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Original Article

Difficulties in rebuilding historic bridges after conflicts: the case of the Mosul stone bridge

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Abstract: Historic bridges are crucial city landmarks, requiring expert input to preserve them in accordance with international policies and approaches. This ensures the protection of their historical and architectural value and their preservation for as long as possible. During conflict and war, bridges often suffer significant damage, leading to extensive destruction or complete demolition. The historic stone bridge over the Al-Khosar River in Mosul, constructed during the Ottoman era in 1856, sustained direct damage during the military operations in 2017, resulting in the substantial destruction of parts of the bridge. The objective of this study is to examine the challenges and constraints encountered during the reconstruction of this significant urban landmark. To this end, the architectural and engineering aspects of the project will be analysed, while also highlighting the difficulties in adhering to the standards and requirements set forth in international conventions and legislation pertaining to the preservation of historical urban landmarks and the protection of these structures from extinction. Subsequently, a series of conclusions and recommendations will be presented, offering insights to inform future endeavours involving the restoration of similarly invaluable edifices.

Keywords: historic bridges, built heritage, urban conservation, sustainability, post-war reconstruction

1. Introduction

The redevelopment of infrastructure and transportation facilities in historic cities presents numerous challenges and considerations that must be addressed to ensure the success of such projects (Al-A'abachi and AlAlaf, 2023). Post-conflict cities often face difficulties that require extraordinary efforts to revive communities. Bridges are among the structures most severely damaged or destroyed during armed conflicts due to their critical logistical importance in connecting parts of settlements and cities (Abdulrahman and Al-Allaf, 2023). The reconstruction of damaged historic structures presents a significant challenge, and there has been a recent resurgence of interest in these valuable monuments, which have often been replaced with newer structures or neglected until they have deteriorated to the point of collapse (Ramos et al., 2008; Karasin and Isik, 2016). Many engineering efforts have successfully reconstructed famous historic bridges using modern methods while adhering to international resolutions and documents related to the preservation and protection of historic and cultural heritage (Azar and Sari, 2023). These include the reconstruction of the Mostar Bridge, a 16th-century Ottoman bridge in Mostar, Bosnia and Herzegovina (Zilha, 2022), the historic Old Tweed Bridge in Scotland (Grubb et al., 2019), and the historic River Witham Bridge in Lincoln, UK (De'Ath and Heap, 2019). Mosul has several significant architectural structures that require effective safeguarding and conservation measures, both curative and preventive (Ismaeel, 2023). One such structure is the Old Stone Bridge, constructed in 1854 during the Ottoman period to connect the city centre with neighbouring towns and districts. The reconstruction process faced numerous architectural and engineering challenges, requiring critical decisions to ensure the preservation of this vital structure near Mosul's historic core. This paper aims to elucidate the primary challenges encountered and propose solutions to overcome them, establishing a set of guiding principles for future engineering projects of a similar nature.

2. Related literature

Bezgin (2024) studied the locations of historic stone bridges in Turkey and their performance in relation to seismic faults. He assessed the Mimar Sinan Bridge, which remained fully functional for over four centuries despite severe earthquakes. The bridge's structural consistency and homogeneous behaviour contributed to its success. In the late 1980s, it was decommissioned and repurposed as a public park and cultural centre. Vičan et al. (2023) studied a unique method for rehabilitating a road bridge over the Hrun River in Slovakia, using a composite superstructure made of steel and concrete. Gheitasi et al. (2022) examined the rehabilitation and retrofit design of the John G. Lewis Memorial Bridge in Virginia, focusing on a balanced design that blended old and new elements. The project involved collaboration with stakeholders and incorporated innovative materials and techniques to meet historic preservation standards. The historic nature of the bridge and high stakeholder involvement made the project distinctive and of considerable public interest. The Min-Zhe Bridge, a historic structure, has been built and maintained by highly trained craftsmen in the region for generations without academic analysis or field tests. Reconstruction is a traditional practice in some communities, often undertaken periodically or after damage. Contemporary conservation techniques are often used to preserve the bridge's physical authenticity. The project is currently being carried out using traditional craftsmanship techniques and modern restoration methods to enhance its durability (Chen et al., 2021). The Cigacice Bridge, built around a century ago, showcases the quality of interwar engineering. It was first opened to the public in 1925 and is currently undergoing renovations to conserve the site. Collaboration with preservation services is crucial for significant regional buildings, as it requires heightened attention, increased costs, and alternative technologies. The bridge must also meet contemporary vehicular and pedestrian traffic standards (Mielczarek and Nowogońska, 2021). The River Witham Bridge in Lincoln, UK, is a listed railway bridge with two tracks crossing the River Witham. It was designated a listed structure in 1999 for its historical significance and was successfully reconstructed in 2017 to preserve its original structure (De'Ath et al., 2019). The Murray Morgan Lift Bridge in Tacoma, built in 1913, was closed to vehicular and pedestrian traffic in 2007 due to deteriorating systems. However, in 2010, funding was secured for its restoration, which included repairs, structural reinforcement, resurfacing, and seismic-resistant modifications. The bridge was completed in 2012, restoring traffic (Marzella, 2019). The Broadway Bridge, built in 1912 in Portland, is a National Register of Historic Places landmark due to its exceptional structural system, which required innovative solutions and complex maintenance in 2018 (Marzella, 2019). The study by Kazaryan and Sakharova (2019) discusses the reconstruction of an arch bridge over the Kineshemka River in Russia using prestressed elements. The main metal beams were replaced with new reinforced concrete beams, regulated by high-strength ropes. The reconstruction was completed efficiently, and traffic was rerouted for vehicles and pedestrians. The historic Tweed Stone Bridge is temporarily closed due to structural concerns. The renovation involved temporary support, backfill excavation, wall demolition, concrete saddle pouring, waterproofing, and resurfacing. Innovative works included filling gaps in the arch and stone repair. Environmental challenges included pollution from the city's largest salmon river and the impact on bird and bat habitats. The study by Grubb et al. (2019) highlights these issues. Colak (2016) highlights the historical significance of the Old Bridge in Mostar and the reconstruction project undertaken in 1997 after its destruction during war. The project, under UNESCO's auspices, was one of the largest and most valuable historical projects in recent decades. Built in 1566 by Mimar Hayrudin, the reconstruction faced numerous challenges, including detailed architectural documentation, original building materials, construction procedures, and foundation strengthening methods. The implementation process also involved selecting appropriate scaffolding and an effective mortar for securing the stones. The 16th-century bridge in Mostar, Bosnia and Herzegovina, was destroyed during the 1992-1995 war, disrupting the city's urban fabric. The bridge, a renowned landmark connecting the Neretva River banks, has undergone significant transformation due to violence and armed conflicts. Despite constructing a new bridge, social relations within the local community remain unresolved (Mandić, 2023). The Danube Bridge in Bratislava, built between 1889 and 1890, was destroyed during WWII. In 1945, a new road section was built. In 2010, a collapsed section caused traffic closure. A proposal for the railway portion's reconstruction was made, considering the reuse of original key structural elements (Agócs and Vanko, 2016). Fábry et al. (2016) discussed the reconstruction of the 'Old Bridge to the Island' in Trenčín, spanning the Vah River and the Kukovský Canal. The bridge was extended and renovated to accommodate a neighbouring recreational area, with proposed solutions aiming to maintain traffic throughout the reconstruction period. Eitelberger et al. (2015) discussed the rehabilitation of the Emirate Bridge in Ghana, emphasising the importance of a comprehensive understanding of the existing structure. The bridge's deterioration was due to various factors, requiring extensive repairs. Engineering assessments showed the bridge's primary structure was satisfactory, allowing it to be rehabilitated and continue in use. The rehabilitation required significant technical expertise. Paeglītis et al. (2013) studied the historic Vinta River Bridge in Koldega, Latvia, aiming to assess its physical characteristics and determine its suitability as a brick arch bridge for reconstruction and renovation. The study stressed the need for thorough investigation of materials and deterioration causes, and the use of appropriate materials that do not hinder water movement. Laser scanning was used for engineering data collection.

3. Stone arch bridges

The earliest known stone bridges date back to the Roman era in Europe. The Romans utilised stone construction and the technique of roofing with vaults due to the durability of this method, which enabled them to create larger spaces that were previously unfeasible from a structural perspective (Floroni and Juravle, 2019). Stone arch bridges, originating in the Roman era, have a long and successful history of serving local communities' transportation needs. They have become an integral part of international history and local heritage. However, many existing bridges have exceeded their intended service life and are now experiencing functional or structural issues (Chróścielewski, et al., 2013). To ensure the preservation and rehabilitation of stone arch bridges, it is essential to understand appropriate evaluation methods, analysis techniques, and repair and strengthening options (Citto and Woodham, 2015). Stone arch bridges exhibit a high degree of diversity, with various shapes, cultural influences, and stylistic variations, and are found in many geographical locations (Karaś and Jankowska, 2018; Arslan, 2020). They bear witness to historical events and are a prominent feature of the built environment, imbued with economic and cultural significance (Antoniszyn, 2016). Their continued existence represents an important work of art in itself (Ding, 2022). A comprehensive historical and archaeological survey, coupled with a detailed structural assessment, is crucial for the success of protection and maintenance work. These processes involve determining the date and chronology of the structure's construction, identifying potential disruptions in the construction process, devising a plan for addressing damages, and analysing previous interventions and treatments. The intervention method is then determined, and various proposals are considered, including dismantling and reshaping the structure, strengthening and supporting it, fully reinforcing the upper structure, reducing loads, balancing mass and rigidity distribution, enhancing structural cooperation between arches and supports, and improving the bridge's fundamental system (Yanik et al., 2019). In some cases, the reconstructed bridge may be relocated to a nearby site to facilitate economic reconstruction or enhance safety. Historical records of bridges provide evidence of the construction and reconstruction processes, offering a valuable means of ensuring the continuity of the cultural and heritage values associated with the structure (Chen et al., 2021).

3.1. Conservation of historic bridges as a sustainable initiative

Bridges are crucial components of urban infrastructure, facilitating connectivity and regulating vehicular traffic within specific sectors or regions. They often respond to natural obstacles, such as rivers and valleys, necessitating the creation of a physical link between isolated locations (Alabaachi and Alalaf, 2023). Historic bridges, such as Tower Bridge in London, Rialto Bridge in Venice, the Golden Gate Bridge in San Francisco, and the Bosphorus Bridge in Istanbul, embody the identity and symbolism of the cities in which they are situated. The preservation and protection of monuments and heritage buildings represent a vital source of urban sustainability, providing benefits across all three pillars: economic, social, and environmental (Klimek, 2016). Safeguarding these structures confers advantages in each of these areas (Elbelkasy and Hegazy, 2024; Pal, 2023; Hamad and Ismaeel, 2023a). The conservation of such constructions necessitates compliance with international and national resolutions and legislation, including design principles, construction specifications, and methods of operation and maintenance. For example, the Venice Charter stipulates the use of suitable materials and techniques that are consistent with the original materials and design. The objective is to restore the structure to its original function or to reuse it with a comparable or appropriate function (Jasim and Ismaeel, 2023). Additionally, the charter emphasises the preservation of the structure in its original context and the maintenance of neighbouring structures to the greatest extent possible. To preserve a historic bridge, it is essential to use methods that facilitate the assessment of its condition while minimising the potential for damage through a reduced number of inspections. Any incorporation of additional materials should ensure that they blend seamlessly with the monument, considering factors such as construction method, materials, colour, and texture (Hamad and Ismaeel, 2023b). The Burra Charter (Australia, 1981) delineates the types of significance inherent in a structure and methods of dealing with them, while the Nara Document on Authenticity (Japan, 1994) specifies indicators to measure them, including rarity and authenticity (Ismaeel, 2023). It is imperative that the type of damage, its cause, and the structural behaviour of the bridge be studied prior to reconstruction. This ensures that the appropriate intervention is selected and the reconstruction is completed effectively and safely (Ramos et al., 2008). The continued viability of rebuilt bridges depends on adherence to criteria pertaining to their living heritage status. These include the continuity of use and function, the maintenance of community connections, the preservation of cultural expressions, and compliance with living heritage standards. The preservation and maintenance of historic buildings require genuine participation from multiple disciplines and individuals, along with access to appropriate decision-making processes (Chen et al., 2021).

4. Challenges and difficulties of reconstructing historic bridges

In light of the aforementioned considerations, and by analysing previous studies, the most significant requirements and constraints associated with the reconstruction of historic bridges, particularly in post-conflict scenarios, can be distilled into four key domains: architectural and engineering specifications, human constraints, technological requirements, and natural factors. The most significant of these determinants are summarised in Table 1.

Table 1. Determinants and difficulties of the reconstruction of historic bridges. *Source:* [Researchers]

Key domains	Most significant determinants
Architectural and Engineering Specifications	Availability of architectural documentation, archives, engineering plans, documentary photographs, and representational elements
	Architectural style of detailing and similar designs
	Structural, durability, and safety issues: foundation corrosion, foundation failure, cracks in bridge components, soil movement, failure to bear weight, corrosion and loss of structural and bonding materials, damage to walls, footing displacements
	Availability of traditional construction, finishing, and bonding materials
	Limitations of engineering standards and specifications
	Criteria and legislation for the preservation and protection of built heritage
	Preparation requirements for reconstruction and debris removal
Human Restrictions	Availability of skilled artisanal construction personnel and traditional technical labourers
	Inadequate, inefficient, or inappropriate interventions
	Remnants of war and military operations: mines and unexploded bombs
	Obstacles to vehicular and pedestrian movement and overload
	Control of negligence, intentional damage, and misuse
	Financial requirements and project budget
	Social and cultural issues: social participation and community awareness

	Political and legal issues: administrative corruption, competition among implementers
	Confronting trends of renewal, modernisation, and rejection of the old and traditional
Technological Requirements	Limitations of traditional building techniques
	Availability of technology and equipment for pre-construction surveys and inspections
	Provision of technologies and devices required for implementation and construction
Natural Factors	Environmental and climatic factors: sunlight, heat, cold, moisture, and wind
	River water movement, flooding, rain, snow, and water infiltration
	Earthquakes, volcanoes, tornadoes, and storms
	Animal and bird habitats
	Plants, trees, climbers, fungi, and herbs
	Biological pollution

5. The case of the Mosul Stone Bridge

5.1. Description of the original bridge

The Mosul Stone Bridge, located at the Khosar Basin, connects Faisaliyah and eastern Mosul with the western bank via an old iron bridge (see Fig. 1). Constructed during the Ottoman era in 1856, the bridge features seven pillars, each 2.6 meters wide, and eight arches, facilitating connectivity between the city and other settlements in eastern Mosul.

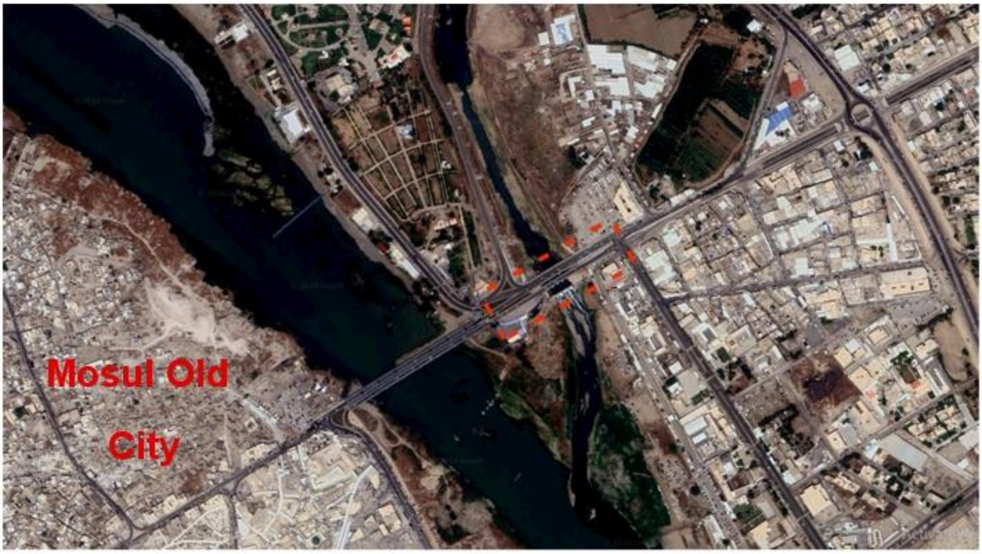

Fig. 1. Mosul Stone Bridge is located on the Al-Khosar River, with the Tigris River nearby and the old iron bridge connecting to Mosul's old city, which lies adjacent to it on the left. *Source*: [Google map]

The bridge in Mosul, located on a hill, was built in 1854 by the Ottoman government to protect the city from floodwaters. The bridge, 90 meters long and 10 meters wide, extended to a high point on the left bank (Al-Mallah, 1992). Initially, a wooden pontoon bridge was erected to connect the two sides, but a fixed iron bridge was later constructed in 1934. The wooden bridge was dismantled, leaving the stone bridge spanning the Tigris intact. However, engineers determined that the walkway in the middle of the river would impede water flow, leading to the bridge's demolition. In 1935, a flood inundated the left bank, disrupting transport routes. The government responded by expanding the stone arches on the Khosar River and constructing a dam to prevent water flow. The bridge's history underscores the importance of maintaining natural flood barriers in Mosul (Al-Nish, 2007), see Fig. 2.

In 2017, a bridge in Mosul was targeted by direct bombing during military operations, resulting in the destruction of Pillar 2 and its supporting arches. In 2018, the Nineveh Roads and Bridges Directorate conducted a survey to assess the feasibility of reconstructing the bridge. The Ministry of Construction, Housing, and Municipalities aims to restore the bridge to its original form, preserving an important element of urban heritage. The Nineveh Roads, Bridges, and Municipalities Directorate served as the financing and supervisory body, while Saad General Company was responsible for the implementation. Both entities are part of the Ministry of Construction and Housing.

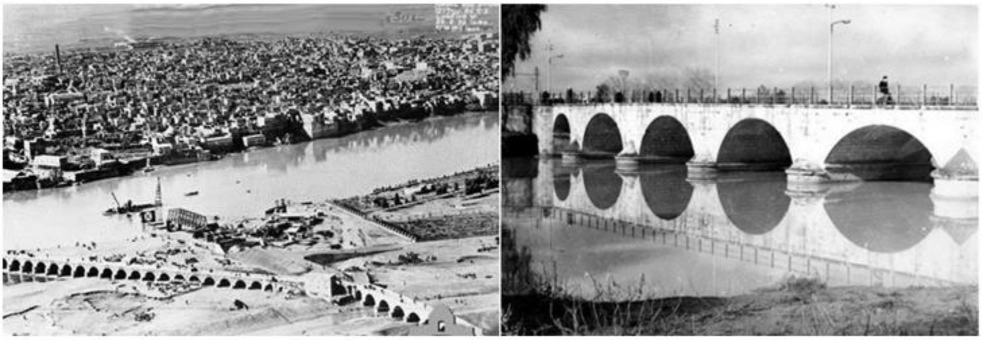

Fig. 2. Archived photos of the Mosul Stone Bridge *Source:* [Civilization Mosul Encyclopaedia, 1992]

5.2. Reconstruction phases of Mosul stone bridge

To identify the most crucial aspects of the Mosul Stone Bridge reconstruction process, the committee responsible for overseeing the project was interviewed. The following individuals were consulted: Dr. Engineer Abdul Rahman Abdullah Saeed, Engineers Yassin Ibrahim and Mahmoud Khaled, and the implementing engineers Ammar Ahmed and Al-Waleed Khaled. A series of open-ended questions were posed, and their responses were analysed to ascertain the stages of work and the most significant challenges currently facing the project.

The reconstruction of the bridge was undertaken according to the following stages:

5.2.1. The bridge was reconstructed using a reverse engineering methodology, involving a thorough analysis of its architectural and structural elements. This process included meticulous documentation of the existing structure, precise site elevation using total station surveying instruments, detailed examination of stone samples in specialised laboratories, and the formulation of necessary plans for the bridge's reconstruction, in alignment with its original architectural form and engineering specifications. All architectural and structural engineering plans and drawings were created using the AutoCAD engineering program.

5.2.2. The selection of materials for the reconstruction of the central pillar and associated arches was based on various criteria. Stone samples were obtained from the site and analysed in a laboratory. The stone had a density of 0.00227 g/mL, an absorption rate of 4.8%, and compressive strength of 250 N/mm² in the dry state and 195 N/mm² in the wet state, classifying it as type B according to Iraqi standards. Samples from various stone quarries were also tested for potential use in the reconstruction. The stone from the Salamiya quarry had a density of 0.0019 g/mL, compressive strength of 250 N/mm² in the dry state and 75 N/mm² in the wet state, and an absorption rate of 9%, classifying it as class A. The stone from the Al-Kasr quarry had a density of 0.00222 g/mL, compressive strength of 234 N/mm² in the dry state and 191.7 N/mm² in the wet state, with an absorption rate of 5.1%. The stone from the Al-Kasr quarry was selected due to its physical characteristics, which closely resembled those of the original stone used in the construction of the bridge. Additionally, the stone from the Salamiya quarry was found to contain gaps and organic matter, leading to a significant loss of compressive strength when submerged in water. This made it unsuitable for the reconstruction, as the stone would be submerged year-round due to the continuous flow of river water.

5.2.3. The epoxy materials used for implanting iron skewers to connect the stone components of the side walls were examined. The objective was to ensure the walls function as a single unit, resisting the lateral forces generated by the vertical loads applied to the bridge structure. This approach mirrors the methodology employed in the original construction, where stainless steel and hammering were used to connect the stone masonry units. The materials used in the rehabilitation process, including aggregate materials (gravel and sand) and salt-resistant cement, underwent standard testing procedures to verify that the structure is watertight and compliant with the specified requirements.

5.2.4. Once the debris was cleared from the site, the remains of the destroyed pillar were revealed (see Fig. 3). The outer shell was constructed using stones with regular geometric shapes, while the core was filled with stones, cement mortar, and additives (see Fig. 4). The bridge abutments were reinforced and protected from collapse due to erosion caused by water runoff near the abutments through the construction of a gravel foundation. Additionally, capillary baskets (BRC baskets filled with coarse gravel) were installed at both the upstream and downstream locations of the bridge, before and after the installation of the gravel foundation. Grouting operations were also conducted near the abutments after the completion of the gravel foundation to fill voids beneath the stone abutments and prevent potential future collapse.

Fig. 3. The bridge before reconstruction and the beginning of rubble removal.*Source*: [researchers]

Fig. 4. Locating the destroyed pillar and rebuilding it.*Source*: [researchers]

5.2.5. In the subsequent phase, an iron mould was constructed to replicate the original arch of the stone vault. The initial row of keystone stones was installed without the use of a binder, with the keystones securing the arch. To prevent the formation of longitudinal joints between the rows, stones of varying sizes were used for the remaining components. Additionally, cement mortar was applied between the stone units, with additives incorporated to improve the mortar's properties and enhance adhesion between the stones (see Fig. 5).

Fig. 5. Installing iron molds and constructing arches for destroyed vaults. *Source*: [researchers]

5.2.6. The subsequent phase involved the construction of retaining walls between the arches, using the same stone material. The stone pieces in the old walls featured grooves from the hammering of iron rods that connected each stone to its neighbours, ensuring the wall functioned as a single unit to resist the horizontal lateral thrust forces generated by vertical loads (both live and dead) on the bridge structure. This detail was replicated in the new section. A clay-free, non-volumetric, moisture-resistant soil mix with a relatively low density (1.6 g/cm^3) was then used to minimise the impact of dead load and horizontal lateral thrust forces.

5.2.7. In the final stage, finishes were completed on the bridge. All of the bridge's stones were polished, the street was paved, and the sidewalks, lighting installations, and painting works were carried out (see Fig. 6).

Fig. 6. Mosul Stone Bridge during the final stage of reconstruction. *Source*: [researchers]

5.3. The difficulties of reconstructing the Mosul stone bridge

The application of the determinants set out in Table1 to the reconstruction of the Mosul Stone Bridge has allowed for the identification of key factors that significantly influenced the process. Additionally, other factors were deemed insignificant or were not required as part of the bridge rehabilitation procedures. The most important of these influential factors include the following:

5.3.1. Architectural and engineering specifications

The process of rebuilding damaged bridges is subject to a series of complex and strict engineering standards that impose various restrictions and limitations on construction. The Stone Bridge, an ancient historical structure, is not governed by modern engineering standards due to its original construction techniques, which were passed down through generations of skilled craftsmen and technicians. This presents a significant challenge regarding the architectural and structural techniques and specifications required for reconstruction. Complete architectural and engineering documentation of the bridge’s details, whether in two or three dimensions, was not available, except for a small collection of documentary and photographic images from different periods. To address this, efforts were made to provide the necessary engineering requirements related to safety and construction, while collating as many documents and photographs of the structure as possible. This was done as part of a descriptive and spatial information management approach to ensure high-quality implementation while preserving the bridge’s identity as much as possible. Another significant challenge in the rebuilding process was the lack of identical materials used in the original construction. Red plaster, which served as a bonding agent for the stone units in the original bridge, is no longer available in the local market.

5.3.2. Human restrictions

The construction of historic bridges required the involvement of skilled workers and craftsmen with expertise in stone construction and techniques for building arches and vaults. However, the number of such craftsmen is now limited, as many have passed away and their expertise has not been passed on to younger generations, largely due to the rarity or absence of construction projects using these traditional techniques. This presented a significant challenge in assembling a workforce with the necessary skills to rebuild the bridge in its original form. To address this issue, current craftsmen were employed to work on the stone material under the direct supervision of architects and civil engineers, who provided guidance on execution details and methods for laying the stone. Additionally, the removal of rubble raised concerns about the potential presence of unexploded ordnance, posing a significant risk to the safety of project personnel. In response, vehicular traffic was completely prohibited in the devastated area, with access limited to pedestrian and vehicular traffic for essential purposes related to the site, its commercial zones, and the city centre.

One of the potential drawbacks of the reconstruction process is the possibility of ill-considered and inaccurate interventions, which may arise due to the lack of expert consultants and the fact that the design and implementation were carried out by non-specialist engineering staff. However, the project budget was not an issue, as sufficient funds were allocated through the post-military reconstruction campaign. A key challenge remains the weak level of community participation in heritage reconstruction projects, which is limited to a small group of participants with vested interests. This is largely due to low community awareness of the cultural, social, economic, and environmental benefits of such monuments. There was no local or regional opposition to the reconstruction of the stone bridge, as the city's need for it was clear. This contrasts with other historical buildings and monuments, where opposition to reconstruction in their original form may exist due to a movement advocating for the removal of old structures in favour of modern, contemporary buildings. The political context did not negatively impact the process, as the project was managed by a government body using a direct implementation method, without the presence of competitors. This ensured that the quality of the work was maintained.

5.3.3. Technological requirements

A notable absence of traditional construction techniques was observed, including stone cutting, stone engraving, lifting, and the use of traditional construction tools. This was due to the disappearance of these techniques in the present era and their absence in the region. As a result, modern technologies were employed throughout the reconstruction process in an engineering manner, covering inspection, documentation, and implementation. A total station was used for recording levels and producing architectural and engineering documentation. Additionally, laboratory tests were conducted to ensure the safety of the remaining sections of the bridge near the damaged area, using various soil types and structural assessments. Modern machinery and equipment were employed for excavation, preparation, construction, support, and consolidation work.

5.3.4. Natural factors

Floods are one of the most significant risks to stone bridges, particularly due to the role of wide abutments in managing the flow of running water. In the event of flooding, these abutments may become obstructed, potentially causing severe damage. However, the Mosul Dam, located to the north of the city, regulates the water level for most of the year, except for a brief period in the spring when snow melts in the mountains, leading to a notable rise in the water level. As a result, flooding has not posed a significant threat during the reconstruction process and is not expected to do so in the future. Other natural factors have a negligible impact on the stone bridge, as Mosul is located far from major seismic zones, and there are no nearby volcanoes or hurricanes. Periodic maintenance is essential to remove vegetation that could affect the structure. Additionally, the bridge does not contain structural elements susceptible to damage from extreme temperatures – whether from summer heat or winter cold – or from rain or wind.

6. Discussion

The shortage of proficient artisans and labourers skilled in traditional construction techniques has made the establishment of educational institutions and training facilities essential for cultivating expertise in methods such as stone construction, marble encapsulation, engraving, weldless blacksmithing, and woodworking. To preserve these skills as a form of intangible heritage protection in the city, it is crucial to maintain this type of work. This initiative not only helps safeguard the heritage identity of the local community but also creates job opportunities for unemployed youth.

One shortcoming of the process was the lack of input from experts in urban conservation, architectural history, and other relevant fields. The implementing entity relied too heavily on its engineering teams and failed to seek advice from specialised experts. This was due to the assumption that the structure did not contain many significant heritage elements. Such a failure to engage relevant expertise is a common issue in many large-scale engineering projects related to the reconstruction of heritage sites and facilities across the country. This highlights the urgent need for societal and governmental awareness of the importance of consulting specialists and giving them a leading role in such projects, allowing them to contribute their knowledge and experience to improve project outcomes.

A checklist of all the factors and determinants mentioned in Table 1 can be used to represent the levels of influence these determinants had on the reconstruction of the Mosul Stone Bridge. The levels of influence can be quantified using values ranging from 2 (indicating a good or significant positive impact) to -2 (indicating a bad or significant negative impact). These results can then be used to assess the extent to which the objectives of the reconstruction process have been achieved, as shown in Table 2.

Table 2. Result of the reconstruction of the Mosul historic bridge. *Source:* [researchers]

Key domains	Most significant determinants	
Architectural and Engineering Specifications	Availability of architectural documentation, archives, engineering plans, documentary photographs, and representational elements	0
	Architectural style of detailing and similar designs	0
	Structural, durability, and safety issues: foundation corrosion, foundation failure, cracks in bridge components, soil movement, failure to bear weight, corrosion and loss of structural and bonding materials, damage to walls, footing displacements	2
	Availability of traditional construction, finishing, and bonding materials	0
	Limitations of engineering standards and specifications	1
	Criteria and legislation for the preservation and protection of built heritage	-1
	Preparation requirements for reconstruction and debris removal	1
Human Restrictions	Availability of skilled artisanal construction personnel and traditional technical labourers	-1
	Inadequate, inefficient, and inappropriate interventions	-1
	Remnants of war and military operations: mines and unexploded bombs	-2
	Obstacles to vehicular and pedestrian movement and overload	1
	Control of negligence, intentional damage, and misuse	0
	Financial requirements and project budget	2

	Social and cultural issues: social participation and community awareness	-1
	Political and legal issues: administrative corruption, competition between implementers	1
	Confronting the current of renewal, modernisation, and rejecting the old and traditional	1
Technological Requirements	Limitations of traditional building techniques	0
	Available technology and equipment required for pre-construction surveys and inspections	2
	Provision of technologies and devices required for implementation and construction	2
Natural Factors	Environmental and climatic factors: sunlight, heat, cold, moisture, and wind	1
	River water movement, flooding, rain, snow, and water infiltration	1
	Earthquake, volcano, tornado, and storm	0
	Animal and bird habitats	0
	Plants, trees, climbers, fungi, and herbs	0
	Biological pollution	0

7. Conclusions

Historic buildings represent the most valuable evidence of cultural heritage, playing a crucial role in establishing a sustainable link between the past and the present. This connection is achieved by understanding, interpreting, and tracing a civilizational era. In light of technological advancements and infrastructure modernisation, the primary objective of protecting historical monuments is to ensure the preservation of cultural heritage in its most optimal form and condition for future generations. When constructed with the necessary care and attention, historic bridges can function for an extended period and continue serving their intended purposes for many generations. The aim of this paper is to provide general guidance and guidelines for diagnosing the characteristics of historical stone bridges damaged in conflicts, as well as the factors affecting their preservation, maintenance, and rehabilitation. The use of new technologies has a positive impact on the reconstruction process, offering a suitable alternative to traditional inspections, which are often labour-intensive, costly, and unsafe. The most significant factors influencing the reconstruction of historic bridges, particularly those damaged in post-conflict scenarios, can be broadly categorised into four key domains: architectural and engineering specifications, human constraints, technological requirements, and natural factors.

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