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Interdisciplinary research and computer technology for the study of Devil's Bridge in Castellbisbal – Martorell (Barcelona)

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Computer sciences; GIS; databases; infography

The extension and complexity of the historical sequence of the Devil's bridge, located over the Llobregat river, just between the borders of Castellbisbal and Martorell (Barcelona) is a suitable example for applying the archaeological methodology to the study of the monuments, combined with new computerised technologies used in the research process as well as the presentation and spreading of the results.

The historical sequence of the Devil's bridge's starts around the years 10 to 1 C, when the III, VI and X Roman legions built the bridge and the triumphal arch located on the west side. This is a construction within the *Via Augusta* reform, in which part of the bridge and the foundation of cities such as Saragossa (*Cesaraugusta*) and Barcelona are included, both with the same mentioned Roman legions.

Things seem to point out to the fact that the Roman construction lasted until the early Middle Ages, when a strong flood of the Llobregat River destroyed it. The bridge was not rebuilt until quite some time later between 1283 and 1295, taking advantage of part of the foundations and the bridgehead of the Roman work as well as a lot of the materials not swept along by the river. Among the reused materials, we find the blocks of stone that belonged to the honorific arch of the entrance, from which only the bases remain at the moment, while from the rest of it only the inner mortar is visible, without the blocks of stone.

The structure of the construction from 1283, of Gothic style, was built due to other requirements of the road from those of the Roman times, which were again different from the 18th century onwards. This meant carrying out a strong transformation of the platform slope of the bridge during this century.

The latest intervention over this monument dates from 1962, when the central Gothic arch of the bridge, which was deliberately destroyed in 1939 during the Spanish Civil War, was rebuilt.

In spite of the fact of its importance, a systematic and interdisciplinary study was made before for the bridge, neither for the Roman period when the *Via Augusta* passed by it, nor for the medieval one or during the later reforms of the road network in the 18th century.

For almost two years, a team of archaeologists, geologists, engineers and architects have studied the bridge. The purposes of this study were:

- To have the planimetry of all the elevations of the bridge.
- To make a record of the historical sequence of the work.
- To make a record of the documentary and graphic sources about the bridge.
- To restore in a computerised way the various phases of the bridge so as to analyse its structure, the processes of destruction and reconstruction, the materials used, as well as the building techniques.
- To know the structure and the evolution of the territorial environment in each phase of the bridge.
- To analyse the technologic capacities as well as the environmental impact on the process of construction during the Roman period and the medieval one.

The construction of the Barcelona-Lleida main road close the bridge has favoured several ar-

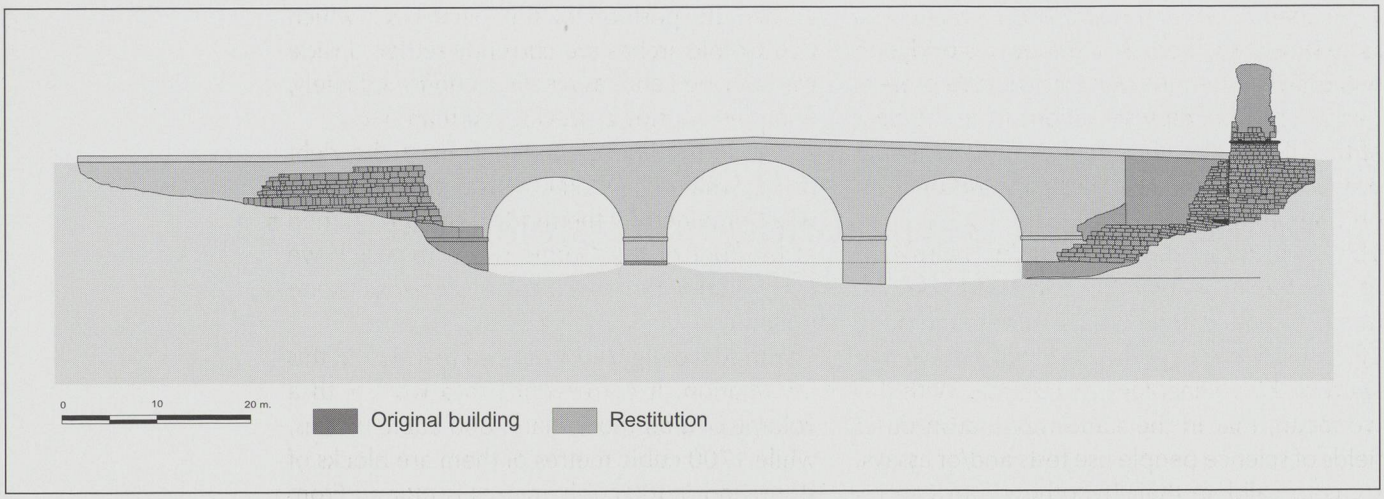

Fig. 1: Restoration of the Roman bridge from the preserved remains.

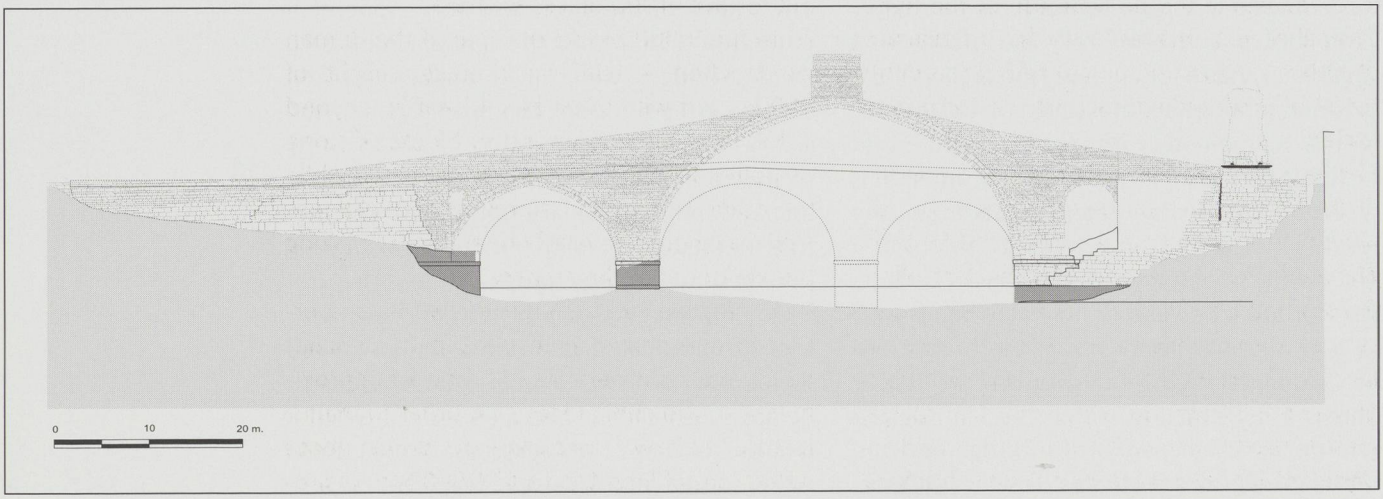

Fig. 2: Group of the different phases of the works.

chaeological interventions in the river-bed and its surroundings. And the results have been added to the current study.

The complexity and diversity of information handled, made it necessary for the research team to use a Geographic Information System. As a basic starting point of the study, we used the photogrametric elevation of the bridge, carried out by the Laboratory of Territorial Photogrametry from the Polytechnic University of Catalonia. This planimetry was incorporated into the GIS in a way that we were able to define some characteristics for each block of stone and each break line identified in the bridge. Regarding the blocks of stone, the GIS records their rocky typology, the size, the stratigraphic unit that they belong to, and, if it is the case, the existence of epigraphic data. With respect to the break lines, the stratigraphic unit (SU) identification was recorded.

The information about the bridge also included a geologic map of the area, the evolution of the road network, the population structures, the use of the territory, etc., which made it possible to investigate the different periods of the bridge, as well as its territorial context. Thus, for example, it has been possible to identify the position of some of the stones used in the Roman work and also in later phases.

Once the constructive sequence is defined and the matrix of the bridge was made, we needed to identify the materials used as well as their volume and origin, etc. These data

were used for the inphographic recreation so as to show two models of the devil's bridge in two different periods of its history. We present two 3D graphic representations from the data of the historical-archaeological study. The first one belongs to the Roman times and the second one to the medieval period.

The purposes of the inphographic recreation of the Roman and Gothic bridge are, on one hand, to demonstrate the usefulness and need of having some hypothesis so as to move forward in the archaeological research. With this we mean, that in the same way that in other fields of science people use tests and/or assays, so as to validate their hypothesis, we can do the same in the archaeological field, something similar to what the experimental archaeology proposes. On the other hand, we want to demonstrate the didactic use of the hypothetical recreations, not only for the teaching of history to children and academic students, but also for spreading research into the current society.

The methodology used for developing the three-dimensional models is based on the work related to the planimetric plans from the archaeological excavation and the face elevations of the Devil's bridge. This is very important, so as to be able to reconstruct the various faces. In both models, Roman and Gothic, all data coming from the analysis of their materials was used, such as the size of the blocks of stone, which were bigger and more homogeneous in the Roman period and more diversified in the medieval one. Finally, the hypothesis presented with inphographic models are also related to that of the bridge's destruction, which we believe was due to a flood. We can identify a pillar and the piers, both steady elements in the Roman and the medieval constructions.

The study has allowed a hypothetical reconstruction of the Roman bridge, from which only the piers remain, one pillar on the river-bed as well as the honorific arch. Thus, the proposal is a bridge with three arches, a larger central span, a platform with a two sided slight slope and a total length of 130 m.

In order to determine the span that the Roman construction had to bridge, we have three reliable references available:

- The spring line of the arch from the left bank of the river, which is given by the vertex of the protection step.
- The safe position of the pillar over which two Gothic arches are currently settled, inside the river-bed and, as we have confirmed lately, completely using a previous Roman base.
- The spring line of the arch from the right bank, which is obtained from the measurement provided by the mortar which remained at the foot of the Gothic work, to which we have added the size of the blocks of stone pulled up.

The model of figure 1 has been made from this information. It corresponds to a work with a volume of a bit more than 7000 cubic metres, while 1700 cubic metres of them are blocks of stone and 5.300 cubic metres is mortar. From an approximate total of 9.000 blocks of stone, there are 1.300 out of them remaining *in situ*. The study of the Roman work has been carried out for over 1000 blocks of stone.

From the 9.000 blocks of stone of the Roman construction – with an average weight of 400 kg, but with some blocks that go beyond 1.000 kg – 2/3 correspond to blocks of stone of potter's clay of Buntsandstein (BC), while the other 1/3 would be *arenites bioclàstiques* (AB) and would be used preferably for making the keystones of the arches.

Regarding the mortar, it is made with a proportion of one part of lime per 3 parts of sand, which means a necessity of lime of approximately 1.400 cubic metres. In order to manufacture it, it was necessary to utilise about 4.000 tons of limestone and 3.600 tons of firewood, which implies the exploitation of the undergrowth and part of the firewood from approximately 1.000 ha. The transport of the stone, from the stone quarry to the bridge, went over a distance of about 9.000 km in round trips. As a whole, it gives us an approximate idea of the technological capacity of the constructors of the Roman work and the impact of the work on the environment.

Regarding the Gothic bridge, we also follow the information provided by its study. The bridge is designed taking into account the following premises:

1 To avoid building the pillars in the river-bed area, which can be more damaged by water.

2 To reuse the pillar that has resisted the force of the river.

3 To raise the level of the inner part of the arches in order to leave it over the known flooding level, so as to avoid a new destruction of the bridge.

Fig. 3: Current overview of the bridge.

4 To increase the span of the bridge so as to increase the drainage capacity.
5 To reduce the work of building as much as possible. This is the reason that the new bridge was designed with a narrower platform.
If these premises show an obvious technical capacity of those responsible for the work, the construction shows a shortage of resources available. We can assume, that the Gothic construction was built between 1283 and at least the end of 1295.
It is carried out reusing a lot of materials from the Roman bridge. We point out to the fact that the pillar on the river-bed and the base of the main Gothic arch, on the left side of the river, are settled on a lot of blocks of stone from the decoration of the honorific arch, which was almost demolished till down to the base.
The figures of the volumes and the materials used show some amounts beyond those of the Roman work. The total volume of the Gothic work is about 1.574 cubic metres, from which 262 cubic metres were blocks of stone and 1.312 cubic metres were mortar.
A remainder of approximately 1.000 cubic metres is still left from the original construction, which represents approximately 63%. From these 1.000 cubic metres, 144 cubic metres are preserved blocks of stone, counting those from the lateral faces and those of the inner arches. The sample analysed is from the blocks of stone from the lateral faces of the bridge, with a total of 3.398 blocks of stone studied, and with an average weight of about 150 kg.
From the 263 cubic metres of blocks of stone that we think were in the full Gothic work, there are only 50 cubic metres of new ones. The rest of them, more than 212 cubic metres, dating to Roman and medieval times, come from demolishing, not the blocks of stone from the honorific arch, but from the bridgehead, which was preserved in both sides of the piers.
If we calculate the volume pulled out from the arch, plus the volume of stone of the break lines of the Roman bridge, and the ones from the settlement of the Gothic work, we get a total volume of stone available of about 200 cubic metres. The rest of the material needed to finish the bridge, about 50 cubic metres, were taken out from the closest stone, from the Costa Brava, as well as the necessary materials for producing the lime for the work.
In this work, the consumption of lime is much lower, not only because of the volume built, but also because of the proportions used in the production of mortar. If the proportion used in

the Roman work was one part of lime and 3 of sand, the Gothic one was one part of lime and 5 of sand. We are talking of about 220 cubic metres of lime needed for carrying out the work.

If we apply the previous calculations to this volume, we will obtain the following: in order to produce 220 cubic metres of lime, it was necessary to use 260 cubic metres of stone (640 tons), surely taken from the area of the Costa Blanca. The limekilns would use about 570 tons of firewood, which means the exploitation of about 163 ha of wood. In any case, this exploitation should have been smaller, according to the duration of the bridgework, which would help to regenerate the already exploited areas.

The interdisciplinarity of the research and the use of the computer media for managing and analysing data, allows us to obtain a much more accurate approach to the evolution of the bridge, to the technological knowledge in each period, to the impact of the constructive process over the environment, etc. Thus, the two inphographic models presented try to give a graphic and didactic answer to the global hypothesis around a work of civil engineering, related to its social, environmental, economic and political context of the Roman and the late medieval worlds.

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