The Gates of Paradise
LORENZO GHIBERTI'S RENAISSANCE MASTERPIECE

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Casting the Panels of the Gates of Paradise

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Introduction

"I executed this work with the utmost diligence and discipline, and it is the most singular creation that I have produced, reflecting every art, measure, and invention at my disposal." This is how Ghiberti described the Gates of Paradise in his Commentarii. These writings, which record the principles behind Ghiberti's painting and sculpture—disciplines that at the time were shifting in the general perception from craft to art—also highlight the major role the artist played in the early Renaissance.

Aside from a few references to metal alloys, Ghiberti's account does not touch on his rediscovery of art foundry techniques from the age of the "white temples," nor does he discuss the metalworking processes he used. Perhaps he did not yet consider it the right time to try to legitimize this type of work, or he may have planned to cover these methodologies at some later point in the Commentarii, in the portion that was left unfinished. It does not seem likely, however, that he failed to make reference to the significance of metalworking and the methods used—much discussed by a range of authors in the following century—solely because he did not wish to reveal his processes or the nature of his methodology. This is even more obvious if we consider that by the early fifteenth century, after the second Baptistery doors were created, Ghiberti's workshop had become a reference point for many others ("I have received great honors in their works") and was undoubtedly the period's most important training center for artistic casting. Such renowned early Renaissance artists as Michelozzo, Donatello, Paolo Uccello, and others were members of the shop.

Ghiberti's pride in playing this role likely motivated another glaring omission from his commentary on modern art—there is almost no information about his own training, with the exception of a vague reference to his family life. He states, "My soul was focused mostly on painting," and then a few lines later he celebrates his victory in the contest for creating the second Baptistery doors in bronze, his "first work" of sculpture.

Despite these omissions, Ghiberti's account is the only source that offers any concrete insight into the metalworking techniques of the fifteenth century, information gleaned chiefly from his chronology and the detailed description of his works (e.g., the artist's "hierarchy" of materials: bronze,
brass, fine brass, and gold). In fact, no studies or archival documents exist containing information on casting techniques, despite the impressive bronze production of the period. The only contributions other than Ghiberti's are found in the Zibaldone of his nephew Buonaccorso, and the notes of Leonardo da Vinci in the Codice Atlantico, which can be dated to the end of the century and which in any case focuses on the preparation of molds for casting bells and artillery.

What was drawn from “ancient commentaries,” Pliny’s encyclopedia Natural History, Theophilus’s treatise On Diverse Arts, or from other lost sources—as well as what was newly introduced—cannot be derived from direct or indirect testimony. Neither can workshop techniques simply be reconstructed by transferring technical descriptions from Gaurico, Vasari, Cellini, and Biringuccio to the prior century. Even in their own context, these texts require interpretation, verification, and integration regarding many working procedures.

Technological Study of the Gates of Paradise

For several decades now, greater credence has been given to the idea that a history of art foundry techniques can be best written by using a multidisciplinary scientific approach based on close study and instrumental analysis of individual pieces. The call for experimentation has been growing louder as well. Using these methods, a significant amount of information on ancient processes has been assembled, and the first important results with regard to Renaissance bronzework are beginning to emerge, although we are far from painting a complete picture and disagreements and often debatable interpretations abound.

Various issues make reconstructing technical processes through the study of the original work, macro- and micro-structural peculiarities, compositional analysis, and experimentation especially complex. Additional related factors arise from the inherent multiple interpretations of archaeometric data, the difficulty of determining reliable and representative analytical data, and the obstacles encountered when trying to plan, conduct, and summarize a multidisciplinary study. Even in the face of valid analyses, conclusions too often take the form of distinctly separate summaries in which each party attempts to provide interpretations that are cohesive in and of themselves, thereby inevitably sidestepping the problem of interaction, agreement, and harmonious coexistence with the others.

The approach to studying Renaissance bronzes endorsed by the Opificio delle Pietre Dure in Florence was developed with an awareness of these issues and of the need to get past them, and of the limits of planning and interpretation that run the gamut from “too academic” to “too empirical.” A working method was chosen based on ongoing coordination of the various disciplines and professionals involved, thereby ensuring interaction and mutual agreement on the ensuing results.

Study of the processes used to create the Gates of Paradise—the metalworking knowledge that developed in Ghiberti’s workshop—comprises a fundamental step in this research. The chance to carry out an accurate study of the ten main panels and eight ornamental panels removed for restoration, together with the availability of advanced analytical methods, allowed for exhaustive comparison, which means we avoided an entire series of limitations encountered by past work-groups due to certain specific technological aspects of this complex masterpiece.
Provided here is a summary of the interpretive developments regarding techniques for casting the panels. These were formulated on the basis of information drawn from studying and analyzing the alloys of nine of the ten main panels, X-rays of panel VIII (Joshua), experimentation, and information that emerged through metallurgical studies undertaken in the early 1980s.²

The Preparation of Waxes
On the backs of the panels are indentations that clearly, if somewhat roughly, follow the projections on the fronts. For example, on the back of panel II (Cain and Abel), one can see a negative image of not only the three figures that project from the lower section of the front (a pair of oxen and the two representations of Cain), but also of all the rest of the panel, including less prominent areas such as the sacrifice scene (fig. 7.1).

These indentations are characteristic of indirect lost-wax casting, in which a positive wax relief to be cast in metal is produced using a negative mold of the initial model, which has been sculpted from a plastic material (wax, clay, etc.). In the case of these panels, creation of a mold indicates that the model's projections were cut when necessary, as were any undercuts that might have stood as impediments to extraction.

The use of the indirect technique, defined clearly by Leoni as use of a "salvageable mold," is also supported by the presence of numerous other morphological details on the backs of the panels, the surfaces of which quite closely resemble the surfaces of the wax models used for casting, with the exception of areas that were chiseled off or filed down.

The presence of numerous drips, brushstrokes, and manual thickening of the corners, with fingerprints visible in some cases (fig. 7.2), confirms that the various steps involved in creating the wax relief were performed from the back of the relief, working with a horizontally positioned mold. Furthermore, such evidence suggests certain methods were also used to thicken the wax. Specifically, the regular and leveled profiles, together with the presence of corners that are "reinforced" through local application of wax, suggest the use of the so-called "slush" technique, usually performed by first brushing on a thin wax layer in order to best capture all the surface details.

The "slush" phase continues by filling the entire mold cavity with liquid wax and waiting for it to harden to the desired thickness along the cavity walls. Once this process has been completed, the excess wax, while still liquid, is poured out into a container. In this way, uniform thickness is achieved, with the occasional exception of some corners where the hot wax has shifted, leaving thin spots. When this occurs, wax must be applied manually
as reinforcement. It is clear that this was done on some of Ghiberti’s panels (see fig. 7.2).

When numerous brushstrokes are detected along with the morphological characteristics discussed above, this indicates that additional liquid wax was applied either locally or over the entire surface after the slush and the possible reinforcement of the corners. This final step is performed after it has been determined that the first slush needs to be thicker. Conversely, if there are no brushstrokes and the profiles reveal abrupt undulations, sometimes accompanied by fingerprints, it is likely that the walls were thickened (in selected places or overall) by manual application of soft, pliant wax.

This second type of application applies to panels VI (Joseph), VII (Moses), VIII (Joshua), IX (David), and, at first glance, III (Noah), although such manual application is not always easy to determine, since the traces left vary greatly depending on the plasticity of the wax and the technique of the person applying it. In fact, this is starkly evident only on the back of panel VII, where we see the kind of deformation that frequently results from a thumb applying pressure, in addition to a large number of actual fingerprints (fig. 7.3).

There are, however, traces of brushstrokes on all or most of the back surfaces of panels II (Cain and Abel), IV (Abraham), and X (Solomon and Sheba). On panel X, the brush marks are not very visible due to the use of either
lumpy wax or coarse earth on soft wax. Representing a middle ground between these two possibilities are panels I (Adam and Eve), which has traces of brushstrokes on the upper part and shows signs of manual application on the lower part, and V (Jacob and Esau), which was painted only at the very top and bottom, with a small amount of manual activity in the remaining central area.

The use of the salvageable model technique and these conclusions about wax processes were further confirmed by studying three-dimensional digital images. For example, figure 7.4 shows details of the profiles of panels I and VII that clearly show strict front-to-back correspondence, and the greater grading of the front than the back, as compared to the unjustified variations in thickness that can be seen in panel VII, which may be attributed to manual deformation. In this last case, the presence of such strong modulations in which the wax is spread, as well as an average thickness that is less than those of the other panels (I, II, and VI were studied), led us to believe that the entire process had been performed manually. Such a significant conclusion would, however, require further verification and instrumental analysis of all the panels that present characteristics of spreading in their surface profiles.

Assuming that the above interpretations are correct, we can easily imagine what happened next, based on the standard art foundry processes still in use today. The wax relief was made in the mold and then was probably extracted and completed by working on the front, where projections that had previously been detached from the model and created separately would then be attached. Any background areas that had been left in rough form in order to allow the cast to be extracted would then be modeled directly. Various details would also be subjected to refinishing. The last step before covering the wax panel with an earth-based casting material (investment) would have been to create the channels, or spruing.

**Spruing and Gating**

X-ray studies of panel VIII (Joshua), together with information already gathered in the 1980s on panels II, VI, and IX, indicate the presence of macro-porosity concentrated in the upper region of the bronze relief (fig. 7.5). The frequency of this phenomenon leads us to exclude the idea that the molds were positioned horizontally during casting, although it does not allow us to determine whether the molds were perfectly vertical, either in a natural position (erect) or upside down.

Information from earlier radiographic studies indicates "upward bubbling"—evidence that the molds were vertically positioned—with the understanding
that the figures remained in their natural (or viewed) position. However, the weighty issue of establishing how compatible this interpretation is with the detailed traces of spruing found on the backs of all the panels was not dealt with, nor were theories formulated on the configuration and dynamics of the casting. Before turning to this important point, we present the evidence.

Strange markings (fig. 7.2) can be discerned on the backs of all of the panels. These may be interpreted as traces of channels that ran along the surface. Losses due to their removal and chisel marks produced during the cleaning phase indicate that molten metal flowed through these channels, which connected to the main cavity at various points. Figure 7.6, showing the backs of panels VIII (Joshua) and IX (David), demonstrates that the arrangement of such channels can be deduced from the traces. Highlighted in white on panel VIII are the principal areas where liquid metal traveled through the channels and the relief cavity. These correspond to the surface losses and marks mentioned above.

This is extremely significant given that no other similar cases of channeling on bronze works have been documented. Nowadays—and we believe this to be true for the past as well—spruing is arranged to run upward (siphon-style) and is joined to the casting surface at a certain angle of incidence relative to the perpendicular direction—usually between 0° and 60°—and in any case never parallel (90°), as we find here.

While examining the peculiar configurations of the imprints, we first wondered whether these marks might truly correspond to spruing, given that during initial examination the possibility had been raised that the traces had been left by a support structure for the wax made from pieces of cane that burned off during the firing of the mold and the filling of metal during casting.

Closer observation of the surfaces and the residual paths of the channels visible on panel IX (David) allowed us to verify that this structure, applied when the wax-thickening process was completed, was basically made from pieces of cane of an appropriate diameter that were cleaned and cut to size. These were placed on the surface, joined together with soft wax, and then fixed in place with other small daubs of wax (fig. 7.6). Nevertheless, given the peculiarity and significant variation among the marks left when they were removed from the backs of the panels, and the imperfect adherence of the cane to the wax panel that these suggest, we can exclude the possibility that the structure was intended to offer support. Instead, it may have been of some help during the extraction of the wax relief from the mold and its later manipulation, but its primary purpose was to serve as a spruing and gating system.

Based on the information above, we can interpret the use of channels adjacent to the panel’s surface as an ingenious solution that allowed the artist to overcome the difficulty of casting rather thinly across the width of the panel, which was further complicated by the use of a quickly hardening alloy (see below). Ghiberti probably went through a long period of experimentation in order to come up with this optimal system.

In addition to contact between the panel and the channels behind it, further observation turned up traces of predictable frontal connections between the projecting heads of figures and the main surface of the panel but no other gates, except for perhaps an additional channel on the back of panel II (Cain and Abel) and panel VI (Joseph).
Finally, there is a fundamental casting issue to be resolved: Where and how did the liquid metal enter the channels described above?

There are two possible approaches. In all cases, the central channel and the two corner channels in the lower portion of the panel (fig. 7.6) appear to be sized to meet just below the base, and it would thus seem that a natural entry point—what Tuscan casters refer to as a beveta (funnel-shaped cup for introducing the metal)—was located here. In this case, casting would have occurred with the metal flowing downward into the mold with the figures positioned upside down. Conversely, if casting took place with the panels in their natural position, upward or siphon casting must have been implemented. If we exclude, due to its obvious impracticality, the possibility that metal might have flowed from a single entry point at the bottom corresponding to the previously mentioned point where the channels met, the only remaining possibility is that the system was filled through contact with another network of channels situated farther from the surface.

There is little to support this latter theory that channels were inserted along the panel walls. In an earlier work, we theorized that such a longitudinal system might have resulted in creating an air-hole that would have helped reduce the number of bubbles in the cast metal if the mold had not been perfectly vertical but positioned at a slight angle. Despite its complexity, this possibility was taken into consideration, and since it bears greater similarity to the modern downward-casting technique, it promised more likelihood of success during the planned experimentation phase.

**Alloys**

There is a marked difference between the composition of the alloys used in the panels of the Gates of Paradise and those used by Pisano in casting the first door, by Ghiberti on the second door, and by Ghiberti for the framework of the Gates of Paradise themselves. Even though quaternary alloys of copper (Cu), zinc (Zn), tin (Sn), and lead (Pb), with significant traces of iron and antimony, were used for all, there are enormous variations in their relative weight percentages. Instead of the large amount of zinc present in earlier works (approximately 10 to 20%), which together with tin and lead amounted to somewhere between 17 and 26% total white metals, it seems that a bronze alloy with a low content of alloying elements was created especially for use in these panels. Table 1 provides figures for three panels, selected to give a representative overview of the whole.
Panel IX (David) contains the lowest alloying element content, with a total of 2.64% white metals, while the percentage in the others falls somewhere between the percentage for panel VII (Moses) and the percentage for panel I (Adam and Eve), which has a higher alloying element content.

These alloys lend themselves well to mechanical intervention, such as work with a punch or chisel, and on account of their high copper content and low lead content also lend themselves well to mercury-amalgam gilding. The low alloying content and minimal amount of lead, however, contribute to low fluidity and relatively high hardening temperatures, both of which make casting difficult. Like the choice of spruing, the choice of alloys was the end result of extensive preparatory study by the artist. It is therefore reasonable to believe that the spruing system was a direct consequence of the choice of alloy.

**Experimentation**

Once the studies described above were completed, we believed it would be useful to perform some specific casting experiments, in order to more closely examine the relationship between the information collected and the various identified phases of the work and, above all, to offer a cohesive interpretation of the configuration of the casting.

To begin, two “slushed” wax copies were made from a silicon rubber version of panel V (Jacob and Esau), with the most protrusive parts of the figures at the bottom removed. Following the conclusions of earlier study, after slushing it was necessary to reinforce some corners. Furthermore, the

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<th>SAMPLE</th>
<th>Cu w/o%</th>
<th>Sn w/o%</th>
<th>Pb w/o%</th>
<th>Zn w/o%</th>
<th>Fe w/o%</th>
<th>Ni w/o%</th>
<th>Ag w/o%</th>
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<td>0.14</td>
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<tr>
<td>I (Adam and Eve)</td>
<td>91.52</td>
<td>2.09</td>
<td>3.77</td>
<td>4.44</td>
<td>0.47</td>
<td>0.22</td>
<td>0.03</td>
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<tr>
<td>IX (David)</td>
<td>95.49</td>
<td>0.70</td>
<td>0.84</td>
<td>1.10</td>
<td>0.38</td>
<td>0.17</td>
<td>0.05</td>
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first of the two reliefs had to be thickened manually throughout because the time required had been underestimated.

The spruing contacts revealed by X-ray on the back of panel VIII (Joshua) provided us with a model. The sprues were made of canes joined to one another with wax. Small quantities of wax were then spread in the cavity between the pieces of cane and the panel walls in order to ensure thorough contact and subsequent transfer of liquid metal during casting.

Once the reliefs were removed from their molds, only one of the two was subjected to direct finishing on the front, while the other was left as it was. We then proceeded to apply a branched spruing system to the back, using the two different methods described above and the corresponding vents. For the first test, in both cases we chose to maximize the number of sprues, taking advantage of the frame as much as possible so that the attachment points would be rendered invisible after chasing. Figure 7.7 summarizes the various experimentation steps described above. Please note that in the photo in Figure 7.7(e), the downward branched spruing is on a copy of panel VI (Joseph), which was then replaced by another copy of panel V (Jacob and Esau) during experimentation.

In order to begin simulating the investment of the originals, we performed a series of preliminary tests using an earth-based slurry as similar as possible to the one found in small quantities on the backs of the panels. This mixture consisted of a clay binder, sand, and plant fiber (straw). The combination of materials, completely different from the substance used in present-day casting techniques (plaster and slaked plaster), made construction of the investment very painstaking and time-consuming.

This was followed by carefully brushing the wax with thin layers of a finer slurry—without any plant fiber—waiting after each application for the preceding layer to dry gradually and completely. Given how critical this work was since it risked compromising the entire experimental phase, we limited ourselves to creating a layer of earth only a few centimeters thick on the panels (figs. 7.8a and 7.8b) and then completed construction of the investment with a modern substance, which was also used to cover the second panel. It is interesting to note that the application of a layer of earth a few centimeters thick took more than one month's time.

After the forms were invested, they were left to dry for a few days. They were then subjected to moderate heat in order to remove the wax and gradually fired to a maximum temperature of approximately 600°. After slowly cooling, the molds were buried at a slightly angled position and then
filled with molten metal, using a quaternary alloy with a composition similar to the average of those identified for the various panels.

Results obtained using the panel with the downward spruing and plaster coating were excellent (fig. 7.8f)—intact walls, few drips, and good coverage of the surface. This result was quite significant, since it demonstrated for the first time the practicability of downward casting.

Conversely, the use of upward spruing using traditional investment with earth yielded gaps due to the settling of the mold in the central area. This incident, which is not particularly relevant for the purposes of evaluating the experiment, stemmed from excessive compression of the containment earth during burial. It is significant, however, that small drips formed in the lower section and that there were small bumps due to erosion of the mold (fig. 7.8e).

Both panels were then X-rayed in order to examine where bubbles had occurred and for comparison with panel VIII (Joshua). We were surprised to discover that there was no significant bubble formation in either case and therefore no discriminating factor that might have helped us to choose between the two methods. However, this fact turned out to be fundamental to working out the final resolution of the casting problem.

Discussion and Conclusions

The information that emerged from close study, three-dimensional scanning, and experimentation leaves no doubt regarding the techniques Ghiberti used to create the wax reliefs. This was performed indirectly, using molds made from models that had previously been sculpted by the artist. Direct modeling was then performed to attach the projections, which was followed by the finishing of certain details.

In order to emphasize again the solidity of this conclusion—rather than looking further into already considered technical details—we suggest that the reader look at figure 7.9, which provides a comparison between the original and the panel created through experimentation with slush. The almost exact match between the profiles of the cavities is evident. This, together with specific details in the profiles themselves, leads us to conclude that the working methods were similar. The differences, however, stem from the manual work performed on the original: the brushing, the presumably reduced fluidity of Renaissance-era wax, and the slightly different cut of the figures, in addition to the obvious differences between the plaster mold and the silicon rubber mold that we used. While there are no documents that refer explicitly to the working methodologies demonstrated here, we believe it is useful to offer some commentary on sixteenth-century treatises as well as Ghiberti's own accounts.
Vasari's detailed description of all the steps involved in the indirect method (sculpting the model, creating the mold, casting, etc.) leads us to believe that this was a widely used procedure. Furthermore, he reports that Ghiberti began working on the second Baptistery doors by creating "a large wooden frame ... with head ornaments ... and with friezes around it," from which he derived the mold. Thus he would have made a salvageable mold from the frame that, again according to Vasari's account, could be used to make another mold immediately if a first round of casting went badly. As already described in the introduction, the technical content of these sixteenth-century accounts must be considered cautiously. In addition to the vital importance of the account itself, we think it is interesting to note that an astute observer of such sixteenth-century techniques should describe quite naturally what (before the late fourteenth century), some—including Cennino Cennini—failed to mention at all. In fact, Cennini speaks of plaster and wax molds and mentions that wax casting is useful when making a model in pieces, but with regard to metal he defers to foundry workers ("Masters who understand casting and smelting") or only discusses casting in lead.

One of the reasons to create a model is that it gave the option of repeating the casting and adding the missing parts, but when crafting a complex piece like the Gates of Paradise there are other reasons to use a model. One is explained clearly by Cellini himself: "having that good model finished ahead, many young people and good workers can help to chase the figure while, without the model, to the poor master's dissatisfaction, the chasing of such works is performed in such a way that it requires more time and is not even done very well at all."

As expected, Ghiberti's account also seems to make veiled reference to this methodology. Indeed, he describes the conception of the ten panels as a single, unified act: "I began the work in squares ... stories from the Old Testament in which I had to call on all my ingenuity. ... I performed that work. ... There were ten stories all in settings, because I reasoned that the eye takes them in that way, and at a distance they appear to project."

What runs through an artist's mind, many years later, when he recalls the various steps that were part of the birth of his masterpiece? What methods
and materials does he use to create his work? He models, corrects, and adds, observing the scenes on the individual panels, but it seems that he also refers to figurative choices and corrections in perspective that are very precisely executed on the group as a whole, which theoretically we can imagine in a wooden framework like the one Vasari described being used for the second door. There is indirect, if not definitive, proof of this process to be drawn from the complex metric relations between the figurative elements of the panels. For example, the eye and the mind work together to create harmony between the very tall Eve and young Cain nearby, who is somewhat shorter, and then the stonebearers, who are shorter still, positioned closer to the viewer. As Vasari essentially said (“This work presents itself as a whole”), the results of this integral approach can be seen in its figurative choices. In terms of perspective, the most salient point is the placement of the figures—there are few of them in the upper portions of the doors and crowds of them in the panels that are closer to the viewer. This is, of course, due in part to the story being told, but it also seems to have been done to achieve a certain effect.

Clearly, we have no incontrovertible proof that the ten panels were conceived together at one time or in groups. However, evidence of the indirect method leads us at least to consider these possibilities, as such work would have required more time than the casting. Conversely, it seems improbable that Ghiberti would have worked on the figurative group providing for the cast of the original, the preparation of the mold, and the casting of the mold soon after finishing each single panel unless he handled all design issues during the preparatory phase. In the future, we will look more closely at these aspects, which, since they involve the design and archival spheres, require further multidisciplinary analysis. In the meantime, we return to our main concern: casting technique.

What material did the artist use to make the models? It would need to have been plant and easily manipulated, with the possibility for subsequent corrections and additions over relatively long periods of time. Most likely it was wax, the first material that Vasari mentions for small figures. From wax models Ghiberti likely moved to plaster molds and from these to creating reliefs for casting (basically, rinse casting).

In addition to the advantages of the indirect method, we should recall that the use of molds also offers the best method for creating thin walls, which allowed for savings on materials and for lightweight casting results while also emulating ancient techniques, which was clearly of interest to Ghiberti. This technical goal did not appear in the earlier bronze works Saint John the Baptist and Saint Matthew, while it can be seen clearly in the reliefs of the Gates of Paradise; it is interesting to note that it is also evident in the works executed by Donatello beginning in the 1430s. Before drawing conclusions in this regard, however, an in-depth study of Ghiberti’s first door is required.

Vasari, in claiming for the artist “an utterly ingenious mastery of casting,” shows great respect for the technical aspect of metalworking. He says that mastery of this art was the great secret of Ghiberti’s workshop—as does Buonaccorso in his Zibaldone—where he does not furnish any details on the methods and alloys used.

The indirect and rinse methods are an essential part of “the secret of casting things so that they remain thin,” but it is difficult to know the overall effect of this process due to a lack of information about earlier work. Other parts of that “secret” include spruing, the choice of investment, and
proper construction of the shell. For reasons of space, we will address the technical aspects relative to investment elsewhere. Here, we wish to focus on the first aspect and the important conclusion we drew from that.

Before beginning our experimentation, like those before us, we had overlooked one aspect that had been right in front of our eyes for nearly twenty years. The porosity made visible through X-ray examination, which had always been considered a result of bubbles, does not represent bubbles in the strictest sense. That is, these are not bubbles produced by gas. They are, instead, cavities in the metal made by trapped pieces of earth from the shell carried into the mold by the flow of molten metal. This was revealed clearly in X-rays (fig. 7.10), where the polygonal shapes of the cavities certainly demonstrate that they were not generated by trapped gas. The fragments of the shell that they enclosed came off from the branched channels applied to the back of the panel, as can be deduced from the irregular and random surface in the recognizably related areas above the arrows in figure 7.10.

We can thus conclude that, after a wax relief was created and finished, Ghiberti performed downward casting through an utterly ingenious spruing system that ran along the back of the panel. A likely solution is dictated by the fact that casting through a certain number of descending channels applied to the upper edge of the frame would not have given good results due to the alloy’s lack of fluidity and rapid solidification. Ghiberti had to use this alloy composition because it was optimal for cold work (chasing) and resulted in good amalgam gilding, as had been decided from the beginning.

The flow of metal that reached the cavity through the channels effectively complemented the material that came from the base of the frame placed at the top, due to the short flow distance and the distribution across the width of the panel. This also resulted in a moderated flow of the metal through the most projecting figures, thereby helping to avoid serious erosive effects that would have had a significant negative impact on the casting.

The visible traces of such channels lead us to believe that these barely rested against the back of the panel and that the layer of earthy investment almost isolated them from the cavity of the mold. That means that as the mold was filled, the molten metal moved through it, partially breaking the fragile walls of earth bordering the small area between the channels and the mold itself. This was another ingenious trick for easily removing the metal structure that the channels left after casting. Ghiberti knew that this method “dirtied” the casting in the level area, but evidently this was considered a necessary evil. We even asked ourselves whether perhaps fragments of the
mold had been introduced on purpose, but at the moment that possibility does not seem to be supported in any way.

At least five different spruing systems were used to create the ten reliefs. This suggests two diametrically opposed possibilities: on the one hand, perhaps there was a series of incidents during the course of the work that then made it necessary to repeat some casting and caused some rethinking of the spruing; on the other, perhaps the underlying idea was considered so solid that workshop assistants were allowed a certain degree of freedom to apply their own interpretations. Assuming that attaching and distributing the channels over the entire surface of the panels was given, we find the second possibility more likely than the first.

Final Notes
This project resulted in information and discussions that represent considerable advances in the knowledge of the techniques used to create the Gates of Paradise and of artistic casting in general as it was practiced in the early Renaissance. The conclusions reached open a window on Lorenzo Ghiberti's truly inventive casting technique and the basic methodologies that he used to achieve his artistic ideal through a complex command of bronze plastic arts, which in the case of the Gates of Paradise became sculpture in the strict sense of the word, considering the enormous amount of chasing that was done.

There is still, however, much to discover about this work and the work of Ghiberti's close collaborators in order to better understand the virtuosic evolution of metalworking techniques that reached complete maturity in the following century. We would like to conclude this voyage of discovery through one of the most brilliant minds of the Renaissance with a quotation from one of the most skilled artists and craftsmen of the sixteenth century. Cellini writes, "Lorenzo Ghiberti was truly a goldsmith, both because of the refinement of his skill and even more in terms of his infinite neatness and extreme diligence. This man can be considered an excellent goldsmith, who put all his ingenuity into the art of casting those small works . . . and that is why we call him truly a master of casting. He paid such attention to his profession and practiced it so well, that even today no other man has reached his level."19
NOTES
2. Ghiberti uses the metaphor of the "white temples" (Classical precepts) in the Commentarii in reference to ancient monuments that have been destroyed, ignored, or whitewashed [translator's note].
10. Vasari.
12. Cellini.
13. Commentarii.
15. Krautheimer; Caglioti, in this volume.