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Review paper
Doi 10.61892/stp202401058I
ISSN 2566-4484

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GEOMATIC DATA FOR TREATMENT OF HISTORIC BRIDGES. THE CASE STUDY OF THE RIBNICA BRIDGE IN PODGORICA, MONTENEGRO

Abstract

Stone bridges, all around Europe stand as enduring testaments to engineering mastery, cultural heritage, and historical continuity. They served as crucial infrastructural lifelines, connecting communities and fostering trade routes. Their enduring presence symbolizes the craftsmanship and innovation of their eras, reflecting diverse regional styles and technological advancements. Geometric documentation of a stone bridge provides critical insights into its structural integrity, aiding in preservation efforts. Accurate data obtained through geomatic techniques ensures informed conservation decisions, safeguarding the bridge's historical significance for future generations. This paper focuses on the geometric documentation of the Ribnica Bridge in Podgorica, Montenegro.

Keywords: cultural heritage, stone bridges, geo-spatial methods, technical documentation, terrestrial laser scanner, structural integrity

ГЕОДЕТСКИ ПОДАЦИ ЗА ТРЕТМАН ИСТОРИЈСКИХ МОСТОВА. СТУДИЈА СЛУЧАЈА МОСТА НА РИЈЕЦИ РИБНИЦА У ПОДГОРИЦИ, ЦРНА ГОРА

Сажетак

Камени мостови широм Европе представљају трајни доказ инжењерског мајсторства, културног насљеђа и историјског континуитета. Они су служили као кључне инфраструктурне линије спаса, повезујући заједнице и подстичући трговачке путеве. Њихово трајно присуство симболизује занатско умјеће и иновације њихових епоха, одражавајући различите регионалне стилове и технолошки напредак. Геометријска документација таквог каменог моста пружа критичан увид у његов структурални интегритет, помажући у напорима за очување. Тачни подаци добијени геодетским техникама осигуравају информисане одлуке о очувању, чувајући историјски значај моста за будуће генерације. Овај рад се фокусира на геометријску документацију моста на ријеци Рибници у Подгорици, Црна Гора.

Кључне ријечи: градитељско насљеђе, гео-просторне методе, техничка документација, интегритет конструкције

1. INTRODUCTION

In pre-industrial Balkans, the main building material was stone, and one of the most significant issues that concerned the residents, especially in the mainland and less so in the island areas, was the safe passage of pedestrians and transportation means over rivers, streams, and torrents.

Until the 20th century, the only feasible and functional engineering work that the skilled craftsmen of that era could construct to address the transportation problem that affected not only themselves but all their fellow citizens was a stone bridge, either single-arched like the one in Konitsa (fig. 1a) or multi-arched like the one in Arta (fig. 1b).


Figure 1. a) The single-arched stone bridge of Konitsa (https://www.allovergreece.com) b) The multi-arched stone bridge of Arta (https://discoverarta.gr/)

The construction work was so significant that it led to the creation of related songs, traditions, and legends that even referred to human sacrifices to solidify the coveted bridge. However, the construction of such bridges has ceased since 1940, and this complex art has already faded into oblivion, so today there is not a single "bridge builder" or "kioproulis," as the popular and almost always illiterate bridge builder was typically called. Stone arched constructions have been characterized by specialized scientists as one of the greatest discoveries in architecture for pre-industrial humanity and as the first major milestone in the evolutionary path of global bridge construction.

Stone bridges across Europe encapsulate a rich tapestry of history, engineering excellence, and cultural significance. These structures, often centuries-old, crafted with meticulous precision and enduring craftsmanship, serving as vital links connecting communities, trade routes and civilizations.

The importance of stone bridges in Europe is multifaceted, encompassing their pivotal role in transportation, their architectural splendor, and their symbolic resonance within the collective consciousness of diverse societies. Historically, these bridges acted as lifelines, fostering economic growth by facilitating the movement of goods, people, and ideas across regions. Their strategic placements over rivers and valleys were fundamental in expanding trade networks, enhancing commerce, and consolidating cultural exchange throughout the continent.

Beyond their utilitarian function, stone bridges embody architectural excellence and engineering ingenuity. They stand as enduring testaments to the mastery of ancient builders, showcasing diverse styles, techniques, and artistic flourishes reflective of their respective epochs. The construction of these bridges required immense skill, utilizing local materials and specialized knowledge passed down through generations. Their enduring presence serves as a testament to human innovation, withstanding the test of time and natural elements.

Moreover, stone bridges hold profound cultural and symbolic significance. They serve as landmarks, anchoring cities and towns, and often becoming iconic symbols of regional identity. Many of these bridges are steeped in folklore, legends, and historical events, enriching the collective heritage of the communities they serve. Their arches, spandrels and intricate designs narrate stories of societal evolution, technological advancements, and the resilience of human creativity.

Through the years stone bridges have suffered physical phenomena and disasters, like earthquakes, strong winds, snow and last but not least, the continuous flow of the water.

While all of them are a particular kind of cultural heritage and tourist attractions, some of them are still used as a way of crossing the river on which they are built. So, their geometric documentation is necessary not only for preservation and restoration reasons but also to ensure the stability of the construction and the safety of the people who use it.

In this paper, the procedure for documenting the Ribnica Bridge in Podgorica, Montenegro is presented. It's a typical Balkan stone bridge with a history of centuries and historical and architectural value, which is fully operated till today.

The paper focuses on the geometric documentation of the of the bridge, carried out with geodetic methods, while it also attempts the overall recognition of the monument, based on the perspective of revealing, saving, and exploiting this unique historical monument of Podgorica.

Going a bit further a 3d structural model of the bridge is created and tested for its integrity to various types of loads.

The rest of the paper is organized as follows; Section 2 explains the importance of geometric documentation of stone bridges, records the various methods and techniques for documenting a stone bridge and numbers some characteristic examples of similar documentations. Section 3 the methodology of the specific case study is described. The data field operations, the equipment and the process of the data for the development of the 3d model and the integrity tests are explained thoroughly. Finally, Section 4 discusses practical application of produced results, and provides the concluding remarks.

2. BACKGROUND

Preservation and documentation of these stone bridges are imperative to safeguard their historical, architectural, and cultural value. Geometric documentation plays a pivotal role in this endeavor. Reliable planning for the conservation and prevention of damage to historic stone bridge structures requires theoretical and experimental research that includes the problems of the historic stone structure in terms of mineralogical and petrographic aspects, the problems of chemical and biochemical degradation processes and the effect of these processes on the properties of the building materials and the life of the historic structure as a whole [1]. Accurate measurement and detailed mapping through geomatic techniques enable comprehensive understanding of these structures. Laser scanning, photogrammetry and other advanced methods provide precise geometric data, aiding in assessing their condition, identifying potential vulnerabilities, and formulating conservation strategies [2].

Furthermore, geometric documentation ensures that the intricate architectural details and structural complexities of these bridges are preserved digitally, allowing for meticulous reconstruction or restoration in case of damage or decay. This documentation not only serves as a blueprint for maintenance but also facilitates scholarly research, educational outreach, and public appreciation, fostering a deeper understanding of these historical treasures, like the two stone bridges in Plaka, Greece and Stari Most of Mostar, Bosnia & Herzegovina [3].

Stone bridges are exposed to conditions, like the river flow, strong winds and natural disasters. The evaluation of their integrity can show weaknesses, prevent their collapse and implement possible repairs or reinforcements.

Their structural vulnerability assessment is a pivotal part of a risk mitigation strategy for preserving them. The development of digital twins has gained much attention lately to provide an accurate digital model for performing finite element (FE) analyses [4].

After their modeling, finite elements analysis, is a method that has been used on several occasions, not only in Balkans, like the stone bridges of Ivanjica, Serbia [5] and Pasha bridge, Greece [6], but all around the world [7, 8]. Going a bit further, apart from finite element method, there have been proposed and compared more methods for the structural analysis of a stone bridge. Some of them are described in a case study of the stone bridge of Cernadela, Spain [9].

Moreover, some of them are still in use not only by people but also by cars, like the famous Roman bridge of Alcantara, Spain [10]. So, their frequent assessment of structural integrity is vital for ensuring public safety too.

3. CASE STUDY – RIBNICA BRIDGE

3.1. HISTORICAL AND GEOGRAPHICAL DATA

Ribnica Bridge or Adži-paša Bridge is in Podgorica, Montenegro. Podgorica, the capital and the largest city of Montenegro is located at the south part of the country. The city is just north of Lake Skadar and close to coastal destinations on the Adriatic Sea. Historically, it was Podgorica's position at the confluence of the Ribnica and Morača rivers and at the meeting-point of the fertile Zeta Plain and Bjelopavlići Valley that encouraged settlement. The surrounding landscape is predominantly mountainous terrain.

In the area around the confluence of Ribnica and Morač, during the reign of the Romans in this area, there was the city of Birziminium. It was the trade center of the province of Prevalis, through which the caravan route passed.

The oldest bridge in Podgorica is considered to be the stone bridge on Ribnica, on today's Skaline, which is believed to date back to the Roman period.

This bridge is one of the rare remnants of the former Roman city, which was apparently almost completely destroyed in the catastrophic earthquake that struck this area in 618 AD.

The people of Podgorica call this bridge “Most na Sastavci”, because the area around the delta of Ribnica in Morač was called Sastavci.

The bridge was rebuilt sometime in the first half of the 18th century by Adži Pasha Osmanagić, so this bridge is also known as Adži Pasha's Bridge [11].

In figures 1a – 1d and 2, one can see the bridge in 100 years’ time span (1922-2022).

The locals call it "the stone bridge of Ribnica" and the area surrounding it is a notable townscape for them, who also refer to it as Skaline or Skalimost since about the 1950s, meaning "staircase", because of the steps built from the bridge to the fort next to it.

It belongs to the category of arched stone bridges and has a single arch and two relief arches.

Architectural heritage is one of the most important contents of the cultural heritage of Montenegro. Old stone bridges are a recognizable segment of that heritage. They bear witness to the historical duration of the community [12].

Podgorica is a city of rivers, so it is undoubtedly also a city of bridges. Numerous bridges connect the banks of the Morača, Ribnica, Mareza, Cijevna and Zeta rivers. However, one stands out. It is in the heart of Podgorica and has preserved traces of history for centuries. It is the bridge on Sastavci, popularly known as Hadji Pasha's bridge [13].

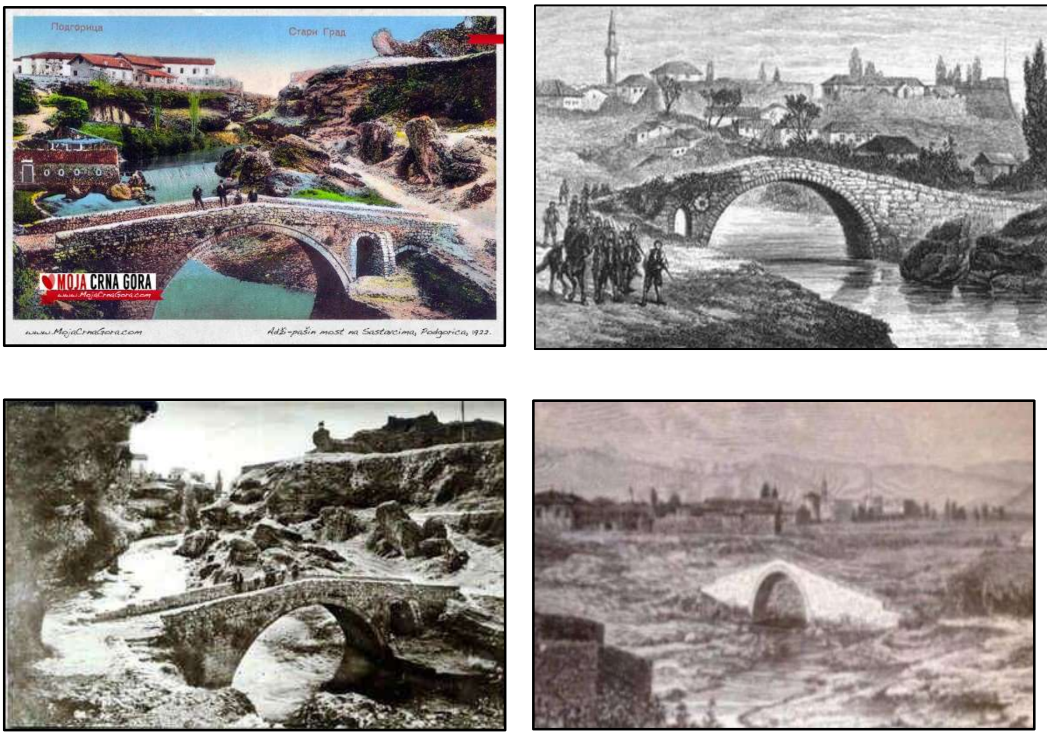

Figure 2. a) View of the bridge from 1922 (http://www.mojacrnagora.com/) b) View of the bridge [12] c) View of the bridge [12] d) View of the bridge [16]

Figure 3. View of the bridge (authors, 2022)

The bridge at Sastavci - over the river Ribnica, just before its confluence with the Morača - is the oldest bridge in Podgorica. The layout of the bridge, i.e. its vertical projection and width, indicate that it is an asymmetric bridge structure that spans the Ribnica river, and is dominated by the main opening of 10.8 m. Two smaller openings are located towards the right abutment of the bridge. Dimensionally, the opening with a width of 1.18 mm, which is located next to the arch of the bridge, is more conspicuous [14]. Facilitating openings served for greater water flow, when the high waters of Ribnica and Morača (autumn-spring) would rise due to heavy rainfall, often turning the Sastavci zone into a real lake (fig. 4a, 4b). The total length of the bridge is approx. 25m.

Figure 4. a) Passing Ribnica bridge in a boat b) Ribnica bridge flooded on 27/2/2023 (authors)

Historical sources and literary data primarily indicate that the bridge is a creation of bridge construction of the Middle Ages [15]. It was restored in the first half of the 17th century by Hafiz Pasha Osmanagić, who also built the Clock Tower in Podgorica. [16]. However, there are indications that the bridge was built on the foundations of earlier structures, especially from the Roman period. It is assumed that the bridge is one of the rare remnants of the former Roman city that was situated in this location. The bridge is built of stone and paved with river pebbles.

The bridge was rebuilt and restored after World War II. Today, the people of Podgorica especially love the bridge, it is a distinguishable place that is integrated into the modern urban settings of the city and the arrangement of the Morača and Ribnica riverbeds.

The capital city of Podgorica (1441 km2) is in the southeast of Montenegro and belongs to the largest part of the Podgorica-Skadar basin. The altitude is in the range of 4.6 masl (minimum level of Lake Skadar) and 2487 masl (Kučki Kom). The very center of the Podgorica city center is about 52 meters above sea level. Podgorica is the central settlement of the Zeta plain, and since 1946 it has been the capital of Montenegro. It is characterized by a diverse climate - from sub- Mediterranean to high mountain. The geospatial base of Podgorica is located between two seas (the Adriatic Sea and the Black Sea) and three large river basins (the Morača, Tara and Lim watercourses). It is well connected by traffic with all urban settlements in Montenegro and the immediate surroundings [17].

The terrains of the Capital City of Podgorica mostly belong to the regional geotectonic unit of Visoko karst, and to a very small extent, to the geotectonic unit of Durmitor thrust fault.

The geological structure and geomorphological characteristics have determined the hydrogeological characteristics of the terrain, which in time alternate and overlap in intensity with geomorphological phenomena. The terrains in question are made up of rock masses characterized by effective supercapillary intergranular porosity. These are terrains that are also built up by quaternary granular fluvioglacial, alluvial, glacial and deluvial sediments. Subterranear waters are present in them in the form of compacted outcrops [17].

The bridge on Sastavci - over the river Ribnica, which springs from Vrela Ribnička below Kakaricka Gora (Vojna 199 masl, Bojčin 235 masl), runs its entire length through Ćemovsko polje, to the mouth of Morača, flows almost through the very center of the city, its bed is located in the zone of fluvioglacial sediments of the so-called II terrace. Terrace sections in the Ribnica bed can be clearly seen. Its course is about 10 km long. Its water level is directly dependent on the variable yield of the spring and Ribnica almost dries up in the summer months. [17, 18].

Subterranear waters from the terrain of the Capital City are drained towards the main erosion bases. The main erosion base is Lake Skadar with its tributaries, i.e. the main tributary which is the Morača River. The speeds and directions of subterranear waters movement in the area of the Capital City of Podgorica are highly variable and depend on the hydrogeological and geomorphological characteristics of the terrain and the climatic characteristics of the region. All the waters of the Capital City flow into the erosion bases of Lake Skadar with the Zeta plain and watercourses that flow over the terrain of those basesBased on the determination of underground connections in the karst terrain of the Capital City, it was found out that these velocities are very variable and range from 1 to 11 cm/s. In summary, the intergranular rock masses of the Zeta Plain have a filtration coefficient Kf=1x10-1 do 1x10-3 cm/s [19].

Everything mentioned above about the composition, structure and features of the terrain is of influence - it conditions the engineering-geological features of the terrain. Terrains built from unbound sediments on flat or slopes below 5o if they are further away from the action of water are stable. The bearing capacity of such terrains depends on the granulometric and mineralogical petrographic composition, the degree of sorting and settlement of the sediments, the presence of occasional or permanent water, etc. For these reasons, it is necessary to define each location or stretch in terms of bearing capacity, as it is generally significantly low (below the bearing capacity of the terrain built from well-bound petrified rocks) and rarely exceeds2-3 kg/cm2. Large bearing capacity can be terraces of glaciofluvial sediments, with a deeper level of subterranear waters and further from watercourses, such as larger parts of the Zeta plain above 15 masl [19]. Historical and instrumental records show that the area of the Zeta-Skadar depression was shaken by harmful and destructive earthquakes from its own hotspots and from neighboring hotspots, and so the terrain of the Capital City Podgorica is shaken as well The most recent document that investigated the seismicity of these areas is the „Proučavanje seizmičnosti balkanskog regiona“ ("Study of the seismicity of the Balkan region") as part of an international project UNDP/UNESCO. According to the aforementioned research, it was shown that the maximum intensities of earthquakes in the Zeta depression were from VIII units of the MCS scale. This is confirmed by earlier research and studies after the Skopje earthquake (1963), and especially after the Montenegrin earthquake (1979). In addition to all this, it is known that the old Roman city of Duklja was destroyed in the 6th century by an earthquake which, based on circumstantial evidence (the degree of destruction of buildings), is estimated to have an intensity of 90 MCS [20].

3.2. MEASUREMENTS AND DATA PROCESSING

Geometric documentation of stone bridges presents several challenges owing to the intricate nature of these structures. The irregular surfaces, intricate details, and varying textures of aged stone pose difficulties during the measurement process. Moreover, a big part of the documentation concerns the lower part of the bridge which stands on the shore of the river. In Ribnica river, the water has continuous flow (Fig. 4), which made the procedure even more difficult. In this work, the terrestrial laser scanner of Leica Geosystems BLK360-G1 was implemented.

Leica BLK360-G1 is a terrestrial laser scanner with integrated spherical imaging system and thermography panorama sensor system. It is easy to use (one-button operation) with an accuracy of 6mm at 10m range of scan. It scans up to 360,000 points per second in a range of 60m, having a field of view of 360^{o} horizontal and 300^{o} vertical. The points can be downloaded to a pc through type-C port or Wi-Fi [21].

Figure 5. Ribnica bridge during scanning process (authors)

All scans were performed with a 4 mm step and the distance between the object and the scanner was always less than 20m. The percentage of the scan overlap ranged from 40% to 70%. (fig. 5)

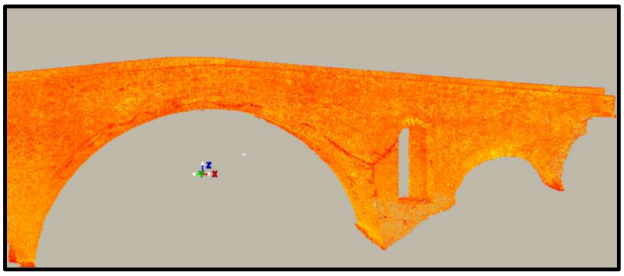

Figure 6. Snapshot of the scanning process (left) and example of a pointcloud output (right).

In total 13 setups were made, so that the whole bridge would be covered with the aforementioned overlap (fig. 7a, 7b). Moreover, 18 black and white targets were used as tie points.

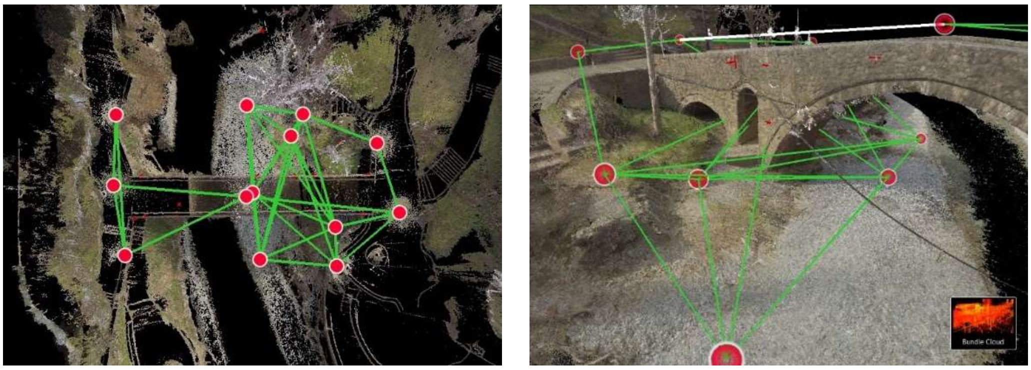

Figure 7. a) Setup distribution (plan view) b) Setup distribution perspective view

The process of the point clouds conducted in the Leica Cyclone Register 360 and Leica Geosystems Cyclone environment [19]. The alignment of the individual scans was performed using tie points in an independent reference system. From the 13 setups, 29 links were created using common points from adjacent setups. As a whole the point cloud was aligned with a mean square error (RMS) of 7mm, an average overlap of 53% and strength of the total model of 77%, consisting of more than 427 million points (fig. 8)

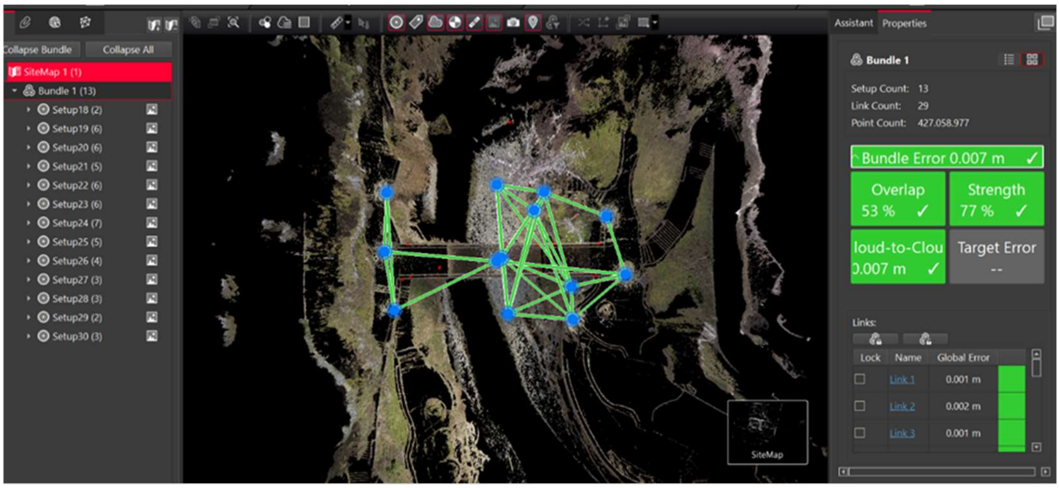

Figure 8. The links between the setups and the final results from the point cloud alignment

The point cloud was cleaned from noise (e.g. vegetation, obstacles etc.) and inserted in the Leica 3DR software for further processing and modeling. The cleaning of the point cloud is an essential procedure for all similar application. Keeping only the information that concerns the construction itself, reduces the final size of the file and makes the modelling more precise. The final 3D model is given RGB colors derived from the pictures than were taken from the laser scanner during the scanning process (fig. 9a, 9b, 9c)

Figure 9. a) Perspective view of the model b) c). Facade and plan view

3.2.2. CREATION OF DRAWINGS AND ORTHOPHOTOS

One basic aspect of the current study was the creation of drawings and orthophotos so that they can be used in the future for projects of restoration, preservation or reinforcement of the bridge. Moreover, these drawings can also be used for the touristic or cultural promotion of the monument. The proper projections and coordinate systems in CAD environment and the corresponding orthophotos were created (fig. 10, 11). The orthophotos were digitized so that the floor plan of the deck, the 2 façade and 4 cross-sections of the bridge were prepared (fig. 12)

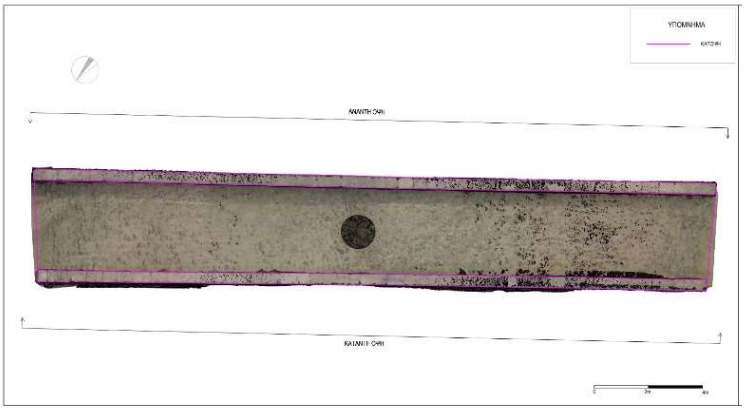

Figure 10. Orthophoto / floor plan of the deck.

Figure 11. Orthophoto of the downstream façade

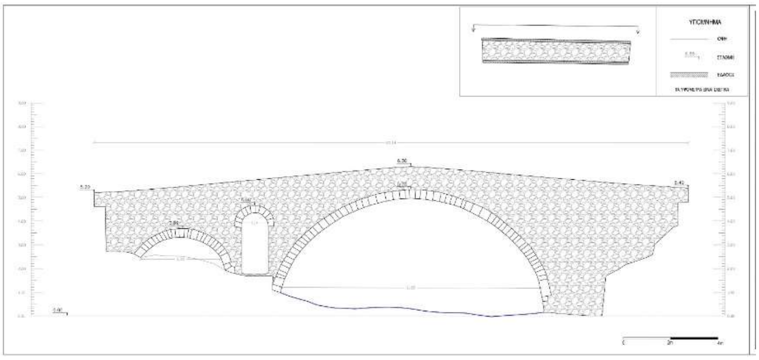

Figure 12. Drawing of the upstream façade

3.2.3. MODELING OF THE POINT CLOUD

On the merged point cloud, the region-grow algorithm was applied, and surfaces of planes and cylinders were modeled on the three arches of the bridge (Figures 13 and 14). The fit quality was with a standard deviation of 6 mm. From this modeling the initial geometric elements of the bridge were extracted.

Moreover, the mesh of the bridge was created by implementing triangle edges of 20 cm (fig. 15). This model was used for the integrity checks of the bridge that are described in the next paragraph.

Figure 13. Snapshot of the point cloud of the first relief arch (left) and the modeled surfaces output (right).

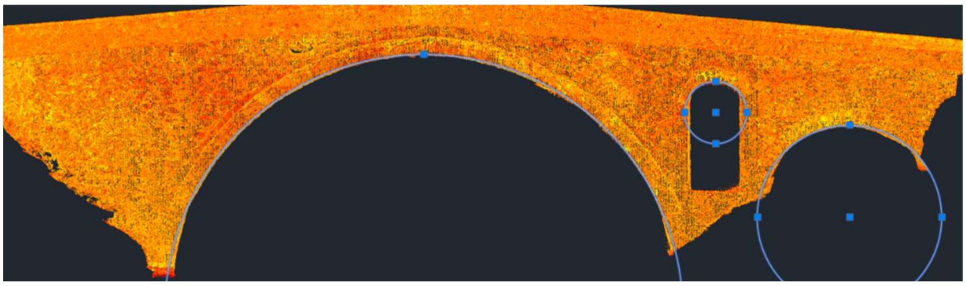

Figure 14. Adjustment of circles to the three arches of the bridge.

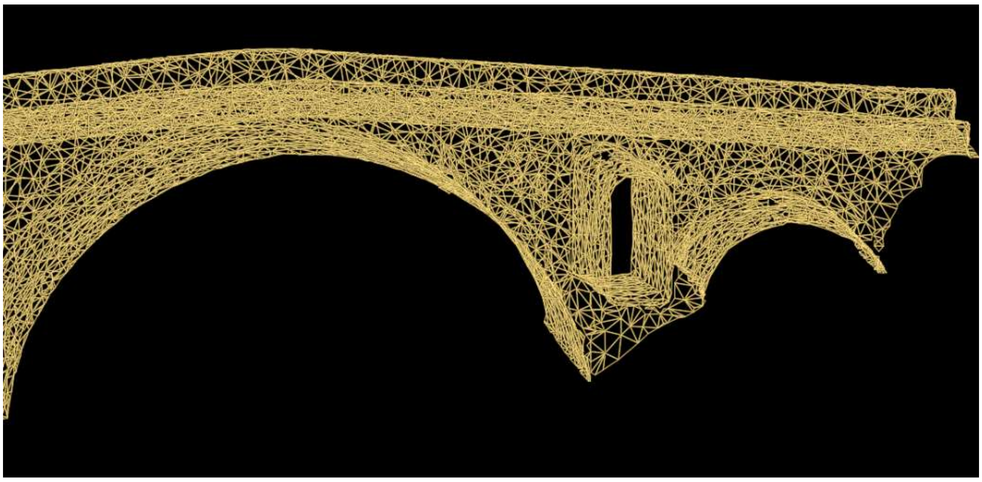

Figure 15. Mesh of the bridge

3.2.4. INSPECTION AND ASSESSMENT OF THE BRIDGE

To check bridge integrity, the 3D structural model was created in Radimpex Tower 8 (Figure 11). The model was created based on geomatic data using shell elements of adequate thickness and dimension. The bridge was modeled with empirically estimated material characteristics, because no measurements at site were made. The Young's modulus of elasticity is adopted in the amount of 1 GPa, and compressive stresses are limited to 1.5 MPa in static and 2.0 MPa in seismic design situation (bridges made of sandstones and limestones) [14].

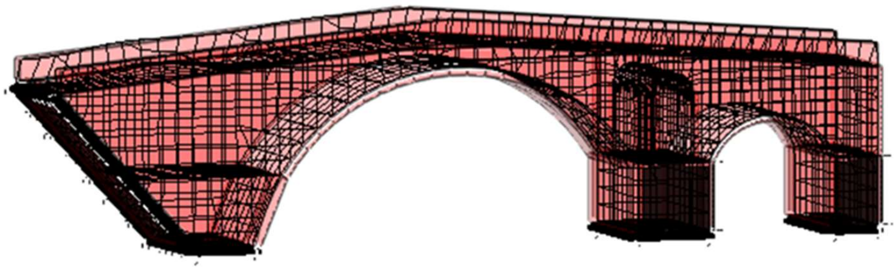

Figure 16. 3D view of the bridge structural model

The main objective was to determine whether the arches, as a main structural part of the stone bridge, have adequate load capacity and if doesn't to propose rehabilitation and strengthening measures. The static and seismic design situation were carried out. In static load situation self-weight and pedestrian load of 5 KN/m^2 were considered. For the seismic analysis the lateral force method according to Eurocode 8 was used. The first vibration period of the structure in the longitudinal direction is Tx=0.213s, and in the transverse direction is Ty=0.325s (Figure 12). For the relevant load combinations (static and seismic), internal forces are calculated (Figure 13), and stresses and deflections are controlled in all cross-sections of the span structure.

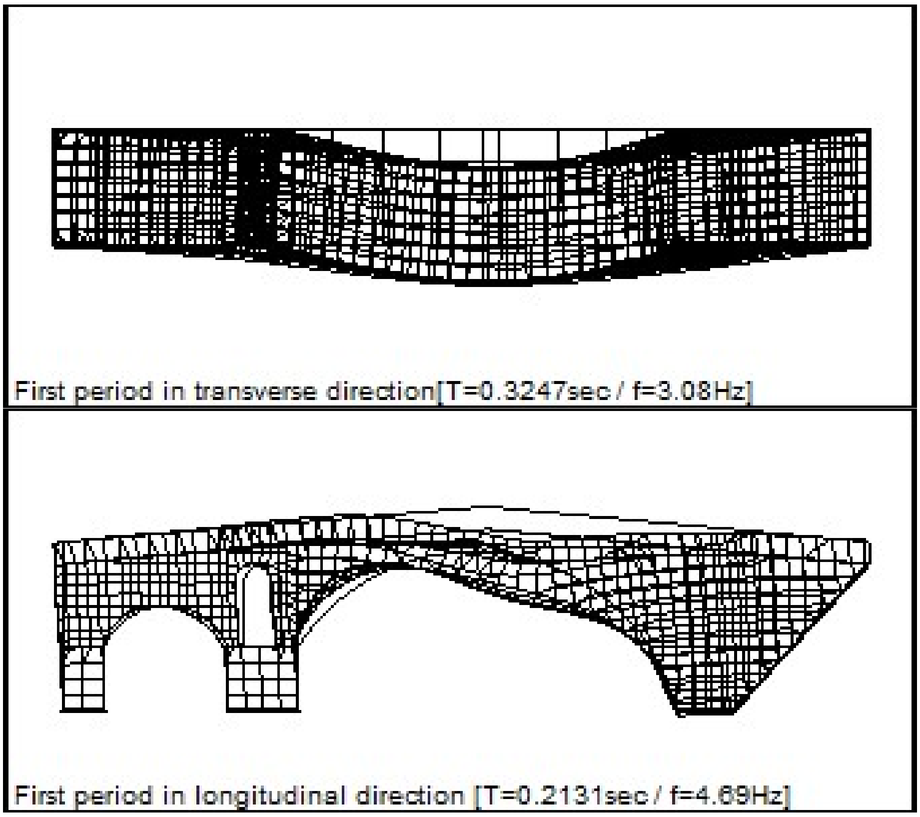

Figure 17. First two vibration periods of the bridge

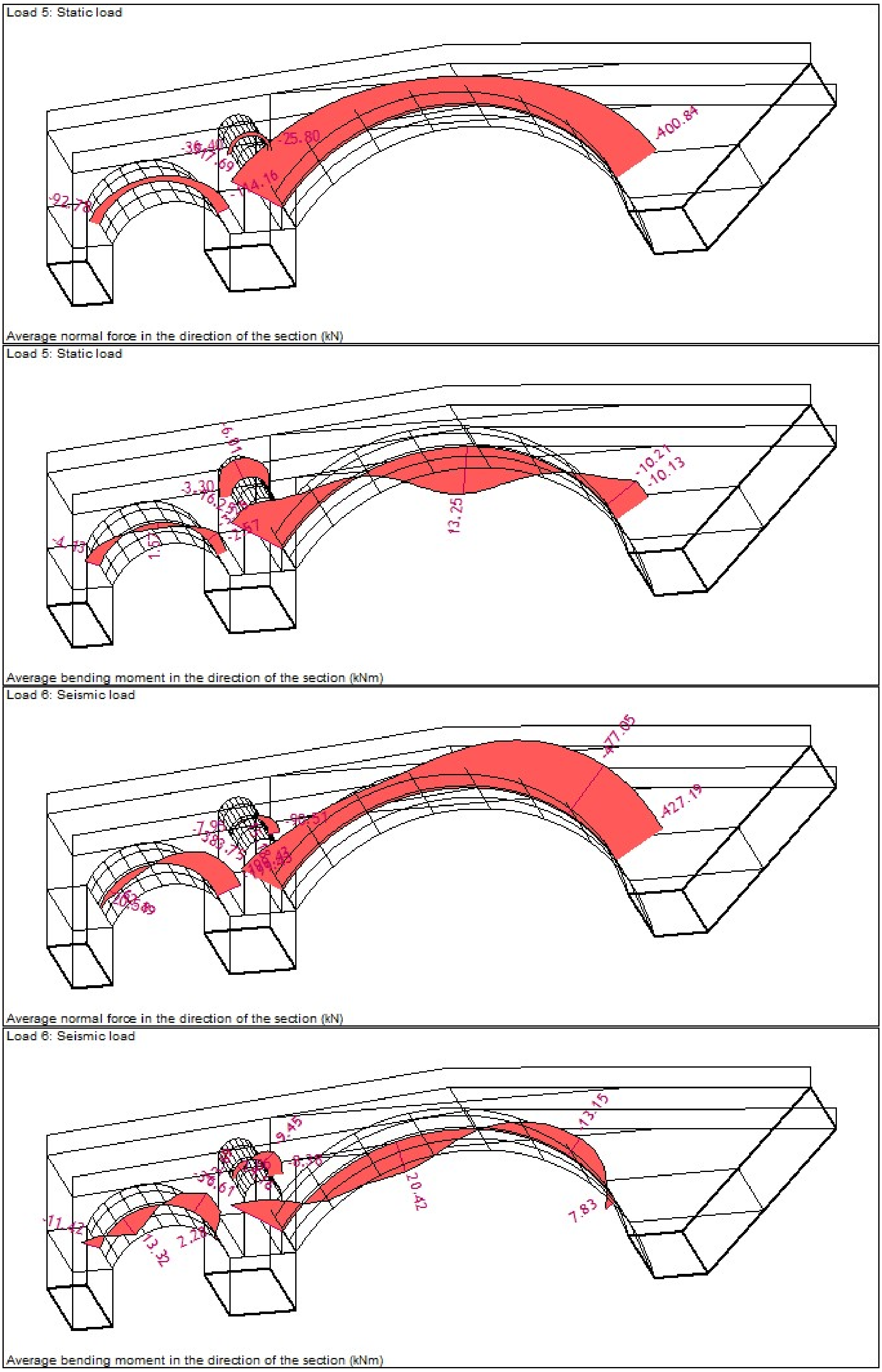

Figure 18. Mean value of internal forces at the arches

In all controlled design situation, the tensile stresses do not occur (or can be neglected), and the compressive stresses are within the permitted limits, while deflections are around L/800, as can be seen at the Figure 14 and Figure 15.

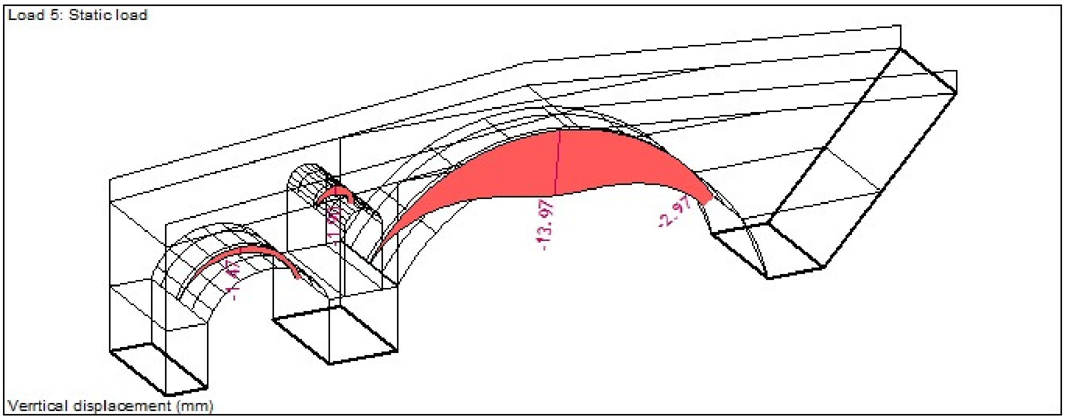

Figure 19. Deflections in the arches due to static load

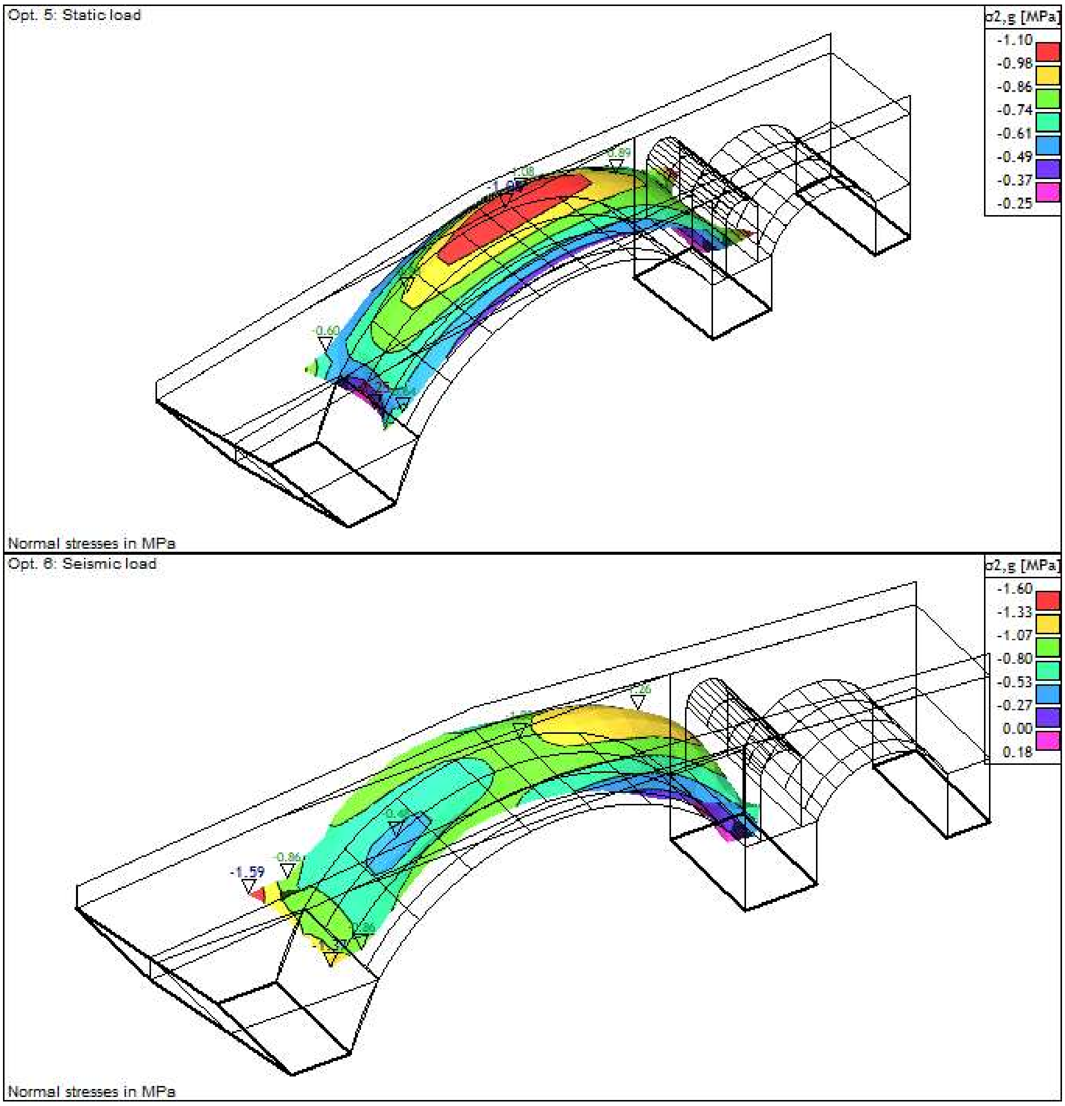

Figure 20. Normal stresses in the main arc due to static and seismic loads

4. DISCUSSION AND CONCLUSIONS

The evolution of technology has given many equipment and methods to reach the desired precision and minimize the measurements' time in the geometric documentation of complex structures, such as a stone bridge.

This paper explained the use of laser scanner technology for treatment of historic bridges. The focus was on electronic regeneration to facilitate the preservation and possible renovation of the bridge. Therefore, the data of Adji-Pasa stone bridge recorded by laser scanner and the integration of this data into various systems were investigated.

Nevertheless, a substantial understanding a stone bridge and a fundamental condition for any intervention, should include not only geometric documentation but also the recognition of the structure (i.e. the synthetic and functional composition) and its form (i.e. its construction characteristics). The specific bridge exhibits a high degree of integrity and resistance to static and seismic loads. The choice of the ratio of arch arrow and span contributed significantly to the good load conditions of the bridge, which confirms the experience and knowledge of the old one's craftsmen.

Particular attention must be paid to the effects of moisture on the stress and deformation of the stone bridge structure and its interaction with the bridge filler. Future work in this context could be the classification of point cloud data, where individual points are categorized into different classes based on their characteristics. These classes could represent wet or dry areas of the bridge. Supervised learning is a basic approach (data-driven method) that relies on labeled data to train algorithms for pattern recognition in the point cloud. Machine learning improves this process by automating classification based on learned patterns on the bridge surface.

In conclusion, stone bridges in Europe stand as more than mere infrastructure; they are enduring symbols of human ingenuity, cultural identity, and historical continuity. Their preservation through geometric documentation ensures that these iconic structures continue to inspire awe and admiration while serving as invaluable heritage assets for generations to come.

ACKNOWLEDGEMENTS

The authors would like to thank the Administration for Protection of Cultural Property for its response to our request to carry out the measurements at the Ribnica Bridge

LITERATURE

[1] J. Witzany and R. Zigler, "THE ANALYSIS OF NON-STRESS EFFECTS ON HISTORICAL STONE BRIDGE STRUCTURES (MONITORING, THEORETICAL ANALYSIS, MAINTENANCE)," *Journal of Civil Engineering and Management*, vol. 13, no. 2, pp. 157–167, Jun. 2007, doi: https://doi.org/10.3846/13923730.2007.9636432.

[2] N. Haala and M. Kada, "An update on automatic 3D building reconstruction," ISPRS *Journal of Photogrammetry and Remote Sensing*, vol. 65, no. 6, pp. 570–580, Nov. 2010, doi: https://doi.org/10.1016/j.isprsjprs.2010.09.006.

[3] Vasileios Tzoumas, "Extensive Restorations of Arched Stone Bridges: the Examples of Plaka Bridge in Greece and Stari Most in Bosnia and Herzegovina," *Technical Annals*, vol. 1, no. 3, Jul. 2023, doi: https://doi.org/10.12681/ta.34836.

[4] A. Shabani, M. Skamantzari, S. Tapinaki, A. Georgopoulos, V. Plevris, and M. Kioumarsi, "3D simulation models for developing digital twins of heritage structures: challenges and strategies," *Procedia Structural Integrity*, vol. 37, pp. 314–320, Jan. 2022, doi: https://doi.org/10.1016/j.prostr.2022.01.090.

[5] N. M. Soković, M. Petrović, A. Kontić, S. Koprivica, and N. Šekularac, "Inspection and Assessment of Masonry Arch Bridges: Ivanjica Case Study," *Sustainability*, vol. 13, no. 23, p. 13363, Dec. 2021, doi: https://doi.org/10.3390/su132313363.

[6] L. Kotoulas, L. Melidis, I. Giannaris, E. Stylianidis, K. Katakalos, and G. Manos, "STRUCTURAL ASSESSMENT OF STONE-ARCH BRIDGES THROUGH PHOTOGRAMMETRY," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. XLVIII–M2–2023, pp. 879–884, Jun. 2023, doi: https://doi.org/10.5194/isprs-archives-xlviii-m-2-2023-879-2023.

[7] I. Lubowiecka, J. Armesto, P. Arias, and H. Lorenzo, "Historic bridge modelling using laser scanning, ground penetrating radar and finite element methods in the context of structural

dynamics," *Engineering Structures*, vol. 31, no. 11, pp. 2667–2676, Nov. 2009, doi: https://doi.org/10.1016/j.engstruct.2009.06.018.

[8] R. Silva, C. Costa, António Arêde, Rui Calçada, and D. V. Oliveira, "Structural analysis of a stone arch bridge under incremental railway static loading," Report, Jan. 2019, doi: https://doi.org/10.2749/guimaraes.2019.1536.

[9] P. Morer, I. de Arteaga, J. Armesto, and P. Arias, "Comparative structural analyses of masonry bridges: An application to the Cernadela Bridge," *Journal of Cultural Heritage*, vol. 12, no. 3, pp. 300–309, Jul. 2011, doi: https://doi.org/10.1016/j.culher.2011.01.006.

[10] J. Pérez, J. de Sanjosé Blasco, A. Atkinson, and L. del Río Pérez, "Assessment of the Structural Integrity of the Roman Bridge of Alcántara (Spain) Using TLS and GPR," *Remote Sensing*, vol. 10, no. 3, p. 387, Mar. 2018, doi: https://doi.org/10.3390/rs10030387.

[11] "Most na Sastavcima - najstariji most u Podgorici," Moja Crna Gora, Mar. 28, 2013. http://www.mojacrnagora.com/most-na-sastavcima-najstariji-most-u-podgorici/ (accessed May 08, 2024).

[12] M. Gojkovic, Stari kameni mostovi: anatomija, patologija, zaštita, sanacija, konzervacija. Beograd: Naučna knjiga, 1989, pp. 7–60.

[13] M. Gojkovic, Stari kameni mostovi: anatomija, patologija, zaštita, sanacija, konzervacija. Beograd: Naučna knjiga, 1989, pp. 148-150.

[14] Bojat V., ‘'Podgorica je most". Podgorički mostovi' "Glasnik", JU NB "Radosav Ljumović", Podgorica, 2022, pp. 26-27.

[15] "Mostovi Podgorice," dobrodosli. https://starapodgorica.wixsite.com/dobrodosli/mostovi-podgorice (accessed May 08, 2024).

[16] Prirodne osnove: Potencijali povećanja kvaliteta životne sredine i ograničenja za razvoj. Prostorno urbanistički plan Glavnog grada Podgorica do 2025 godine Glavni grad Podgorica, Urbi Montenegro, Podgorica, Urbanistični institut Republike Slovenije, Ljubljana WINsoft, Podgorica Geateh, Ljubljana, Podgorica, 2014, pp151-167

[17] Prostorno urbanistički plan Glavnog grada Podgorica do 2025 godine Glavni grad Podgorica: Plan predjela (2014),pp-1-59

[18] "Leica BLK360 Imaging Laser Scanner," leica-geosystems.com. https://leica-geosystems.com/products/laser-scanners/scanners/blk360

[19] "Leica Cyclone 3D Point Cloud Processing Software," Leica-geosystems.com, 2019. https://leica-geosystems.com/products/laser-scanners/software/leica-cyclone