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An engineering investigation on the Bronze Age crossbar wheel of Mercurago

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ABSTRACT

The Bronze Age crossbar wheel found in the XIX century in Mercurago (Italy) is an amazing example of the technical innovations stimulated by the diffusion of horse draught war chariots in Europe across the third and second millennium B.C. It is a tripartite wheel, with two felloes attached to a diametric crossbar by means of internal dowels, and four thinner rods departing from the crossbar near the hub and ending into the felloes. A separate nave is inserted into the crossbar hub. Many question are still open about this wheel, concerning in particular its constructive concept, the materials and the role of each member.

In this paper the tools of modern engineering, in particular the laser-scanner acquisition technology and the finite element method, were used to study the structural issues concerning the crossbar Mercurago wheel under the hypothesized operating conditions. Verisimilar explanations of some technical choices, such as the shape and the materials of the members, were obtained; furthermore, the presence of a leather tire was hypothesized on the basis of the rim-soil contact analysis. Finally, the role of the inserted nave was investigated. It was hypothesized that it could have a role similar to modern bushings, thus being a very innovative device for that time.

1. Introduction

The invention of the wheel was a key factor in the development of prehistoric cultures in the Old World. A fundamental work was provided by Piggott (1983) about the diffusion and evolution of wheeled vehicles in Europe. The archeological evidences suggest that important social, economic and technological changes occurred across the fourth and the third millennium B.C., providing the preconditions for the development of the earliest wheeled vehicles. In particular, cereal cultivation and animal domestication spread out all over the continent, stimulating the employment of the ox as draught animal. The availability of this animal allowed the development of sledges and wheeled vehicles for transport. The earliest wheels were massive wooden single pieces, with integral nave, obtained from planks cut from tree trunks through wedges (see Fig. 1a). According to the diameter of the found evidences, the trunks were at least 1 m in diameter, therefore even 200 years old oaks should be used. Given the relative scarcity of such trees even in the richly forested environment of that time, a natural evolution of this technology was the development of tripartite wheels, obtained by assembling three planks cut out from a narrower log, as depicted in Fig. 1b. The three parts of the wheel could be assembled by internal dowels and/or external battens. In some cases, the wheels were turning around the fixed axles, and could have integral or inserted nave. In other cases the wheels were fixed to the turning axle through square mortises. The evidences of vehicles equipped with these wheels are usually four wheeled wagons and, more rarely, two wheeled carts, suitable for heavy and slow transport by means of couples of yoked oxen.

The scenario of the wheeled vehicles dramatically changed by the end of the third millennium B.C. with the diffusion of domesticated horses throughout Europe. The new motive force provided by this animal allowed multiplying by something like 10 the ground transport speed, stimulating the development of lighter and faster vehicles for different purpose with respect to the existing wagons. The new invention was the chariot, a light, resistant two-wheeled vehicle, aimed at rapidly displacing one or two persons. This innovation likely started from the Near East, mainly for war and ceremonial purposes, subsequently spreading all over Egypt and Europe and becoming a key device up to the ancient empires (Macdonald, 2009; Rossi et al., 2016; Sandor, 2004a; Sandor, 2012). In particular, the six complete chariots found in 1922 in the tomb of the Egyptian Pharaoh Tutankhamun, and two other similar ones (the “Florence chariot” and the “Yuia-Tuiu” chariot)

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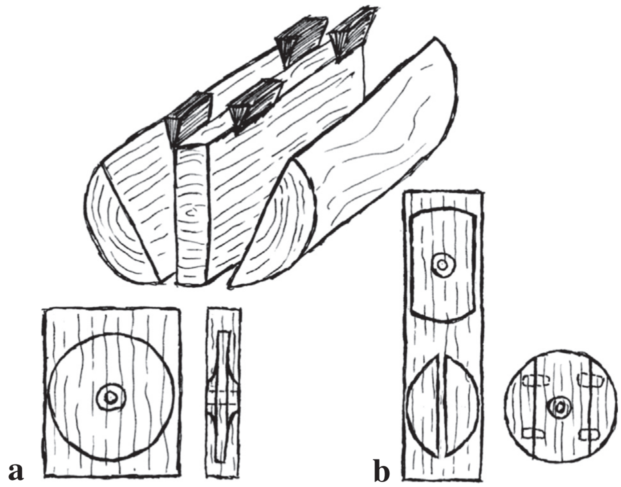

Fig. 1. Scheme of wheel fabrication: a) block wheel; b) tripartite wheel.

attracted the attention of scientists of ancient technologies. They highlighted the high efficiency of these machines and the surprising level of technological knowledge required for realizing these true jewels of mechanical engineering (Sandor, 2004b; Rovetta et al., 2000).

The chariots of Near East and Egypt communities in the second millennium B.C. had spoked wheels, particularly efficient in terms of strength/weight ratio. In particular, the Tutankhamun chariot spokes were assembled by means of a very complex technology, requiring concepts of solid mechanics even in absence of the modern mathematical formalism. This result could be achieved in highly organized societies such as the Near Eastern ones were, where specialized craftsmanship could be developed.

At an intermediate technological level between the earlier bulky wheels and the advanced spoked ones stands the crossbar wheel, whose a well-known evidence is the one found in the XIX century in Mercurago, in northern Italy (Fig. 2). This wheel was found together with other two tripartite massive wheels, clearly aimed at different applications, meaning that in that place a workshop specialized in wheels construction and repair was likely present. Nowadays, a plaster clast of this wheel remains, conserved in the Antiquity Museum of Turin (Italy), as the technologies available at the time of the finding did not allow the conservation of wooden evidences. This wheel, dated between the XVIII and the XIII century B.C., is characterized by a diametric bar, thick enough in the central region to accommodate an inserted nave, with four thinner rods departing eccentrically on each side of the nave, and terminating with their ends mortised into the felloe. In the past some archaeologists underestimated the importance of this wheel, that chronologically coexisted with spoked wheels, considering it merely a collateral device or an unsuccessful attempt of constructing a six-spoked wheel. However, Littauer and Crouwel (1977) showed that the crossbar wheel was held in high consideration both in Near East and European societies; furthermore, on the basis of the direct descendants found in other Italian regions, it was argued that this kind of wheel had a local Italic development, independent on other crossbar wheels.

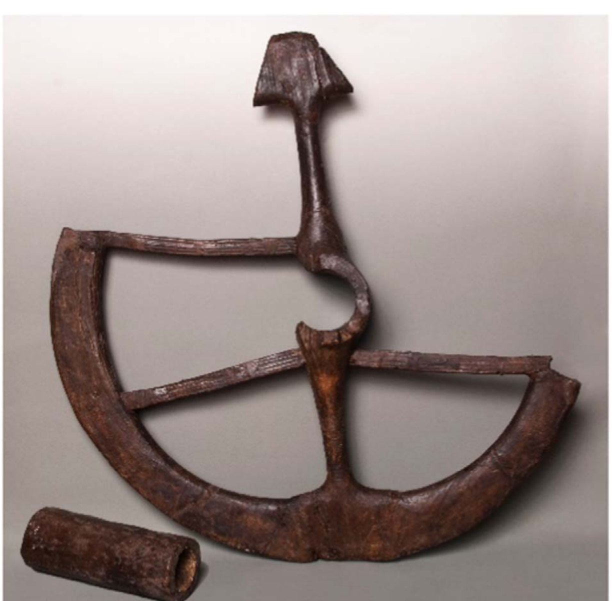

Fig. 2. The Mercurago crossbar wheel.

This evidence captures the interest of archaeologists and even engineers for multiple reasons. Its overall shape and assembly shows a particular care of the manufacturer for optimizing its weight and strength. The assembly and the shape of the parts are not trivial, as well as the solution of the inserted nave. This wheel was able to rotate around the axle, therefore it was suitable for steering vehicles; the nave-axle interface was likely greased by animal fat, which was diffused at that time according to some evidences (Piggott, 1983; Sandor, 2004b). This fact, together with the constructive complexity and optimized structure, makes the hypothesis that it was destined to a war chariot the most probable.

Many questions arise when observing this evidence, among which the following:

- How was it built and assembled? Which was the role of each member? Were the felloes obtained by cutting a plank or by steam bending of slats? Were the rods obtained by two sticks crossing internally the crossbar, or were they four independent sticks? How were the joints between the members realized?
- Which kind of woods was used for constructing the wheel parts?
- Was there any tire around the rim? Metallic tires had still to be introduced in Europe at that time; however, indications that some sort of wooden or leather tires were in use in Europe and Mesopotamia were found (Littauer and Crouwel, 1977): how crucial was their role?
- What was the function of the inserted nave? Even in previous times, inserted naves were used for reducing the thickness of the plank from which the wheel had to be worked out. However, this was crucial for massive wheels, extracted from large planks. In the case of the Mercurago wheel, the crossbar might be obtained from a rather thin log (no $>$ 30–35 cm in diameter) even with an integrated nave. On the contrary, the inserted nave solution required that the coupled surfaces were worked with great care. Therefore, why was the nave separated from the crossbar?
- Why was this kind of wheel later abandoned and completely replaced by the spoked wheel?

The aim of the present paper is to propose some answers to such questions by employing the investigation tools of modern engineering research, coupling the historical competence of archaeology with the technical skills of engineering. The methodology includes the use of optical devices for the direct investigation of the evidence and the simulation of the wheel performance in battle by means of numerical calculation tools, giving results to be compared with the current archeological knowledge about the technology available at that time.

2. Direct investigation of the original wheel plaster clast

The original plaster clast of the Mercurago crossbar wheel and the nave was was analyzed by means of both digital photography and 3D laser scanner technology. The aim of this phase was twofold: 1) to search details that can give any clue about the questions still open; 2) to obtain a digital 3D model of the evidence for accurate measurements.