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Imaging Hadrian in Britain between Coinage and Sculpture: A New Digital Approach to the Study of Roman Imperial Portraiture

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ABSTRACT

This paper presents a new approach to an old problem, the provincial reception of the image of Roman emperors. Applying 3D computer modelling, we captured the portrait features of Hadrian as represented on coinage minted for the British province, produced a 3D model from a coin and compared it with the bronze head of Hadrian found in London. The aim was to test the possibility, previously posited by other scholars, that the London portrait might have been produced by an artisan who used coin portraits of the emperor as his main – if not only – model. More generally, the paper examines the dependencies of coinage and sculpture on shared models and applies new technology to Roman portrait studies.

Keywords: Roman Britain; sculpture: Roman imperial portraiture; Roman coinage; 3D imaging; Emperor Hadrian

INTRODUCTION

This paper presents the findings of a pilot-project originally undertaken by the University of Warwick in collaboration with the British Museum in autumn 2019, which has been completed within the ERC RESP Project 2021–2026 (see Acknowledgements). Applying 3D scanning and computer modelling, the project explores the connection of a bronze head of Hadrian found in London and coins made for the province of Britannia. In the absence of a clear correspondence with the emperor's official portrait types, scholars in the past have speculated on the sources that the sculptor of the bronze head used, noting the importance of two-dimensional numismatic portraits. The first part of the paper, providing an overview of the state of digital technology in the field of archaeology, presents the reason for its application in this case. The second part focuses on the imperial image of Hadrian in Britain. The results show that the head was produced by a local artisan who had access to models of the emperor

beyond the numismatic portraits. The discussion demonstrates the potential of the use of 3D modelling in the study of imperial portraiture as well as its shortcomings, showing the advantages of its application in future projects.

3D IMAGING IN ARCHAEOLOGY AND RATIONALE FOR ITS APPLICATION IN THE CASE OF HADRIAN IN BRITAIN (DC)

Over the past 15 years, three-dimensional (3D) imaging has been usefully applied in classical archaeology, both to provide advanced research tools and to support teaching practice and dissemination by virtually reconstructing ancient landscapes and artefacts. Alongside architecture, the main field in which 3D scanning and visualisation have found fertile ground is the study of Greek and Roman sculpture, especially in four key areas: (a) documentation and archive; (b) comparative studies; (c) digital restoration and integration of fragmentary objects and chromatic details; (d) learning activities in education and cultural heritage. In the study of Roman sculpture and portraiture in particular, important work has been done on developing 3D laser-scanning techniques so that scholars can consider biometric identifiers and digital measurements of key facial features when seeking to determine whether two or more images were derived from the same original by a process of serial copying.[1] Large-scale projects such as 'The "Face" of Roman Britain' project (Bournemouth University) have used 3D laser scanning and photogrammetry to create digital archives of portraits by surveying the extant population of sculptures among archaeological finds and collections, especially on a regional basis.[2] Case-study projects have used this technology to propose new interpretations of a portrait's identification or provenance or to get a better understanding of how they were produced. The marble bust of Antinous restored from two separate parts, one in Chicago and the other in Rome, provides an excellent example of how the traditional approach can be supported and complemented by 3D visualisation.[3] Scanning has been used as a diagnostic tool for comparing and identifying recut portraits by enhancing the different layers of carved surfaces[4] and to facilitate the identification of portraits of provincial provenance and of uncertain attribution.[5] Furthermore, 3D prints of ancient sculptures and portraits are increasingly used instead of originals to expand the boundaries of learning and museum experience, promote outreach activities[6] and provide multisensory access.[7]

In recent years, scholars have also employed 3D technology in numismatic research, developing targeted laser-scanning techniques for studying, measuring and identifying coins and medals.[8] 3D

[1] Schofield *et al.* 2012.

[2] https://www.bournemouth.ac.uk/research/projects/face-roman-britain. Newcastle University has also launched a similar programme for scanning in 3D the entire population of sculptured stones from Hadrian's Wall, alongside stone inscriptions and small finds: http://www.nu-digitalheritage.com. Similarly, the Fitzwilliam Museum at Cambridge has planned to scan all the sculptures of its cast gallery.

[3] See the 2016 travelling exhibition *A Portrait of Antinous, in Two Parts* at the Chicago Art Institute and at Palazzo Altemps in Rome: https://publications.artic.edu/roman/reader/romanart/section/496.

[4] See especially Pollini 2010.

[5] See Russell and Manley 2013 on the identification of the bronze head of Nero at the British Museum (inv. 1848,1103.1), long thought to be Claudius.

[6] Tucci *et al.* 2017; Stanco *et al.* 2017.

[7] This is particularly useful, given the growing corpus of research showing that multisensory experiences, where senses beyond sight are utilised in interpretation, enable more meaningful learning and memory generation; cf. Wilson *et al.* 2018a; 2018b; Ballarin *et al.* 2018.

[8] The most straightforward use of 3D visualisation in the numismatic field is, of course, for large-scale dissemination and display. Museums are beginning to enrich their online collections with virtual shows of high-definition coin scans that can be enlarged and flipped to 360°. See, for instance, the collection of the Smithsonian Museum in Washington: https://3d.si.edu/collections/numismatics and those of German universities

models are generated primarily to analyse coins in microdetail for documentation and conservation,[9] as well as to reconstruct production techniques – for instance, to identify casts made from the same mould.[10] One of the first applications of this approach was the image-based recognition system designed by the COINS project in Vienna to fight counterfeiting, illegal trade and theft of coins from museum collections.[11] This led to more focused procedures to automate the classification of ancient coins based on image matching, using algorithms to measure the similarity between each specimen and all the coins of the same issue entered in the database.[12] The latest step in this process has been the development of an optical data acquisition system based on photometric stereo analysis that records measurement, colour and surface structure of coins to generate a unique recognition key associated with each specimen, like a digital fingerprint.[13]

Our study uses 3D scanning in a novel way, to respond to iconographic questions that bridge visual fields. High-definition scanning of coins enhances the legibility of facial features impressed on small and often worn objects. The acquisition of data in high-definition 3D allows for magnification and reduces the degree of potential subjectivity in the identification of portrait typologies, as the captured point cloud can be used as an objective, measurable frame of reference for comparison between originals and copies. We combined 3D laser scanning and 3D modelling to integrate data from two different genres of artefacts, coinage and sculpture, so as to assess their interdependencies. We used 3D modelling and visualisation as a form of experimental archaeology, substituting physical sculpting tools and materials for 3D modelling software. This exercise provides insights into the maker's perspective, highlighting the technical differences between the processes of engraving and carving to transfer the same portrait type into two different materials and objects. The project was designed to address a long-standing question in Roman studies – how the emperor's image was disseminated – in a new way. Its importance lies in the development of a digital method that integrates the two main media in which the imperial image is preserved. This new approach does not claim to alter or supersede the established methodology used to study imperial portraiture, but to offer an alternative, which includes new digital technology to tackle problematic case studies.

The portrait of the emperor, the most ubiquitous symbol of Roman power, was designed to embody the imperial ideals and to transmit them in all visual media throughout the Roman world.[14] Although this was a large-scale propaganda industry, we are not able to reconstruct its practical workings, because we lack written testimony.[15] The process by which the sculpted portraits of members of the imperial family were designed, transferred and disseminated remains one of the most debated themes in Roman art and archaeology.[16] The landmark studies by the 'German School' of specialists in Roman portraiture – such as *Das römische*

involved in the NUMID project on Sketchfab: https://sketchfab.com/numid. An example of this technology being used commercially is: https://www.artec3d.com/de/3d-models/coins.

[9] An alternative method to enhance the legibility of metal and low-relief surfaces of coins is reflectance transformation imaging (RTI); cf. Mudge *et al.* 2005; Hameeuw 2018. This, too, can be used to enhance museum visitors' experience, allowing the 'virtual manipulation' of lighting conditions of coins on display to discover hidden technical and artistic features: http://vcg.isti.cnr.it/PalazzoBlu/.

[10] See, in particular, recent research on Renaissance medals and copies of Roman medallions pursued by the University of Padua: Faresin *et al.* 2012; Asolati *et al.* 2013a; 2013b; Asolati and Crisafulli 2019.

[11] https://cvl.tuwien.ac.at/project/coins/. Cf. Zaharieva *et al.* 2007; 2008; Zambanini *et al.* 2008; 2009.

[12] This was achieved by using initially 2D images (Zambanini and Kampel 2011) and later 3D models (Huber-Mörk *et al.* 2012).

[13] See the OSCAR scanner (Optical System for Coin Analysis and Recognition) designed by Magdeburg's Fraunhofer-Institut für Fabrikbetrieb und automatisierung (IFF) for the Sachsen-Anhalt State Office for Heritage Management (https://www.iff.fraunhofer.de/en/press/2019/facial-recognition-for-coins.html); Trostmann *et al.* 2019.

[14] Stewart 2006.

[15] Cf. Ando 2000, 229, with comments on the literary evidence from Late Antiquity.

[16] For an early discussion, see especially Swift 1923 and Stuart 1939.

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Herrscherbild and the *Katalog der römischen Porträts in den Capitolinischen Museen und den anderen kommunalen Sammlungen der Stadt Rom* – have provided the reference taxonomy of portrait types for each emperor and a methodology to identify most imperial portraits. These studies convincingly posited that the production of such portraits began with the creation of common models (or types), which were replicated for use and distribution throughout the empire in different media. The process would have been centrally controlled with types introduced at different stages of each emperor's reign, possibly marking special occasions and celebrations.[17]

Sculpted portraits in the round – large, exciting and imposing objects collected since the Renaissance – are only one output. Coinage was another major category of objects bearing the emperor's likeness. State mints produced coins that conformed to the same metropolitan models as sculpture, and they were the largest and most widespread medium through which the official portraits of the emperor were disseminated. Portraits on coins are also more frequently preserved and more easily identified and dated, thanks to the presence of legends. Numismatic evidence is thus of prime importance for the study of imperial portrait taxonomy,[18] but it does not always play a leading role in the identification of new or uncertain sculpted portraits. There are two justifiable reasons for this approach, both of which relate to the problem of understanding how a model was transferred into different media. First, it is still unclear whether coins and sculpture relied on the same form of the imperial model. Second, as bi-dimensional objects, coins only give a partial and incomplete view of the imperial image compared to portraits in the round.[19]

It is clear, however, that sculptural and numismatic imperial portraits were strictly related, both at Rome and in the provinces. Fittschen suggested both sculptures and coins were modelled after a related prototype in the round.[20] One expects that an engraver would have adapted a three-dimensional model to the bi-dimensional scope of a coin die, but we cannot rule out the possibility that it also worked the other way round. In our case study of the bronze portrait head of Hadrian, scholars have in fact suggested that a three-dimensional object was made from a two-dimensional object, because of the limited resources available to its maker.

THE IMAGE OF HADRIAN IN BRITAIN (DC, FB)

Many imperial portraits that elude easy identification and do not clearly follow a metropolitan model occur in the provinces.[21] Fittschen believes that none of these unconventional variations were made 'without knowledge of the portrait types in Rome', and that for all copies diverging 'in conspicuous ways from the official portrait types [...] the explanation can only be found, however, if at all, in the workshops'.[22] How much an emperor's features could be distorted

[17] A general overview is presented in various recent contributions summarising previous studies and discussing the current state of the art: Stewart 2008, 77–107; Fittschen 2010; Zanker 2010, 74–80; Fittschen 2015.

[18] Stewart 2008, 81–3.

[19] Fejfer 1998, 47. Fejfer also points out that most coin sequences do not provide absolute chronology of portraits, but this is probably a minor hindrance, as even the relative chronology based on coins is still a crucial dating element that the study of sculptures cannot provide, unless they are accompanied by inscriptions.

[20] Fittschen 2015, 53. Beckmann has recently questioned the underlying construct that there always had to be a shared model for both media. His comparative studies suggest that, at least for some members of the imperial family, more bust types are known from coins than from existing sculptures (Beckmann 2014). This may well be explained in terms of higher survival rate, as coinage was produced on a much larger scale than sculpture. Equally, sculptural workshops might not always have been able to keep abreast of the changes in official metropolitan portraiture (dictated, for instance, by female hairstyle fashion), while it may have been easier for the mint in Rome to keep up with them and transfer up-to-date typologies into coinage.

[21] Zanker 1983; Smith 1996.

[22] Fittschen 2010, 233.

when lacking a proper model is exemplified by Arrian's famous passage. Upon reaching the provincial city of Trapezus, the author noticed a statue of the emperor bearing 'no resemblance to the original' and urged Hadrian to send a new one showing his actual likeness.[23] Provincial workshops may have been responsible for creating 'variations' on the existing types, due either to the lack of up-to-date models, the absence of craftspeople with appropriate skills, the individual discretion of a local artisan (offering a personal interpretation of the reference-model), or the demands and preferences of the patron who commissioned the portrait.[24] The art trade in particular may have played a significant role in the dissemination of imperial portraits, which in the provinces could depend also on established networks of communication between workshops.[25] In order to address this question with 3D modelling and scanning, we sought two representations of the same emperor in different media but from the same province. We wished to compare 3D scans of two imperial portraits, one a sculpture in the round and the other a coin, in order to view them together on the same scale and from different angles, as well as overlapped with each other, for a more analytical mesh comparison.

The collection of Roman antiquities of the British Museum includes a well-known portrait from Roman Britain that fits into the category of provincial sculpture of an emperor, an over life-size bronze head of Hadrian found in 1834 on the bed of the Thames near London Bridge, on the southern side of the river, during infrastructure development works (FIGS 1–2).[26] It belonged to a full-figure statue, now lost, that was probably displayed in a public area of Roman *Londinium*.[27] Scholars connect the erection of the bronze statue with Hadrian's visit to Britain in A.D. 122.[28] The head was later hacked from the body and disposited in the river. While Toynbee's traditional interpretation was that the removal of Hadrian's head might date to Late Antiquity and be an act of iconoclasm,[29] Perring has recently put it in relationship to a British war that is believed to have taken place in the late A.D. 120s or early 130s, mainly in the north of the province, but possibly also involving the city of London.[30] He suggested that the head was disposed of at the time of this conflict as a symbolic deposit, a ritual act of rejection of the imperial authority,[31] which would be reminiscent of the disposal of the head of Nero in the river Alde in Suffolk, connected with the Boudiccan revolt.[32] This provides a possible date for the deposition of Hadrian's statue. Fronto, the writers of the *Historia Augusta*, and two inscriptions make reference to instability in Britannia at the beginning of Hadrian's reign,[33] and material evidence also suggests a date early in his reign.[34] Perring has proposed a date around A.D. 125–6 for the fire that concluded the war, destroying the Forum and the basilica in London

[23] Arrian, *Periplus* I, 3–4, commented in Zanker 1983, 6–10.

[24] See Fittschen 2010, 232–4 on Riccardi 2000. See Zanker 2010, 160 on how the supply and demand principle may have fostered artistic autonomy on a local basis.

[25] Stuart 1939.

[26] Coombe *et al.* 2015, 115–16 with bibliography, reporting Roach Smith's notes on the discovery: 'The head was raised with gravel and ballast, along with bronze statuettes and gold coins … in this case it is very likely that the recorded find spot is close to the statue's original location in a central area of *Londinium*'. The head immediately entered the private collection of John Newman, surveyor of the Bridge House Estates, and was purchased by the British Museum in 1848.

[27] Opper 2008, 80–5; Hobbs and Jackson 2010, 103–6.

[28] Lahusen and Formigli 2001, 192.

[29] Toynbee 1964, 50–1.

[30] Frere 2000; Perring 2017.

[31] Perring 2017, 52.

[32] Russell and Manley 2013.

[33] Fronto, *Ep.* 2; SHA, *Hadr.* 5.2; *CIL* XI 5632; *CIL* X 5829.

[34] Perring mentions the military occupation of London evidenced by the building of the Cripplegate fort soon after A.D. 120, and the second-century concentration of skull depositions in the upper Walbrook, which may perhaps be associated with the rebellion.

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FIG. 1. Bronze head of Hadrian from the Thames (British Museum, inv. 1848,1103.1): frontal view. (© *The Trustees of the British Museum 2023*)

FIG. 2. Bronze head of Hadrian from the Thames (British Museum, inv. 1848,1103.1): right profile. (© *The Trustees of the British Museum 2023*)

(the *terminus ante quem* is A.D. 128), and he suggested that the statue escaped the fire because it had been pulled down and mutilated when the revolt broke out.[35]

Wegner, Fittschen and Zanker, and Evers have interpreted the London bronze portrait as an adaptation of an official model created in A.D. 117–18 upon Hadrian's accession and named by modern scholars the 'Stazione Termini Type', after its best known marble version from Rome.[36] Wegner listed it among the '*Einzelstücke*'[37] and Evers among the variants of the replicas of the Stazione Termini type made in the western provinces,[38] highlighting the stylised facial features and its hieratic structure, as well as some errors in the physiognomy (over-large

[35] Perring 2017, 61. Perring also cited scholars who had suggested that the issues minted at Alexandria in A.D. 124/5 and A.D. 125/6, which featured Nike on the reverse, celebrated military victories related to a British War: Casey 1987; Hoffman 2013. However, the mint of Alexandria adopted reverse designs alluding to imperial victories and triumphs almost uninterruptedly from year 2 of Hadrian's reign (cf. *RPC* III 4987, 4999, 5035, 5103, 5110), so the coins issued in years 9 and 10 (A.D. 124–26) cannot be used as numismatic evidence to support this interpretation.

[36] Stazione Termini type: Wegner 1956, 8–10; Fittschen and Zanker 1985, 44–6; Evers 1994, 224. Because this type was designed while the emperor was still away from Rome, after his acclamation in Syria, it may have been based on existing images of him predating the death of Trajan. On the role of portraits of young Hadrian, Opper 2008, 59–61.

[37] Wegner 1956, 27–8, cat. 30c.

[38] Evers 1994, 217, b.7, n.55. In earlier studies it has been defined as the product of a Romano-British atelier (Schoppa 1957) or of a Gallo-Roman one (Toynbee 1958, 138; Zanker 1983, 16). Wegner's initial idea that it came from a metropolitan workshop has been completely abandoned.

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eyes, unusual chin profile, narrow lower face).[39] More recently, the portrait has been identified as the product of a local workshop, showing little resemblance to any of the emperor's official portrait types.[40]

Because the unconventional London portrait lacks a strong reference point in extant sculpture, scholars have sought explanations and comparisons elsewhere. A distinctive feature of the portrait is that it shows marked variations in the treatment of its parts, suggesting it was meant to be viewed mainly from the front. According to Zanker, its author had access to limited reference sources, and the authors of the *CSIR* proposed a large-scale frontal likeness of the emperor, possibly aided by coins for the profile.[41] Lahusen and Formigli as well as Opper suggested that the sculptor did not have a model in the round to copy at all and instead used a two-dimensional one, possibly a coin or a medallion.[42] In addition to these sources, a provincial sculptor may well have access also to painted likenesses. Such portraits are mainly lost but are attested in ancient sources, and their fidelity to metropolitan models is clearly shown by the surviving Severan tondo.[43] Equally small-scale objects depicting the emperor would have made a local artist familiar with the general outlines of the imperial portrait. These included *imagines* and *insignia* travelling with the military,[44] or sceptre-heads used during ceremonial processions, like those found in south-east Britain.[45] This speculation made the head a perfect test case for the application of 3D technology.

Notwithstanding this variety of possible sources, coins were the most ubiquitous mode of image dissemination. So from a methodological point of view the ideal numismatic candidate for the investigation of the bronze Hadrian would have been a product of a locally based mint, that is, a Roman provincial coin minted in Britain around A.D. 122. Yet the communities in the northern provinces of the Empire never had a civic coinage production (as opposed to an imperial one which started only in the fourth century A.D.). However, Rome did mint the 'Britannia Asses', a series of issues specifically designed for Britain, featuring the personification of *Britannia* on the reverse (FIG. 3), and these serve our purpose just as well. They were struck in the third consulship of Hadrian (A.D. 119–21) and constituted a significant group of the first portraits of the new emperor circulating in the province. More than 130 coins have been recorded so far and they were found almost exclusively in the UK.[46] As the best documented example of coinage produced in Rome for a specific provincial destination, the imagery reflected the intent of the central authority to target the local audience with a tailored visual message.[47] The portrait on the obverse of these coins unarguably shows Hadrian in the

[39] Evers 1994, 124.

[40] Lahusen and Formigli 2001, 192; Coombe *et al.* 2015, 115; Mevorah *et al.* 2015.

[41] Zanker 1983, 16 and Coombe *et al.* 2015, 115.

[42] Lahusen and Formigli 2001, 192, 'über eine Münze oder ein Medaillon, also nur eine Profilansicht'. Thereafter, Mevorah *et al.* 2015, 'the artist might have used a two-dimensional model, possibly a coin'.

[43] Antikensammlung Berlin inv. 31329 (https://id.smb.museum/object/681547). On painted portraits, see *POxy.* 12, 1449; Fronto, *Ep.* 4, 12, 4; *SEG* 4.515; *SEG* 11.923.

[44] Hoff 2011, 24 and n. 39; Riccardi 2002.

[45] Walker 2014; Pearce and Worrell 2016. These include a small bust of Marcus Aurelius from Steane (Northants), one of Antoninus Pius from Willingham (Cambs), one of Lucius Verus from Duston (Northants), one of Commodus from Cottenham (Cambs), a small head of Hadrian or an Antonine emperor found at Bix (Oxon), together with a possible Hadrian from Mildenhall (Suffolk) (*contra* Walker 2014, 234 where the author identifies the small bronze head with the god Cernunnos). To these can be added a sceptre-head bust probably depicting Marcus Aurelius, part of a hoard recently found at Ryedale (North Yorks) and now at the Yorkshire Museum (PAS n. YORYM-870B0E).

[46] These figures, based on both published archaeological reports and data entries in the Portable Antiquities Scheme Database, were generously shared by Andrew Brown and Sam Moorhead (British Museum), who are preparing a comprehensive analysis of the so-called British Association coinage. The reference study on this phenomenon is still Walker 1988, 290–1, on the coins from Bath, reviewed in Clay 1989. See recently *RIC* II.3, 46–8.

[47] On 'audience targeting' through coin messages, see especially Kemmers 2006.

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FIG. 3. *As* of Hadrian minted in Rome, featuring the personification of Britannia on the reverse (32 mm diameter. British Museum, inv. 1959,1019.4). (© *The Trustees of the British Museum 2023*)

manner in which Rome wished the British audience to receive him. These coins, paired with the bronze head from London, presented a good opportunity to extract and compare two models of the emperor's likeness especially created for the British population, one produced in Rome and one in the western provinces.

MAKING THE MODELS FROM HEAD AND COINS: USING COMPUTER TECHNOLOGY TO RECREATE THE ANCIENT ARTISAN (DC, FB)[48]

Our aim was to work and think as an ancient maker would have when faced with the challenge of creating a portrait of the emperor without a model in the round to copy, as seems to have been the case for the sculptor of the bronze Hadrian. We noted that a similar situation occurred in modern Europe. From the sixteenth century onwards, imperial portraits, especially the twelve Caesars of Suetonius,[49] had a key role in aristocratic collections and also generated interest in imperial women.[50] Collectors were keen to acquire complete series of emperors and empresses, even when ancient sculptural portraits were rare or lost. Numismatic portraits, in contrast, were readily available, and they included the much sought-after likenesses of emperors and imperial women for whom portraits did not exist. As a result, Renaissance artists used coins to develop models for the realisation of portraits in the round, either in marble or plaster. One notable example is the artist and numismatist Jacopo Strada who, in preparation for his work on the Antiquarium of the Munich Residenz of Albert V of Bavaria, produced a complete series of

[48] For details of the technical process, see Appendix.

[49] For a recent discussion on the continuing engagement throughout history with representations of the emperors, see Beard 2021.

[50] See Enea Vico's *Le immagini delle donne Auguste* in 1557, reproducing a complete series of portraits based on coins.

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FIG. 4. Nero head in stucco (Padova, Museo di Scienze Archeologiche e d'Arte, inv. MB82): (a) frontal and (b) profile views. (*With permission of the Università degli Studi di Padova*)

drawings of busts of Roman emperors and empresses, some of them completely conjectural.[51] Rather than being shown in profile, his subjects innovatively came to life with three-quarter views and, when lacking actual statues to copy, he drew inspiration from different iconographic models. Strada based his imperial women on numismatic portraits, implemented using statues 'all'antica' produced by contemporary Venetian workshops or drawings of ancient marble busts.[52]

Strada was not alone in this pursuit. A stucco head of Nero from the Mantova Benavides collection in the Museo di Scienze Archeologiche e d'Arte in Padua (FIG. 4) created by an unknown artist provides an excellent three-dimensional example of this creation based on coins.[53] The head presents a close likeness of the emperor when viewed in profile, however, its frontal aspect has little connection to ancient portraits in the round of Nero. The frontal view of the London Hadrian has a similar effect on the viewer.

Positing a similar approach for the realisation of the bronze head of Hadrian, we assumed an ancient sculptor had easy access to a Britannia *as* with the profile of the emperor and so we chose it as their – and our – starting point. First, we laser-scanned four Britannia *asses*[54] and the head of Hadrian at the British Museum. As these objects differ in size, we used different

[51] Jansen 2019, 673–80; Riccomini and Barello 2021.
[52] Riccomini 2022.
[53] Favaretto 1994. See: https://phaidra.cab.unipd.it/detail/o:333633?mycoll=o:74191. We wish to thank Alessandra Menegazzi, the Museum's curator, for giving us the opportunity to examine and study the head, alongside other objects from the collection.
[54] These coins were chosen based on their good preservation and legibility of Hadrian's profile. Eventually, the best specimen was selected for generating a model in the round (British Museum inv. 1959,1019.4).

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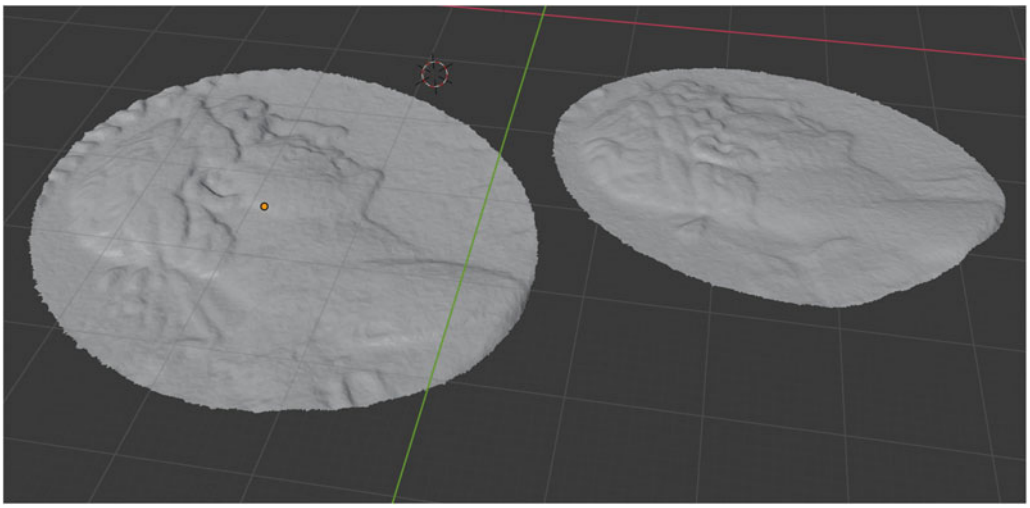

FIG. 5. 3D mesh of two copper *asses* of Hadrian scanned at the British Museum.

FIG. 6. Roundel of coin portrait of Hadrian.

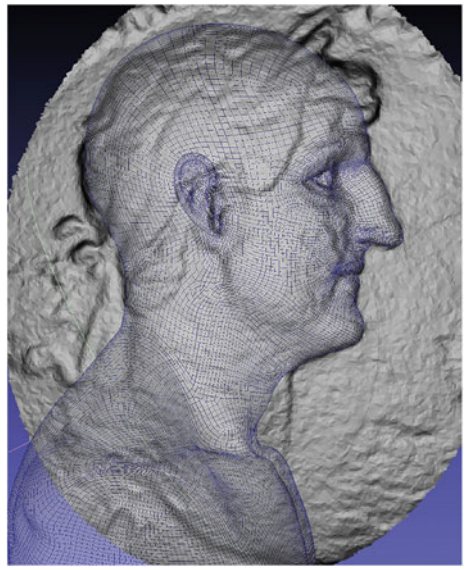

FIG. 7. Processing the 3D low relief of Hadrian's coin portrait.

approaches to collect the surface data. Coins were scanned individually, while for the larger-than-life bronze head the left and right sides had to be scanned separately, then merged using shared features (FIGS 5, 6 and 7).

The second part of the process was to derive a bust of Hadrian in the round from the low-relief profile portrait of one of the scanned coins. The whole process was carried out by ThinkSee3D (Oxford), a specialised company of 3D designers with extensive experience in cultural heritage

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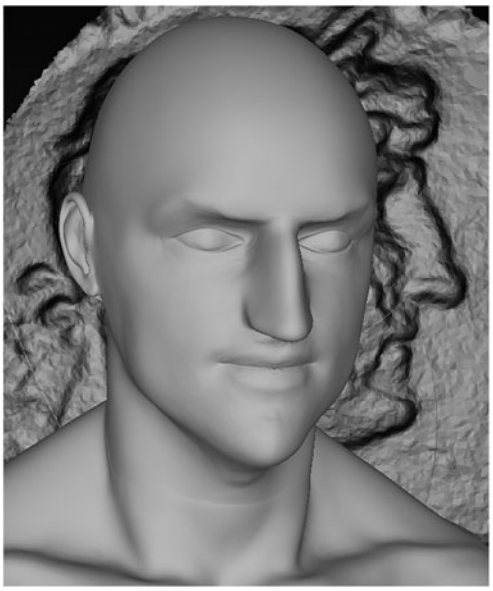

FIG. 8. Generic male 3D portrait being aligned with the portrait from the coin within the 3D editor.

FIG. 9. Initial 3D mesh of Hadrian's bust next to coin portrait.

projects.[55] We assumed that an ancient sculptor had a sense of average human facial proportions so, to obtain a three-dimensional portrait starting from a low-relief profile, we used a generic 3D face and transferred the scanned right profile of the coin onto it (FIG. 8). We then pulled the anatomy of the generic face to align with the position of the eyes, jaw line, beard line and cheekbones of the scanned coin profile. We created a virtual model in the round by mirroring the right profile and aligning the two halves (FIG. 9).

At this stage it became clear that a knowledge of human anatomy alone was not sufficient to complete a portrait bearing a suitable resemblance to the depicted subject; the three-quarter and frontal views proved particularly challenging to reconstruct based on the profile data alone (FIG. 10). We thus opted to repeat the whole modelling process, enhancing the profile data obtained from Hadrian's coin with elements extrapolated from contemporary portraits in the round. The 3D designer was provided with images of the Chiaramonti 392 type of Hadrian (FIG. 11) as it corresponded to the portrait on the Britannia coin more closely than any of the other Hadrian types.[56] The goal was to simulate a situation where an ancient maker had no easy access to a model in the round to replicate accurately, but some familiarity with the general appearance of the emperor, possibly from another portrait seen in the city, like a statue or a smaller, portable object, or even a drawing. Images of the Chiaramonti 392 type were used as a visual aid to inform exclusively facial features; they were not employed to develop the

[55] We are extremely grateful to Steven Dey for his patient work and unique insights into the subsequent stages through which the process was developed and unfolded.

[56] The date of the Britannia *as* means that the portrait is an early Hadrian. In the round, scholars have recognised two early types, the Stazione Termini (see n. 36) and the Chiaramonti 392 type (Wegner 1956, 10–12; Fittschen and Zanker 1985, 46–9; Evers 1994, 231–2). The latter was probably introduced in July A.D. 118, when Hadrian entered Rome, and replaced by a new one in A.D. 121, when he left for his first long journey. These two metropolitan portraits differ not in the shape of the hair around the temples, but in the form of the curls over the front of the brow. This distinction is difficult to capture in coinage.

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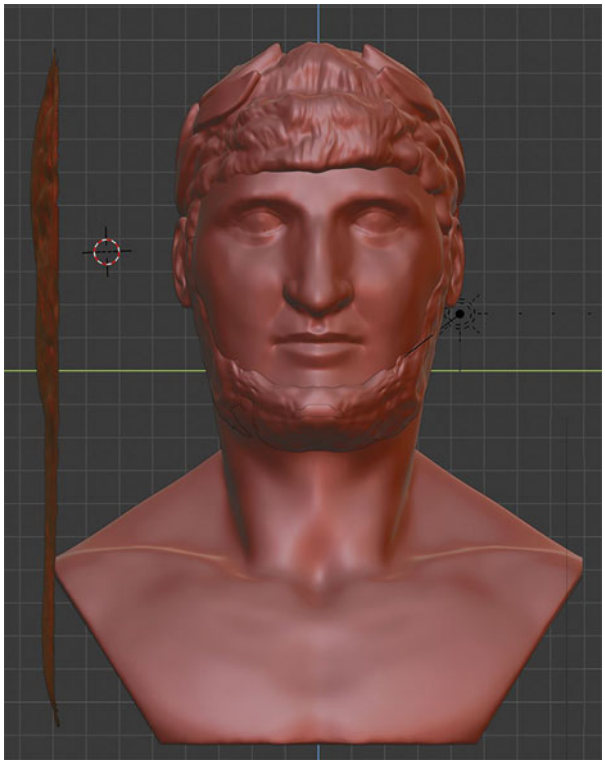

FIG. 10. Frontal view of initial 3D reconstruction of Hadrian's bust, developed exclusively from coin portrait.

characteristic locks arrangement on the forehead. In the 3D model, the fringe derives from the coin portrait alone. Details of the beard, however, were also informed by the images of the marble bust, as the coin was too worn to see them precisely. The forehead is the only part of the model diverging from the coin profile, as it was slightly raised. This seemed necessary to normalise the disproportion in the coin, where the portrait was probably adapted to make it fit into the coin design, bound as it was by the shape of the flan and the necessity to leave enough room for the legend. The result (FIG. 12) is a virtual model of a portrait in the round derived from the coin to a varying degree of approximation, from 100 per cent on the profile, to 100–75 per cent on the three-quarter view, to 75–60 per cent on the front. This digital process of informed adaptation and experimentation corresponded to the basic principle of an ancient maker's process.

INTERPRETATION (PW, MD, MW)

The virtual creation of a bust in the round from a bi-dimensional portrait produced a credible reconstruction of the process by which a sculptor with limited access to three-dimensional imperial portraits might have produced a likeness of the emperor. A comparison between the coin, the bronze head from London and the head of the Chiaramonti 392 shows discrepancies between the profiles of the coin and the marble portrait (FIG. 13b), while the bronze offers a

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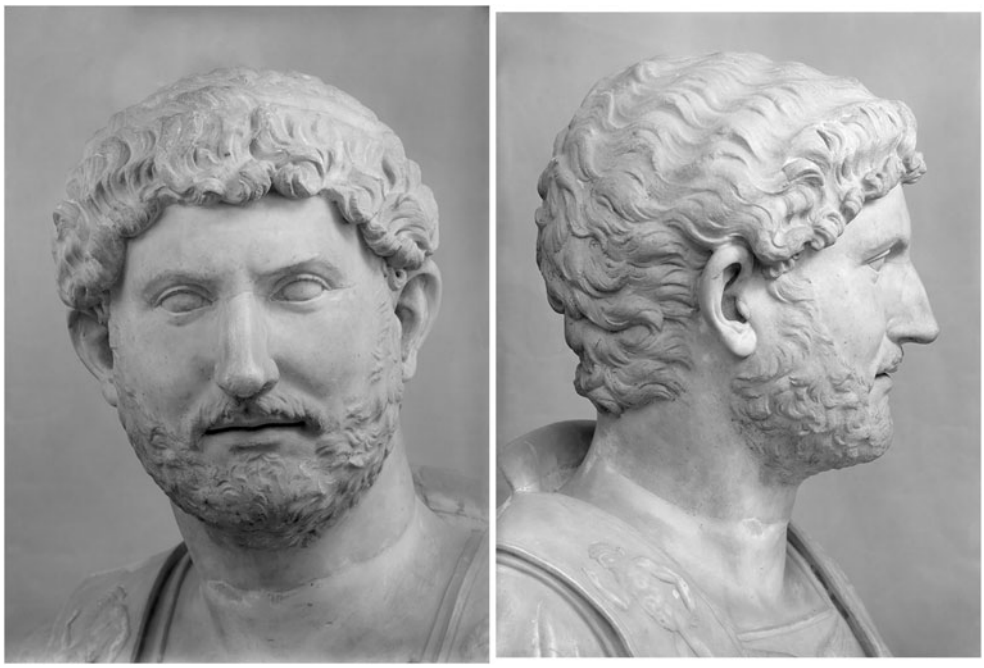

FIG. 11. Marble portrait of Hadrian, Chiaramonti 392 type (Musei Vaticani, inv. 1230): frontal and profile view. Images provided as visual aids to 3D designer (D-DAI-ROM-42.708 and D-DAI-ROM-42.709).

FIG. 12. New 3D reconstruction of Hadrian's bust: frontal and profile view.

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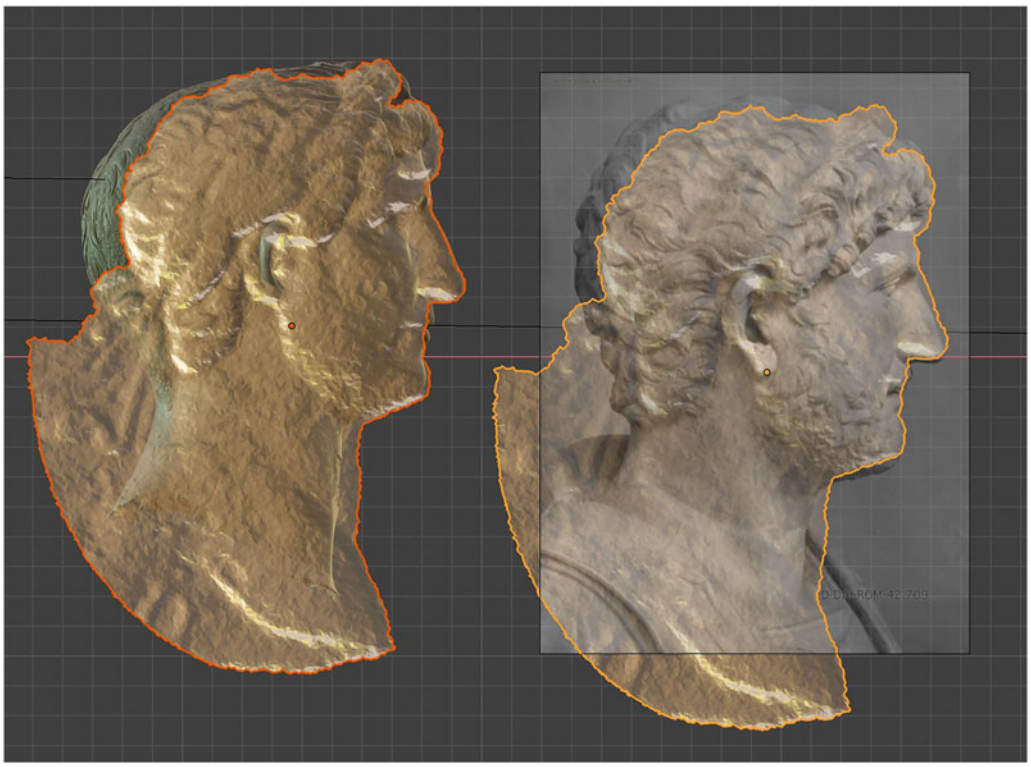

FIG. 13. Alignment of the right profile of the coin portrait with (a) the London bronze head and (b) the Chiaramonti 392.

closer match to the numismatic portrait (FIG. 13a). This lends credibility to the idea that the coin was used as a starting point to produce the bronze head of Hadrian (FIG. 14).

To check this possibility, we compared our 3D modelled bust to the scan of the bronze head from London, digitally scaling and aligning them.[57] FIG. 15 displays the two datasets after the best-fit alignment process, in which the bronze head, in grey, was set as the fixed reference model, and the bust-model, in blue, was set as the floating test. The image simply illustrates the relationship between them without quantifying deviations. Even before a deviation analysis, some discrepancies between the models become evident, particularly in the protruding ears (FIG. 16) and in the lower portion of the face.[58] Of particular interest is the asymmetry of the bronze head as opposed to the bust-model, as clearly shown in the frontal view, where the blue regions around the nose show different shapes on the right and left half of the face. This could result from the casting process, be a sign of inaccuracy, or perhaps reflect the archaeological history and restoration of the bronze head. In addition, when creating our 3D virtual model, we did not consider movement and asymmetry. Lacking any sense of what the full statue would

[57] See Appendix for details.

[58] The profile views allow us to appreciate the slight misalignment of the ears, which diverge in position and shape between the two models. Note that these differences are much more apparent on the left profile than on the right one, possibly because the large crack on the left portion of the face may have contributed to further stretching the distance between key features on this side. The deviation is somewhat disguised in the comparison colour map (FIG. 17).

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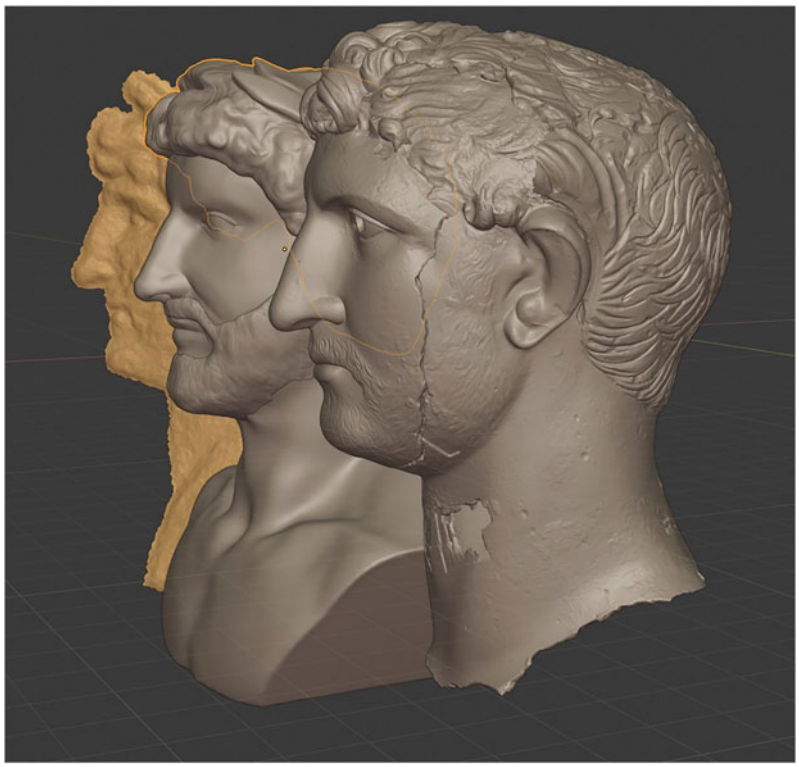

FIG. 14. 3D mesh of the coin portrait, 3D bust-model and 3D scan of the bronze head, all seen from left profile.

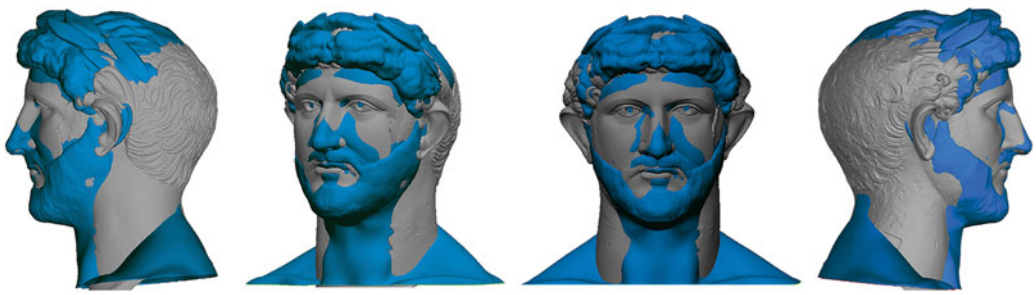

FIG. 15. The aligned 3D models of the bronze statue (grey) and the bust-model (blue) shown from four viewpoints: (a) left profile view; (b) angle view; (c) front view; (d) right profile view.

have looked like, we only focused on the head, designing it as completely frontal and symmetrical. In this we strayed, however minimally, from our desire to mimic the ancient artisan, who would have considered the turn of the head on the body.

After aligning the models, we also conducted a surface comparison, which is illustrated in FIG. 17. The stronger blue and red areas mark the highest divergences. Blue areas indicate regions where the bust-model's surface sits beneath the bronze head's surface, and red where

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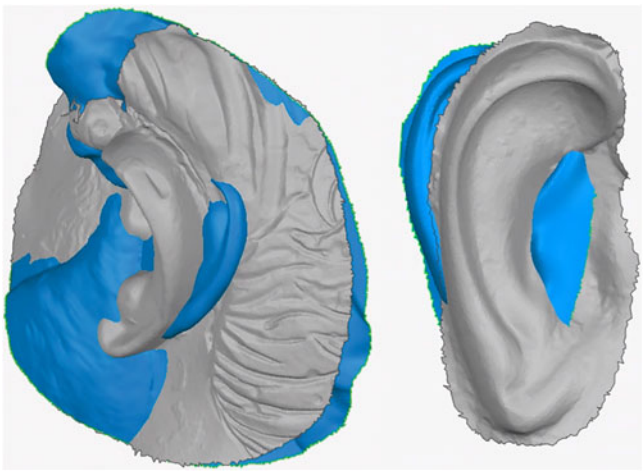

FIG. 16. Detail of the best-fit alignment showing misalignment between the ears: (a) left and (b) right.

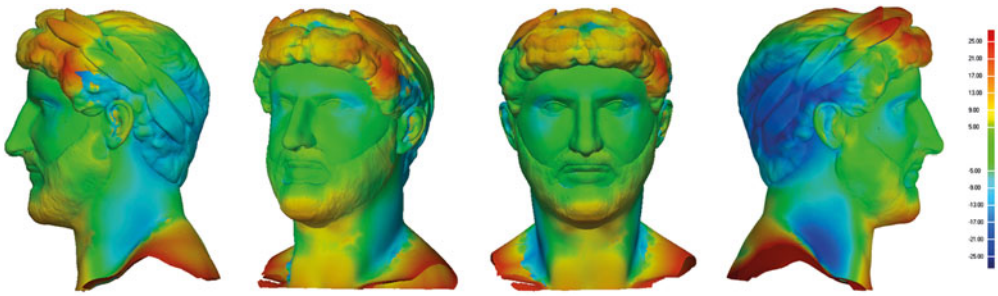

FIG. 17. Bust model with 3D deviation colour map overlaid. Colours indicate surface deviation of the bust-model from the bronze statue. Scale bar in mm. (a) left profile view; (b) angle view; (c) front view; (d) right profile view.

the bust-model exceeds the bronze head. Small divergences between –5 and –10 mm appear in the frontal and in the three-quarter views, not only in the proportions of key facial landmarks (seen around the eye-socket and chin), but also in their shape.[59] The eye socket and cheekbones display differences, with the upper half of the bronze head appearing to feature a wider, flatter face. This contrasts with the lower half, where the chin and jawlines are narrower than our model. The neck also demonstrates significant differences in width, proving anomalously larger in the London head than in the average metropolitan busts.[60]

In the bust-model the hair around the forehead also shows considerable differences, as it protrudes significantly when compared with the London head.[61] This is to be expected, since the reconstruction of the fringe was largely hypothetical, based as it was on the profile view of the coin. In addition, the arrangement of the forehead locks on the bronze portrait is

[59] Discrepancies in the nose that are visible in the global alignment (FIG. 15) are too small to be seen in the deviation map.

[60] The deviations around the shoulders, based on the coin portrait, are irrelevant since the bronze head in London does not preserve shoulders.

[61] The wreath should of course be discounted, as the bronze portrait of Hadrian is bare headed.

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problematic, as it does not closely follow any of Hadrian's types. This might prove that our 3D designer and the ancient artisan faced similar challenges.

Despite these differences, the predominance of green areas across the aligned busts means that the degree of deviation between them is low, falling within the ±5 mm we set as deviation tolerance. Despite the micro-discrepancies detected by the surface comparison, the alignment reveals a good compatibility between the bronze head and the coin-portrait virtual projection.

CONCLUSIONS (DC, FB)

In the specific case of the Britannia coinage and the bronze head of Hadrian from London, our digital model, mainly derived from a Britannia *as*, shows a high degree of compatibility to the head. The divergencies cluster around the eye-socket region, the ears and the neck. The region of the nose is remarkably aligned, with distances measured between the upper tip and the inner eye-corner and between the bottom tip and the cheek giving an almost perfect match.

Several scholars had suggested that a coin was used as a reference for the bronze head because of the awkward mismatch between the profile and the frontal views. In the best-fit alignment image taken from the front, the protrusion of the ears, the unnatural width of the neck, the shape of the nose-tip and the line of the jaw show differences which are not visible in the profile view. If the maker of the bronze head used a coin as their main reference, then we should expect that the modelling process started from the right profile, as we did in our reconstruction, and subsequently informed all the other parts, almost going by memory or intuition when shaping the frontal view. Yet the best-fit alignment of the two models displays discrepancies in the profile too. In the bronze head the brow is more bulging, the chin is less projecting, the ears are in a different position and the back of the head is more voluminous. The latter, however, could be explained by the necessity, on the coin, to flatten the back of the skull to make space for the legend. This suggests that even the profile of the bronze head was not modelled exactly on a coin portrait and that the ancient maker, rather than taking exact measurements and scaling them up, was working with a certain degree of freedom, as shown by the discrepancies with official portrait types in the ratio between facial features and the rendering of the hair.

In his seminal work on ancient copying,[62] Pfanner suggests that sculptors of portraits in the round and reliefs both used three-dimensional models as a guide for their work. Combining speed of execution with the highest possible degree of resemblance with the subject, these sculptors developed an ingenious copying process that paid particular attention to the profile, while the sides of the head were more cursorily executed. Pfanner describes this approach as more economic, the costs of having a model sent to the workshop for copying being far lower than having to create a completely new piece.[63] This does not appear to have been the case for the London portrait of Hadrian, where it is unlikely that the maker had access to a model in the round. Interestingly, Pfanner's remarks about imperial portraits on bas-reliefs, which he believes were – whenever possible – also based on three-dimensional prototypes,[64] might apply to coin portraits as well, lending weight to the idea that a common model was used for different media. This raises an interesting point about the province of Britain, where the surviving evidence suggests the absence of a metropolitan model of Hadrian. In this view, the minting of coins bearing the emperor's image specifically produced for Britannia takes on a new meaning.

This paper shows that a profile portrait could not have been the sole model for the London Hadrian. Given the superior quality of the profile view, a coin may well have been used as the

[62] Pfanner 1989.
[63] Pfanner 1989, 222.
[64] Pfanner 1989, 217–18.

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main source of reference, yet a familiarity with the frontal likeness of the emperor would have been indispensable. Very plausibly the London Hadrian was the product of a local artisan who did not have direct access to a metropolitan model in the round and had to draw inspiration from a variety of sources, including bi-dimensional images which did not allow them to produce a typologically correct result. Their mental and technical processes were probably similar to those of Renaissance artists who produced three-dimensional images from two-dimensional coins. The appearance of the bronze head indicates that the metropolitan portrait types of Hadrian, one of the most beloved emperors and whose public image was most extensively disseminated, were not fully available in Britain at the time of his first visit to the province. This may not be a novel hypothesis, but the mode in which it is arrived at is. Moreover, the method presented here has provided a new view into the sculptor's workflow and the practical problems they may have faced.

The main challenge of this experiment was the speculative nature of its theoretical premise. We cannot, at this stage, assume that coinage and sculpted portraits made use of the same shared model, even though the results of this initial investigation showed that it is reasonable to assume this might occasionally be the case. The ideal scenario to test this hypothesis using 3D technologies would be assessing how emperors were portrayed both on coins and in sculptures produced by local workshops of the same provincial region or city, to compare and juxtapose portraits of the same subject produced in the same area in different media. The example of Hadrian from Britain meets these criteria only in part: the coin was minted for Britain, but in Rome. Future tests on provincial coins and sculptures made contemporaneously and in the same geographic region may yield even stronger results.

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APPENDIX: TECHNICAL PROCESS (PW, MD, MW)

SCANNING

The objects were removed from public display and scanned in the study room of the Department of Britain, Prehistory and Europe of the British Museum under the supervision of curators Richard Hobbs and Richard Abdy. Scanning equipment consisted of a Nikon ModelMaker H120 scan head mounted on a portable MCAx25+ scanning arm, the data being collected using Nikon's proprietary Focus software. The Blue Light laser scanning system has a minimum resolution of 35 µm and combined accuracy of 32 µm (2σ), making it a useful tool for collecting very fine surface details. This is particularly beneficial for capturing the raised reliefs on the coins, which had varying degrees of wear on the profile of Hadrian.

The obverses of four coins (British Museum, inv. 1838,0317.2; 1872,0709.568; R1935,0404.57; 1959,1019.4) were laser-scanned individually, focusing on the raised relief of Hadrian (FIG. 4). The scans were then processed in order to remove data that was not relevant to the study of imperial portraits (the edges of the flan and the coin legends circling the portraits).[65] We adopted a different approach for the scan of the three-dimensional bronze head. Due to its size (H: 43 cm), it was necessary to collect surface data in two orientations to scan the entire object, scanning the left-hand and right-hand sides separately. The scanning operations created 3D point clouds of the object surfaces. Using Nikon Focus, the left- and right-hand-side scans of the bust were manually aligned to each other using shared features such as the nose and mouth and then algorithmically aligned using a point-registration method. All point clouds were then converted into a tessellated surface mesh of the laser scan data. Each scan was then exported as an .stl file for further analysis.

Copper-alloy objects are well suited for optical laser scanning, since they are mainly devoid of dark or highly reflective surface areas which absorb or reflect the beam that cause holes or noise in the triangulated point-cloud.[66] Nonetheless, some of the coins had slightly burnished surfaces, which caused a loss of detail in the resulting meshes in those specific sections. This particularly applied to the beard of Hadrian in one of the coins, which was poorly resolved in the final mesh and lacked fine detail.[67] These problems reduced spatial resolution in certain sections of the datasets for both coins and bust. The specimen used as the source for generating a model in the round (British Museum, inv. 1959,1019.4) was selected on the basis of the lower degree of wear in the key facial features of the portrait (eye, nose, mouth) compared to other available coins in the collection, also having the plainest bust type (nude), to reduce the incidence of additional elements that were irrelevant to the scope of the project (FIG. 5).

MAKING A MODEL

The second part of the process was to derive a bust of Hadrian in the round from the low-relief profile portrait of the coin. The whole process was carried out by ThinkSee3D (Oxford) and the workflow was intended to

[65] This procedure was a security measure to prevent forgery: as a result, only the roundels enclosing the imperial bust have been retained, while all other data have been permanently deleted. As a procedure it conforms to the protocol established by Philip Attwood, former Keeper of the Department of Coins and Medals, in agreement with curators Amelia Dowler and Richard Abdy, expressly to define terms and conditions of data usage in 3D visualisation.

[66] In the future we will test capturing additional images with RTI, a technique particularly suitable for low-relief surfaces to reveal hidden details by changing the projection of lights on the object.

[67] The same applied to the drapery on Hadrian's bust, where burnished sections produced noise within the point-cloud that needed to be removed prior to conversion to a mesh.

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follow as closely as possible the processes and choices of an ancient maker who might equally have been faced with the challenge of creating a portrait in the round starting from a profile image. It immediately became clear that obtaining a three-dimensional portrait starting from a low-relief coin profile was significantly aided by an understanding of human anatomy and by having some familiarity with the appearance of the subject himself. We therefore created a generic male 3D portrait (FIG. 8) and aligned it with the coin portrait using the 3D editor Blender 3D 2.8.[68]

The profile of the head on the coin was transferred to the base model by creating a semi-transparent view through the 3D model to the coin and then dragging the model into position over the coin. Further details shown on the low relief of the coin, such as the eye positions and the jaw, were also aligned. Facegen was initially used to get the alignment, but it proved unsuitable.[69] We opted for other digital sculpting tools, mainly ZBrush, to pull the surface of the generic portrait bust to match it as closely as possible to the coin. Once the profile was aligned, other details from the coin portrait were transferred to the portrait bust, such as the line of the beard and position of cheekbones. Lastly, we augmented details not explicitly defined on the coin portrait, such as the depth of the nose, the curls in the hair and the shape of the eyes. The other half of the head was produced by generating a specular image of the profile and then integrating the two halves to create a round virtual model. This first attempt was unsatisfactory (FIGS 8–9): even if the profile of the model fitted perfectly with the one shown on the coin, the frontal view bore little resemblance to the emperor Hadrian. The test was repeated using a profile and frontal image of a marble bust of Hadrian (Chiaramonti 392 type, FIG.11) as additional visual aids, to inform the three-quarter and frontal views (FIG. 12).

PRINTING THE MODEL

To allow for its use for educational and engagement purposes, the modelled bust mesh of emperor Hadrian was 3D-printed via material jetting and then post-processed to remove excess support material. The mesh was imported into Geomagic Studio 2014 (3D Systems) for processing and shelled, the process by which surfaces are duplicated and offset internally to provide a thickness and create volume inside the mesh – this reduces the overall printing volume and material costs. Once shelled, the mesh was repaired using the auto-repair tool in Geomagic Studio, to ensure the result was manifold and with no overlapping facets. The mesh was then exported in .stl file format for printing. It was imported into GrabCAD for bed arrangement and slicing and then sent to a Stratasys J750 Multi-material 3D printer for printing. The part was printed in high-mix mode with a layer thickness of 28 µm using VeroWhite resin. This gave the final model the visual appearance of carved marble, but could not replicate its physical properties (FIG. 18).

3D printing has some limitations, particularly when it comes to the verisimilitude of the print to authentic materials. The only 'rock-like' materials currently available on the 3D printing market are the so-called 'sandstone' and 'colour sandstone', which are fabricated by binder-jetting layers of gypsum powder together with an adhesive. [70] Metals would more accurately replicate these properties, but the process of laser sintering implies that such models typically have a coarse layer thickness, resulting in unsightly lines across the surface.[71] These issues will be resolved in time as more complex, affordable materials reach the

[68] The process of integrating the missing portion of the face from the three-quarter and frontal view is clearly the most challenging step, for which further options will be certainly explored in the future (see further below). One will be to integrate the model with information acquired from 3D scans of metropolitan or provincial sculpted portraits of the same emperor, to be used as a reference or comparison to study and measure the proportions of the different facial features.

[69] A variation of this method could be attempting to scan the 3D surface of the coin using experimental magnified photogrammetry techniques. Then, using the digital 3D portrait derived from the coin, the depth would be stretched and digitally wrapped on a 3D base model.

[70] Squelch 2017. Naturally, the result would be significantly weaker than an actual marble sculpture and poorly verisimilar, being less dense and with divergent mechanical and thermal properties: Kong *et al.* 2018.

[71] These methods are also associated with considerably higher costs, namely due to material costs and the expense of their operation. Similar constraints apply to other materials. Resins are capable of higher resolution prints but do so at greater expense than more cost-effective methods. Methods such as fused filament fabrication or extrusion are not capable of such fine layer thicknesses, resulting in an end-product with poor fidelity compared to the original. They are, however, significantly cheaper, which may be a better fit for applications with limited funding.

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FIG. 18. White resin 3D print of bust-model.

market, but as it stands creating an authentic bust replica that appeals to the human multisensory suite is a challenging endeavour. However, since the Hadrian bust is not a replica of an existing artefact but a virtual model resulting from experimental research, the 3D print in VeroWhite resin perfectly serves the purpose of this study. This type of material is also most suitable for learning and outreach activities, and it may be the best compromise for potential use in display projects. The print was used for a workshop held at the British Museum in autumn 2019, aimed at exploring imperial images and their reception in the provinces and involving students from the University of Warwick as well as museum staff.

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