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Digital archiving and preservation of historical bridges: addressing environmental challenges

Arquivamento digital e preservação de pontes históricas: abordando desafios ambientais

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Abstract

Documenting historical buildings in digital environments is crucial for preserving their value and passing on cultural heritage to future generations. Studies of historical bridges face significant challenges due to the difficulty of accessing bridge elements and the changes caused by surrounding water sources. This study aims to investigate the historical On Gözlü (Ten-Eyed) Bridge in Diyarbakır and to provide documentation strategies for its immediate surroundings. The study adopts a mixed research approach in which both qualitative and quantitative data are considered together. The methodology consists of five stages. The first stage involves identifying existing studies and establishing a conceptual framework related to the bridge. The second stage involves fieldwork around the bridge and its surroundings. The third stage focuses on analysing the data obtained from the fieldwork and examining the local environment. The fourth stage focuses on developing strategies for the conservation and documentation of the bridge. The fifth stage evaluates changes in the surrounding area and discusses strategies for documenting difficult-to-access structures such as the bridge. In this context, the first and last stages of the study are based on qualitative research, while the second, third, and fourth stages include quantitative research. Over a period of approximately twenty years, changes around the bridge have been documented, revealing ongoing efforts to remove new multi-story buildings as part of its preservation. The resulting model provides a detailed archive of the bridge's current condition for future generations. In conclusion, new strategies can be developed for other challenging bridges, using advancing technology for effective conservation.

Keywords: Cultural heritage. Cultural studies. Documentation. Historical bridge.

Resumo

Documentar edifícios históricos em ambientes digitais é fundamental para preservar seu valor e transmitir o patrimônio cultural às futuras gerações. O estudo de pontes históricas enfrenta desafios significativos devido à dificuldade de acesso aos elementos estruturais e às mudanças causadas por fontes de água ao redor. Este estudo tem como objetivo investigar a ponte histórica On Gözlü (Dez Olhos), em Diyarbakır, e propor estratégias de documentação para sua área circundante. Foi adotado uma abordagem de investigação mista em que os dados qualitativos

e quantitativos são considerados em conjunto. A metodologia consiste em cinco etapas. A primeira etapa envolve a identificação de estudos existentes e o estabelecimento de um referencial teórico relacionado à ponte. A segunda etapa abrange o trabalho de campo na ponte e em seus arredores. A terceira etapa foca na análise dos dados obtidos no trabalho de campo para examinar o ambiente local. A quarta etapa visa o desenvolvimento de estratégias para a conservação e documentação da ponte. A quinta etapa avalia as mudanças na área ao redor e discute estratégias para documentar estruturas de difícil acesso, como a ponte. Neste contexto, a primeira e última fases do estudo baseiam-se na investigação qualitativa, enquanto a segunda, terceira e quarta fases incluem a investigação quantitativa. Ao longo de aproximadamente vinte anos, as mudanças ao redor da ponte foram documentadas, revelando esforços contínuos para remover novos edifícios de vários andares para sua preservação. O modelo resultante fornece um arquivo detalhado do estado atual da ponte para as gerações futuras. Em conclusão, novas estratégias podem ser desenvolvidas para pontes desafiadoras, utilizando tecnologias avançadas para uma conservação eficaz.

***Palavras-chave*:** *Patrimônio cultural. Estudos culturais. Documentação. Ponte histórica.*

Introduction

The preservation of cultural heritage sites and their interaction with future generations is crucial for sustainable development, social memory, and identity (Jokilehto, 2017). These heritage sites reflect the cultural values, traditions, and lifestyles of their geographical context in regions with thousands of years of history (Schafer, 2001; Ulvi, 2020). Heritage sites that contain the traces of past social, economic, and political dynamics serve as tangible elements of local identity while also functioning as documents that convey significant parts of human history to future generations (Akyıldız; Olğun, 2020; Lowenthal, 2015; Remondino *et al.*, 2011).

Documenting and digitally preserving historical buildings is more than simply recording their current physical condition. Such efforts are essential for monitoring changes over time, analysing the impact of environmental factors, and ensuring that restoration efforts are based on scientific principles. Digital archives provide datasets that allow for modeling the deterioration processes of structures, contribute to the development of more accurate and sustainable conservation methods, and serve as valuable resources for future academic research and the intergenerational transmission of cultural heritage. Furthermore, sharing digital models and archives online increases public awareness and contributes to the preservation of these cultural heritage elements as "collective memory" in the digital realm. Global digitisation projects, supported by international organisations such as the United Nations Educational, Scientific and Cultural Organization and the International Council on Monuments and Sites, increase the applicability of these structures in both local and international conservation efforts. Digital documentation plays a critical role in the sustainability of architectural heritage by creating a valuable repository of information that will serve as a reference for future scientific studies and restoration processes.

In recent years, the documentation and digital preservation of historical structures have been addressed in an integrated manner with conservation and restoration efforts (Bekar; Kutlu, 2024; Koutsoudis *et al.*, 2014; Logothetis; Delinasiou; Stylianidis, 2015). Three-dimensional models created using various techniques such as photogrammetry, laser scanning, and aerial/satellite imagery enable detailed recording of the current state of structures (Grussenmeyer *et al.*, 2008; Remondino; El-Hakim, 2006; Rönnholm *et al.*, 2007; Willkens; Liu; Alathamneh, 2024). This not only generates scientific data for future interventions but also facilitates the accessibility of these valuable cultural heritage elements in virtual environments (Pietroni; Ferdani, 2021). The creation of metric digital models supports not only as-built documentation but also traditional survey methods. Detailed examination of the architectural features, material compositions, and deterioration conditions of

structures in digital environments assists in the decision-making process for restoration projects (Galeazzi, 2016).

Historical bridges have served as significant transportation and connection points throughout history, playing a central role in the development of cities and the socio-economic lives of their populations (Akın; Sezer, 2023; Salamak; Fross, 2016). In regions such as Anatolia, where numerous historical bridges exist, these structures not only provide physical access but also serve as tangible indicators of cultural identity, memory, and heritage (DeLony; Klein, 2005; Hong *et al.*, 2009). The literature includes many important studies on historical bridges in Anatolia. For instance, Yeşilbaş (2016) prepared documentation and restoration projects for the Silifke Bridge, while Özmen and Sayın (2020) investigated the engineering properties and seismic behaviour of historical masonry bridges. Ceylan (2011) discussed the functional characteristics of historical bridges in the Gediz Basin and their role in cultural heritage interactions. Karaton *et al.* (2017) identified the behaviour of the Malabadi Bridge under various seismic loads. Bayraktar, Türker and Altunışık (2015) conducted studies to analyse the behaviour of historical masonry bridges. A search in the Web of Science database using the keywords "historical bridge AND Anatolia" revealed only four studies in the architecture category (Hamzaoglu; Özkar, 2023; Halifeoğlu; Sert; Yilmaz, 2013; Hensel *et al.*, 2012; Uygun Gençer; Hamamcıoğlu Turan, 2017). This indicates that there is a clear lack of sufficient national and international studies on historical bridges in Anatolia. All these data highlight the necessity of increasing efforts to preserve bridges, given their significant role in Anatolia's rich historical context.

Diyarbakır, a city with many historical bridges, is located in the Mesopotamian basin. The city has hosted numerous civilisations throughout history and has been an important commercial and cultural center (Ergün; Akın, 2024; Koç; Kejanlı, 2022; Serçek; Hassan, 2016; Yeşilbaş, 2015; Yıldırım, 2017). This has played a vital role in the construction of many cultural heritage sites in the region. One of the most significant structures constituting these cultural heritage sites is the Historical On Gözlü Bridge (Ten Eyed Bridge, Dicle Bridge), located over the Tigris River. With its long history, this bridge has played a crucial role in the cultural and economic development of the region. However, natural and man-made factors over time have raised concerns about the bridge's preservation and future transmission. Existing studies regarding the bridge include analyses of its surroundings (Biçen, 2023; Güneroğlu; Oğuztürk, 2021) and studies on its preservation using traditional methods (Dalkılıç; Halifeoğlu, 2009; Demir, 2019; Demir, 2021; Halifeoğlu; Toprak; Kavak, 2011; Karasin; Işık, 2016).

When the literature was examined, it was determined that there was no study on the digitisation of the On Gözlü Bridge. This study fills an important gap in the literature by analysing the digitisation of the On Gözlü Bridge in Diyarbakır and the urban transformation in its immediate surroundings. The physical changes that have occurred around the bridge over time were systematically documented through archival photographs and satellite imagery. Additionally, the study generated a metrically accurate 3D digital model of the bridge and established a heritage archive for interdisciplinary use. In addition, the fact that the digital data obtained can be used in areas such as developing urban conservation policies, supporting restoration planning, and producing digital content for education and tourism purposes increases the social and managerial benefits of the study. In this respect, the research reveals that digital heritage archiving is not only a technical process but also a strategic tool that makes it possible to transfer cultural values to wider audiences.

Material and Method

The Historical On Gözlü Bridge is located on the Diyarbakır-Mardin road, at the foothill of Kırklar Mountain, spanning the Tigris River. In the literature, this bridge is referred to as the On Gözlü Bridge (Ten Eyed - due to its ten arches), Tigris Bridge, and Silvan Bridge (Halifeoğlu *et al.*, 2009). It is believed that the bridge has been partially or completely destroyed and reconstructed over time, with the most accurate date of construction derived from the inscription on the bridge indicating the year 457 AH (1065 AD) (Bell, 1909; İlter, 1978; Tekin, 1997). (Figure 1). Since its construction, the bridge has played a central role in the urban development of Diyarbakır, the effective use of transportation routes, and the improvement of the local economy.

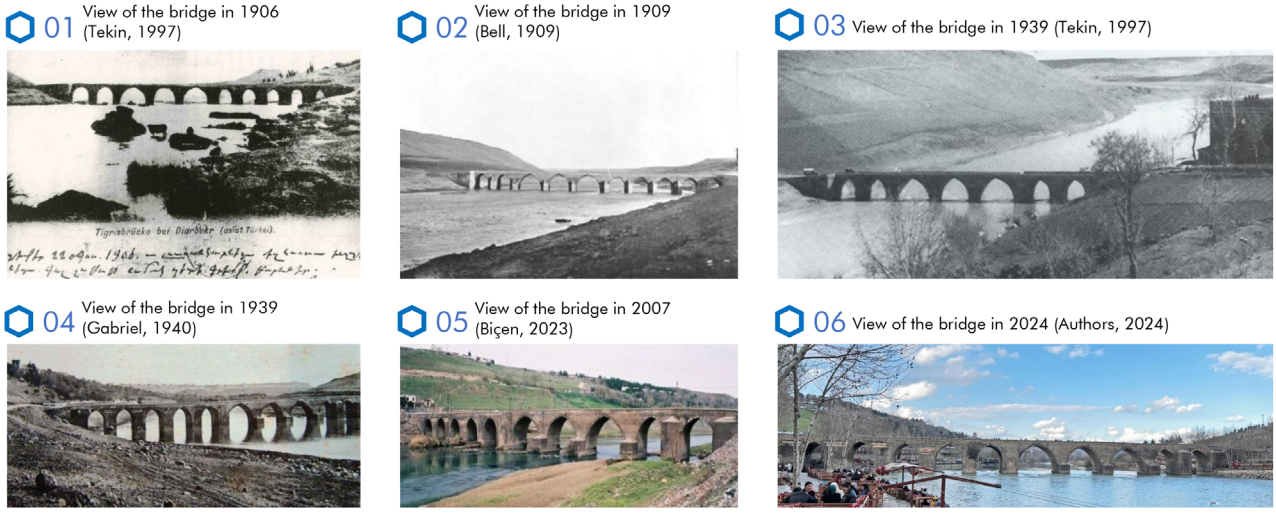

Figure 1 – Views of changes on the On Gözlü Bridge over the years.
Source: Elaborated by the authors (2025).

The study involved a five-stage process (Figure 2). In this process, a mixed research approach was adopted by using both qualitative and quantitative methods. The first stage involved conducting a comprehensive documentary analysis of academic and technical studies on historical bridges. This analysis was structured to identify common themes that emerged in the areas of cultural heritage, digital documentation, and preservation of historical bridges. The studies in literature were classified using a categorical analysis matrix according to the conceptual framework (citation, method, field, result, limitation). Thus, the common themes of the studies on historical bridges were identified, and it was determined which elements were missing in the previous analyses of the On Gözlü Bridge. In the second stage, data was collected using on-site field observations and semi-structured observation forms on the bridge and its immediate surroundings as of 2024. During the field studies, the existing physical condition of the bridge and its environmental impacts were observed. Photographs were also taken using Unmanned Aerial Vehicles (UAV-drone). The images provided an up-to-date archive for the bridge and were also used in the digital modelling process. The third stage involved the combined analysis of satellite imagery (archival images obtained through Google Earth Pro) and visual data collected in the field. In this analysis process, satellite images obtained between 2002 and 2024 were analysed using visual comparative analysis techniques. A visual time series for the change analysis was created using the raster overlay method and reference points. This method made spatial variables, such as construction, loss of green space,

and morphological transformation around the bridge, measurable. The fourth stage involved converting the acquired UAV images into a three-dimensional model using photogrammetry-based digital modelling software (Agisoft Metashape). This modelling process was performed with the Structure-from-Motion technique based on depth-sensing algorithms. The model is a digital archive documenting the current physical condition of the bridge on a millimetre scale. The final stage was the evaluation of the 3D model and environmental change analysis. The transformation of the immediate environment over time was analysed, and the opportunities offered by digital archiving are discussed. In conclusion, the data collection techniques, analysis methods, and software used at each stage of the study were clearly described, and a methodological framework was presented as a model for digital cultural heritage documentation.

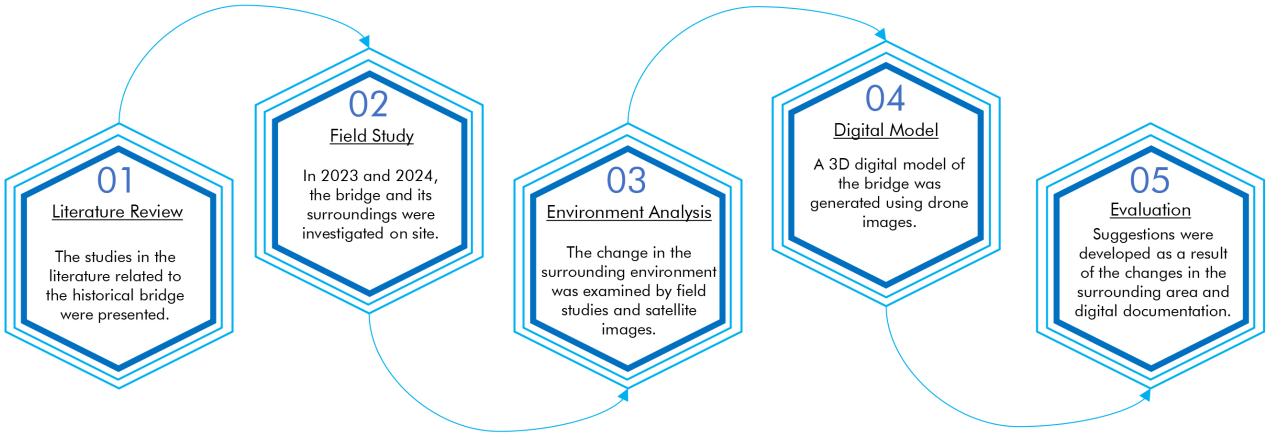

Figure 2 – Representation of the stages of the study
Source: Elaborated by the authors (2025).

This study evaluates the changes in the environment of the historical bridge and discusses the digital modelling process. An analysis of the results and limitations of similar research in literature provides a significant basis for understanding the current state of the field. Although the use of digitalisation and technological innovation in the documentation and preservation of historical structures has become increasingly common in recent years, complex structures such as historical bridges still present challenges. The intersection of architectural, engineering, and environmental dynamics complicates the digital modelling processes of these structures. Therefore, research in this area is invaluable not only for the scientific literature but also for the preservation of cultural heritage. Table 1 details the methods, results, and limitations of the studies found in the literature, highlighting current approaches to the digital modelling of historical bridges and identifying areas for further development.

The number of detailed modelling studies on how to systematically apply digital technologies to historical bridges is limited. Therefore, the main research problem of this study is how to archive historical bridges, which are currently surrounded by urban pressures, through digital methods and how these archived documents can be integrated into conservation strategies. This problem is not only specific to the On Gözlü Bridge but also a common problem faced by similar historic bridges in sustainable heritage management. Based on these problems, the measurable research objectives of the study are to 1) document and analyse the structural transformation of the On Gözlü Bridge and its surroundings over time; 2) 3D model the current state of the bridge with digital photogrammetry

Table 1 – Studies on digital archiving of bridges using modelling techniques.

Citations	Method	Field-work	Results	Limitations
Arias *et al.* (2007)	Photogrammetry, GPR and FEM	Galicia, Spain	A FEM was created using close-range photogrammetry GPR techniques, and structural analysis was performed	During the data collection stage for the photogrammetry, difficulties were faced such as narrow dimensions of the bridge and the impossibility of taking images from the riverbed
Stavroulaki *et al.* (2016)	Photogrammetry, GPR and FEM	Pontevedra, Spain	A FEM was created using photogrammetry and GPR to analyze the structural behavior of stone bridges	The narrow field of view of the camera limited the ability to capture images of the entire historical bridge
Pepe *et al*. (2019)	UAV, Photogrammetry and FEM	San Cono, Italy	Photogrammetric data were used to create a FEM of historical structures	Technical limitations were encountered due to low-cost UAVs not adequately capturing the underside of the bridge
Bruno *et al*. (2019)	UAV and Photogrammetry	Parma, Italy	The study modeled the geometry of a 19th-century bridge using digital tools	UAV operations were limited to 70-75m flight altitude due to the proximity of an airport
Doğan (2019)	UAV and Photogrammetry	Mersin, Turkey	A digital photogrammetric model of the Roman Bridge was created	Photographing the bridge was difficult due to the heavy pedestrian and vehicular traffic on the bridge
Pepi *et al*. (2021)	UAV, Photogrammetry, Environmental Vibration Testing, FEM	Todi, Italy	The 3D model provided valuable data for engineering, restoration, and visual inspection of the complex bridge geometry	The proposed structural analysis methodology relied on the quality of photogrammetry and highlighted limitations in applying it to different structure types
Trizio *et al*. (2021)	Laser scanning and Photogrammetry	L'Aquila, Italy	Digital tools were found to be effective and reliable for data integration and intervention planning	The effectiveness of the method depended on the physical and environmental conditions of the analyzed structures
Pepe; Costantino (2021)	Multi-view, UAV and Photogrammetry	Torcello, Italy	The study created a 3D model of a 19th-century masonry bridge using UAV and terrestrial photogrammetry	Obstacles such as vegetation and external elements around the bridge hindered the accurate and realistic construction of the model
Shabani; Kioumarsi (2023)	Laser scanning, Photogrammetry and FEM	Rhodes, Greece	It was concluded that creating digital twins of structures allows for effective seismic analysis	It was noted that gaps could arise in photogrammetric models obtained from digital images
Kotoulas *et al*. (2023)	UAV and Photogrammetry	North Macedonia	The partially collapsed form of the historical bridge was documented in 3D, and a structural analysis was conducted	Limitations were experienced in accurately identifying the original geometry of the collapsed bridge
Paris; Rossi (2024)	Laser scanning, Photogrammetry and GIS	Rome, Italy	It was found that historical bridges can be documented through digital modeling and integrated into HBIM processes	Technical limitations such as data density and processing time may exist in HBIM applications

Source: Elaborated by the authors (2025).
Note: FEM: Finite Element Modelling; GIS: Geographic Information System; GPR: Ground-Penetrating Radar; HBIM: Heritage Building Information Modelling; UAV: Unmanned aerial vehicle.

techniques that can be used when access is difficult; 3) transform the obtained data into a digital archive that can be integrated into future restoration and conservation processes; and 4) discuss the role of digital archives in the conservation of historical buildings at a conceptual and practical level.

Results

This section of the study discusses the changes that have occurred over the years in the area surrounding the Diyarbakır On Gözlü Bridge. In addition, a metric-digital model of this bridge was created and details of the process were provided. It was determined that periodic conservation and documentation efforts are necessary due to the probability that the bridge will reach a state of deterioration as a result of the natural and man-made impacts.

Changes in the surroundings of Diyarbakır On Gözlü Bridge

On Gözlü Bridge, one of the historical structures of Diyarbakır, is remarkable for its restoration and changes in its surroundings. The restoration of the bridge, completed in 2008, was

aimed at improving the structural performance of the bridge. The bridge has attracted the interest of many tourists with its monumental architectural features (Genç, 2015). Following the restoration, the bridge was intensively used for social and cultural activities.

The first step in the restoration process was the pedestrianisation of the bridge. The aim was to remove heavy moving loads such as cars and trucks from the bridge, while creating alternative routes that were constructed, and restore the historical bridge for tourist visits only. This prevented deformation caused by heavy dynamic loads on the bridge and allowed the bridge to be accessible only to pedestrian crossing (Figure 3). The restoration process also included structural and physical interventions applied to the bridge. Over time, the damaged bridge piers were reinforced, cracks that had formed were solidified through grouting injections, non-original concrete-asphalt pavements were removed to reveal the original pavement, foreign materials were cleaned, natural moss and plant roots formed by natural factors were removed, stone surfaces were restored, and pedestrian access routes leading to the bridge were provided (Sert *et al.*, 2009).

Figure 3 – Historical bridge images by year.
Source: Elaborated by the authors (2025).

With these recent interventions, the original function of providing vehicular access between Bağıvar town and surrounding villages was discontinued in order to ensure long-term preservation. As an alternative, a new bridge with a reinforced concrete system was built to facilitate this traffic flow. Today, the most significant change that has enabled social and cultural activities around the bridge and its surroundings is this change in its function. This transformation has not only changed the use of the bridge but has also led to the emergence of new areas for social interaction in its immediate surroundings.

The post-restoration period has seen significant changes in the immediate surroundings of the bridge. Cafes, redesigned seating areas, and reinforced concrete buildings have increased around the bridge, gradually affecting its historical and cultural integrity. The riverside restaurants

and tea gardens are particularly busy during the summer season. Residents often gather around the bridge to perform traditional dances with musical instruments, visit during Hıdırellez celebrations and religious holidays, and take photographs. However, this increase in activity has brought with it several challenges (Halifeoğlu; Toprak; Kavak, 2016). The transformation of the bridge into an activity area has led to rapid construction despite the recreation area boundaries specified in the conservation plan (Biçen, 2023). Satellite images indicating that the changes in the bridge and its immediate surroundings were most intense in the last 20 years are presented in Figure 4.

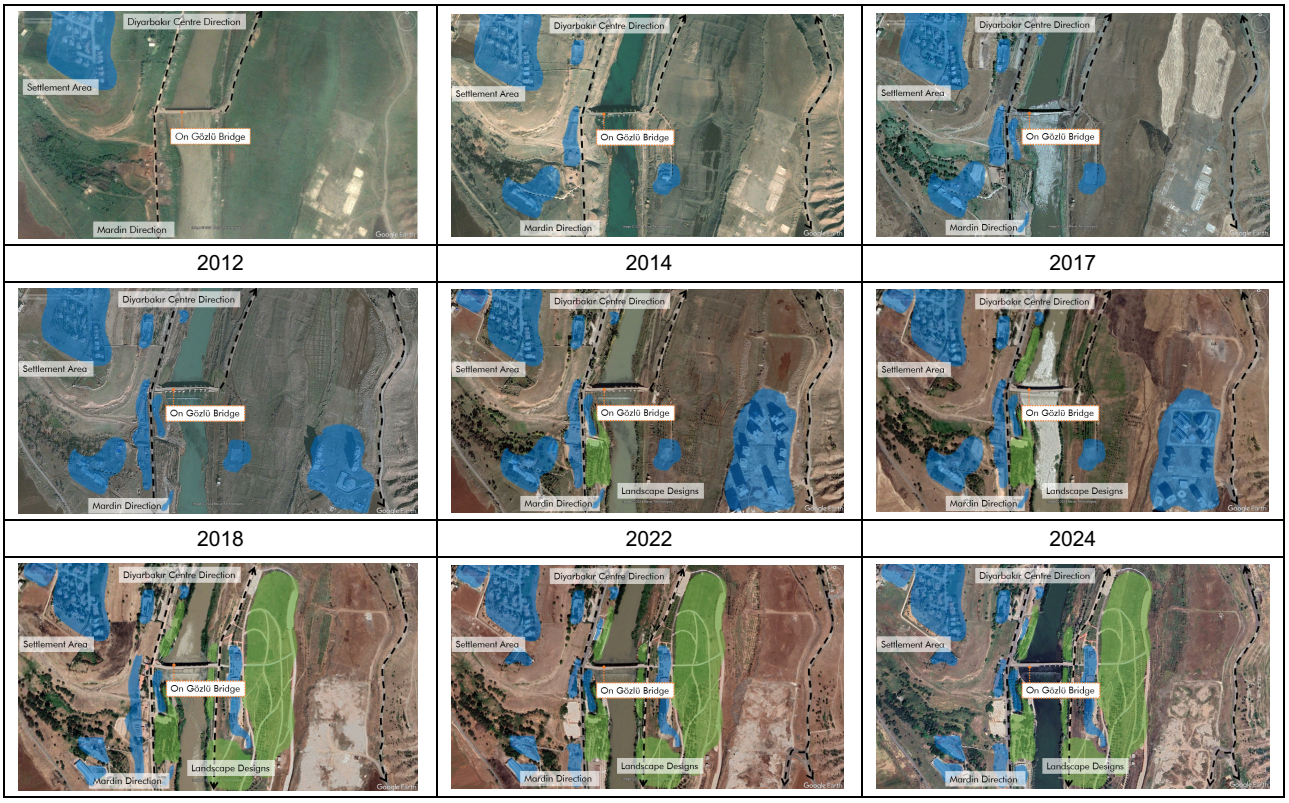

Figure 4 – Chronological comparison of satellite images of the On Gözlü Bridge.
Source: Elaborated by the authors using Google Earth images (2025).

When the 2002 images of the bridge are considered, it was observed that there was almost no construction or any landscaping in the immediate vicinity; however, as of 2009, small-scale constructions and factories were built around the bridge. In 2012, it can be observed that high-rise reinforced concrete constructions started to be built around the site. One of the biggest differences between the satellite images can be clearly seen between 2017 and 2018. Especially in those years, it was determined that landscaping and roads were built to the east of the bridge. It is also noted that the high-rise reinforced concrete constructions at the top of the mountain to which it provides access, which were called Kırklar Mountain Houses at that time, were demolished by the authorities following a demolition decision. This situation is one of the most significant developments in the immediate surroundings of the historical bridge. In addition to the existing buildings, the number of café-restaurant facilities increased toward the west. From 2018 to the present day, both the field studies and satellite images indicate that the number of commercial establishments and constructions has increased again.

The construction around the bridge continues despite the conservation decisions made by local administrations and relevant institutions. In the conservation plan prepared immediately after the restoration of the bridge, it was stated that the area around the bridge was planned as a recreation area. However, this plan has been inadequate in addressing the rapidly increasing construction around the bridge. Cafes, restaurants, and other commercial buildings have filled the area around the bridge and pose a risk of damaging the historical heritage of the bridge. The interest of local people and tourists increases the commercial potential of this area, and this situation has caused the construction around the bridge to increase.

Consequently, the restoration of the Diyarbakır On Gözlü Bridge and the changes in its surroundings pose the risk of damaging the historical and cultural value of the bridge. The increase in construction and social activities around the bridge continues despite the limits of the recreation area specified in the conservation plan, and this situation threatens the historical heritage of the bridge.

Digital Archiving of Diyarbakır On Gözlü Bridge

The creation of a realistic digital model of the historical On Gözlü Bridge requires detailed photographs of the structure. However, due to the long span of the bridge and its location on the Tigris River, this process is challenging to be carried out from the ground. With today's advancing technology, the number of vehicles developed to overcome such challenges is rapidly increasing. Unmanned aerial vehicle (UAV) drones, which have recently been used in many areas, are one of these vehicles. The photographs obtained from drones were also used in the production process of the digital model of the On Gözlü Bridge.

In the digital model creation of the historical On Gözlü Bridge, video recordings were made with drones. A total of 52 photographs were obtained from this video recording and added to the digital model generation software. The Metashape (developed by Agisoft) software was used in the model generation process. All 52 photographs were aligned by the software and, in the first stage, a model consisting of point clouds with blue frames representing the camera angles was obtained. With the automatic 'dense point cloud' creation command of the software, the point clouds were converted into a model consisting of dense point clouds. The number of points, 47,937.00 in the point cloud, reached 3,351,648.00 points in the dense point cloud model. In addition, the mesh model of the historical On Gözlü Bridge was obtained by linking the points on the dense point cloud. The digital model creation process was completed by defining the textures from the photographs added to the mesh model. Visuals showing the stages of the digital model process are presented in Figure 5.

Unnecessary data can be removed from the digital model. Within a short period of about 5 minutes, unnecessary data was removed from the software and only the model of the bridge was obtained. The model can be exported to many different extensions. Therefore, the model can be used in different disciplines. The digital model obtained within the scope of the study was exported as an OBJ file in Metashape. The exported file was imported into different software programmes and different strategies and perspectives for the studies that can be conducted in this field were presented in Figure 6.

Firstly, the digital model created in the study was imported into the Rhino 7 software, where 3D representations and 2D drawings can be produced. With the possibilities provided by the software, cross-sectional measurements can be obtained from the model, 2D drawings can

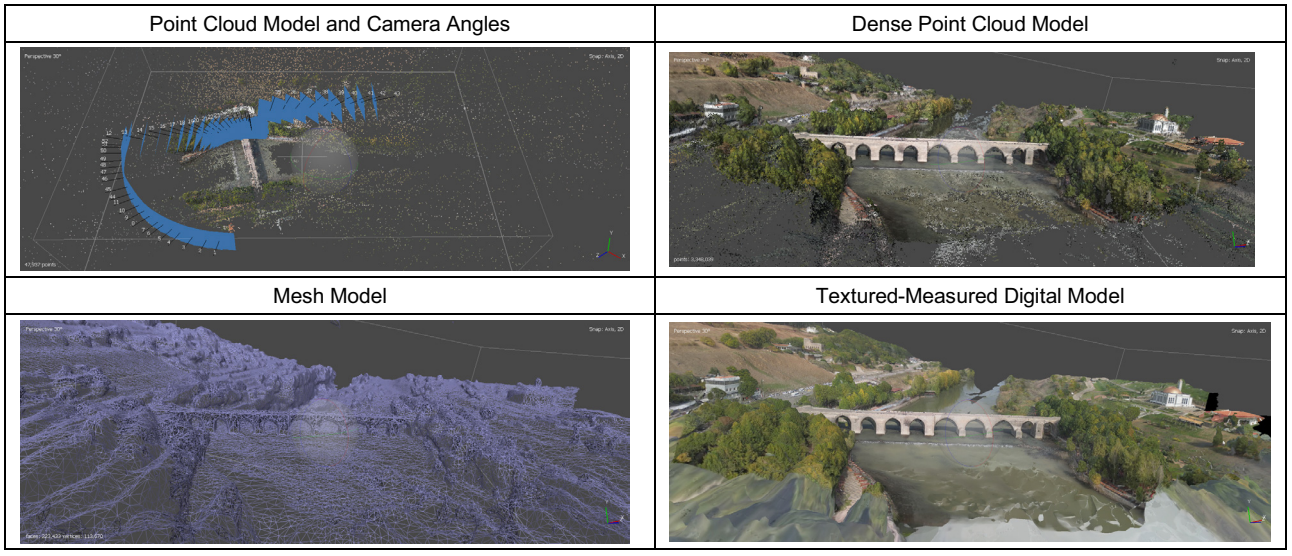

Figure 5 – Stages of digital archiving of the On Gözlü Bridge.
Source: Elaborated by the authors (2025).

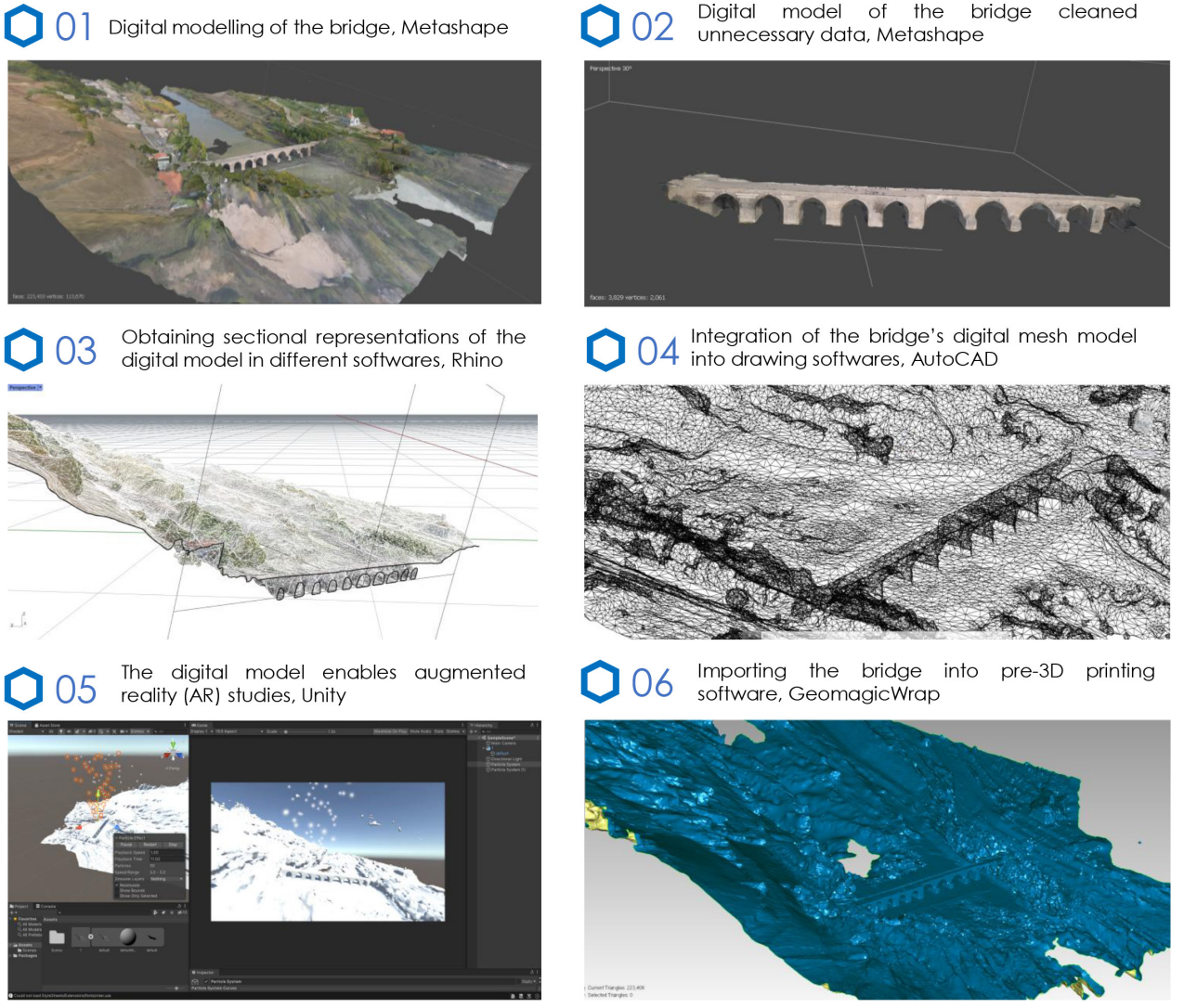

Figure 6 – Opportunities provided by a digital model of the On Gözlü Bridge.
Source: Elaborated by the authors (2025).

be produced, and the digital representation of the restoration projects to be implemented for the bridge can be modelled in this software before the interventions are applied. Therefore, it is possible to have an idea about the image that the bridge will have after the restoration processes.

The model was imported into the AutoCAD software, which is nowadays frequently preferred for the production of 2D drawings. This program is used for 2D drawings and 3D vector drawings rather than visualisation studies. The mesh model of the On Gözlü Bridge, which is included in the software as a mesh model, can be edited and 2D drawings can also be obtained from this model. This enables more practical data to be produced compared to the classical surveying techniques performed today.

The digital model of the bridge can also be included in Augmented Reality (AR) studies, which are rapidly increasing with today's developing technology. The digital model was imported into the Unity software to provide a perspective that the digital model can lead to augmented reality studies. In Unity, gamification and different dynamic representations can be produced on the model. When these models are integrated into Unity, users can see digitised environments such as historical buildings or architectural details placed on the real world and have the opportunity to navigate throughthese environments. Based on the level of detail of the digitised model, Unity can be augmented with enhanced interactions, lighting effects, and a real-time physics engine to increase realism. At the same time, touch, gesture, or voice interactive features can be added to improve the user experience.

Finally, within the scope of this study, the model was imported into the GeomagicWrap software, which is frequently used in 3D printing production. This demonstrates that 3D printing can be obtained from the digital model with the necessary edits. GeomagicWrap has a feature that automatically detected defective meshes (meshes that are not connected to any other mesh or nested meshes) on the model. By importing the model into this software, the mesh defects on and around the bridge can be removed and 3D prints can be created at the desired scale. This shows that the models made by photogrammetry are not only limited to archiving in digital environments, but with the developing technology, they can also be printed and archived in physical environments.

Discussion

The On Gözlü Bridge is a symbol of Diyarbakır's historical heritage and reflects the cultural identity of the region. However, the rapid urban transformation surrounding the bridge has led to a series of problems that complicate the preservation of the historical structure. The social and cultural activities organised by the local people around the bridge make this area a dynamic living space, while overbuilding and increasing commercial activities are among the factors that threaten the historical character of the bridge. Accordingly, it is essential to develop careful planning and conservation strategies around the bridge and to develop these strategies through a sustainable approach. Adopting a sustainable approach should be a common responsibility of local administrations and the community in order to ensure that the On Gözlü Bridge continues to function as a cultural centre in the future and to preserve its historical value.

The construction process around the On Gözlü Bridge reveals the conflict between the preservation of historical heritage and modern urban development. Increasing construction over time has threatened the aesthetic value and historical identity of the bridge, while at the same time leading to an increase in social and commercial activities. In the early 21st century, it is known that there was almost no construction around the bridge, and the natural landscape was dominant. Today, however, satellite images and images of the immediate surroundings clearly reveal that there

has been a significant change around the bridge. Although this situation enables the surroundings of the bridge to become a centre of attraction, it also creates a pressure that negatively affects the appearance of the historical structure. Regulations and demolitions in the past demonstrate the existence of conservation efforts, but the increasing commercial activities and construction reveal that a sustainable balance should be achieved around the bridge.

The increase in construction and social activities around the bridge continues despite the limits of the recreation area specified in the conservation plan. This situation threatens the historical character and environmental integrity of the bridge. In particular, monitoring the effects of environmental factors on the structural integrity and aesthetic value of the bridge is critical to the success of restoration strategies. Therefore, it is recommended that environmental changes should be monitored regularly with digital tools and transformations tracked and implemented. Digital technologies such as photogrammetry, laser scanning, and drone-based imaging allow for detailed analyses of the density of development, traffic load, and natural factors (e.g. changes in humidity, wind, and temperature) in the surroundings of the bridge. Furthermore, based on the results of these analyses, restoration strategies need to be revised, and active, dynamic conservation measures adopted.

The use of structural analysis software and the development of risk assessment models to model the long-term effects of environmental factors, as well as interventions in the immediate surroundings and ground properties, are crucial. The development of conservation strategies should incorporate advanced computer software and digital tools not only to document the existing bridge but also to improve its resilience against potential future hazards. This process can provide significant data to local authorities and conservation boards for the organisation of social and economic activities around the bridge. Hence, both the historical value of the bridge can be preserved and environmental sustainability can be achieved.

Digital documentation of historical monuments is of great importance for the preservation and passing on of cultural heritage to future generations. In particular, the documentation of complex and inaccessible architectural structures such as bridges is a very complicated process. Measurement and documentation studies conducted by traditional methods are sometimes insufficient to document such structures in detail. However, photogrammetry technology, developed in recent years, enables digital modelling of historical bridges. The Agisoft Metashape software has provided the opportunity to create a detailed 3D digital model of the historical On Gözlü Bridge using photogrammetric modelling principles. By processing high-resolution aerial and terrestrial photographs, many data such as architectural features, dimensions, and material textures of the bridge can be digitalised. In addition, the created model can be exported in different file formats (OBJ, FBX, COLLADA, etc.). This feature allows the model to be used in various disciplines such as architecture, engineering, archaeology, and art history. Digital models can be used in areas such as architectural analyses, static computations, and reconstruction studies. Furthermore, it is also possible to use this model in museology and exhibition activities. Consequently, a more comprehensive examination, documentation and conservation of historical bridges can be achieved by means of interdisciplinary usage possibilities.

On the other hand, there are some limitations to the digital modelling process. While the high resolution of the photographs used in modelling increases the level of detail, low resolution photographs may reduce the accuracy and reliability of the model. In addition, some data that require human intervention (colour, texture, etc.) may not be fully reflected in the digital model. Therefore, it is very important to use accurate measurement methods and, appropriate imaging

and processing techniques in photogrammetry-based digital documentation studies. Another important point to be considered is that if the photographs are taken with the overlapping technique during the modelling process, photogrammetric softwares will align the photographs.

In future studies, the 3D digital model can be integrated with AR and Virtual Reality (VR) technologies. This integration will enable the bridge to be visited, analysed and promoted effectively in virtual environments. For example, AR technology can be used to simulate and evaluate restoration and conservation interventions on a digital model prior to their implementation. Public participation should also be considered as an integral part of this process. With VR technology, people with limited access can also virtually experience the historical bridge in a virtual environment. Thus, new, and innovative methods can be developed for the conservation of cultural heritage and to enhance its interaction with society. Photogrammetry-based 3D digital modelling methods offer an effective tool for the documentation and analysis of complex historical structures. The model can be used in various disciplines and its integration with technologies such as AR/VR in the future will create new possibilities for the preservation and presentation of cultural heritage.

Final Considerations

Digital documentation processes of historical buildings are crucial for the preservation and passing on of cultural heritage to future generations. Especially through the creation of 3D digital models of architectural structures of historical importance, such as bridges, it is possible to record these structures in detail and use them in various disciplines. Digital tools provide great facilities in field studies such as bridges where conducting studies is difficult with classical techniques. The digital models obtained have a wide range of uses from restoration to scientific research, from education to promotional activities. The 3D digital model of the On Gözlü (Tigris) Bridge in Diyarbakır provides a comprehensive documentation and analysis of the architectural features of the bridge. The development of the model is extremely important in terms of recording the current state of the bridge in a digital environment, examining the changes it has experienced from past to present, and creating conservation strategies for the future. The integration of the created digital model with both 3D visualisations and 2D vector drawings, as well as augmented and virtual reality technologies, will provide a more effective presentation and understanding of cultural heritage. With developing technology over time, visitors will be able to access detailed information about the historical and architectural features of the bridge and will be able to travel through the interactive model of the bridge in a virtual environment.

Some limitations of the study should also be considered. The analysis based on satellite imagery could not track environmental change over shorter time periods, as only archival data for certain years was available. In addition, the fieldwork was only conducted over a specific period and did not include data on seasonal or periodic changes. In future studies, more detailed monitoring of morphological changes over time could be achieved through multi-year observations covering longer time intervals. At the same time, it is suggested that future research expand the digital models to include not only physical but also socio-cultural dimensions by integrating social interaction data, such as user behaviour, cultural use patterns, and visitor density.

As a result, the digital documentation of historical bridges and other structures plays a critical role in the sustainable preservation, interpretation, and presentation of cultural heritage to society. Especially the photogrammetric model can be improved with technological developments in future studies and can be made available to remote visitors in virtual environments. Therefore, technological developments and digital modelling techniques will make significant contributions

towards the goal of preserving cultural heritage and passing it on to future generations. Such studies provide both scientific and social benefits and offer valuable solutions for the preservation of historical buildings in the future.

References

Akın, E. S.; Sezer, S. Uses of historical bridges: the case of Yozgat, Turkey. *Online Journal of Art & Design*, v. 11, n. 1, p. 130-148, 2023.

Akyıldız, N. A.; Olğun, T. N. Evaluation of the intangible cultural heritage in the context of conservation and sustainability of historical settlements in Anatolia. *Milli Folklor*, v. 16, n. 128, p. 234-243, 2020.

Arias, P. *et al*. Digital photogrammetry, GPR and computational analysis of structural damages in a mediaeval bridge. *Engineering Failure Analysis*, v. 14, n. 8, p. 1444-1457, 2007. Doi: https://doi.org/10.1016/j.engfailanal.2007.02.001.

Bayraktar, A.; Türker, T.; Altunışık, A. C. Experimental frequencies and damping ratios for historical masonry arch bridges. *Construction and Building Materials*, v. 75, p. 234-241, 2015. Doi: https://doi.org/10.1016/j.conbuildmat.2014.10.044.

Bekar, İ.; Kutlu, İ. Critical analysis and digital documentation of the transformations of heritage buildings. *VITRUVIO-International Journal of Architectural Technology and Sustainability*, v. 9, n. 1, p. 110-123, 2024. https://doi.org/10.4995/vitruvio-ijats.2024.21186.

Bell, G. *Gertrude Bell Archive*. [*S. l.*]: Newcastle University Library, 1909. Available from: https://gertrudebell.ncl.ac.uk. Cited: Jan 10, 2025.

Biçen, A. Problems in the immediate surroundings of a historical bridge: the Silvan (Ten-Eyed Bridge) Bridge in Diyarbakir. *International Journal of Academic Accumulation*, v. 6, p. 152-167, 2023. Doi: https://doi.org/10.5281/zenodo.10004395.

Bruno, N. *et al.* History, geometry, structure: interdisciplinary analysis of a historical bridge. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 42, p. 317-323, 2019. Doi: https://doi.org/10.5194/isprs-archives-XLII-2-W11-317-2019.

Ceylan, M. A. Historical bridges in the Gediz Basin and their functional features. *Eastern Geographical Review*, v. 16, n. 25, p. 103-132, 2011.

Dalkılıç, N.; Halifeoğlu, F. M. Historical bridges located in Diyarbakir province and towns. *In*: International Symposium on Diyarbakır, City of Prophets, Sahabis, Saints and Kings, 1., 2009, Diyarbakır. *Proceedings* [...]. Diyarbakır: Dicle University, 2009. p. 369-381, 2009.

DeLony, E.; Klein, T. H. Rehabilitation of historic bridges. *Journal of Professional Issues in Engineering Education and Practice*, v. 131, n. 3, p. 178-186, 2005. Doi: https://doi.org/10.1061/(ASCE)1052-3928(2005)131:3(178).

Demir, H. Safeguarding of the Dicle (Ten Eyed) Bridge as Tangible and Intangible Heritage. *Milli Folklor*, v. 17, n. 132, p. 226-249, 2021.

Demir, O. *Analysis of historical Dyarbakir Dicle (on gözlü) bridge by using finite element method*. Master thesis (Graduate School of Natural and Applied Sciences) – Erzincan Binali Yıldırım Univerrsity, 2019.

Doğan, Y. 3D Modelling of Bridges by UAV Photogrammetry Method. *Mersin Photogrammetry Journal*, v. 1, n. 1, p. 7-11, 2019.

Ergün, R.; Akın, C. T. A Comparative Analysis of Traditional Turkish Courtyards in Hot-Dry and Hot-Humid Climate. *Journal of Architecture and Planning*, v. 36, n. 2, p. 253-267, 2024. Doi: https://doi.org/10.33948/JAP-KSU-36-2-4.

Galeazzi, F. Towards the definition of best 3D practices in archaeology: assessing 3D documentation techniques for intra-site data recording. *Journal of Cultural Heritage*, v. 17, p. 159-169, 2016. Doi: https://doi.org/10.1016/j.culher.2015.07.005.

Genç, A. F. *Restoration works effect on structural response of historical bridges*. Master thesis (Graduate School of Natural and Applied Sciences) – Karadeniz Technical University, 2015.

Grussenmeyer, P. *et al.* Comparison methods of terrestrial laser scanning, photogrammetry and tacheometry data for recording of cultural heritage buildings. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 37, n. B5, p. 213-218, 2008.

Güneroğlu, N.; Oğuztürk, G. E. Investigation of the Historical on Gözlü Bridge and its neighborhood in terms of coastal landscape value. *Journal of Bartin Faculty of Forestry*, v. 23, n. 3, p. 754-766, 2021. Doi: https://doi.org/10.24011/barofd.940251.

Halifeoğlu, F. M. *et al. The measured drawings, restitution and restoration projects of Diyarbakır Tigris* (Ten-Eyed) Bridge. *In*: International Symposium on Strengthening Historical Buildings and Transferring them Safely to the Future, 2., 2009, Diyarbakır. *Proceedings* [...]. Diyarbakır: TMMOB Chamber of Civil Engineers, 2009. p. 649-666.

Halifeoğlu, F. M.; Sert, H.; Yilmaz, S. Restoration of historical Kurt Bridge (Mihrapli bridge, Vezirkopru) design and application studies. *Journal of the Faculty of Architecture*, v. 30, n. 2, p. 81-105, 2013. Doi: https://doi.org/10.4305/METU.JFA.2013.2.6.

Halifeoğlu, F. M.; Toprak Z. F.; Kavak, O. *Architectural and hydrological features of the historical basalt bridges in Diyarbakır Turkey*. *In*: International Multidisciplinary Scientific GeoConference, 16., 2016, Alben. *Proceedings* [...]. Alben: Bulgarian Academy of Sciences, 2016. p. 51-62.

Halifeoğlu, F. M.; Toprak, Z. F.; Kavak, O. *Tarihi Diyarbakır köprülerinin mimari, hidrolojik ve jeolojik açıdan değerlendirilmesi. In: Symposium on Water Structures*, 2., 2011, Diyarbakır. *Proceedings* [...]. Diyarbakır: TEMMOB, 2011. Doi: https://doi.org/10.13140/RG.2.1.1917.6724.

Hamzaoglu, B.; Özkar, M. Rule-based Milling of Medieval Stone Patterns. *Nexus Network Journal*, v. 25, n. 4, p. 945-960, 2023. Doi: https://doi.org/10.1007/s00004-023-00726-z.

Hensel, M. *et al.* Towards an architectural history of performance: auxiliarity, performance and provision in historical persian architectures. *Architectural Design*, v. 82, n. 3, p. 26-37, 2012. Doi: https://doi.org/10.1002/ad.1402.

Hong, N. K. *et al.* Toward a balanced heritage management plan for old stone bridges considering the embedded cultural significance. *International Journal of Architectural Heritage*, v. 3, n. 3, p. 195-211, 2009. Doi: https://doi.org/10.1080/15583050802344554.

İlter, F. *Osmanlılara Kadar Anadolu Türk Köprüleri*. Ankara: General Directorate of Highways Publication, 1978.

Jokilehto, J. *A history of architectural conservation*. Oxfordshire: Routledge, 2017.

Karasin, I. B.; Isik, E. Protection of Ten-Eyed Bridge in Diyarbakır. *Budownictwo i Architektura*, v. 15, n. 1, p. 87-94, 2016.

Karaton, M. *et al.* Nonlinear seismic performance of a 12th century historical masonry bridge under different earthquake levels. *Engineering Failure Analysis*, v. 79, p. 408-421, 2017. Doi: https://doi.org/10.1016/j.engfailanal.2017.05.017.

Koç, Ü. C.; Kejanlı, T. Yerli turistin kültürel turizm algısı: Diyarbakır Suriçi Örneği. *Online Journal of Art & Design*, v. 10, n. 3, p. 226-244, 2022.

Kotoulas, L. *et al.* Structural Assessment of Stone-Arch Bridges Through Photogrammetry. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 48, p. 879-884, 2023. Doi: https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-879-2023.

Koutsoudis, A. *et al.* Multi-image 3D reconstruction data evaluation. *Journal of Cultural Heritage*, v. 15, n. 1, p. 73-79, 2014. Doi: https://doi.org/10.1016/j.culher.2012.12.003.

Logothetis, S.; Delinasiou, A.; Stylianidis, E. Building information modelling for cultural heritage: a review. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 2, p. 177-183, 2015. Doi: https://doi.org/10.5194/isprsannals-II-5-W3-177-2015.

Lowenthal, D. *The past is a foreign country-revisited*. Cambridge: Cambridge University Press, 2015.

Özmen, A.; Sayın, E. Evaluation of earthquake behavior of a historical masonry arch bridge. *Nigde Omer Halisdemir University Journal of Engineering Sciences*, v. 9, n. 2, p. 956-965, 2020. Doi: https://doi.org/10.28948/ngumuh.715121.

Paris, L.; Rossi, M. L. Digital models for the knowledge, protection and enhancement of historic bridges. Definition of an operational protocol. *Procedia Structural Integrity*, v. 64, p. 2222-2229, 2024. Doi: https://doi.org/10.1016/j.prostr.2024.09.348.

Pepe, M. *et al.* 3D modeling of roman bridge by the integration of terrestrial and UAV photogrammetric survey for structural analysis purpose. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 42, p. 249-255, 2019. Doi: https://doi.org/10.5194/isprs-archives-XLII-2-W17-249-2019.

Pepe, M.; Costantino, D. UAV photogrammetry and 3D modelling of complex architecture for maintenance purposes: the case study of the masonry bridge on the Sele river, Italy. *Periodica Polytechnica Civil Engineering*, v. 65, n. 1, p. 191-203, 2021. Doi: https://doi.org/10.3311/PPci.16398.

Pepi, C. *et al.* An integrated approach for the numerical modeling of severely damaged historic structures: Application to a masonry bridge. *Advances in Engineering Software*, v. 151, p. 102935, 2021. Doi: https://doi.org/10.1016/j.advengsoft.2020.102935.

Pietroni, E.; Ferdani, D. Virtual restoration and virtual reconstruction in cultural heritage: terminology, methodologies, visual representation techniques and cognitive models. *Information*, v. 12, n. 4, p. 167, 2021. Doi: https://doi.org/10.3390/info12040167.

Remondino, F. *et al. UAV photogrammetry for mapping and 3D modeling*: *current status and future perspectives*. *In*: International Conference on Unmanned Aerial Vehicle in Geomatics (UAV-g), 2011, Zurich. *Proceedings* [...]. Zurich: ETH Zurich, 2011. p. 25-31.

Remondino, F.; El-Hakim, S. Image-based 3D modelling: a review. *The Photogrammetric Record*, v. 21, n. 115, p. 269-291, 2006. Doi: https://doi.org/10.1111/j.1477-9730.2006.00383.x.

Rönnholm, P. *et al.* Integration of laser scanning and photogrammetry. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 36, n. 3/W52, p. 355-362, 2007.

Salamak, M.; Fross, K. Bridges in urban planning and architectural culture. *Procedia Engineering*, v. 161, p. 207-212, 2016. Doi: https://doi.org/10.1016/j.proeng.2016.08.530.

Schafer, J. Preserving the World's great cities: the destruction and renewal of the historic metropolis. *Library Journal*, v. 126, n. 14, p. 176, 2001.

Serçek, S.; Hassan, A. destination branding in tourism and Diyarbakır Example. *Journal of Travel and Hotel Business*, v. 13, n. 1, p. 6-27, 2016.

Sert, H. *et al. Tarihi he Restoration and Strengthening of Historical DiyarbakırTigris (Ten-Eyed) Bridge*. *In*: International Symposium on Strengthening Historical Buildings and Transferring them Safely to the Future, 2., 2009, Diyarbakır. *Proceedings* [...]. Diyarbakır: TMMOB Chamber of Civil Engineers, 2009. p. 633-648.

Shabani, A.; Kioumarsi, M. Seismic assessment and strengthening of a historical masonry bridge considering soil-structure interaction. *Engineering Structures*, v. 293, p. 116589, 2023. Doi: https://doi.org/10.1016/j.engstruct.2023.116589.

Stavroulaki, M. E. *et al.* Modelling and strength evaluation of masonry bridges using terrestrial photogrammetry and finite elements. *Advances in Engineering Software*, v. 101, p. 136-148, 2016. Doi: https://doi.org/10.1016/j.advengsoft.2015.12.007.

Tekin, A. *Anadolu tarihinin taşlara yazıldığı kent*. Diyarbakır: Dicle University Publishing House, 1997.

Trizio, I. *et al.* Survey methodologies and 3D modelling for conservation of historical masonry bridges. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, v. 8, p. 163-170, 2021. Doi: https://doi.org/10.5194/isprs-annals-VIII-M-1-2021-163-2021.

Ulvi, A. Importance of unmanned aerial vehicles (UAVs) in the documentation of cultural heritage. *Turkish Journal of Engineering*, v. 4, n. 3, p. 104-112, 2020. Doi: https://doi.org/10.31127/tuje.637050.

Uygun Gençer, F.; Hamamcıoğlu Turan, M. The masonry techniques of a historical bridge in Hypokremnos (İçmeler). *METU Journal of the Faculty of Architecture*, v. 34, n. 1, p. 187-207, 2017. Doi: https://doi.org/10.4305/metu.jfa.2017.1.6.

Willkens, D. S.; Liu, J.; Alathamneh, S. A case study of integrating terrestrial laser scanning (TLS) and building information modeling (BIM) in heritage bridge documentation: the Edmund Pettus Bridge. *Buildings*, v. 14, n. 7, p. 1940, 2024. Doi: https://doi.org/10.3390/buildings14071940.

Yeşilbaş, E. Identification of the Silifke Stone Bridge and analysis of historical period. *Journal of Akdeniz Sanat*, v. 9, n. 19, p. 92-123, 2016.

Yeşilbaş, E. The protection and re-use advices of Çifte Han in Diyarbakır. *Mukaddime*, v. 5, n. 1, p. 65-88, 2015. Doi: https://doi.org/10.19059/mukaddime.63990.

Yıldırım, M. Cultural tourism and heritage conservation: case of Diyarbakır Hasan Pasha Khan. *Dicle University Journal of Engineering*, v. 8, n. 2, p. 335-344, 2017.

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