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THE DEVELOPMENT OF WOODEN BRIDGES THROUGH THE AGES – A REVIEW OF SELECTED EXAMPLES OF HERITAGE OBJECTS. PART 2 – THE ICONIC STRUCTURES FROM THE WESTERN SLAVDOM AREA AND THOSE THAT INSPIRED THEM

ROZWÓJ MOSTÓW DREWNIANYCH POPRZEZ WIEKI – PRZEGLĄD NA WYBRANYCH PRZYKŁADACH OBIEKTÓW DZIEDZICTWA KULTUROWEGO. CZĘŚĆ 2 – IKONICZNE KONSTRUKCJE Z TERENU ZACHODNIEJ SŁOWIAŃSZCZYZNY, A TAKŻE TE STANOWIĄCE DLA NICH INSPIRACJĘ

Abstract

In the second part of this article, the development of the timber bridges is shown in detail in relation to the historical and cultural contexts specific to different regions subjectively selected from around the world. For such a purpose, some iconic timber bridges are presented and discussed on a country by country basis. Their mutual comparison allows us not only to appreciate the craftsmanship of both ancient and medieval builders but also to see the diversity of the proposed structural solutions.

Keywords: wooden bridge, cultural heritage, historical testimonies, old design solutions

Streszczenie

W drugiej części niniejszego artykułu pokazano szczegółowo rozwój mostów drewnianych, odnosząc go do historycznych i kulturowych kontekstów specyficznych dla różnych regionów subiektywnie wybranych z całego świata. W tym celu niektóre ikoniczne obiekty mostowe są prezentowane i omawiane kraj po kraju. Ich wzajemne porównanie pozwala nie tylko na docenienie rzemiosła starożytnych i średniowiecznych budowniczych, ale również na dostrzeżenie różnorodności zaproponowanych rozwiązań konstrukcyjnych.

Słowa kluczowe: most drewniany, dziedzictwo kulturowe, świadectwa historyczne, dawne rozwiązania konstrukcyjne

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1. A brief introduction to the second part of the article

In the first part of this article [1], some historical wooden bridges were presented and discussed in detail by the authors but only those which have been subjectively selected by them as milestones in the development of bridge engineering. The purpose of this section is to provide a more detailed presentation of additional heritage structures – this makes it possible to present them in a broader context which takes into account both the place and the time of their functioning. The presented review refers firstly to the countries which are joined by a common Slavic history. Bridges assigned to this group were selected to emphasize the similarity in the development of crafts techniques commonly used by former Slavic bridge builders. Other regions considered in the second part of this presentation were selected taking the alternative criterion – to show the way in which some design concepts which were inspired by the solutions developed earlier in medieval Europe have been creatively transformed and improved away from Europe, despite the lack of information exchange especially with regard to technological know-how.

2. A short description of the heritage wooden bridges in Poland

The oldest relicts of a wooden bridge which have been found in Poland are those excavated near the village of Biskupin. They date back to the period of Lusatian culture, to the year 737 BC, as was confirmed by dendrochronological research. The remains of the bridge with a length of 120 m leading to a fortified settlement were discovered in this location. Moreover, thanks to the archeological excavations, which were frequently carried out under water, many other remnants of heritage wooden bridges have been identified across the country; however, these date back to the Middle Ages. Most of these structural remnants are described in detail by Szulca [2].

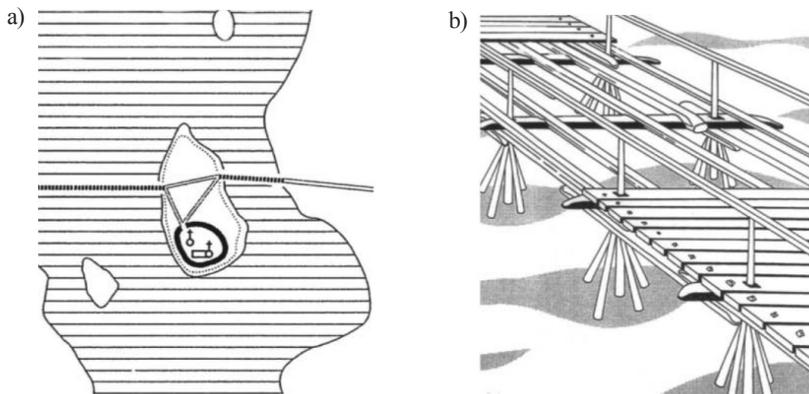


Fig. 1. Reconstruction of the timber bridges on Lednickie Lake: a) bridge location, b) bridge structure (according to [3] and [4])



Fig. 2. Model of the medieval bridge across Lednickie Lake (from the collections of the Museum of the First Piasts at Lednica)

(source: http://eloblog.pl/wp-content/uploads/2015/07/DSC05537_DxO.jpg, access: April, 2016)

One of the best known early medieval timber bridges built at the beginning of the Polish state was located on Lednickie Lake, 50 km southwest from Biskupin. This bridge was erected in the tenth century which means that it was constructed over 1,700 years after the bridge erected near Biskupin which was built by the people from Lusatian culture. Two wooden bridges with lengths of 438 m and of 187 m connected the fortified settlement built on the island named Ostrow Lednicki to the western and eastern shores of the lake respectively (Fig. 1a). These structures were from 4.1 m to 4.5 m wide and their spans were from 4.0 m to 4.5 m long and they were constructed from oak timber. Girder spans supported by intermediate transverse beams constituted the load-bearing structure of the bridges and these beams were in turn supported on two groups of piles (Fig. 1b). Since the maximum depth of the lake in this location was 8–10 m, some of the piles had to be 12–14 m long. All bridge components were connected to each other using carpentry joints, without the use of any metal elements. On the basis of the results of dendrochronological examination of the excavated piles, it was established that these bridges were used from the year 963 up to the year 1038 when they were destroyed by invaders from early-medieval Bohemia. The medieval bridges built across Lednickie Lake are precisely described in [5] and [6].

The other iconic heritage timber bridge in Poland was the floating bridge built on the Vistula River near Czerwinski monastery during the war between the Kingdom of Poland and the State of the Teutonic Order in the years 1409–1410 (J. Dlugosz – *Annales*). This bridge made it possible to concentrate the united Polish–Lithuanian army under the command of the king Władysław Jagiełło on the required bank of the river to facilitate victory in the battle of Grunwald (Tannenberg) on July 15, 1410. It was essential that before assembly of the bridge, the prefabricated deck elements were hauled on boats down the Vistula River and mounted at their destination, this task took half a day. Other wooden floating bridges with a similar structure were used in medieval Torun slightly later in 1433. However, from other sources, it is known that since the year 1500, there was a permanent timber bridge used in that town which was built with a bascule middle span (Fig. 3).

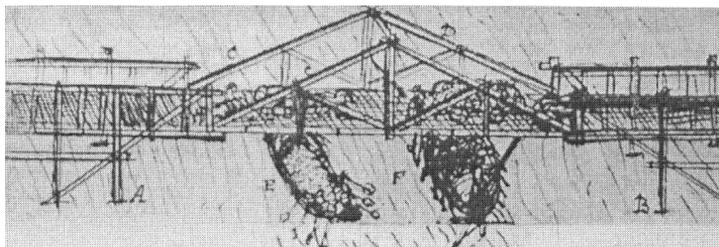


Fig. 3. The oldest permanent wooden bridge in Torun originating from the year 1500 with a bascule middle span – drawing by Peter Mundy (1643) (according to [7])

The temporary floating bridges were not the first timber bridge structures built in medieval cities located in what is now Poland. It is confirmed by historical records that two permanent wooden bridges were erected in Wroclaw in 1149. The first bridge linked the city with the island named Na Piasku whereas the second bridge led from that island to St. Vincent Monastery. Furthermore, in 1226, the St. Maurice Bridge was completed in Wroclaw over the Olawa River and a little later, in 1267, the next bridge was erected across the Odra River, leading from Na Piasku island to the most noble city island called Ostrow Tumski. Another timber bridge was subsequently built in Wroclaw, also over the Odra River, in 1369. Similarly, some permanent timber bridges were used in the thirteenth century in medieval Poznan. The first of these was constructed at the site of today's Chwaliszewski Bridge, it was about 90 m in length and about 7 m in the span width. The second and much larger structure was The Great Bridge built across the Warta River with the length of about 200 m – it linked the old Grobla district with St. Roch suburb. The historical timber bridge is known also from fourteenth-century Cracow, the former capital of the Kingdom of Poland. It was named The Pons Regalis which means “The Royal Bridge” and was linking each bank of the old bed of the Vistula River from Cracow city to the neighbouring city named Casimir after the name of its founder, King Casimir III of Poland (Fig. 4).



Fig. 4. Two cities, the old Cracow and much younger Casimir as they were seen in 1493 with the Pons Regalis and the other timber bridges existing at that time (a woodcut from the Hartmann Schedel's “Nuremberg Chronicle”) (source: https://upload.wikimedia.org/wikipedia/commons/thumb/2/2f/Nuremberg_chronicles_-_CRACOVIA.png/1024px-Nuremberg_chronicles_-_CRACOVIA.png, access: April, 2016)

In the sixteenth century, Zygmunt August (Sigismund Augustus), the last Polish king from the Jagiellonian dynasty, founded the first permanent wooden bridge over the Vistula River. The construction of this bridge started in 1568 in Warsaw, which at that time was not yet the capital of Poland. As one can see in the old pictures preserved to this day (Fig. 5 and 6), the bridge was about 500 m long and consisted of twenty-three timber spans. The eighteen main spans, each of which measuring 23 m in length, were constructed as triangular truss superstructures with timber bars and iron joint connections. Five shorter spans (approximately 10 m long) were movable to enable the passage of shipping, which was intensive at that time. The bridge was opened in 1573 and was operated until 1603 when drifting ice destroyed the structure.



Fig. 5. The oldest view of Warsaw from approximately 1573 with a Sigismundus Augustus timber bridge on the right (source: https://upload.wikimedia.org/wikipedia/commons/3/3b/Warsaw_after_1573.jpg, access: April, 2016)

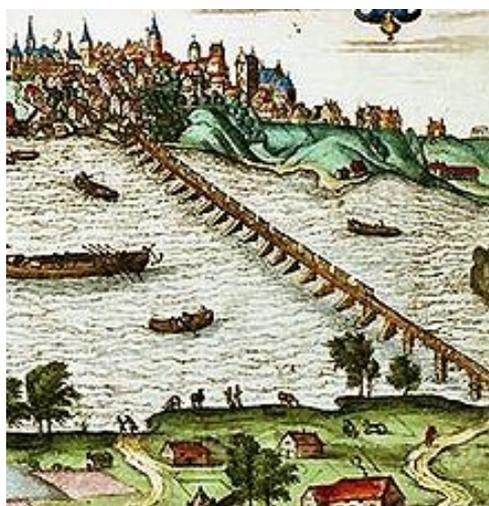


Fig. 6. The Sigismundus Augustus timber bridge over the Vistula River in Warsaw in the old picture (source: https://upload.wikimedia.org/wikipedia/commons/0/0a/Sigismundus_Augustus_Bridge_in_Warsaw.jpg, access: April, 2016)

Writing about the old wooden bridges located in what is now Poland would be incomplete if there is no mention of the bridges designed by Johannes Gross in the late eighteenth century, especially in the area of the Austrian annexation. He constructed many covered timber bridges at that time which had previously not been specific to the Polish building tradition. The bridge over the Biala River located near Tarnow is a good example of such the structure (Fig. 7); it was completed in 1780 but during the World War I, in 1914, it was destroyed by fire. Its history is described in detail in [8].



Fig. 7. The covered timber bridge built on the Biala River near Tarnow in 1780 by Johannes Gross which burnt down in 1914 during World War I
(source: <http://joemonster.org/p/853947/46>, access: April, 2016)

3. Some historical timber bridges erected in Bohemia and Slovakia

The oldest Bohemian timber bridge seems to be the structure excavated in Moravian Mikulčice, it dates probably from the ninth century. The length of this bridge leading to the fortified settlement located on the island on the Morava River was about 50 m whereas the width of its deck was approximately 5 m. The deck was supported on vertical piles grouped in eleven rows. The rows of these piles formed single as well as double yokes which were supported on the sides of the piles by diagonal braces. Four double yokes were made of the piles arranged in pairs, from 18 to 27 piles in one pillar (Fig. 8).

Many remains of very old timber bridges were also discovered in what is now Slovakia. The most interesting seem to be the remnants of a pile bridge which was found in Dievčenský Hrad – Leányvár (which means the Girls Castle) located close the present village of Iža near Komárno. This bridge was completed within the site of a former Roman fortress called Brigetio. Such fortifications were built around the first or second century AD as part of the Limes Romanus. The other iconic Slovak heritage timber bridge is the one completed over the Váh River in the former Roman military camp called Eleutheropolis which was located near the present city of Hlohovec. Furthermore, some pontoon bridges

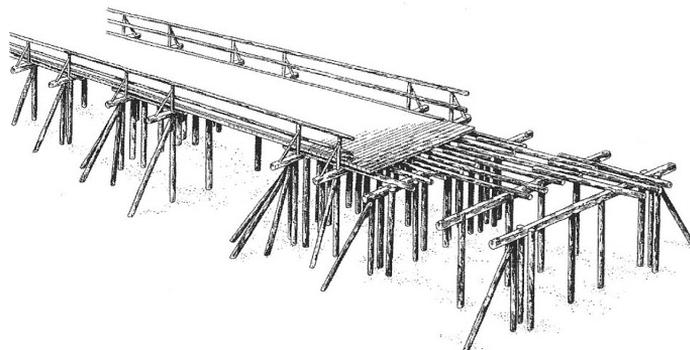


Fig. 8. The scheme of the structure of the early-medieval timber bridge in Mikulčice (according to [9])
(source: http://www.bylotojinak.cz/images/stories/ostatni/Most_Mikulice.jpg, access: April, 2016)

over the River Danube were first mentioned by chroniclers in the seventh century AD. As far as the much more recent Slovak heritage timber bridges are concerned, an interesting covered timber bridge should be listed here which may be seen in a painting from 1599 by J. Willenberg (Fig. 9). This bridge over the Hron River was completed in Zvolen. Let us note that at the same time in Zvolen another timber bridge existed over the Slatina River. Its structure is presented in an engraving originating from the seventeenth century which was made according to a painting by Gérard Bouttats.



Fig. 9. A covered bridge built in Zvolen over the Hron River, as can be seen in a painting from 1599 made by J. Willenberg (Courtesy of The Monument Boards of The Slovak Republic)

In the authors' opinion, one Slovak timber bridge should be especially honoured in this short presentation. This is the 27 m long, 3.48 m wide and 6m tall Kluknava Bridge erected over the Hornád River (Fig. 10) [10]. Its structure, made of spruce wood, was completed in 1832 for the transport of building materials for factory construction in the neighbouring Štefanská Huta. This bridge was never seriously damaged. Moreover, it was not repaired until 1981; only the shingled covering and the side boarding were renewed in 1932. The extensive renovation of the structure begun in 1982 with it being totally dismantled before being reconstructed in 1984. Finally, the deck was repaired from 2003 to 2004.



Fig. 10. Combined system of covered timber truss bridge used in Kluknava (Courtesy of The Monument Boards of The Slovak Republic)

4. Selected heritage covered timber bridges built in Canada and in the USA

As we have seen in the previous section of this article, the heritage covered wooden bridges were built in the nineteenth century in both the present Polish and Slovak territories. Undoubtedly, however, these structures were not typical either of the historical region previously considered or of the building tradition corresponding to it. It is obvious that this concept was borrowed first from the medieval timber bridges erected many years ago over the Alpine Rivers (some of these bridges are described in the first part of this article [1]) and next from the former Anglo-Saxon building trade. It is noteworthy that bridges of this type were constructed at the same time in Canada and in the USA – many of these are still well preserved and remain in service. Even a cursory review of their development would require a separate article; for this reason, only three examples of such bridges, which are considered by us to be the representative of the entire group, are briefly presented and discussed below. These examples are considered to be sufficient in order to show the individuality of structural solutions used in these bridges in relation to the bridges which were developing in Europe.

Currently, the oldest heritage timber bridge in Canada which remains in service is the Percy Covered Bridge built in Powerscourt in the Province of Quebec. It was erected in 1861 to carry people and horse-drawn wagons over the Châteauguay River. Its atypical structure is an interesting example of an inflexible arched truss (Fig. 11). This bridge was designed by Daniel McCallum, the general super-intendent of the New York and Erie Railroad until he founded the McCallum Bridge Company in 1858. This design was later used throughout the whole of Canada and also the United States for subsequent timber railway Bridges; however, it has become obsolete with the advent of modern steel bridges.

The second structure considered here is the Cornish–Windsor Covered Bridge which is a good example of a traditional heritage timber bridge which was constructed in the eastern USA in the nineteenth century. It is a two-span Town's type lattice truss (Fig. 14) crossing the Connecticut River between Cornish in New Hampshire and Windsor in Vermont. This structure, built in 1866, with a length of 140.2 m, remains the longest covered bridge in the whole of the United States.



Fig. 11. The Percy Covered Bridge built in Powerscourt in the Province of Quebec – the oldest heritage timber bridge in Canada which remains in service (sources: a) https://c1.staticflickr.com/1/646/23671000872_e29a8ee27a_b.jpg, access: April, 2016, b) <http://static.panoramio.com/photos/large/34017925.jpg>, access: April, 2016)

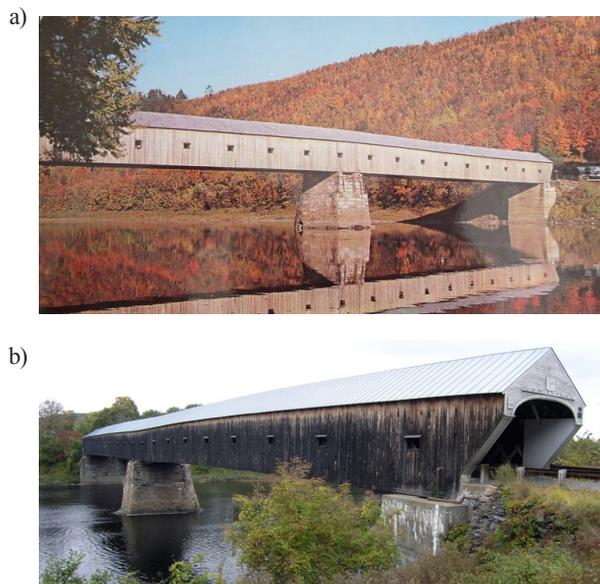


Fig. 12. Two views of the Cornish–Windsor wooden covered bridge built in 1886 over the Connecticut River between two American states: New Hampshire and Vermont (sources: a) <http://www.meyette.us/CornishCoveredBridge.jpg>, access: April, 2016, b) https://upload.wikimedia.org/wikipedia/commons/thumb/2/25/Cornish-Windsor_Covered_Bridge%2C_Cornish%2C_New_Hampshire_and_Windsor%2C_Vermont.jpg/800px-Cornish-Windsor_Covered_Bridge%2C_Cornish%2C_New_Hampshire_and_Windsor%2C_Vermont.jpg, access: April, 2016)



Fig. 13. Entrance to the heritage Cornish–Windsor wooden covered bridge
 (source: <http://uppervalleynhvt.com/wp-content/uploads/2015/04/Windsor-VT-Cornish-NH-Two-Span-Covered-Bridge.jpg>, access: April, 2016)

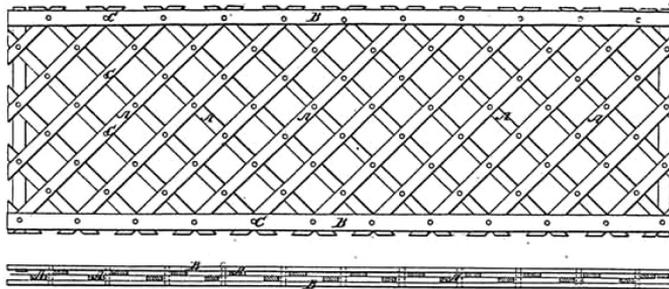


Fig. 14. The scheme of the conventional wooden Town's type lattice truss
 (source: <http://www.past-inc.org/historic-bridges/Townstrusspatent.JPG>, access: April, 2016)



Fig. 15. The heritage Bunker Hill Covered Bridge in North Carolina in the USA with the Haupt's type wooden truss girder (source: <http://d.lib.ncsu.edu/collections/catalog/bh0241pnc006>, access: April, 2016)



Fig. 16. Entrance to the Bunker Hill Covered Bridge (source: <http://images.fineartamerica.com/images-medium-large-5/bunker-hill-covered-bridge-2-randy-scherkenbach.jpg>, access: April, 2016)

It is worth mentioning that the conventional concept of the timber Town's type lattice girder was improved by Brigadier General Herman Haupt who was, during the Civil War, the chief of Military Railroads for the Union Army. In a letter, he described the faults of such a lattice truss which was "composed of a system of braces and counterbraces arranged at equal angles in opposite directions and pinned with wooden pins to horizontal chords at top and bottom". Continuing his letter, he concluded that: "Theory, observation, and experiment all agree in favor of the conclusions that one half of the inclined pieces are of no use as counterbraces and badly answer the purpose of ties, that from their inclined position they are exposed to a very considerable cross strain, which tends to split the timbers along the line of pins, and that the pins of the lower intersections are caused to bear a disproportionate share of the weight". To correct such disadvantages, a more efficient timber lattice truss was designed which consisted of web members positioned only at locations which required support, redundant members were removed. This new type of timber girder was used, for example, in the structure of the heritage Bunker Hill Covered Bridge built in 1894 by Andy L. Ramsour over Lyle's Creek in North Carolina (Fig. 15 and 16).

5. Concluding remarks

In the second part of the article presented by the authors, the development of the wooden bridges is discussed in detail on the examples selected from the regions associated with the culture of the Western Slavs. It is noteworthy, however, that the knowledge of how the timber bridges should be constructed to be stable, durable and useful for people is much older than the Slavic origins in these areas. Indeed, this knowledge must be associated with

the people from the ancient Lusatian culture. Nevertheless, a cursory analysis of the early-medieval wooden bridges built by the Slavs from the tenth century AD shows numerous similarities that they share, irrespective of whether the compared structures were erected in the areas that are now Poland, Czech Republic or Slovakia. Let us note that the loadbearing structure of the bridge excavated in Moravian Mikulčice is not much different from the slightly more recent structure used in the bridges erected in Lednica. Furthermore, both of these structures are very similar to the wooden bridge identified in Ober-Ückersee near the present-day town of Prenzlau in German Brandenburg [2], which was reconstructed by archeologists based on the preserved relics. Obviously, the territory of today's Brandenburg was at that time inhabited by Polabian Slavs, which was gradually superseded by incoming people of German origin in subsequent years. In general, the wooden bridges built by early Slavs were usually simple beam bridges appropriately braced by applied struts. Timber bridges of this type were associated with the Western Slavs throughout their history, until the conventional wooden bridges were replaced by modern bridges made of structural steel or reinforced concrete. Timber bridges were much less expensive both in terms of their construction and maintenance than stone bridges built at the same time. Stone bridges, due to their relatively high cost, could be built only in the very affluent cities. For this reason, and also because of their easier renovation possibility wooden bridges were much more commonly used than stone bridges although they were undoubtedly less durable. A more detailed presentation related to development of wooden bridges on the territory described here can be found in [11]. Let us note that it is hard to find more complex heritage timber bridges, especially the wooden arch bridges, typical for the Western Europe in the entire area of the Western Slavdom. Heritage timber truss bridges are also very sparse. The authors want to particularly emphasise the fact that so many wooden bridges built in the considered territory were covered timber bridges originating from an engineering tradition that had not been developed before by the Western Slavs. This tradition is admittedly well known from medieval Europe, rather, the bridges representative for it were built over Alpine rivers. The covered wooden bridges were later, starting from the beginning of the nineteenth century, developed by bridge designers in North America, especially in Canada as well as in the eastern part of the USA. Some examples of the American bridges of this type are presented in detail in this article. However, at the end of the nineteenth century, before steel bridges were widespread, covered timber bridges again became very popular in Europe; these were mainly designed by military engineers. Some of these covered bridges are preserved to this day, like, for example, the wooden truss bridge in Kluknava (Fig. 10). Many covered timber bridges are still in service, especially those built in what is now the Bohemian territory. Bridges of this type completed in Cheb or the one erected in Český Krumlov are good examples of such structures.

At the end of our brief review, let us present the wooden bridge built in Slovak Kolárovo over the Malý Dunaj River (Fig. 17). This bridge is only 86 m long and 2.25 m wide, but it has no concrete pillars or even any other prefabricated components. This fact allows it to be granted the title of the longest structure in Europe built entirely of wood; however, the current bridge is not the original heritage wooden structure but only a copy built in 1992. The original bridge was only 60 m long and was destroyed by floating ice blocks. The other inspired heritage timber bridge is still in service in Bulgarian town of Lovech. A detailed

description of this famous bridge, relating to both the historical and the present structures, is given by the authors in a separate article [12].

Wooden bridges are still one of the most frequently used bridge type which may be seen worldwide; however, one cannot say that their contemporarily-designed structures are always more modern than those relating to the historical bridges identified as being of cultural heritage. An enlightening example in this field seems to be the “modern” timber bridge recently erected in Vietnam (Fig. 18). Let us hope that it is not the most outstanding achievement in bridge engineering in this country.



Fig. 17. The covered timber bridge in Slovak Kolárovo – the longest bridge in Europe built entirely of wood (source: <https://upload.wikimedia.org/wikipedia/commons/thumb/1/14/G%C3%BAta093.JPG/1280px-G%C3%BAta093.JPG>, access: April, 2016)



Fig. 18. An example of a contemporary “modern” wooden bridge in Vietnam (source: <https://s-media-cache-ak0.pinimg.com/736x/ae/90/cd/ae90cddc187a70b5421b82814553f14e.jpg>, access: April, 2016)

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