The Budapest New Danube Bridge

A creative and international Collaboration

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Abstract The Budapest New Danube Bridge (BNDB), a major new multimodal bridge over the Danube River in Budapest, Hungary, is a testament to the power of international collaboration. The bridge will be located south of the city centre, adding to Budapest's rich history of extraordinary bridges and becoming a new landmark.

The bridge's design was conceived during an international design competition in 2017 by Buro Happold and UNStudio, two renowned firms in the field of engineering and architecture. Their innovative and striking design, particularly the cranked pylon, stood out among the entries and was awarded the first prize. This international collaboration brought together the expertise and creativity of different cultures and disciplines, resulting in a design that is not only aesthetically pleasing but also structurally sound.

The BNDB project also involved collaboration with CÉH, a leading Hungarian engineering firm in building and bridge design. This partnership further emphasizes the international nature of this project and the benefits of global collaboration in tackling large-scale infrastructure projects. The combined expertise of these three entities - Buro Happold, UNStudio, and CÉH - has resulted in a design that is set to become a new landmark in Budapest.
The design process required complex structural, geotechnical, and hydraulic analysis. This highlights the technical expertise of the design team and their combined commitment to creating a design that is considered and feasible. The innovation in the design emerges through the adoption of cutting-edge international best practice. The design also underwent extensive third-party a rigorous independent checking, and approvals, ensuring its safety and compliance with international standards.

In conclusion, the BNDB is an exemplar of how international collaboration can lead to innovative and successful project. It showcases how different entities, each with their unique expertise, can come together to create something extraordinary. This project serves as a model for future international collaborations in the field of architecture and engineering.

1 "An Inviting Gesture of Hand"

The proposed New Danube Bridge in Budapest, Hungary, aims to improve connectivity and address the growing traffic demands by spanning the Danube River, linking Újbuda and Csepel. This new landmark bridge was conceptualised through an international design competition in 2018, won by Buro Happold and UNStudio. Developed with Hungarian engineering firm CÉH, the design received all necessary approvals by late 2022 (refer to **Figure 1**).

The bridge features two distinctive pylons and two back spans, supporting the main span with an array of cable stays. It accommodates public transport, including trams and buses, as well as vehicular traffic, pedestrians, and cyclists. The crossing connects Galvani Street in the Újbuda district with Csepel Island, thus giving the bridge its name (see **Figure 2** for the location plan). While the Újbuda district on the west bank is urbanised, the bridge is expected to spur development on the relatively undeveloped Csepel Island.

Figure 1: Rendered image of the proposed Budapest New Danube Bridge – © UNStudio/ZOA

Key participants in the project include:

- The National Infrastructure Development Private Company Limited [NIF] / Építési és Közlekedési Minisztérium [ÉKM] (client)
- The Centre of Key Government Investments Nonprofit Plc [KKBK] / Budapest Development Centre [BFK] (competition promoter, design guardian)
- United Network Studio (architect)
- Buro Happold (engineer)
- CÉH (engineer)

This paper focuses on several stages of the project and some of the challenging features of the design, including but not limited to:

- Working as a multinational design team
- The complexity associated with constructing a crossing in a capital city
- Skewed river piers and pylons
- Many stakeholders and related consultations and approvals
- Balancing social, environmental, and economic sustainability demands

The Design Competition (Concept): "In Balance – an inviting gesture of hand"

Buro Happold and UNStudio's entry, described as a bridge **"In Balance – an inviting gesture of hands"**, proposed a contemporary, structurally innovative landmark that integrates seamlessly with Budapest's urban fabric and future development. The jury unanimously praised the design for its simplicity, elegance, and harmonious concept. The design team maintained this vision throughout development, ensuring the bridge would provide a safe passage and stand as a proud landmark for Budapest.

2 Collaborative Success

The design of the bridge took over three years, involving extensive collaboration among the design team members. This successful partnership required almost 100 engineers and architects, and more than 150 international meetings held in Budapest, London, Amsterdam in person and online.

The complex geometry of the bridge necessitated the use of a coordinated 3D model. Initially developed by UNStudio, the fundamental geometry was further refined by the engineering team from Buro Happold and CÉH. Regular workshops, facilitated discussions on engineering and architecture, fostering a collaborative environment. Parametric modelling was employed to enable rapid prototyping in the initial phases. Initial discussions with steel fabricators provided insights into optimising the complex geometry to ease fabrication and costs. Engineering optimisation focused on the geometry, constraints and details, particularly the relationship between fore stays and backstays cables, enhancing structural integrity and aesthetics. Additionally, we explored opportunities to use alternative proprietary products, opening new avenues for innovation and efficiency in bridge construction. These efforts highlight the need for combining different areas of expertise to improve bridge design and engineering.

Throughout the engineering design phases, Buro Happold and CÉH worked closely together, independently reviewing each other's work at every stage. This process enhanced the design and facilitated mutual learning between the companies.

The design team collaborated closed with an independent checker to resolve technical issues and update the design as necessary.

3 Budapest's New Pathway

The primary motivation for the new bridge project is to address the immediate and future transport needs of Budapest. The city requires a new crossing that can accommodate all modes of transport, particularly to alleviate vehicle congestion in the city centre. This bridge is part of a broader road proposal that forms an inner ring road, connecting the southern districts of greater Budapest. **Figure 2** illustrates the locations of the existing Danube bridges and the proposed site for the Budapest New Danube Bridge.

Figure 2: Map of existing Budapest Danube bridges (yellow) and the proposed road (red). Base map image © 2022 CNES/Airbus, Landsat/Copernicus, Maxar Technologies, Google

The Danube bridges in Budapest, built over the past 160 years, are key to the city's landscape. Of Hungary's 16 Danube bridges, nine are located in Budapest, but only seven bridges within the 8 km inner section of the 27 km long Budapest stretch are suitable for vehicles [1]. The rise in motor vehicles hasn't been matched by new bridges, causing congestion of the inner-city bridges. A link between the outer districts of greater Budapest remains absent.

There are no crossings over the Danube within an 8.5 km section to the north and a 10.2 km section to the south of the city centre. The Rákóczi Bridge, built in the past 30 years, is the only new inner-city bridge. The city's growth has moved southward, highlighting the need to connect Újbuda in the west to Csepel in the east. The Budapest New Danube Bridge is expected to reduce traffic on the existing city centre bridges by about 42,000 vehicles per day [1]. The bridge will establish a crucial new transport link, fostering additional real estate development in brownfield areas. This development is expected to have both direct and indirect positive effects on the entire population of the city.

4 Navigating through Challenges and Constraints

4.1 Locating the Bridge

The exact location of the bridge was established at the project's inception. The Buda-side abutment was strategically aligned with Galvani Road, while the Csepel-side abutment was positioned adjacent to the Budapest Central Wastewater Treatment Plant (**Figure 3**). Land ownership for both sites had been previously secured.

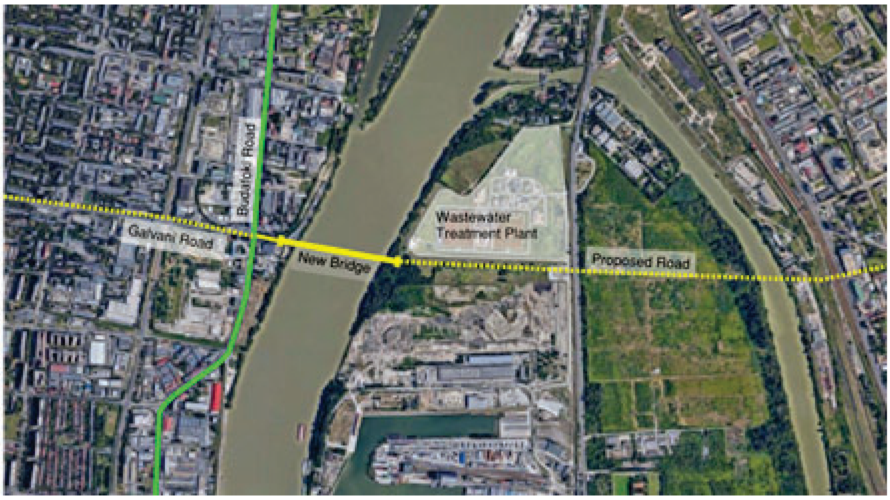

Figure 3: Bridge location. Base map image © 2022 CNES/Airbus, Landsat/Copernicus, Maxar Technologies, Google

The alignment with Galvani Road and proximity to critical infrastructure like the wastewater treatment plant highlight the project's integration with urban planning and environmental considerations. Such strategic placement not only optimises connectivity but also demonstrates a commitment to sustainable development by minimising wider infrastructure changes.

The precise location of the bridge was determined by the constraints posed by existing structures in the vicinity and the infrastructural requirements, including both transport and utilities, that intersect the bridge. Consequently, the bridge spans the Danube at an approximate skew angle of 70 degrees to the river's longitudinal axis.

4.2 From Limitations to Solutions

Several challenges were encountered during the design process of the bridge. The main span accommodated a navigation envelope of 9.5 m high and 180 m wide, accounting for the highest navigation water level (HNWL). On the Buda side, an at-grade highway junction with Budafoki Road was required. The constraints of navigation along with tramway, and highway requirements resulted in a single feasible vertical alignment.

Another challenge was the need for an access road along the riverbank on the Buda side for inspection and maintenance of the Danube flood defenses. This road needed to pass under the approach span of the new bridge.

During the design phases of the new bridge, multiple existing utilities were identified through record data and site surveys. Most were minor and diverted, but a pair of 1,200 mm diameter high-pressure sewer pipes on the Buda side could not be relocated. The bridge design had to include exclusion zones and maintenance access for these pipes, presenting complex spatial challenges.

The final design addressed these issues by implementing an at-grade highway junction with Budafoki Road, incorporating a small road for inspection and maintenance under the approach span, and accommodating the sewer pipes. This comprehensive solution was achieved only after extensive consultation with stakeholders and required multiple design iterations.

The bridge is designed to accommodate 2x2 vehicle lanes, 2x1 public transport lanes, 2x1 bidirectional bicycle lanes, and 2x1 pedestrian lanes. The cross-section necessary to incorporate these elements, along with the vehicle restraint system, lighting columns, stay cables, and the intended architectural design, ranges from a minimum of 42 m to a maximum of 51 m (**Figure 4** and **Figure 5**).

Beyond meeting transport needs, substantial space within the cross-section is allocated for the future installation of utilities. Most of the proposed utilities will be pressurised and therefore cannot be enclosed within the bridge cross-section. The soffit of the bridge, below these utilities, will remain open.

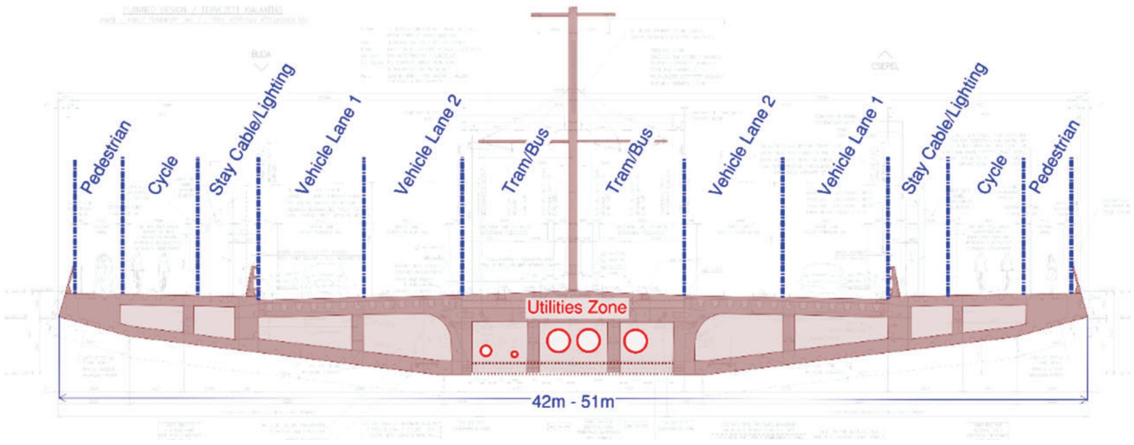

Figure 4: Main span cross section – © Buro Happold

Figure 5: Render showing transport lanes on the bridge – © UNStudio / ZOA

5 The Journey through Third Party Consultation and Approvals

Successful project implementation hinges on obtaining all necessary approvals from interested stakeholders. The Bridge required numerous approvals, making the first year of the design programme particularly challenging. Twenty statutory stakeholders needed full consultation and formal approval, often with conflicting demands. CÉH played a crucial role in engaging with all stakeholders.

5.1 River Piers

The most significant third-party consultation involved the assessment of the river piers. The competition design featured large river piers, which needed to be amended to satisfy a river hydraulic study report which became evident at the detailed design stage. The pier design was updated to minimise impact on the Danube’s flow and avoid potential upstream flooding, while maintaining the competition design intent.

With the bridge alignment skewed, the river piers were aligned with the river flow, resulting in the bridge axis also being skewed to the piers. **Figure 6** illustrates the change in the pier plan geometry from the competition entry to the final design.

Changes to the pier design significantly impacted the pylon design. The relationship between the skewed pier and the pylon was thoroughly assessed. The design team proposed keeping the pylon top, which contains the cable anchorages, orthogonal to the bridge deck axis to simplify the cable arrangement. Below the cables, the pylon geometry twists to meet the skewed pier aligned with the river axis. **Figure 7** depicts the changes to the pylon design.

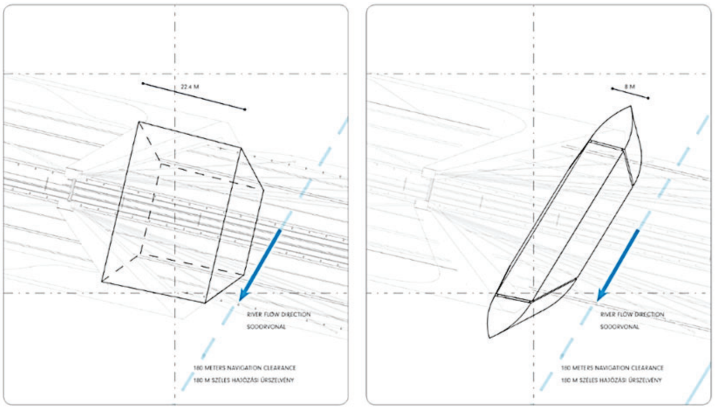

Figure 6: River pier geometry. Left – Original competition, right – final pier design – © UNStudio

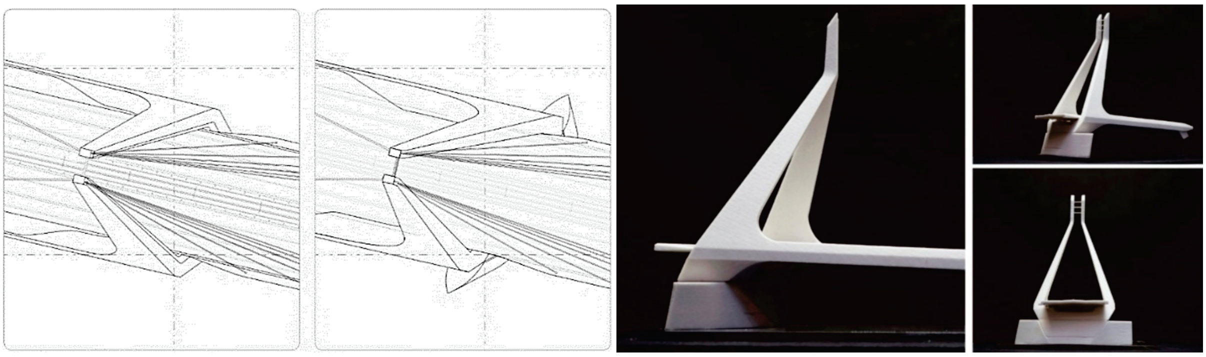

Figure 7: Changes to the river pier pylon (plan and 3D printed geometry) – © UNStudio

The hydraulic behaviour of the updated pier design was initially assessed using a two-dimensional (2D) computational fluid dynamics (CFD) model. This chosen geometry was then tested in a large-scale physical model which resulted with some vortices documented downstream of one pier. This phenomenon was further analysed using a three-dimensional (3D) CFD model. This model proved more accurate than the 2D model and the physical model, closely matching the actual recorded river flow. It also enabled fine-tuning of the pier skewness. The results provided sufficient evidence to gain approval for the pier design.

6 Superstructure Design

The main span is supported by 14 cable stays, symmetrically arranged perpendicular to the bridge deck centreline in a 'fan' configuration. Each backstay consists of four concentrated cables, connecting the top of the pylons to the anchorage piers on the riverbanks. The pylons are formed by tapering steel boxes with a distinctive bend below the cable cluster, creating an aesthetically pleasing shape. This distinctive bend is statically resolved by the eccentricity of the back and fore stays. Under permanent loading, the bending moments caused by the pylon's crank are significantly reduced due to this eccentric stay arrangement.

The main and side spans are fabricated from steel plates forming longitudinal boxes. An orthotropic deck is located below the carriageway and shared bicycle/pedestrian lane. The side spans are continuous with the pylon legs and do not rely on the cable stays for support. They comprise longitudinal edge beams connected transversely by crossbeams arranged in a 'ladder deck' formation.

The central portion of the bridge features an open soffit section for access and maintenance of high-pressure utilities. This section is designed as a composite structure, formed of multiple plate girders acting compositely with the reinforced concrete bridge deck.

The back spans are constructed from multiple longitudinal plate girders acting compositely with a reinforced concrete deck. These girders are arranged to maximise vertical clearance below. A diagrammatic representation of the spans is shown in **Figure 8**.

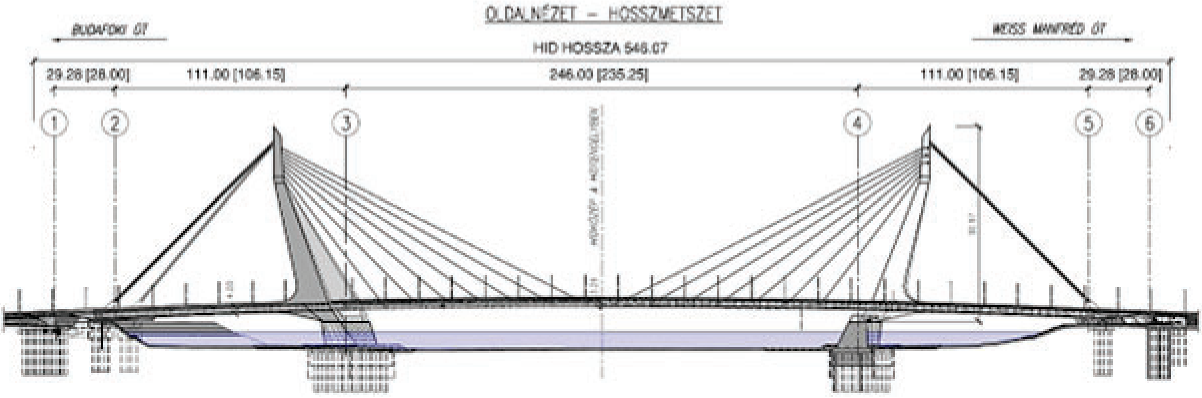

Figure 8: Idealised span arrangements – © Buro Happold / CÉH

The pylons are mounted on river piers using large spherical bearings, which transfer vertical loads while allowing for rotation and translation, except the bearing under the northern pylon leg at pier no. 3, which is fixed. Riverbank abutments support the side spans with spherical bearings, also permitting rotation and translation. Movement joints at the ends of the back spans separate the movement of the main structure from the approach ramps.

Back stays are anchored into the side span structure, thus moving with the main structure. The back span weight balances the back stay forces, eliminating the need for tension anchorage into the foundations. The back span bearings are designed to resist uplift caused by its shorter span compared with the side span.

Leading up to the tender design for the bridge, advances in digital tools have greatly improved design and construction. Sharing of information between modelling software Rhino and TEKLA has helped create a collaborative environment, ensuring efficient and coordinated designs. 3D modelling in TEKLA defined all major structural members and sizes, allowing engineers to virtually build the bridge before construction. This method identifies potential clashes early and streamlines the production of detailed 2D drawings directly from TEKLA.

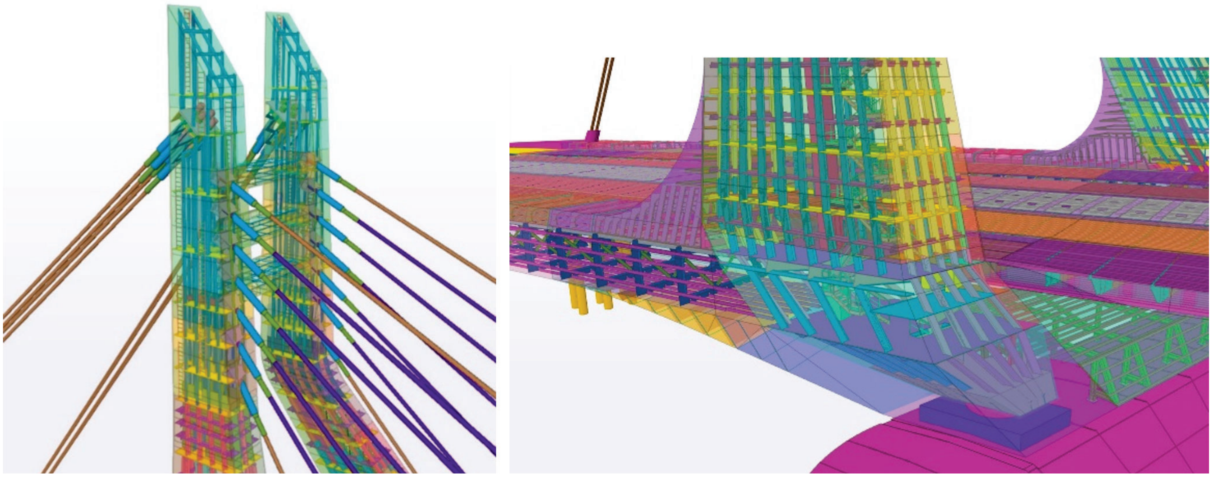

Figure 9: 3D TEKLA model of the pylon head and pylon base – © CÉH

7 Lighting the Way

The lighting design considers the bridge appearance under both natural and artificial lighting conditions. By highlighting the main architectural pylons with light in the evening, the bridge offers unique urban experiences for users. Users are guided onto the bridge by low and mid-level perimeter lighting, that pass through illuminated gateways, experiencing a 3-dimensional "glow" that repeats, emphasising the bridge's dynamic quality and iconic appearance from various vantage points.

The lighting for the Bridge reveals the geometric quality of the pylons and the rhythmic patterns of the structure by creating sophisticated dynamic contrasts in the 3-dimensional space. The bridge becomes a subtle glowing aesthetic feature in the landscape, providing necessary functional illumination for its users. The lighting design respects the natural behaviour and habitat of local flora and fauna by containing light, minimising glare, and reducing light pollution.

8 Concluding Thoughts: Transforming our World for Tomorrow

Sustainable development meets the needs of the present without compromising the ability of future generations to meet their needs. This is achieved by investing in and protecting the social, economic, and environmental needs of today and the future. The "5 Capitals Model" ranks Natural/Environmental Capital as more important than Social Capital and Human Capital. Manufactured Capital and Financial Capital (i.e., Economic Capital) are the least important [2].

The New Danube Bridge in Budapest will connect communities on both sides of the river and open up areas for economic and social development. The new and recognizable landmark for Budapest

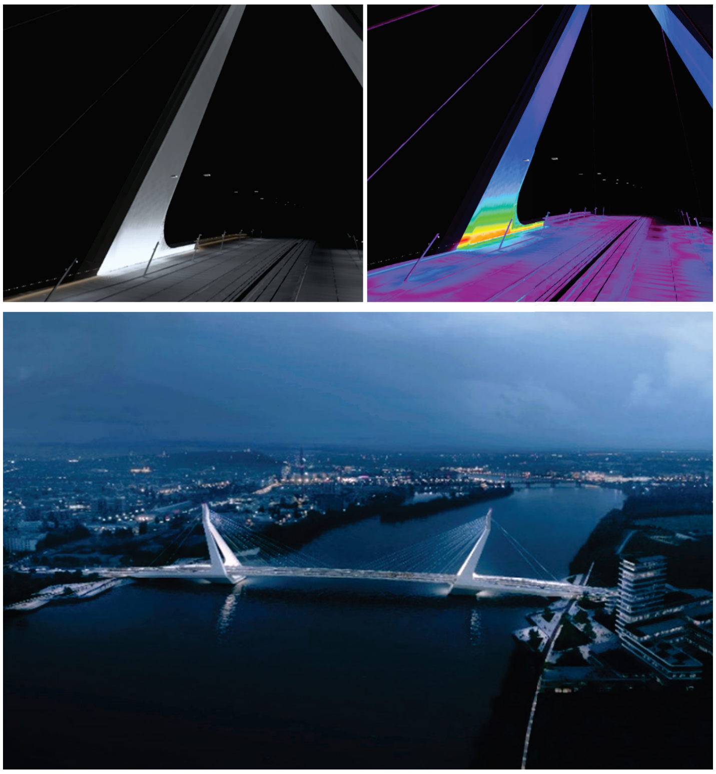

Figure 10: Render of pylon showing lighting intensity – © Buro Happold. Rendered night time image – © UNStudio / ZOA

will enhance Social and Economical Capital, with the challenge is to do so without spending unnecessary Natural Capital.

The existing bridges closest to the New Danube Bridge are approximately 1.9 km north and 8 km south of the proposed location. The new bridge connects two previously unconnected districts of the city, and the reduced vehicle journey distances partially offset the embodied carbon and energy used to construct the bridge.

Dedicated cycle lanes, pedestrian footways, and tram lanes in the central section of the bridge will help promote active travel and use of public transport.

A substantial part of the bridge will be constructed from steel, a highly recyclable material. The design efficiently reduces material use while maintaining architectural quality. Durability is ensured by selecting materials, finishes, and components that extend the bridge's design life.

The Budapest New Danube Bridge project exemplifies a successful international collaboration, addressing Budapest's growing traffic demands by connecting Újbuda and Csepel. The bridge's innovative design, featuring distinctive pylons and cable stays, integrates seamlessly with the urban landscape while promoting sustainable development. Key challenges, such as accommodating existing infrastructure and ensuring environmental considerations, were meticulously addressed through extensive stakeholder consultations and advanced engineering solutions. The project not only enhances connectivity but also fosters economic and social development, making it a significant landmark for Budapest.

9 References

[1] New Danube Bridge. Design Competition. The Brief, Kiemelt Kormányzati Beruházások Központja (2017).

[2] The Five Capitals - A Framework for Sustainability, https://www.forumforthefuture.org/the-five-capitals, last accessed 2024/08/06