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Development of Technological Styles to Produce Monumental Equestrian Sculptures

Ir a la versión en español

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ABSTRACT

Based on archival information, historiographic sources, bibliography, and characterizations carried out in professional conservation projects —in particular, *El Caballito,* by sculptor and architect Manuel Tolsá— this article examines the evolution of the technological styles used in the production of monumental equestrian sculptures made of copper alloys using the lost-wax casting technique in the Western world, from the Renaissance to the 19th century. It analyzes the origins of lost wax, piece molding, and the consolidation of the single-casting technique as the dominant technological style (1699 to early 19th century). It also briefly looks at the introduction of assembled production in Mexico and the United States, and the development of welding during the 19th century. It aims to avoid mistaken assumptions that may compromise the evaluation, historical interpretation, and decision-making related to the conservation and restoration of these sculptures.

KEYWORDS

technological style, casting, equestrian sculpture, lost wax, Tolsá

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INTRODUCTION

Thanks to their large scale and location in public spaces, monumental equestrian sculptures are integrated into the urban landscape and collective memory, conveying leadership and power. The fact that they are made of copper alloys reinforces their permanence and reflects the mastery of those who, throughout history, specialized in sculpture and casting.

Lack of knowledge regarding the production technique has led to errors when interpreting sculptural casting; as when it was claimed that *El Caballito,* a sculpture created between 1796 and 1803 by sculptor and architect Manuel Tolsá (1755-1816) and located today in the eponymous square of Mexico City's Historic Center, was created in parts, and then assembled and welded together (Delgado, in Ventura, March 21, 2016; Noticieros Televisa, January 23, 2016). This contradicted what had been maintained for more than two centuries —and even stated on the marble plaque on its pedestal—: the work was cast in a single operation (*Gazeta de México*, September 17, 1802; Uribe, 1990; Salazar, 1999).

The interdisciplinary team of the INAH, in charge of its conservation between 2016 and 2017, verified through material analyses based on knowledge of the technology's history that, indeed, the rider and horse were achieved in a single casting (INAH, 2017; Contreras, 2021; Contreras & García, 2022).

This text seeks to provide information that contributes to understanding monumental equestrian sculpture made of copper alloys. By analyzing technological styles —modes of production considered appropriate in their temporal and cultural contexts— it examines the evolution of lost-wax casting in the West, from the Renaissance to the 19th century,[1] a period on which we have limited availability of information compared to contemporary monumental sculpture.

It begins by describing the methodology and conceptual tools of the anthropology of technology utilized to analyze the production of monumental equestrian sculptures. Then, based on case studies, documentary information, and material characterizations from restoration projects, it analyzes the origins of the technique, from the production in separate parts to the consolidation of single casting as the dominant technological style between 1699 and early 19th century, briefly addressing the beginning of assembled production in Mexico and the United States and the emergence of welding in the 19th century.

[1] Most of this article stems from the thesis work *Metodología para la construcción de decisiones de restauración* (Contreras, 2021).

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Its purpose is to avoid mistaken assumptions that may compromise the evaluation, historical interpretation, and decision-making related to conservation.

METHODOLOGY

This research emerged seeking to understand the production of monumental equestrian sculptures made of copper alloys, based on the analysis performed for *El Caballito*; in this inquiry, conceptual tools of the anthropology of technology were used to analyze sculptural production in its context and recognize innovation, specialization, labor organization, and economy associated with it.[2]

The first of these concepts was *technological choices*, understood as a response to what is materially possible and socially desirable in a specific time and space (Schulze, 2008, p. 68), in such a way that tradition, experience, and physical and cultural contexts were the drivers of such decisions (Lemonnier, 1993, p. 3; Sillar and Tite, 2000, p. 9).

To understand production, the *operational sequence* (*chaîne opératoire*) was also analyzed. This is a heuristic tool that helps to deconstruct the sequence of activities necessary to transform the raw material into the finished product. Studying it reveals patterns in production at different times and places, making it easier to identify technological similarities (Cresswell, 1976, p. 6; Schulze, 2008).

The last concept, *technological style*, helped to explore how a human group conceives, produces, and uses objects according to their practices and representations (Lemonnier, 2011, p. 299). Defined as the "way of making" particular to an era and context, it is influenced by the *habitus*, understood as the set of socially acquired provisions that structure social life (Bourdieu, 1977; Sanhueza, 2006). Unlike the concept of *style*, used for the typological and temporal classification of objects, technological style emphasizes the choice among equally viable options, generating isocrestic variations that are socially learned and transmitted (Sackett, 1990; Dobres, 1999; Lemonnier, 1992).

By integrating the analysis with these conceptual tools and documentary sources —including the review of archives between 2018 and 2019—[3], inquiry with a bronze founder with more than 70 years of

[2] See the work of Leroi-Gourhan (1964), Mauss (1967), Lemonnier (1986, 1992, 2011), González-Ruibal (2003), Dobres (2006), Sanhueza (2006), and Schulze (2008).

[3] Archives of the Royal Academies of Fine Arts of San Fernando in Madrid, and San Carlos in Valencia, as well as the Historical Archive of the Kingdom of Valencia and

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experience in artistic casting,[4] material information such as the walls' thickness or the absence of assemblies —that was obtained during the conservation performed between 2016 and 2017— it was confirmed that *El Caballito* —rider and horse— was made in a single casting.

Based on the above, the existing historiography and bibliography, and an emphasis on the characterizations of materials and production techniques gained from conservation projects, this article includes information on monumental equestrian sculptures ranging from the Roman *Marcus Aurelius* to some others after *El Caballito*, to identify patterns and technological aspects such as the materials' composition and production techniques.

HOW WERE MONUMENTAL EQUESTRIAN SCULPTURES PRODUCED?

This section shows the results of the analysis performed. For this purpose, the chronology proposed by Giubbini and Sborgi (1987 [1973]) is used to date the development of the technological styles of monumental equestrian sculpture made of copper alloys.

Figures 2, 3, 5, and, 10 included in this section are tables that gather information on equestrian sculptures from the *Marcus Aurelius* mentioned above to the work of Tolsá that we are studying, plus others from the 19th century, detailing the dates of creation, the authors, and founders, the techniques used in their fabrication as well as data on the composition of alloys, casting methods, structural innovations, and documented works of conservation, as well as historical references that contribute to the analysis of the technical and material evolution of these works.

Casting, pouring and lost-wax casting

For *casting* and *pouring* —synonymous terms used interchangeably— high temperatures are used to melt the metal and pour it —cast it— into a mold, which is a material that has a hollow —negative— shape. As it solidifies, the metal retains the positive shape.

The first molds were made of sand —*sand casting*—; others, more durable, were made of stone or baked clay in order to achieve objects with a modeled surface and another smooth, undecorated surface. Later, about 4,000 years ago, in the Far East and Egypt,

the National Library of Spain, were consulted to investigate the process of acquiring materials and Manuel Tolsá's possible training in metalwork at the academies, together with comparisons with similar works.

[4] Ernesto Contreras Ballesteros, who was inquired from 2013 to 2024.

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the lost-wax process was developed; using a mold with two hollow shapes made it possible to produce more complex objects, with two molded surfaces. These molds were made by coating wax elements with clay, creating other ones that allowed the wax to be removed later by casting and burning, leaving a negative space to be filled with the liquid metal (Mattusch, 2014; Arminjon & Bilimoff, 1998).

The use of cores and piece molds was decisive in the development of the casting technique. Initially, the —positive— wax model was solid, resulting in equally solid metal sculptures, limiting their use to small-format works. This method was called *full casting.* The use of clay cores made it possible to reduce the weight and the amount of metal required, which gave rise to the so-called *hollow bronze*. This technique, known as *direct lost wax*, involves the loss of the original model when the wax is lost —that is, each work thus produced is unique— and, if the casting fails, the process needs to be started from the outset (Mattusch 2014, p. 81; Baudry 2011).

Afterwards, the indirect lost-wax casting technique was developed, whose main advantage is that the original model is not destroyed —hence the name of *preserved model*—. To preserve it, a mold of removable pieces is used, which allows adjustments and corrections to be made, thus reducing the chances of error. With this technique, different pieces can be produced separately, either by joining the metal pieces cast separately using complementary assemblies, nails, hinges, or complementary fillers, or by creating a second wax model, in which the sections are assembled, used to produce a new mold into which the molten metal is poured.

In indirect casting, the interior of the figure is filled with a clay core, designed to support the structure during pouring, that is removed when the metal work is complete, so it must be relatively loose. This technique —used in ancient Greece and Rome to create large-scale works— allowed for greater flexibility and, thus, the production of complex and monumental pieces, preserving the original model for adjustments or future reproductions.

Both direct and indirect techniques are illustrated in Figure 1 and, as can be seen, in both it is necessary to install the casting system on the wax model, which is a set of wax tubes strategically arranged to ensure that the molten metal fills the entire mold without blockages. It consists of: *a)* the liquid metal inlet, *b)* the molten wax outlet and *c)* the outlet of gases and vapors resulting from the burning of the wax and the melting of the metal. Due to its shape, it is also known as a *tree*. The wax model and casting system, or tree, are coated together with the casting mold: a refractory layer reinforced to withstand the pressure of molten metal.

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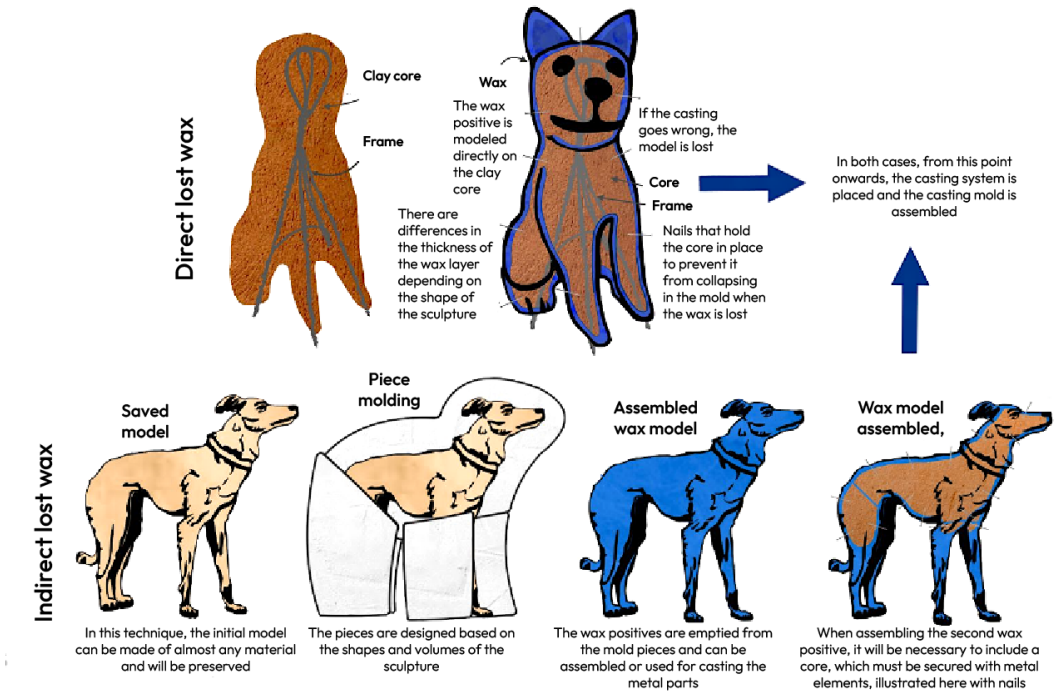

Figure 1. Comparison of casting techniques: above, direct lost-wax casting, in which the wax model is directly coated with a ceramic mold for casting; below, indirect lost-wax casting, which uses a piece mold to generate a new model that is coated with the ceramic mold, into which the liquid metal will be poured (Drawings: courtesy of the author).

Monumental equestrian sculptures made in parts

Production in parts is the first technological style to produce monumental equestrian sculptures addressed in this article.[5]

When discussing this topic, the statue of the Roman emperor Marcus Aurelius in Rome is often mentioned, one of many such statues at the time, but the only one that has been preserved to this day.

Those who made sculptures in ancient Rome poured liquid metal into the areas that had to be joint together, which required both the surfaces and the filler metal to be hot, since liquid metal does not bind to cold metal (McCreight, 2004, p. 67). This was accomplished by heating the surfaces directly over the fire or reeds, however, the process did not produce firm welds, but rather discontinuous and imperfect ones, such as those seen in the *Marcus* Aurelius. This is because the heat reached did not allow the liquid metal to wet and bond the surfaces properly; in addition, they surely had undergone numerous repairs throughout their history (Melucco 1992, p. 116).

[5] Prior to lost-wax casting, metal sculptures were produced using the *sphyrelaton* technique, which consists of sheets of bronze or copper hammered onto a wooden core, assembled and riveted together.

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Figure 2 summarizes information about the chronology and production of the sculpture, such as the use of piece molds.

Sculpture	Date	Sculptor	Founder	Manufacture
Marco Aurelio, Roma	Around 170 A.D.	Unknown		Lost wax and molds for the pieces of each section, seventeen parts for the rider: head, arms, legs, and hands sections. Fifteen pieces for the horse: eight for the body, legs, and tail, besides the muzzle and the neck. Sections joint by assembly (Melucco, 1992, p. 116; Marabelli, 1991; Schenker, 2003).

Figure 2. Production data for the monumental equestrian sculpture of Marcus Aurelius, Rome.

With the fall of the Western Roman Empire (476 A.D.), Western metallurgy also declined. Only at the end of the Middle Ages were artistic casting techniques recovered to produce the bronze doors of European cathedrals, thanks to the work of expert founders, influenced by Middle Eastern techniques and, since 1453, by the migration of those who, after the fall of the Eastern Roman Empire, left Byzantium (Corredor, 1997).

During the Renaissance, the emergence of a small but powerful class of *condottieri*[6] in the Venetian republic re-ignited interest in large equestrian statues and lost wax. Among Lorenzo Ghiberti's (1378-1455) apprentices that were learning to produce the doors of the Florence Baptistery was a young man nicknamed *Donatello* (1386-1466), who later modeled and cast the statue of the *condotiero* Gattamelata. This was the first full-scale equestrian statue cast after the fall of the Western Roman Empire, achieved by casting pieces (Schenker, 2003).

Equestrian sculptures stood as evidence of power in the territories of present-day Italy and were later requested in other places. Their export to France and Spain by sculptors such as Giambologna and Pietro Tacca was made easier because they were made in parts, keeping their weight relatively low.

Figure 3 shows European monumental equestrian sculptures made in parts and assembled between 1444 and 1642: Donatello's Gattamelata in Padua, Verrocchio's Bartolomeo Colleoni in Venice, and the statues of the Spanish monarchs Philip III and Philip IV in Madrid.

[6] Mercenary soldiers, captains of fortune who played an important role in the military and political events of Italy in the 14th, 15th, and 16th centuries (García, 2015, p. 38).

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It is very important to note that these sculptures have welds like those of the *Marcus Aurelius*, fillers that make it possible to homogenize the surfaces, achieving continuity and strengthening the mechanical assemblies.

Sculpture	Date	Sculptor	Founder	Manufacture
Gattamelata, Padua	1444 and 1453	Donatello (1386-1466).		Banker Giovanni Orsato, in his account keeping, where he details the copper and pewter quantities that were taken from Venice to Padua to smelt the sculpture, claims it was smelted in parts (Fémelat, 2013, p. 142).
Bartolomeo Colleoni, Venice.	1479-1496	Andrea del Verrocchio (1435-1488).	Alessandro Leopardi (1466-1512).	Verrocchio managed the horse to keep its front-left leg up in the air without giving it any support (Fémelat 2013, p. 143). After his death, Alessandro Leopardi smelt it and worked on its finishes, placing the sculpture in 1496. It was professionally restored in 1999 by the World Monuments Fund (2014). As shown in Figure 4, it is comprised by 16 assembled parts in precise positions and and weld by pouring metal —complementary casting—. The rider weights 1,300 kilos and the horse 5 tons. Its alloy is ternary: copper, pewter, and lead; and on the welds: copper, pewter, lead and between 3 and 13.2% zinc. The addition of zinc was intentional (Morigi and Ridolfi, 2008, p. 4-5).
Cósimo I, Florence	Inaugurated in 1594	Jean Boulogne/ Giambologna/ Juan de Bolonia (1529-1608).	Antonio Susini (1558–1624), and 2 cannon casters.	Sculptor Giambologna's works are renowned for the way in which he handled copper and piece molding. The smelter Antonio Susini executed a majority of the smelting operations. In its final size, the model was ready in 1591. The molds were arranged in a pit and packed along with earth to protect them from the metal pressure during casting. The horse was smelted in a single cast in September, 1592; and the rider in 1594. The composition of the cape (analyzed part) is 89% copper, 10% pewter and traces of lead, which aligns with the description of *bronzo bombarda* or cannon metal, a copper alloy comprised of between 8 and 12% pewter (Bewer, 1996).
Ferdinando I de Medici, Florence	1602-1608	Giambologna (1529-1608) and Pietro Tacca (1577-1640)		There is no information about its sections. Although a respectful intervention was carried out in 1996, there are no reports of material analyses or production techniques (Francini, 1996). It was casted with bronze from the cannons that were captured by the Knights of the Order of Saint Stephen in what today is Tunisia and Algeria, as stated in the horse's girth: *De 'metallirapiti al fero Trace* (In metals taken from the fierce Thrace).

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Enrique IV, Paris	Inaugurated in 1614	Giambologna (1529-1608) and Pietro Tacca (1577-1640)		It was made by Giambologna and, after his death, finished by Pietro Tacca. It was inaugurated in 1614; by then, Giambologna and King Henry IV were already dead, but the sculpture achieved international acclaim for being the first of its type in France (Barraclough, 1999). It was taken down in 1792 during the French Revolution, but it was restored —produced using a different technological style— in 1818.
Felipe III, Madrid	Inaugurated in 1616	Giambologna (1529-1608) and Pietro Tacca (1577-1640).	Pietro Tacca (1577-1640). Antonio Guidi (¿?-¿?).	The smelting was made using lost wax in Florence, in pieces that were taken to and assembled in Madrid. There is no relation between its sections, since the necessary research in a professional restoration process has not been done. The sculpture can be seen in Figure 5
Felipe IV, Madrid	Inaugurated in 1642	Pietro Tacca (1577-1640).	Pietro Tacca (1577-1640) Ferdinando Tacca (1619-1686).	The statue was built in parts. Horse: head and neck; chest and girth; back and hindquarters, head, ears, mane, and bit. Each of the front legs and the right manes are joint to the chest; the girth to the hind legs. The girth hides the joint between the two pieces that comprise the horse's body. King: head, chest to which two of the arms are joint, abdomen with a saddle and the thighs, and the two joint legs. Furthermore: general banner, sword, flare, and reins. In 1640 it was shipped to Spain and in 1842 it was inaugurated in Madrid (Matilla 1997, p. 25-26; Barrio and García 2009, p. 289). The sculpture of Felipe IV can be seen in Figure 6.

Figure 3. Production data of monumental equestrian sculptures produced in Italy in parts and assembled.

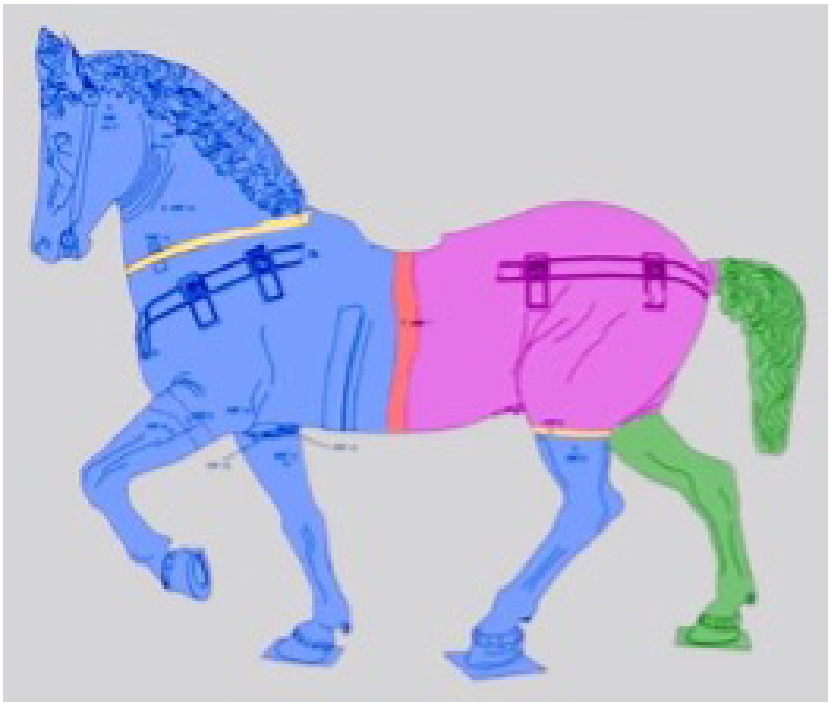

Figure 4. Diagram of the pieces that make up the horse in Bartolomeo Colleoni's equestrian statue (Source: World Monuments Fund. (2014). *Restoration of the Bartolomeo Colleoni Monument*. https://www.wmf.org/content/restoration-bartolomeo-colleoni-monument).

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Figure 5. Philip III: equestrian statue by Giambologna, cast by Pietro Tacca. Lost-wax copper alloy. 1616. Plaza Mayor, Madrid (Photograph: courtesy of the author, 2019).

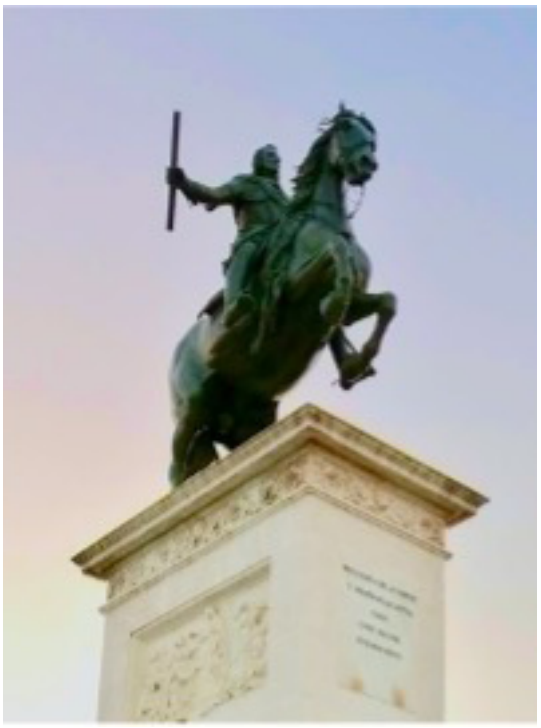

Figure 6. Philip IV: equestrian statue by Pietro Tacca. Lost-wax copper alloy. 1642. Opposite the Palacio Real, Madrid (Photograph: courtesy of the author, 2019).

Monumental equestrian sculptures made in a single casting

The second technological style to be addressed refers to equestrian sculptures made in a single casting. This idea originated in the workshop of Andrea del Verrocchio, in Florence, with his famous apprentice, Leonardo Da Vinci (1452-1519), who proposed changes in the way of producing monumental equestrian statues.

In 1482 Da Vinci was commissioned by Ludovico Sforza, Duke of Milan, to produce his equestrian statue, which, being 7.3 m tall, would be the largest in the world. Leonardo worked on it for the next 17 years, planning to produce it using a new indirect process in a single casting, with which he sought to eliminate the traces of joints that, according to him, were disfiguring and ruined the statues made in several pieces (Fémelat, 2013; Bewer, 1996).

In the second Madrid Codex, at the Biblioteca Nacional de España (National Library of Spain), his notes on the casting can be consulted, displaying the technological knowledge of the time in 34 pages. The method was a complex one: an external, reinforced mold —as can be seen in Figure 7— made using the clay model is

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internally coated with wax or potter's clay and a countermold of refractory clay is made inside; the wax or clay layer is removed, the molds are then baked and placed for casting the liquid metal (Fémelat, 2013).

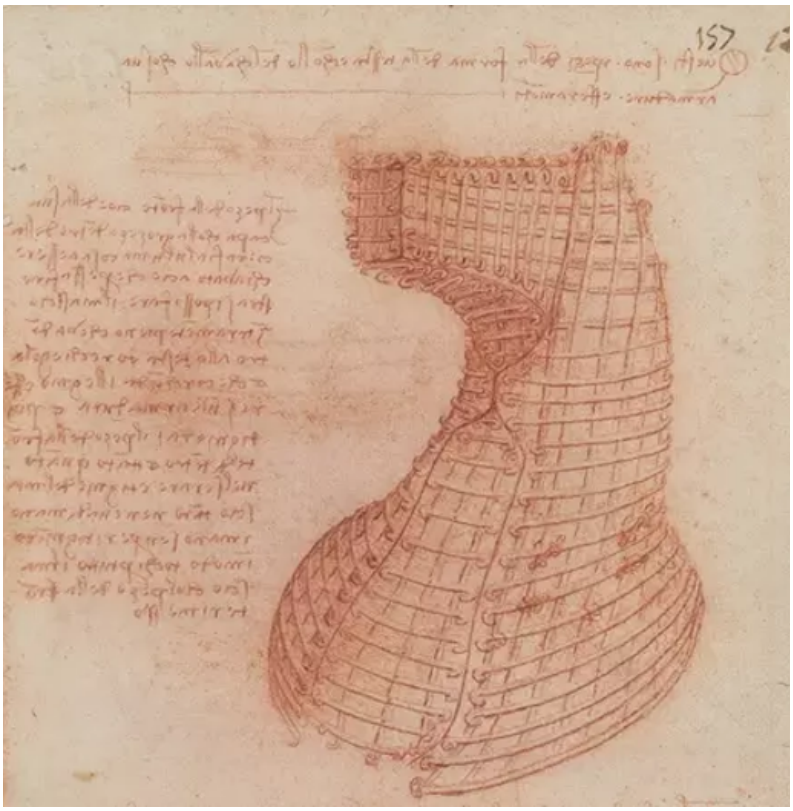

Figure 7. Drawing of the reinforced mold for the horse's head, Codex Madrid II (folio 157r) (Source: Google Arts and Culture, https://artsandculture.google.com/story/0AXhq8B37bafVg?hl=es).

However, the work for Sforza was never completed. In 1499, when the full-scale clay model —*Il Cavallo*— and the necessary molds were complete, French troops took Milan in the Italian War. This forced the Duke to use the bronze allocated for the sculpture to fabricate cannons and ammunition instead. During the conflict, the molds were lost and the archers of the French troops used the model as a target for shooting practices, destroying it (Fémelat, 2013).

The first monumental equestrian statue made in a single casting —rider and horse— was the *Louis XIV* in 1699, by François Girardon (1628-1715), cast by Jean Balthazar Keller (1638-1702). Although inspired by the form described by Da Vinci, Keller found a different way to cast rider and horse together. It is said to have been almost 6.5 m tall and to have used 36 tons of metal in its casting (Desmas 2014, p. 234). Following the format of the previous tables, Figure 8 shows information about this equestrian sculpture, which marked the development of this technological style.

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Sculpture	Date	Sculptor	Founder	Manufacture
Luis XIV, París	Modelo de yeso desde 1685. Fundida en 1692 inaugurada en 1699. Plaster model from 1685. Inaugurated in 1692.	Francois Girardon (1628-1715).	Johan o Jean Balthazar Keller (1638-1702).	The first monumental equestrian sculpture made in a single casting. It represents Louis XIV with a commanding signal in his right hand. It began production in the autumn of 1685. Keller used a special alloy known as *bronze Keller*, whose composition is associated to the success of the melting process. The finishes took nearly seven years. It was taken down in 1792 during the French Revolution (Jollet, 2016; Batissier, 1846, p. 59). His left foot is stored in the Carnavalet Museum in Paris (Welter, 2014, p. 98).

Figure 8. Production data of the monumental equestrian sculpture of Louis XIV, the first to be made in a single casting that led to the development of this technological style.

Thanks to written documents, it is known that this type of production lasted from that time until the early 19th century, with barely any changes. The architect Germain Boffrand (1667-1754), who participated in the process, provided a detailed description of the casting of Louis XIV's statue in his treatise, published in 1743.[7]

Sculpture	Date	Sculptor	Founder	Manufacture
Luis XV, Bordeaux	1731- 1738 and 1739 1743	Jean-Baptiste Lemoyne II (1704-1778)	Brothers Varin, Pierre Varin (1678-1753) (Desmas 2014: 235; Champy-Vinas 2019).	Smelted in a single casting (rider and horse). In 1735 the model was completed. There were failed smelting attempts in 1738 and 1739; a successful smelt was achieved in 1741. Two years of finishes were required to inaugurate in 1743 (Schenker, 2003, p. 211; Champy-Vinas, 2019). It was taken down in 1792 during the French Revolution.

Figure 9. Production data of the monumental equestrian sculpture of Louis XV.

[7] *Description de ce qui a été pratiqué pour fondre en bronze d'un seul jet la figure equestre de Louis XIV: elevée par la ville de Paris dans la place de Louis le Grand, en mil six cens quatre-vingt-dix-neuf: ouvrage françois et latin, enrichi de planches en taille-douce.*

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The engravings that were included in Diderot and d'Alembert's *Encyclopédie*, published in 1771,[8] are an almost exact copy of those by Boffrand. Later, the production of Louis XV's statue by Jean-Baptiste Lemoyne II (1704-1778) was portrayed by the painter and engraver Jean Louis-Simon Lempereur (1728-1807), head of the Parisian city council. His notes and drawings were edited and published by the engraver and collector Jean-Pierre Mariette (1694-1768) in 1768.[9] These documents made it possible to produce other monumental equestrian sculptures in a single casting, *d'un seul jet* (Schenker, 2003, p. 212; Desmas 2014, p. 235; Desmas 2017, March 24; Desmas 2017, March 31).

The material and cultural context of the time was conducive to monumental equestrian statues becoming a French specialty (Fémelat, 2013, p. 148). As the works made in a single casting were considerably heavier than those made in parts, it was easier for French sculptors and founders to travel to other countries to do the modeling and casting. Only in Lisbon and Mexico City these sculptures were made without the participation of French artists. Figure 10 includes monumental equestrian sculptures made between 1753 and 1790 in different European cities: Frederick V, by Jacques François Joseph Saly and Pierre Gor; Joseph I, by Joaquim Machado de Castro and Bartolomeu da Costa; Peter the Great, by Étienne Maurice Falconet, without a stable founder; and Gustav II Adolf, by Pierre-Hubert L'Archevêque and Gerhard Meyer.

Sculpture	Production	Sculpture	Founder	Manufacture
Federico V Copenhagen	1753-1771	Jacques François Joseph Saly (1718-1776)	Pierre Gor (1720-1773)	On February, 1764, a plaster model was ready. It was cast on March 2nd, 1768, having 300 guests as witness. Eighteen tons of metal were casted. The finishes required over three thousand fillings and patches, and continued until 1770. The sculpture was inaugurated on August 1st, 1771 (Lebon, 2012a).
José I, Lisbon	~1770-1775	Joaquim Machado de Castro (1731-1822)	Bartolomeu da Costa (1731-1801)	The first monumental equestrian sculpture smelted in a single cast that did not involve any French craftsman whatsoever, but based on the Boffrand and Lempereur-Mariette treaties. In October, 1774, there was a smelt so successful, only 7 months of finishes were necessary (Desmas, 2014, p. 239; Gomes, 2017, p. 612). Its composition was approximately 81% copper; 14% zinc; 2.6% lead; and 2.4% pewter (Matteini, et al., 2016, p. 81).

[8] *Bronze, Sculpture Fonte des Statues Équestres.*
[9] *Description des travaux qui ont précédé, accompagné et suivi la fonte en bronze d'un seul jet de la statue équestre de Louis XV le Bien-Aimé. Dressée sur les mémoires de M. Lempereur, ancien echevin.*

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Peter the Great, Saint Petersburg	1770-1782	Étienne Maurice Falconet (1716-1791)	With no permanent smelter: Benoit Ersmann (n.d), (Lebón, 2012a), Emelian Khailov (n.d.) Abraham Sandoz (n.d.) (Schenker, 2003).	An attempt was made to smelt it in a single casting: its rearing design, Falconet's stubbornness, and the lack of a permanent smelter made the operations more difficult. Ersmann prepared the core and the frame; touched up the wax mold; placed the frame system; and prepared the smelting mold, but was fired before the casting. In 1775, filled with nearly 20 tons of furnace load, the smelting mold broke during the casting which started a fire. Emelian Khailov, master artillery smelter, stopped the fire, but the casting was useless from the level of the rider's arm and upwards. In 1777, there was a second complementary casting with minor mistakes. The finishes were made by the Swedish clockmaker Abraham Sandoz. It was inaugurated in 1782 (Schenker, 2003; Lebon, 2012b, p. 137).
Gustavus Adolphus, Stockholm	1772-1790	Pierre-Hubert L'Archevêque (1721-1778)	Gerhard Meyer (1704-1784) Charles Adam (n.d.)	Smelter Gerhard Meyer tried to finish the smelt by casting the entire sculpture: horse, rider, and stand in a single operation. The result was catastrophic. For five years, chiseler Charles Adam and two assistants had to perform thousands of reparations (Cederlund, 2011, p. 114). After 17 years of manufacture, the monument was inaugurated in 1790 (Duffey, 1982, p. 60), 11 years after the death of the sculptor.

Figure 10. Production data of other important monumental equestrian sculptures made by lost-wax casting in a single casting in Europe.

Figure 11. Joseph I: equestrian statue by Joaquim Machado de Castro. Lost-wax copper alloy. 1774. Praça do Comércio, Lisbon (Photograph: courtesy of the author, 2022).

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Equestrian statues in America

Although there were projects to place metal equestrian statues in the Americas, the first one, made in England, was transported to New York. Portraying the English king George III on a rampant horse, it was the work of Joseph Wilton (Kauffmann, 1902, p. 114), made in parts, of lead and gilded gold, it is said it weighed approximately 1,800 kg and was almost a meter (three feet) higher than life-size (Ruppert, 2014).

It was dedicated on August 21, 1770 and, after the country's declaration of independence, it was toppled on July 9, 1776 (Kauffmann 1902, p. 114). While it is said to have been turned into bullets, some pieces have been unearthed, such as the monarch's head and part of his horse's tail, now located at the New York Historical Society (Ramirez, 2005).

Carlos IV, *El Caballito*

Its production technique was fully confirmed during the conservation project, carried out between 2016 and 2017, thanks to characteristics such as the great thickness of the metal walls, the impossibility of welding such thick walls with the available technology, the absence of assemblies —with the exception of patches for casting defects, the secondary casting of the mane, and the closure of the hole in the crank used to remove the core—, confirmed even by X-ray imaging, the knowledge of the production processes, the history of the technology (INAH, 2017) and detailed information within the budget that Tolsá sent to the viceroy.

Subsequent work used the results of the conservation project to understand its production *chaîne opératoire*. Material, historical, and technological information was also used for this purpose, both from bibliographic and hemerographic sources —the single casting is mainly documented in the descriptions of the *Gazeta de México*, *El Diario de Madrid,* and *Los tres siglos de Mejico durante el gobierno español hasta la entrada del ejercito trigarante*—, as well as from records, the treatises of Boffrand and Lempereur-Mariette, and the *Encyclopédie* of Diderot and d'Alembert —the described technique coincides with the material evidence observed—. Documentary analysis of similar works, along with inquiry to Ernesto Contreras Ballesteros, a founder with more than 70 years of experience in copper alloys statuary, were central to the research (Contreras, 2021).

Although there is no evidence that Tolsá brought the documents of Boffrand, Lempereur-Mariette, or the work of Diderot and D'Alembert to New Spain (Alcántar & Soriano, 2014, p. 39), he may

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have had contact at the Royal Academy of Fine Arts of San Fernando with the models made for the commission of the equestrian statues of Philip V and Charles III (Martin, 1994, p. 15-16) , which, despite not getting cast in metal, could give him the opportunity to study them and, together with the boilermaker and bell founder Salvador de la Vega, to recreate the production *chaîne opératoire* of monumental equestrian sculpture in a single casting (Contreras, 2021, p. 198).

Figure 12 shows information about the equestrian statue of Charles IV in Mexico City, sculpted between 1796 and 1803 by the sculptor Manuel Tolsá and the founder Salvador de la Vega, the only one produced in a single casting —rider and horse— on the American continent.

Sculpture	Date	Sculptor	Founder	Manufacture
Charles IV, Ciudad de México	1796-1803	Manuel Tolsá (1757-1816)	Salvador de la Vega (n.d.) and Manuel Tolsá himself (1757-1816)	Smelted in a single casting (rider and horse). Its alloy is mainly comprised by copper (87.5-93.5%), lead (4-8%), pewter (1-3%), zinc (~1%). Tolsá had to deal with pirates stealing part of the metal, and, fortunately, the frequent earthquakes did not damage the mold while he was waiting on the zinc. The casting was so good, only 14 months of finishes were necessary. Its coloration was achieved through a pictorial green finish, as Alejandro de Humboldt described. The more recent color black was noted to be layers of asphalt, wax, and soot. It was damaged in 2013 and restored between 2016 and 2017 (INAH, 2017).

Figure 12. Production data of the monumental equestrian sculpture of Charles IV, *El Caballito*.

Figure 13 illustrates the sequence of steps in the production of sculptures using the indirect lost-wax technique in a single casting. From the design and selection of materials to casting, finishing, and installation, it reflects the creative and technical process behind these works.

At the time *El Caballito* was produced, it was internationally known that Maurice Falconet's stubbornness and boastfulness were blamed for the casting failure and the fire that delayed the completion of the sculpture of Peter the Great for almost a decade, because he made its walls too thin (Schenker, 2003, p. 235). This explains why Tolsá and De la Vega's sculpture has an average thickness of around one inch, and even thicker sections, such as in the folds of the king's cape (INAH, 2017), seeking to ensure a

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successful casting,[10] which was so good that the finishes took only 14 months.

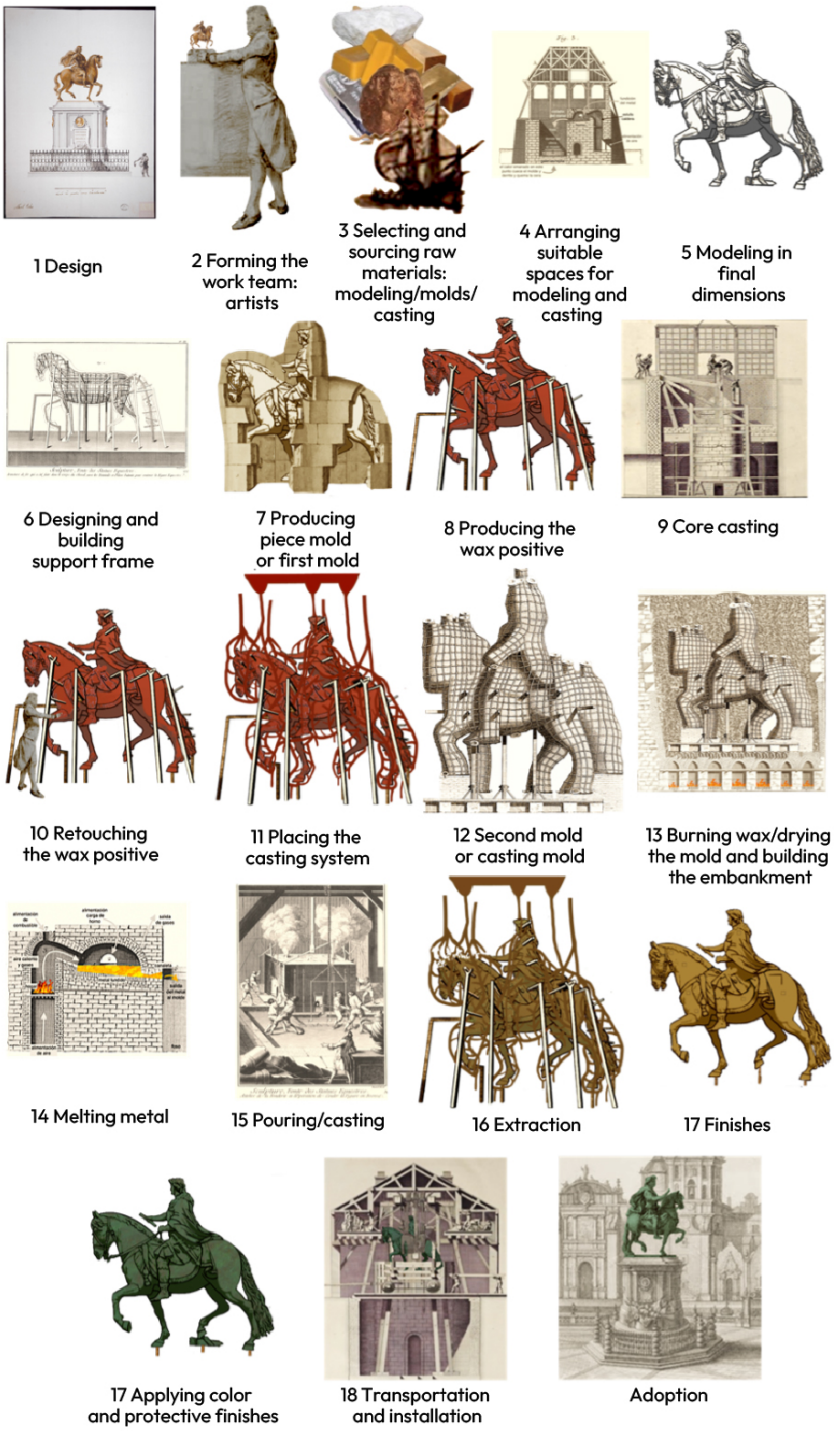

Figure 13. Outline of the sculpture production process using the indirect lost-wax technique in a single casting, illustrating its operational chain: 1. Design; 2. Forming the work team: craftsmen; 3. Selecting and sourcing raw materials: modeling, molds, and casting; 4. Arranging suitable spaces for modeling and casting; 5. Modeling in final dimensions; 6. Designing and building support frame; 7. Producing piece mold or first mold; 8. Producing the wax positive; 9. Core casting; 10. Retouching the wax positive; 11. Placing the casting system; 12. Second mold or casting mold; 13. Burning wax and drying the mold; 14. Melting metal; 15. Pouring and casting; 16. Extraction; 17. Finishes, including applying color and protective finishes; 18. Transportation and installation.

[10] French politician Charles-Jean Lafolie (1780–1824) explained that the caster preferred to make the casting thicker to facilitate the entry of metal into all parts of the mold (Lafolie, 1819, p. 143).

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Figure 14. Equestrian statue of Charles IV by Manuel Tolsá. Lost-wax copper alloy. 1803. Plaza Tolsá. Mexico City. Horse and rider were cast in a single operation. On the left, general view; on the right, illustration of the casting in a single operation, green section achieved in a single casting, the elements in white were added, including the complementary casting of the mane, the pedestal, and ornaments. (Photographs: Francisco Kochen, 2017; courtesy: INAH, 2017; image on the right modified by the author).

Such feats in producing this work characterized Tolsá, De la Vega and their team, who had no experience in monumental artistic casting, whereas much more experienced casters struggled with similar ventures. They got one of the best castings of all those made in this technological style between the late 17th century and the early 19th century, because only the equestrian statue of Joseph I, in Lisbon, was completed in a shorter time —just over 7 months— despite not having any French artists either and its creators lacking experience in castings of this sort. The sculptor himself, Machado de Castro, stated that they worked based on written references and the experience of military engineer Bartolomeu da Costa (1731-1801), a cannon caster.

El Caballito was on the verge of being destroyed, like some of its French counterparts, because only seven years after its inauguration, in the face of the questioned government of Fernando VII and the French intervention in Spain, wars of independence broke out all over Latin America. Therefore, the effigy of a Spanish king was not well regarded and efforts turned toward casting weapons.

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Tolsá himself was instructed to use the facilities where *El Caballito* was cast to produce cannons (Alcántar & Soriano, 2014).

However, at least one monumental equestrian sculpture was produced in a single casting. In Paris, during the Restoration, Francois-Frederic Lemot (1771-1827) emulated and replaced the destroyed work of Pietro Tacca representing Henry IV, whose data is included in Figure 15.

Sculpture	Date	Sculptor	Founder	Manufacture
Henry IV, París	1818	François-Frédéric Lemot (1771-1827).	Piggiani, and Jaquet (Babelon, 2008).	A replenishment made in a single casting from the one that was destroyed during the French Revolution. The infrastructure seemed to be insufficient to smelt the Keller alloy, so they made many changes that did not let them appropriately smelt anyway: the king's body had several holes and the core fell to the horse's abdomen, leaving in its place vitrified sand mixed with bronze. It had to had several expensive reparations. It was placed in 1818 (Daly, 1842; Babelon, 2008).

Figure 15. Production data of monumental equestrian sculpture of Henry IV.

After gaining independence, the economies of American countries were not in a position to produce monumental sculptures. The sculpture of Antonio López de Santa Anna, Mexico's dictator, was an exception, and although information on this sculpture is scarce, it is said to have been 3 meters tall and made of bronze (De la Garza, 2011). To produce it, businessman José Rafael Oropeza hired the Spanish sculptor Salustiano Veza (Zárate, 2003, p. 420). It was cast on March 5, 1844 by José López, of whom no other information is available. The newspaper *El Siglo Diez y Nueve* of March 13, 1844, noted it was the first time that a Mexican had executed a remarkable work of casting for a public monument. However, Santa Anna ended up being more disliked than the Spanish king. In 1844 the piece was toppled for the first time and reinstalled at the Plaza del Volador two years later; in 1855 it was finally destroyed (Díaz, 1971).

SUBSEQUENT FORMS OF PRODUCTION: ASSEMBLIES AND WELDING

The first equestrian statue made in the United States was that of the now controversial effigy of General Andrew Jackson by the sculptor Clark Mills (1815-1883) and the founder Carl Ludwig Richter, inaugurated on January 8, 1853. It was made in 17 parts by

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sand casting and mechanically assembled (Martner, 2011, p. 417; Colletta, 2011, p. 6).

In the second half of the 19th century, Latin America took advantage of the educational significance that bourgeois liberal beliefs placed on public monuments. The *epidemic of statuomania* (Ramírez & García, 2018) reached such levels that sculptures had to be purchased from Italy, France, and Spain to fill urban spaces.

In Mexico, several equestrian sculptures were planned: the Catalan sculptor Manuel Vilar i Roca (1812-1860) would produce the sculpture of José de Iturbide. The budgets laid out the possibility that "Mr. López" —possibly the same person who may have cast that of Antonio López de Santa Anna— or Got Bontemps and company (Báez, 2003), who were iron casters (Silíceo, 1857, p. 80), would be in charge of the casting. Despite the effort, the project never made it past the sketch stage and was definitively canceled in 1860 by orders of President Miguel Miramón (Espinosa, 2015). Miguel Noreña (1843-1894) also considered producing one of Vicente Guerrero (1868) but failed to get it cast in metal. (Ramírez & García, 2018).

The government of Porfirio Díaz supported the training of the extraordinary sculptor Jesús Fructuoso Contreras Chávez (1866-1902) in Parisian foundries, to reduce the importation of sculptures from Europe and establish the Fundición Artística Mexicana (Mexican Artistic Foundry) in 1892 (Cruz, 2018; Ramírez & García, 2018). Contreras's large-scale works were made in parts, using mechanical joints (López Arriaga, personal communication, 2024): they were not cast in a single pour.

The technology that allowed welding large thickness materials, such as autogenous welding or electric arc welding, was available until the end of the 19th century (IARC, 1997, p. 146; Cary and Helzer 2004). In 1836 Humphry Davy (1778-1829) and Jöns Jacob Berzelius (1779-1848) discovered acetylene. However, it was at the turn of the century, in 1895, that Henry LeChatelier (1850-1936) discovered the joint combustion of oxygen and acetylene which enabled the development of the welding torch (Malone 1918: 479, 482).

The 20th century already had commercially available portable oxyacetylene systems. For their part, in 1890 Nikolay Nikolayevich Benardos (1842-1905) and Stanislaw Olszewski (1852-1898) invented the elements that would later enable carbon arc welding, colloquially known as coal welding, the precursor to electric arc welding (WeldingHistory, n.d.)

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Figure 16. Back view of one of Jesús F. Contreras' reliefs for the 1889 Paris World's Fair, now in the Museo de Aguascalientes. Although it's not an equestrian sculpture, this work was created by casting sections and using mechanical joints (Photograph: courtesy of Marcela López, 2017).

CONCLUSIONS

The development of the lost-wax casting technique to depict leaders in monumental equestrian sculptures can first be seen in sculptures made in parts that are the result of the work made by artists such as Donatello, Pietro Tacca, and Giambologna and which spread from Italy to various parts of Europe. Later, in the late 18th century, the influence of Leonardo's project for Sforza prompted the development of monumental single casting, which, replicating the technique used to produce the equestrian sculpture of Louis XIV, by François Girardon and Baltazar Keller —disseminated by French artists who settled for long periods where equestrian statues would be produced—, consolidated as a technological style.

Although monumental single casting has been replaced by simpler and more accessible techniques, such as the mechanical joint or oxyacetylenic and electrical welding, it was the standard for the production of monumental equestrian sculptures for more than a century (1699-1818).

Fundamental to the conservation project, carried out between 2016 and 2017, the analysis concluded —based on structural studies, radiographs, documentary analyses, and inquiry with an expert founder— that this sculpture was produced in a single cast, thus correcting inaccurate assertions that it was made in parts. When reconstructing its *chaîne opératoire* considering material sources, bibliography, and treatises such as those of Boffrand and Lempereur-Mariette, and Diderot and d'Alembert, it can be ascertained that, although there is no evidence that Tolsá brought these docu-

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ments to New Spain, at some point he must have been in contact with one or more of them so that, together with Salvador de la Vega, he could replicate the production in a single cast, almost as successfully as the statue of Joseph I in Lisbon, and unlike the problematic production of the sculpture of Peter the Great.

A comprehensive study of monumental equestrian sculptures cast in copper alloys helps us identify technological advances, stylistic transformations, and the technical mastery achieved across different historical periods, shedding light on the cultural contexts that gave rise to these works. This article illustrates the importance of conservation both for material preservation and for understanding the technological styles of production, the history of the technology, and the distinctive features of each work, all of which contribute to better determining the criteria and decision-making process involved in their study and conservation.

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