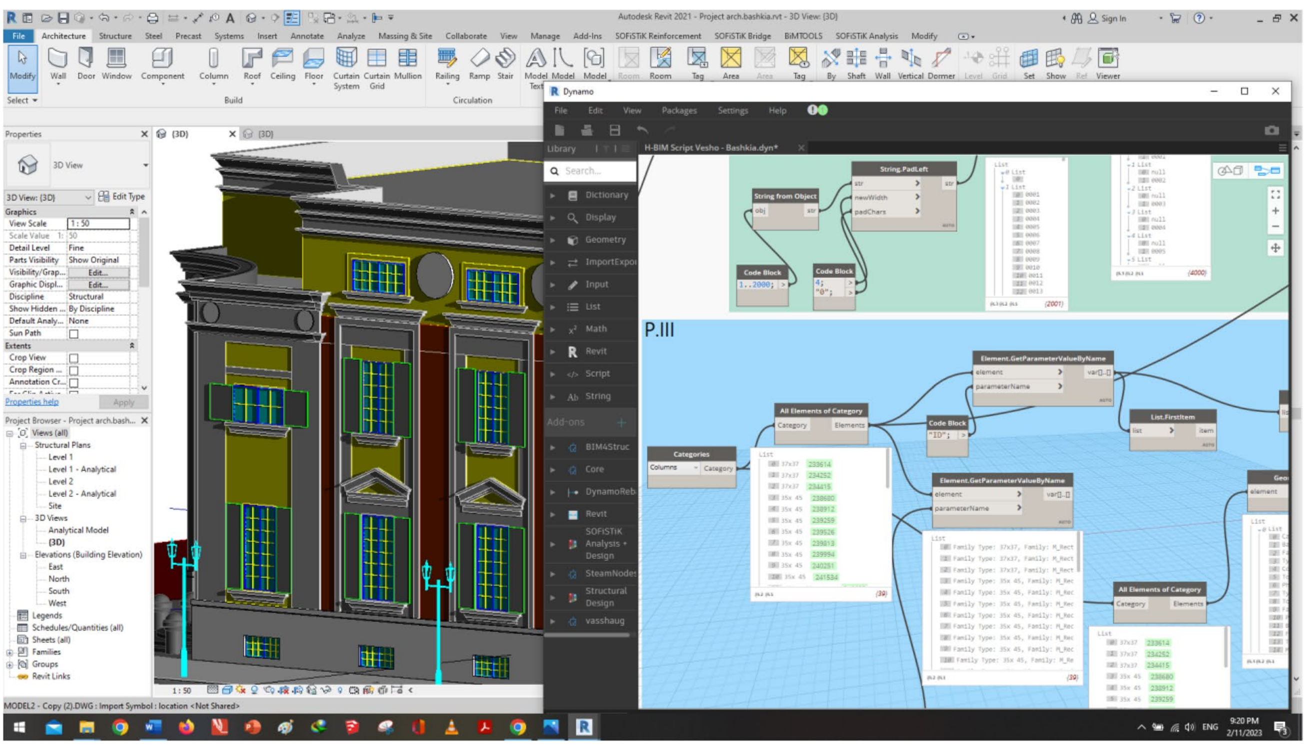


Fig. 7 Applications of an algorithm through Dynamo in Revit Autodesk, creation of digital files with data for building elements and interaction with axonometric explosion in Revit

operation of the analysis phases is summarized in (Fig. 9) [4]. Normally, it is a theoretical diagram which allows the possibility of improvement, for further research and a real adaptation within the Autodesk environment, since currently the analyzes are performed inside and outside the environment, having small losses of numerical data, at the moment of transferring models from one software to another [4]. Specifically, in this study, two special software were chosen

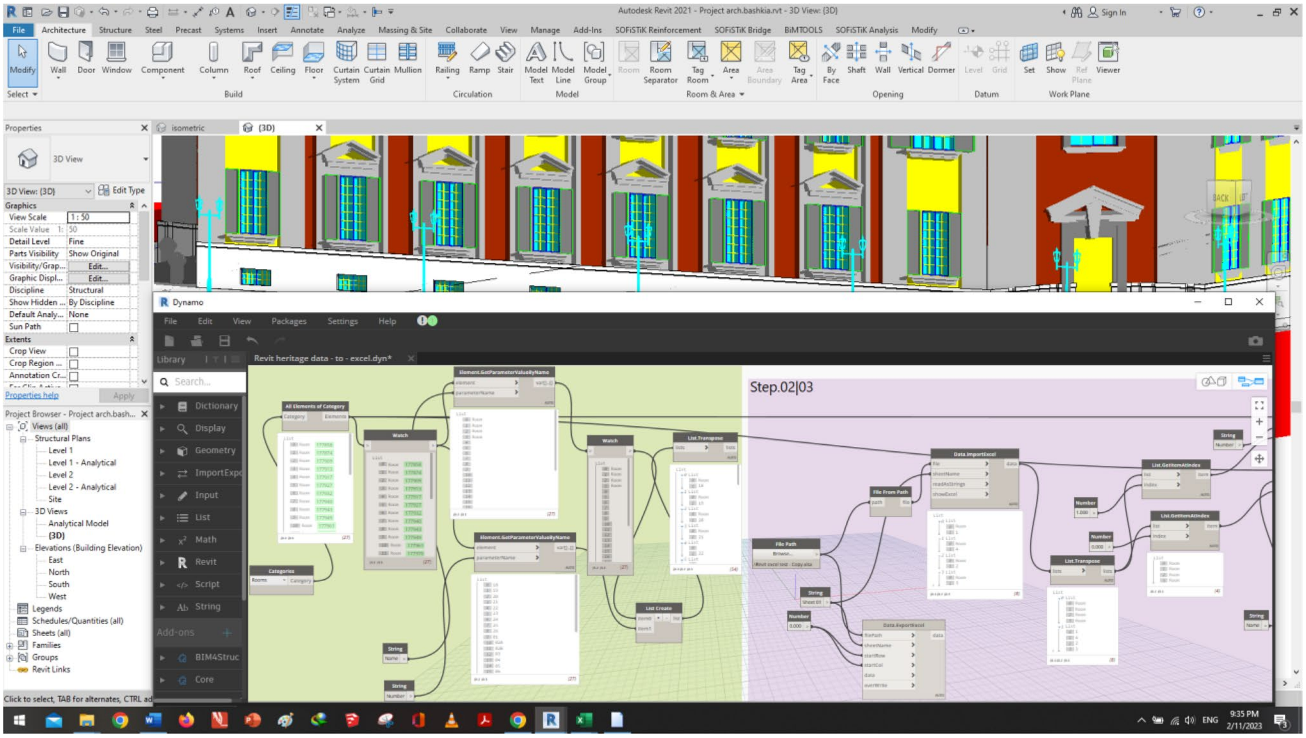


Fig. 8 Data processing and interaction of room-spaces inside the building and transfer to excel file, through Dynamo with an algorithm that accesses the model in Revit, that enables parametric intervention from excel and vice versa

for performing seismic analyses, first in ETABS, for simple seismic performance and then performing advanced "static non-linear analyzes" and simulations in "3muri software", parts of which are shown in detail in (Chapter 3).

Case study

Introduction of "City Hall building" a symbol of Tirana's cultural heritage

The building had a C-shape geometry with the entrances at an angle, connected by circular exedras. The structure of the building consists of the union of two typologies: typical RC frame and structural load-bearing brick masonry. This is a constructive solution that allowed flexibility for large rooms with presence of sunlight, such as the ballroom on the rear side of the Skanderbeg square. Also, at the same time the solution manages to provide the characters of the typical massiveness of the masonry, present on the entire external skin of the building. The main facade of the wall surface is very rich of elements, the numerous decorative layers of the wall surface treated with different materials (stone, bricks and plaster) accentuate the vertical sections of the façade, highlighted by stone colonnades between which the window openings are clearly elegantly framed [1–3, 36].

Data collection, Architectural survey process and 3D model inside BIM

The knowledge of the building for which an investigation and analysis is planned is the first operation to be performed. The immediately visible and detectable information are those of a geometric nature and those relating to the surfaces. To these must be added the historical and documentary information, including those transmitted orally, and, deepening more and more, the knowledge of materials and their mechanical parameters, textures, masonry equipment, mortar parameters, historical evolution and the state of conservation, just to name a few aspects. All these data subsequently require a contextual and coordinated examination, so that the hypotheses for the research and analysis are the result of an organic operation that does not leave out any of the available data, not even the apparently most irrelevant ones.

The research on-site was organized during the academic year 2020–2021, led by the academic staff of the Cultural Heritage Restoration course, also included students of Architecture and Civil Engineering, fourth year, as a cooperation between Polis University, Institute of cultural heritage and PhD program. The field work consisted of comparing the planimetry of the archival project with the real building and measurements. Measurement sessions with laser-meter, photogrammetry, and 3D scanning were carried out

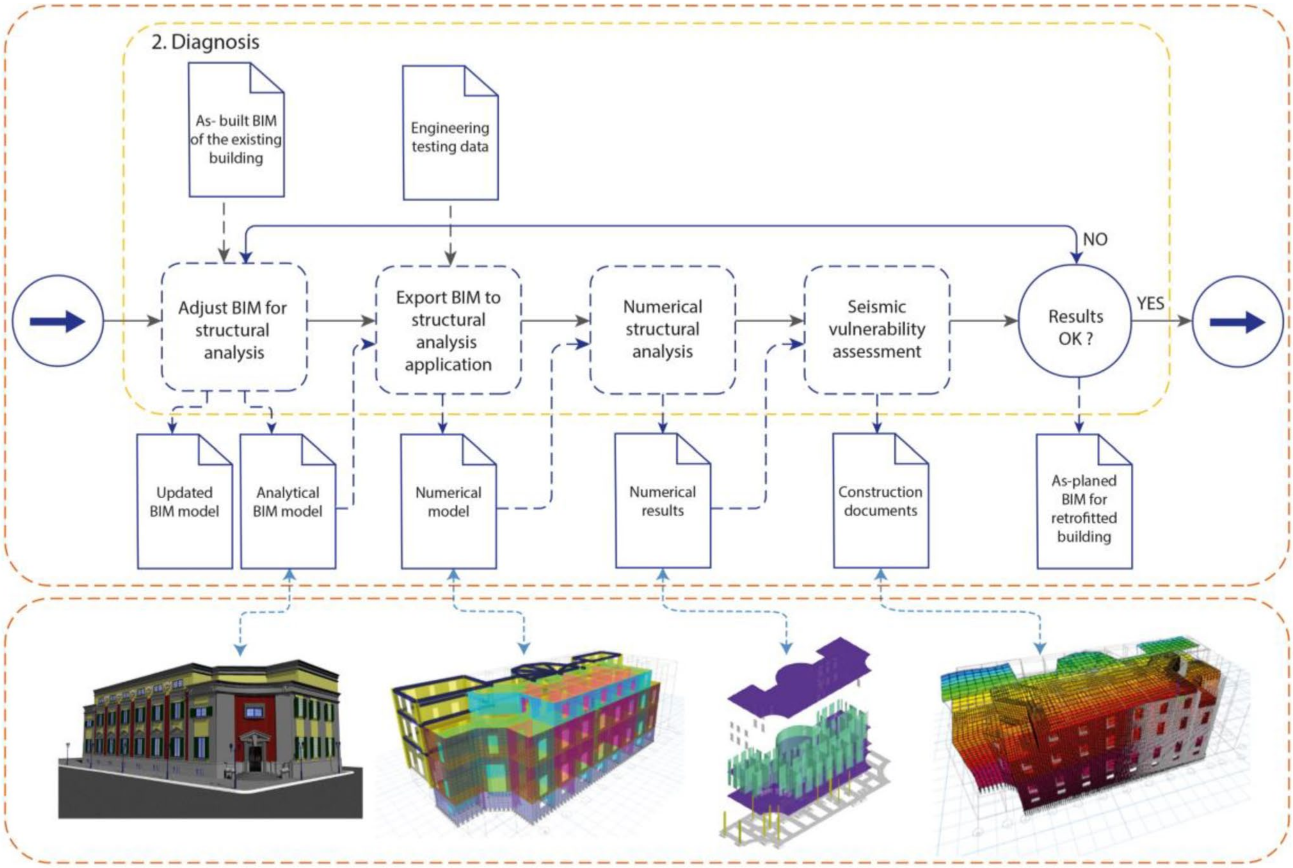


Fig. 9 Optimization of computational processes within BIM environment, reworked [4]

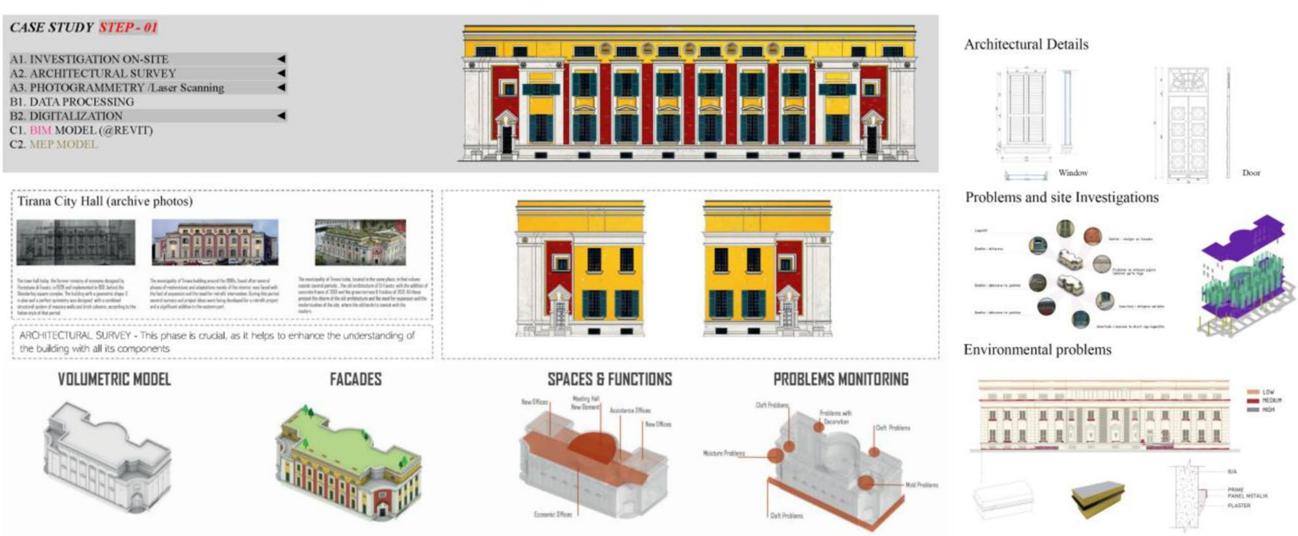


Fig. 10 Summary panel on the surveying process and partial data files in BIM

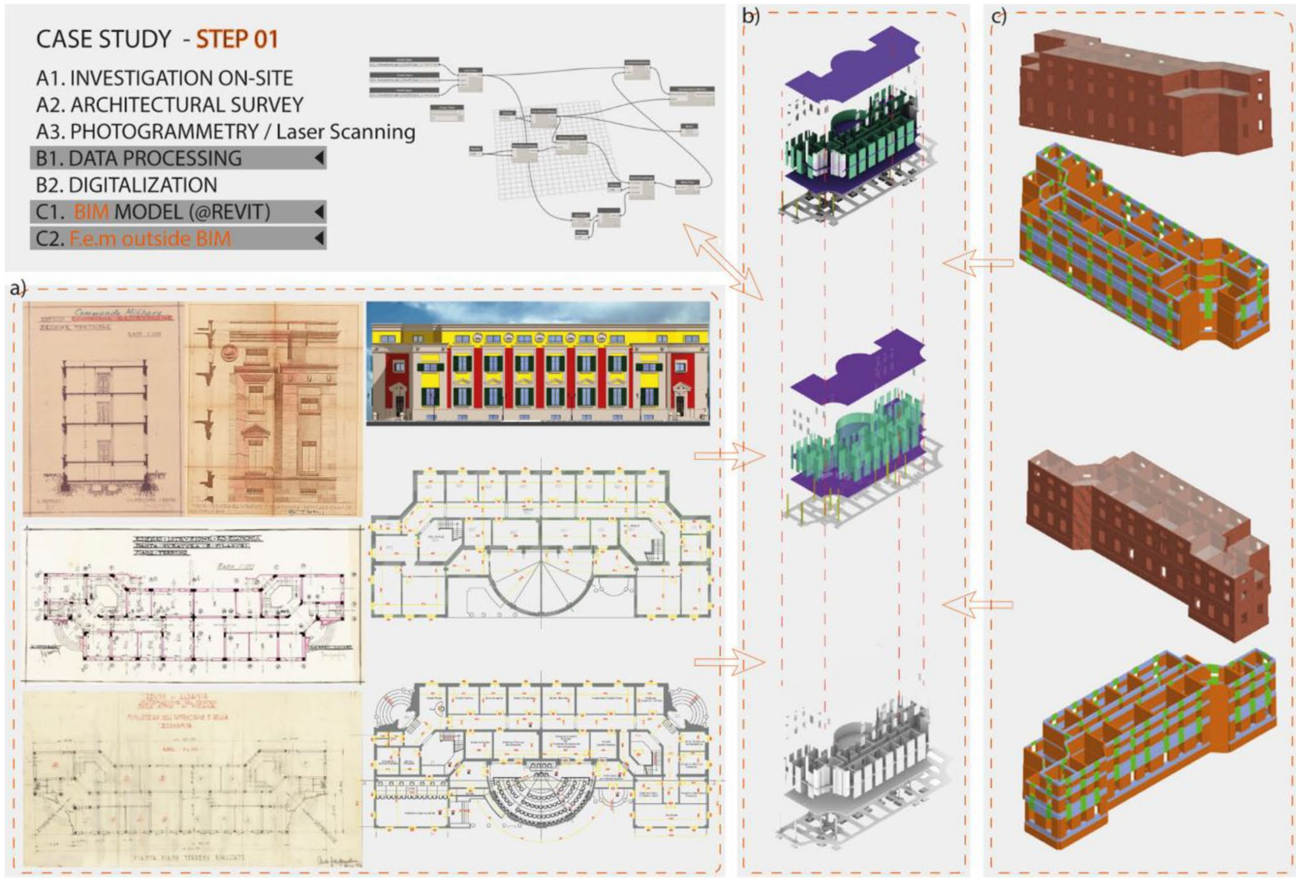


Fig. 11 Information exchange and interaction inside and outside the BIM environment with the assistance of Dynamo: (**a**) transition from archival material to digitization DWG IFC format; (**b**) Basic model BIM format RVT IFC; (**c**) FEM numerical model outside the Autodesk environment in 3muri software in format DB1/2 IFC DXF

to give the exact dimensions that the building has today [1, 3, 36]. In this report from the research on-site, the objects are presented and compared, coming up with some findings. Geometric inconsistencies in plan and elevation were found between the current project and archival projects. Also, based on the photogrammetry of the facades some interesting issues were highlighted to be analyzed (Fig. 10).

Numerical model and calculation assumptions

This paragraph is dedicated to the technical analysis of the project and how the numerical model was built. The structural project and technical specifications for this building are taken from the technical archives of Tirana [1]. While the data regarding the addition of the building in 2001, we are based on the respective drawings of the architectural and structural project [36] (Fig. 11).

The structural typology is a masonry structure (central block). The eastern extension of the building consists of RC Frame structure + infills, typology widely used in that period. A numerical model is shown in (Fig. 12), which compares the theoretical aspects with the specific FEM model used in this analysis.. Are evidenced four different masonry thicknesses, 60cm at basement level, 52cm, 34cm, and 17cm. The last thickness is used as separating walls between rooms [1].

For all case studies treated in this study, laboratory tests were performed, conducted on site by the "Altea & GeoStudio 2000 company" for the generation of data and mechanical characteristics of materials [38]. In the case of the town hall the focus was on taking and conducting tests on the brick and mortar material. The procedure performed starting from sampling the material in the structure, performing the relevant tests and obtaining the test results will be summarized in this section below. Other technical data of the laboratory tests will be summarized in the (Table 1) [38].

Material parameters used for numerical model are set to the current state, referring to the laboratory results performed above (Fig. 11), and reviewing the mechanical parameters according to the literature [8, 10, 39]. The masonry behavior is modeled by two different layers accompanied by stress and strain characteristics [8, 12, 14, 40]. The layers represent the vertical stresses $S_{1\text{-}1}$, $S_{2\text{-}2}$ horizontal stresses and shear

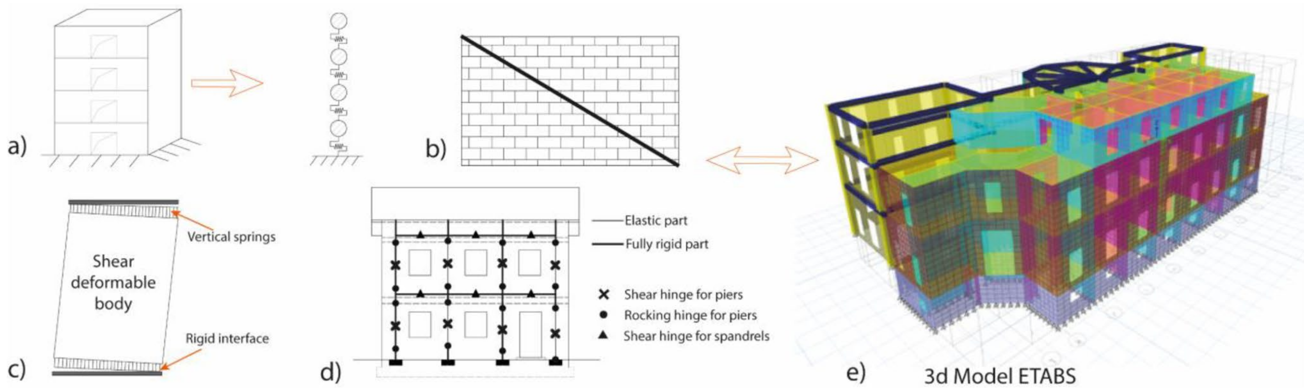
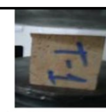


Fig. 12 A unified numerical model for the seismic analysis of URM structures (reworked); (**a**) the transformation of the building into a dynamic model; (**b**) the local mechanism; (**c**) shear mechanism; (**d**) frame equivalent model; (**e**) one of the models built outside the basic BIM environment [37]

Table 1 Data based on the physical-mechanical properties of materials, extracted from the results of laboratory tests of samples from site inspections [38]

Materials & mechanical data | Laboratory test

Nr.	Parameter	Value	Unit	Type of test performed	Sample image
1	Compressive strength – digimax	19.75	MPa	Compression test results for the red brick cubic sample-1	
1.1	Failure load	294	kN		
2	Compressive strength – direct	18.66	MPa	Compression test results for the white brick cubic sample-1	
2.1	Failure load	71.7	kN		
3	Compressive strength – direct	15.13	MPa	Compression test results for the white brick cubic sample-2	
3.1	Failure load	230	kN		
4	Elastic modulus E (The Young's Modulus)	15837	MPa		
4.1	Shear modulus G	1811	MPa		
4.2	Poisson's ratio υ	0.15			

stresses $S_{1\text{-}2}$. It's very important to predict the best possible stress–strain graph for each direction [8, 12, 39, 41].

The foundation is continuous with stone masonry, placed in plan according to two levels. The first level is in the depth of -2.7 m and the second near the level ± 0.00. The foundation is realized using two models: (a) Theoretical model according to "Timoshenko and Euler" principles (accompanied by the geotechnical conditions of the structure-basement interaction); and (b) Numerical model adapted to the corresponding case study [4, 8, 10].

Seismic parameters: Since the objective of this research is to evaluate the seismic performance and capacity curves through linear and nonlinear analysis, we have to show below the elastic response spectrum[10] parameters [31] (Fig. 13).

Eurocode have a detailed specific way to calculate the seismic spectrum. In this case it depends on several factors: peak ground acceleration PGA[11]; soil category and

[10] A response spectrum is a plot of the peak or steady-state response (ground acceleration) of a series of oscillators or earthquakes of varying natural frequency, that are forced into motion by the same base vibration.

[11] Is equal to the maximum ground acceleration that occurred during earthquake shaking at a location. PGA is equal to the amplitude of the largest absolute acceleration recorded on an accelerogram at a site during a particular earthquake.

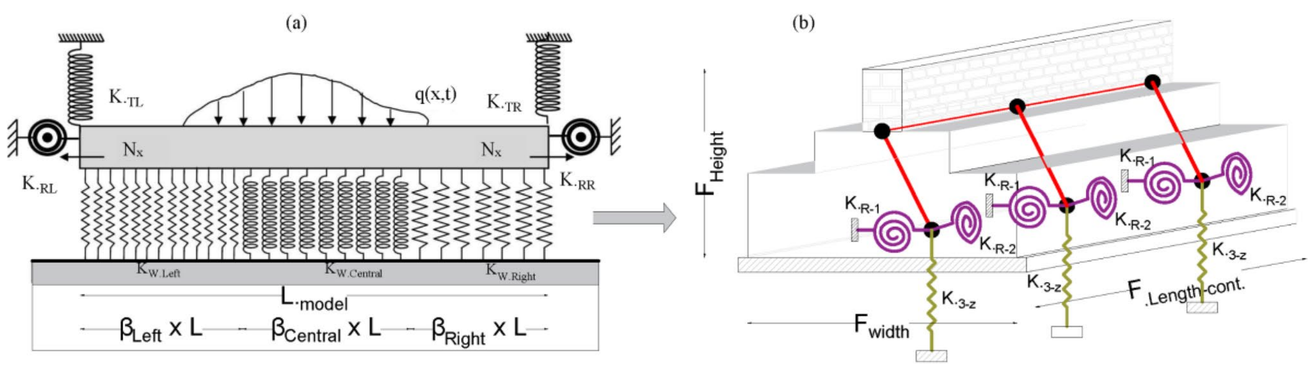


Fig. 13 **a** Timoshenko continuous beam with technical boundary conditions resting or the Winkler model; **b** the case study numerical model [10]

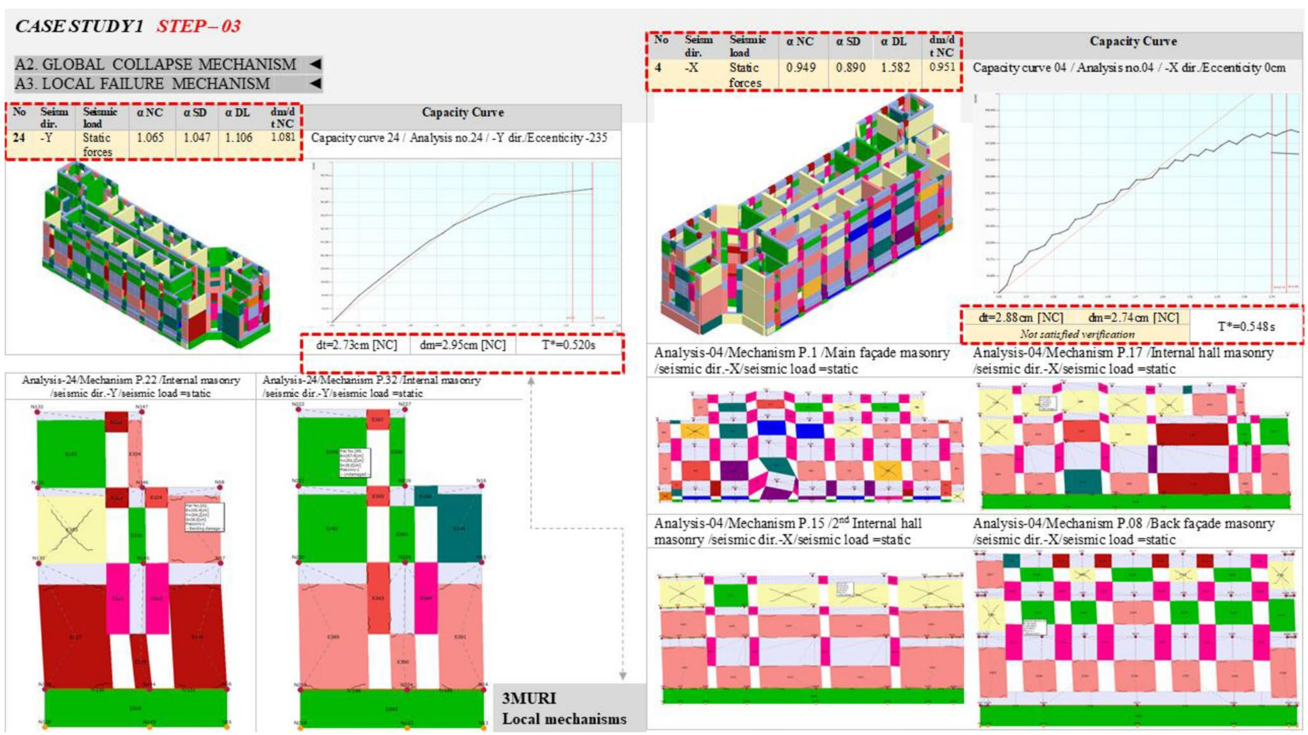


Fig. 14 Results from 3muri and 24 capacity curves related to 24 scenarios of collapse mechanisms

geological profile; the predicted magnitude (*in the case of our country is M > 5.5*) and the behavioral factor [32]. This last one as a concept is comparable to the inverse of ductility. Based on empirical studies and research, Albania has a variety of seismic peak ground acceleration from 0.15–0.3 g [31, 32, 34]. Based on these empirical arguments and several site visits, a series of parameters have been selected related to the spectral acceleration. Eventually the selected parameters are:

a. Soil category: Type-B [36];
b. Spectral acceleration: $ag/g = 0.27 m/s^2$ [33];
c. Eq. direction: Horizontal (type-A);
d. Behavioral factor: 2.6 (calculated according to the building conditions) [36];
e. Damping factor: 5%

Outputs and results

After performing the modal analysis, related to the case study the nonlinear static analysis was performed through the 3MURI software to obtain the capacity curves and target displacement. Also to analyze the possible mechanisms of collapse, the vulnerable parts or elements of the building and

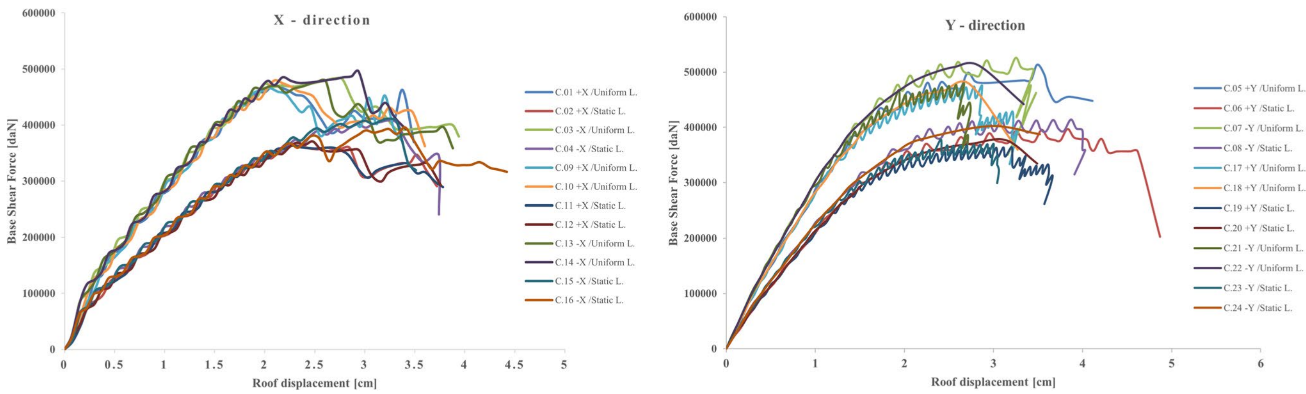


Fig. 15 Data processing from 3muri and generation of diagrams, according to 24 simulations in two directions

the scenarios of local mechanisms. The case of this category of buildings manages to highlight that even in a fairly simple construction, with regular geometry and symmetric distribution of stiffness, can highlight a series of specific technical aspects. This was achieved after a process divided into two phases: on-site investigations and experimental simulations (Fig. 14).

Referring to the analysis, the target of the study requires further investigations on the capacity curves. Meanwhile, the respective mechanisms of these panels and their respective parameters are summarized in (Figs. 14 and 15) discussed in the paragraph above. Re-emphasizing that the study does not attempt to provide solutions or details of reinforcement projects. On the other hand this will not limit researchers to simulate building models with different retrofitting strategies. The use of this integrated hBIM framework & BIM tools enable the extracting as many structural parameters and multi-scale data, to increase the efficiency of modeling in the context of Cultural Heritage objects [26, 28] (see also Section 2.6). So at this stage what will be proven is the testing and simulation of selected panels with some simple intervention techniques, which aim to provide effective solutions to address the structural issue of masonry, increasing their performance, in objects of this category, without directly affecting the architectural aesthetics of the building [6].

Referring to the analysis step Nº 4 pushover simulations, two representative panels were simulated in 3muri software. It is about the panel Nº 1 of the masonry that corresponds to the main facade positioned in the western direction of the building. This represents one of the vulnerable panels that reacts in a weak mode and shows fragility at this step (Fig. 14). Also in the same analysis is selected panel Nº 3 of the internal masonry of the building near the longitudinal hall, this panel shows some areas where the wall fails and creates local collapse mechanisms, which risk the performance of the structure (Fig. 14). Following the analysis, 2 other panels with high expectations were selected for simulation. Since the direction of seismic forces in this analysis comes in the direction -Y, the selected panels are oriented according to the transverse direction, namely panel Nº 25 which corresponds to the southern side facade of the building. The other is Nº 16 which corresponds to a partial internal wall (partially on the first two floors and a perimeter side wall on the second floor level). Also, this panel shows vulnerability and local collapse mechanisms which should be highlighted for further investigation in the proposals for repairing interventions (Figs. 14 and 15) [4].

Regarding the situation presented after performing the second phase of simulations, which shows the mechanisms of collapse of the most vulnerable facades (Figs. 14 and 15), the following has been advanced with an intervention strategy in the framework of seismic retrofit. The proposals are conceived in such a way that they do not affect the aesthetics of the respective facades, but at the same time significantly increase the seismic performance of the masonry. The "FRCM type of reinforcement" method is recommended, where this reinforcing layer is added to the masonry panel in its inner part. Specifically the selected material is “GeoSteel G1200, Kerakoll[12]” with the data showed in (Fig. 16) [42]. The placement of the reinforcing layer presented above will be applied on the inside of the facade masonry, will be fixed with the existing masonry and will perform in normal environmental conditions. Reinforcement applications in transverse masonry are placed on both sides of the building to maintain the sense of symmetrical distribution of masses and rigidities. The application of FRCM from “Kerakoll products” was applied for two longitudinal panels ascertained by analysis Nº 4 according to the + X direction. After simulations this type of application is not enough to avoid failure mechanism on both transverse panels according to the -Y

[12] ISO 9001 CERTIFIED IT10/0327; Kerakoll quality system | BS 18001 CERTIFIED IT255412.

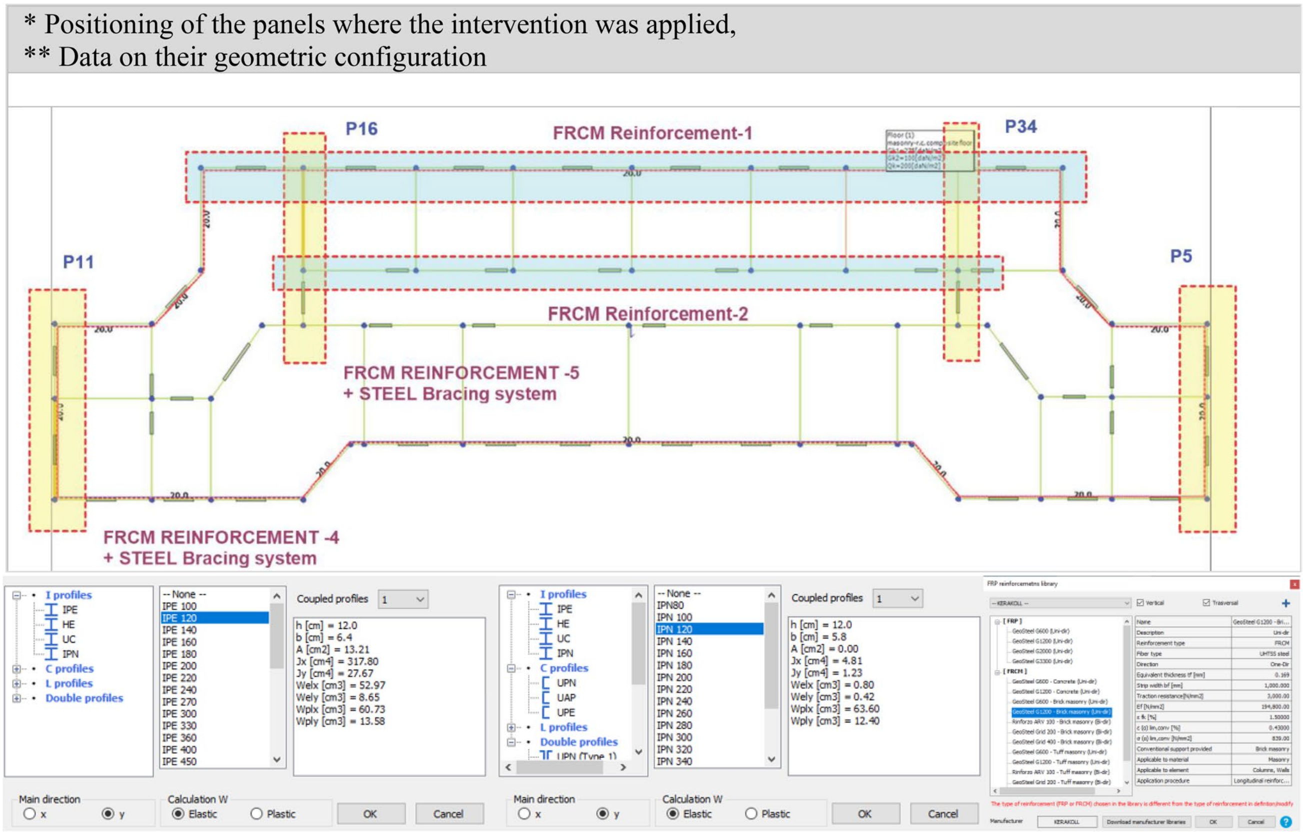


Fig. 16 Proposed retrofit strategy, materials parameters, layers and configurations

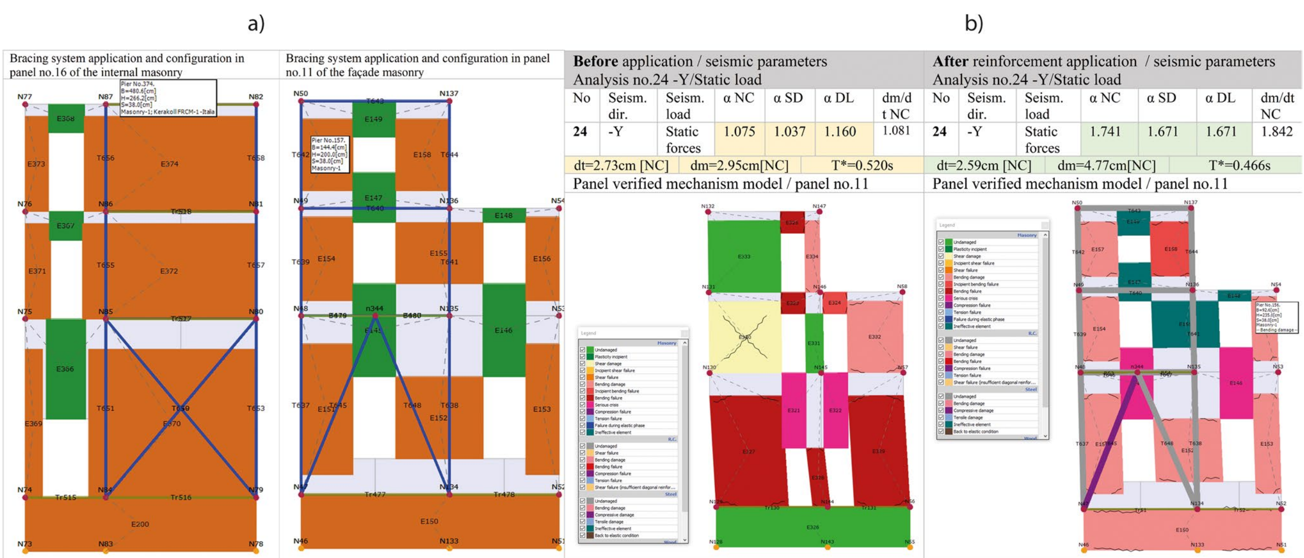


Fig. 17 **a** proposed retrofitting configurations; **b** axis.3 Panel simulations, before and after the interventions

direction [42]. Following the addition of FRCM applications, "The steel-bracing systems" have also been applied to increase the performance efficiently and in harmony with the response of the structure. Their configuration is applied in simple logic according to the openings located in the masonry (doors, windows,), and necessarily their application in the interior of the masonry panels of the facades (Fig. 17).

Based on the results of the simulations, the main findings will be highlighted. This simple interventions, proved effective from the first attempt. Efficient interventions were applied to the inner part of the side walls, specifically in three longitudinal panels oriented in the X-direction of the building plan (Fig. 16). The proposed technique does not affect the aesthetics of the facade of the building, part of the cultural heritage [6]. On the other hand, the intervention in the transverse masonry panels in the Y-direction was carried out effectively, after the interpretation of the results obtained from "analysis N° 24 according to the Push-Y loading". The target was on intervening to improve the mechanical properties of the existing masonry, through the reinforcing layer with "FRCM Geosteel g1200" [42]. The intervention in this case was not enough to eliminate all the local mechanisms, so at this point was followed by a second intervention, the establishment of "steel-bracing systems", with two possible configuration scenarios, positioned in two internal transverse axes of the building (Fig. 17A). This double intervention provided a significant increase of seismic performance in terms of strength and rigidity (Fig. 17B).

Conclusions

Cultural heritage buildings are historically considered as national assets that should be monitored and treated through the most advanced technologies of building science. By introducing the application of HBIM tools gradually, with three to four dimensions in the improvement of the current methodologies of the management of heritage buildings and creating conditions for multiscale integration between BIM environments, efficient outputs of 3D parametric models with massive data can be produced (Figs. 5 and 9). But emphasizing the limitations within the state and academic instances, progress must be advanced by highlighting the problems of restoration in Albania.

The theoretical approach including several disciplines with the help of BIM-Tools, followed in this study and following the path has shown its effectiveness in assessing the vulnerability of the "cultural heritage" building designed by the Italian architect Bosio (Fig. 1) [4]. The research underlines the possible applications of seismic-retrofit interventions in a wide variety of unreinforced masonry buildings, part of the architectural property of this period in Tirana. On the other hand, the study aimed and succeeded in conducting an in-depth research of archival projects; making frequent historical documentation campaigns; surveying with innovative instruments like "UAV, Drone LiDAR Scanner, G.N.S.S. tools, robotics" and digitization of projects including the history of interventions and layering (Figs. 5 and 10). Impact on methodology and the findings of this study will be fully available to other researchers to advance with more applicable aspects regarding restoration strategies and projects.

The database and numerical files of integrated 3D models cannot be effective if they are not properly connected with each other or without creating simulation parameterization. In the diagrams presented in (Figs. 5, 9 and 11) are shown several sets of files that supply with data to the BIM model, and on the other hand how the main model provides or receives information continuously. All this aiming to create frequently updated computational models which are not only used for digitalization, digital archives or restoration projects, but also perform the role of frequently monitoring of the building performance (Fig. 10).

The method developed and adapted for the Albanian case offers several categories of benefits: (1) an experimental model and an opportunity for improvement or reflection on the systematization of the required data; (2) the proper management of restoration processes; (3) a wide range of data collection enabling processing layers without skipping integrated BIM layers; (4) the treatment of structural performance by relating the condition of the building to adequate seismic adaptation; (5) multi scalar management of restoration issues and interoperability of models through BIM; (6) the integration of the information and data associated with different researchers or actors with the main h-BIM model including the multiscale BIM model to command the restoration process and seismic retrofitting management (Fig. 5 and 9). The elaborated method is not rigid, it uses some principles discovered by other researchers, on the other hand, it gives a specific contribution to the connection and communication of models with the help of BIM-tools, minimizing the loss of data (Figs. 5 and 11), also some tangible algorithms (Figs. 6, 7, 8 and 9). The h-BIM model that operates in different environments is a proper tool able to collect a lot of sources and numerical data into main 3D-BIM environment to an important heritage building. In this research each source was collected in the Autodesk environment, which communicated with the 3Muri of the STA Data environment easily converted within Autodesk with DXF & IFC formats. The efficiency of the connection was achieved through the use of the 3D model with geometric data of the building in the 3Muri software, outside the Autodesk environment. 3Muri software used the simplified model in DXF format imported from AutoCAD (Fig. 11).

Regarding the numerical model F.E.M. a good database accessible inside and outside BIM environments was reached. Static Non-linear analysis "Pushover" verifications in 3Muri software have given satisfactory empirical results related to many aspects of seismic engineering, on the scenarios of local and global collapse mechanisms referred to the selected building (Figs. 14, 15, and 17), improving further from [4]. Capacity curves have been generated according to two directions, based on the vulnerability index method, data that serve to identify the vulnerable parts of the building. On the other hand give us indications for efficient intervention projects on the seismic retrofit strategy (Figs. 16 and 17A). Integrated h-BIM linked with numerical model F.E.M. of the Tirana City Hall can be adopted simply for different restoration purposes, including management; seismic or other simulations; the draft-proposal of retrofitting interventions; architectural adaptions; reconstruction and digital management for MEP networks.

A series of limitations and boundaries are still present in this study mainly in terms of the interconnection of models between software's which means few losses of numerical data when the model is transferred outside the BIM environment. Finally, it should be underlined that in general an acceptable level of data integration has been achieved, indicating great potential for further developments for integration and high efficiency in the context of preservation, monitored maintenance and adaptation of cultural heritage buildings.

Funding Open access funding provided by Università degli Studi di Ferrara within the CRUI-CARE Agreement.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Construction Archive (1993) "Central Technical Archive of Construction". A.Q.T.N. Tirane, Albania. https://www.aqtn.gov.al
2. Prifti A (2017) *Ndikime te Arkitektures dhe te Artit Italian ne Shqiperine e viteve 1925–1943*. Tirane: academia.edu
3. Menghini A, Pashako F, Stigliano M (2012) *Modern Italian architecture for the cities of Albania*. Bari: Collana Archinauti 36
4. Vesho N (2022) *A methodology on the treatment of the issue of Cultural heritage restoration in Tirana, period 1920-'40 | BIM modeling, Seismic simulation and Theoretical interpretatios*. Ferrara: Unife
5. Brandi C (2005) *Theory of Restoration* (II ed.). Firenze: Nardini Editore - ISBN-13: 978–8840440897
6. Jokilehto J (1998) The context of the Venice Charter (1964). Conserv Manag Archeol Sites 229–233
7. Asteris P (2008) Finite element micro-modeling of infilled frames. J Struct Eng 8:1–11
8. Koka P, Vesho N, Shehu F (2021) Analysis of 5 floors brick masonry building type 77/5. Eur J Eng Technol Res (EJ-ENG) 6(5):57–62
9. Miedzialowski C (2014) Finite Element Analysis for the Modelling of Building Structures in Three Dimensional Schemes. Am J Civil Eng Archit | Sci Education Publ II(4):143–148
10. Vesho N, Guri M, Marku A (2019) Ferrocement composites for strengthening of existing school structures in Albania, ISSN: 2319–9873. J Eng Technol, India
11. Couto R, Bento R, Gomes R (2020) Seismic performance and fragility curves of historical residential buildings in Lisbon downtown affected by settlements. Bull Earthquake Eng, VIII 18:5281–5307
12. Turnsek V, Sheppard P (1980) The shear and flexural resistance of masonry walls. *the Intern. Research Conference on Earthquake Engineering*, (p. 517–573). Skopje
13. Caliò I, Marletta M, Pantò B (2005) A simplified model for the evaluation of the seismic behaviour of masonry buildings. *The Tenth International Conference on Civil, Structural and Environmental Engineering Computing | B.H.V. Topping (Editor)*(195)
14. Jurina L, Peano A (2009) Characterization of brick masonry stiffness by numerical modelling. Bergamo: Instituto Sperimentale modelli e Strutture s.p.a.
15. Eastman C, Teicholz P, Sacks P (2008) Integration of building maintenance data in application of building information modeling (BIM). J Build Construct Plan Res II(2)
16. Cai J, Feng SF, Huang LL, Xu SC, Lu L, Wen RQ (2023) BIM technology of implicit and explicit parts of historical building components based on point cloud data and digital radiographic image: a review. J Asian Archit Build Eng. https://doi.org/10.1080/13467581.2023.2215845
17. Kjartansdóttir I, Mordue S, Nowak P (2017) Building information modelling BIM, I. POLCEN Sp. z o.o, Warsaw
18. Megahed N (2015) Towards a theoretical framework for HBIM approach in historic preservation and management. Int J Archit Res Archnet-IJAR III(9):130–147
19. Miran F, Husein H (2023) Introducing a conceptual model for assessing the present state of preservation in heritage buildings: Utilizing building adaptation as an approach. Buildings 13(4):859. https://doi.org/10.3390/buildings13040859
20. Cardinali V, Ciuffreda A, Coli M, De Stefano M, Meli F, Tanganelli M, Trovatelli F (2023) An oriented H-BIM approach for the seismic assessment of cultural heritage buildings: Palazzo Vecchio in Florence. Buildings 13:913. https://doi.org/10.3390/buildings13040913
21. Hamed W, El Antably A (2023) Knowledge-based HBIM for conservation: The case of Yahya al-Shabih mausoleum. Digit Appl Archaeol Cult Herit e00278. https://doi.org/10.1016/j.daach.2023.e00278
22. Santoni A, Martín-Talaverano R, Quattrini R, Murillo-Fragero J (2021) HBIM approach to implement the historical and constructive knowledge. The case of the Real Colegiata of San Isidoro (León, Spain). Virtual Archaeol Rev 12:49–65. https://doi.org/10.4995/VAR.2021.13661
23. Radanovic M, Khoshelham K, Fraser C (2020) Geometric accuracy and semantic richness in heritage BIM: a review. Digit Appl Archaeol Cultural Herit 19(2020):1–12. https://doi.org/10.1016/j.daach.2020.e00166
24. Tomazevic M (1978) *The computer program POR*. Report ZRMK., Institute for Testing and Research in Materials and Structures, Ljubljana (1978)

25. Garagnani G, Manferdini A (2013) Parametric accuracy: Building information modeling process applied to the cultural heritage preservation. ISPRS – Int Arch Photogramm Remote Sens Spat Inf Sci XL-5/W1(5):87–92
26. Mammoli R, Mariotti C, Quattrini R (2021) Modeling the fourth dimension of architectural heritage: enabling processes for a sustainable conservation. Sustainability 13:5173. https://doi.org/10.3390/su13095173. (ISSN: 20711050)
27. Pocobelli D, Boehm J, Bryan P, Still J (2018) BIM for heritage science: a review. Herit Sci VI(30):1–15
28. Sammartano G, Avena M, Fillia E, Spano A (2023) Integrated HBIM-GIS Models for Multi-Scale Seismic Vulnerability Assessment of Historical Buildings. Remote Sensing 15(3):833. https://doi.org/10.3390/rs15030833
29. FEMA 440, NEHRP (2005) *Improvement of Nonlinear Static Seismic Analysis Procedures.* Redwood: Department of Homeland Security, Federal Emergency Management Agency
30. Pitilakis K, Crowley H, Kaynia A (2014) *Typology definition and fragility functions for physical elements at seismic risk* (ISBN 978–94–007–7871–9 ed.). New York, London: Springer Science + Business Media Dordrecht. ISBN 978–94–007–7871–9
31. CEN Eurocode 8 (2008) *Eurocode 8: Design of structures for earthquake resistance -Part 1: General rules, seismic actions and rules for buildings* (FINAL DRAFT prEN 1998–1 ed.). Brussels, Belgium: EUROPEAN COMMITTEE FOR STANDARDIZATION, TC250 Technical Committee
32. Sulstarova, Aliaj, Peci, Muco (2004) *Catalogue of earthquakes in Albania with Ms=>4.5 for the period 8–2004.* Tirana: Seismological Institute Tirana
33. Igjeum, Upt (1989-2022) I.GJ.E.U.M., Institute of GeoSciences; The seismological bulletin. Monthly J Seismol ISSN: 2664 – 410X
34. Charleson A, Vesho N (2020) Structural engineering observations from the 26 November 2019 Mw 6.4 Albanian earthquake. *NZSEE 2020 Annual Conference*, 191–200. Tratto da http://www.nzsee.org.nz/
35. Moyano J, Carreño E, Nieto-Julián J, Gil-Arizón I, Bruno S (2022) Systematic approach to generate Historical Building Information Modelling (HBIM) in architectural restoration project. Autom Constr 143:104551. https://doi.org/10.1016/j.autcon.2022.104551
36. Dhimgjini V, Katundi A, Paci E (2001) Reconstruction and extension of the working histroy buildings of the Municipality of Tirana. Tirane
37. Xu H, Gentilini C, Ju Z, Wu H, Zhao S (2018) A unified model for the seismic analysis of brick masonry structures. Constr Build Mater, Elsevier Ltd 184:733–751
38. Altea and Geostudio (2019) *Technical report on laboratory tests of materials for cultural heritage objects.* Tirana: altea., ISO standards: S SH ISO/IEC 17025:2017. https://alteageostudio.com/
39. Valluzzi M (2012) Round Robin test for composite to brick shear bond characterization. RILEM, Mater Struct. https://doi.org/10.1617/s11527-012-9883-5
40. Tomazevic M (2007) Damage as a measure for earthquake resistant design of masonry structures, Slovenian experience. J Civil Eng (Canada) 122:1040–1047
41. Baballeku M (2014) Vleresimi i demtimeve strukturore ne ndertesat tip te sistemit arsimor, Strukturat prej murature. Universiteti Politeknik i Tiranes, Tirana
42. Kerakoll (2021) *Linea edilizia; Ripristino e rinforzo c.a. e muratura.* Tratto da Kerakoll Products: https://products.kerakoll.com/yep-repository/kerakoll/media/GeoSteel_G1200_ITA_2023.pdf