Late Antique Glass Carving as Cross-Craft

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Abstract. Focusing on the related engraving techniques of openwork and opus sectile carving as evidence, this paper demonstrates that glass production in the Eastern Mediterranean in late Antiquity was an example of cross-craft, involving aspects of specialised collaboration among glass producers. As such, it represents the interdependence required of inter-industry relations in terms not only of resources but fundamentally of skills. Beyond just glass, cold-worked carving in various media suggests relatively large-scale late Roman urban production was more likely defined by a transferrable skill set (in this case carving) as opposed to a material.

Keywords. Carving, Craft Production, Glass, Late Antiquity, *Opus Sectile*, Workshop Recycling

Studies in the history of craft are typically approached with a kind of tunnel vision, where the focus is on material – and generally a single material like bronze, clay, glass, rock crystal, and so on – rather than on techniques and skills that were transferable across craft industries. As this article will show, these inter-industry skills were not only present in the late Roman period (fourth through sixth century CE), with particularly noteworthy evidence in Egypt, but also reflected economic and social connections among craftworkers that are much more complex than what has been previously recognised. In short, production in nearly every regard was more nuanced and interconnected than what traditional scholarship suggests.

Particularly regarding late Roman portable visual culture, often an individual material is presented as though it were the only means of defining production.

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There is, however, no evidence to suggest that this is the only option (see the Introduction to this issue). This is largely for convenience, seemingly done to avoid the increase in variables resulting from the introduction of a second material. For instance, discussions of silver *largitio* vessels seldom mention consular diptychs, and vice versa, in more than a limited way.[1] The often implicit assumption – with these pieces and in general – is that objects made out of different materials, such as silver and ivory, each necessarily represent an independent industry.[2] Likewise, glass specialists might work with all of the glass from an excavation site, categorising finds based on object types (such as plates, cups, bowls, and so on) in contrast to window glass and tesserae. Thereby, such overlooked material divisions contribute to the misleading interpretation that production was restricted to isolated materials alone and a resulting compartmentalisation within craft studies. Instead, the evidence, when considered together with finished objects, suggests that completion meant objects passed through various hands as part of *cross-craft* production – that is, contemporaneous working relationships across media, possibly involving multiple materials and producers. In glass, this means making the raw material, shaping objects, etching or carving them, and trading newly made or recycling cullet. Whether or not cross-craft was a late Antique innovation, the invention of glassblowing and the specifics of Roman society clearly contributed to it.

Extant late Roman objects designed for practical use reveal evidence of production incorporating a range of materials. Although fragmentary and incomplete objects may survive in great numbers, examples of 'finished' late Roman objects remain, perhaps most commonly as finished composite objects assembled from parts made in different media.[3] For just one of many examples of a composite finished object comprised of a variety of materials, consider gold-glass with

[1] The same formulaic acclamation – SEMPER VINCAS (*May you always be victorious*) – was inscribed to honour emperor Licinius on the fourth century silver dish and Honorius on the fifth century ivory panels. Following the widespread use of imagistic script in this period, the latter piece includes the benefactor's name and consular rank in the legend prominently at the bottom of each panel. Silver dish with stamped laurel wreath framing an inscription: SIC X SIC XX (*As ten, so twenty*), peripheral inscription: LICINI AUGUSTE SEMPER VINCAS (*Licinius Augustus, may you always be victorious*), *c.* 317 CE, diam. *c.* 178 mm, ht. 43 mm, weight 304.60 g. A stamp notes the dish was made in Nis, Serbia, London, British Museum (1969,0904.1), https://www.britishmuseum.org/collection/object/H_1969-0904-1, accessed April 4, 2024. Additionally, for an ivory diptych (*c.* 406 CE) of consul Anicius Petronius Probus with the depiction of Emperor Honorius, Aosta, Cathedral, Museo del Tesoro, see *CIL* V 6836; C. Olovsdotter, *The Consular Image: An Iconological Study of the Consular Diptychs* (Oxford, 2005), fig. 14. See also A. Cutler, *The Hand of the Master: Craftsmanship, Ivory, and Society in Byzantium (9th–11th Centuries)*, (Princeton, 1994).

[2] The focus tends to be on what these objects say about emperors and rank, for instance, rather than the actual production. For a corrective, see J. Spier, 'A Lost Consular Diptych of Anicius Auchenius Bassus (A.D. 408) on the Mould for an ARS Plaque', *Journal of Roman Archaeology* 16 (2003), 350–4.

[3] On unfinished glassware from this period, see in particular H. G. Meredith, 'The Late Roman Unfinished *Chaîne opératoire*: A New Approach to Inscribed Glass Openwork', *American Journal of Archaeology*, 127, no. 1 (2023), 119–39. On incompletion due to a loss of polychromy, see for

etched gold leaf sandwiched between two layers of decolourised glass (with other colours known), sometimes with subsequent painting added (fig. 1).[4] This is important because, by extension, craftworkers are also typically misleadingly categorised as working in one material rather than in specific process (such as casting) or technique (for instance, repousse).

Late Roman evidence concerning materials that were not naturally occurring but rather were made, such as glass, suggest that changeable materials were not necessarily defining features of a craft industry.[5] I argue that late Roman objects made primarily or in large part by incorporating glass not only represent a subset of glass production in the Eastern Mediterranean at that time, but that fourth to seventh century CE 'glass' also represents at least three distinct but likely interrelated industries (at least to some extent) – in other words, a network – and is a demonstration of cross-craft or multi-craft.[6] This more nuanced understanding will enable the study of late Roman production to focus on the more fruitful and revealing areas of process and technique rather than materials.

The subject of cross-craft is an ideal one with which to focus on the evidence for the process of carving, not only in glass but in other materials, as an example of likely widespread late Roman multi-craft.[7] Production in a range of craft materials and the associated inter-industry relations challenges the largely unexamined assumptions that craft production was defined by material and that workers were only capable of working in a single material.[8] At one extreme is the idea of an *ad hoc* or lone craftworker engaged in domestic production, and at the other an urban complex with dedicated rooms for habitation, an overseer, a shared retail space, and individual rooms as dedicated work spaces each in a single material. Both need to be re-examined as part of cross-craft.

Material-specific models tend to overlook evidence of production networks. This research study is informed by recent work on professional associations that has helped to institutionalise trust networks and facilitate interdisciplinary

instance B. Bourgeois (ed.) '*Thérapéia.* Polychromie et restauration de la sculpture dans l'Antiquité' (journal special issue), *Techne* 40 (2014).

[4] See S. Walker (ed.), *Saints and Salvation* (Oxford, 2018), esp. 98–99. Such paintings appear to have been applied before secondary deposition, suggesting contemporaneous late Roman production.

[5] Just as 'metal' is a general term for specific types (such as bronze, copper, gold, silver, etc.), archaeometry involving petrographic analyses and the scientific study of glass have demonstrated that 'ceramics' and 'glass' are generalised terms that obscure variations in these materials, T. Rehren 30th March 2021 (public presentation), '3,000 Years of Glassmaking in the Eastern Mediterranean – an Introduction,' *American University of Beirut*, https://youtu.be/1Rm71KEQ0z4 (accessed April 4, 2024).

[6] On glass production and connections to other industries such as lime working, see Murphy and Snyder in this issue.

[7] For a discussion of carving in ivory and rock crystal in the same complex as glass, see the discussion of Kom el-Dikka, Alexandria, Egypt, below.

[8] For an important corrective, see A. St. Clair, *Carving as Craft: Palatine East and the Greco-Roman Bone and Ivory Carving Tradition* (Baltimore and London, 2003).

Figure 1. Base of a drinking vessel with imagery and a Latin inscription rendered in incised gold leaf with painted details, *c.* fourth century CE, reportedly from Rome, ORFITUS ET COSTANTIA IN NOMINE HERCVLIS ACERENTINO FELICES BIBATIS (*Orfitus and Constantia, may you live/drink in happiness in the name of Hercules of Acerentina*), diam. 105.30 mm, depth 5.98 mm, weight 79.42 g. London, British Museum (1863,0727.3). Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) license. Source: https://www.britishmuseum.org/collection/image/130931001, accessed April 4, 2024.

exchange.[9] Similarly, investigations concerning Roman labour and retail,[10] as well as economic networks in pottery and marble production in particular, have contributed greatly to our understanding of the complexities of late Roman production throughout the Mediterranean.

[9] On professional associations, see in particular S. E. Bond, *Trade and Taboo: Disreputable Professions in the Roman Mediterranean* (Ann Arbor, 2016); J. Liu, 'Group Membership, Trust Networks, and Social Capital: A Critical Analysis', in K. Verboven and C. Laes (eds). *Work, Labour, and Professions in the Roman World* (Leiden, 2016), 203–226.

[10] On subcontracting, see C. Hawkins, 'Manufacturing', in W. Scheidel (ed.), *The Cambridge Companion to the Roman Economy* (Cambridge, 2012), 175–96. On Roman artisans and the urban economy, see especially, C. Hawkins, *Roman Artisans and the Urban Economy* (Cambridge, 2016); M. Flohr, *The World of the* Fullo*: Work, Economy, and Society in Roman Italy* (Oxford, 2013).

Despite evidence of a flourishing carving industry concentrated in the fourth through seventh centuries CE, carving – and in particular glass carving as part of cross-craft – has not received much attention. Highlighting late Roman glass production as the central case study of this investigation has two aims. This article's main focus is first on material; I argue that 'glass' production was (at least) three related but separate industries. These include making the raw material (*glass making* or primary production), shaping glass objects (*glass working* or secondary production), and the optional stage of carving (tertiary production) associated with luxury objects.[11] Second, and in contrast to such material divisions within the core study of production in 'glass,' the present investigation considers evidence for cross-craft production revealed by the late Roman use of what I will demonstrate were related engraving techniques, in particular openwork and *opus sectile* (that is, cut work), notably the Thomas Panel (fig. 2). The carving stage for glass appears to have been optional. In other words, since carving is rarely associated with low-end objects that only required material and manipulation to make an object functional, the addition of protracted carving is typically a feature of high-end goods.[12] Any study of carved glass from this period would thus involve 'luxury' items in a broad sense. Yet at the same time there are gradations within the varied category of carved glass; it is not monolithic but instead reveals a great deal concerning middle- to high-status objects.[13] Beyond just glass, cold-worked carving in various materials represents skilled production occurring in independent working spaces but adjacent locations as part of a shared working-habitation complex, which suggests (relatively large-scale) late Roman urban production was more likely defined by a skill set (in this case carving) as opposed to a material.[14]

[11] There is evidence to suggest that trade in recycled glass may have occurred independent of production. On the Byzantine shops at Sardis, see A. von Saldern, *Ancient and Byzantine Glass from Sardis* (Cambridge, MA., 1980); J. S. Crawford, *The Byzantine Shops at Sardis* (Cambridge, MA., 1990). See also C. N. Duckworth and A. Wilson (eds) *Recycling and Reuse in the Roman Economy* (Oxford, 2020).

[12] It is worth noting that we are often hampered not only by the state of preservation but also by the state of completion for surviving objects. For example, if stoppers were frequently made from perishable materials that were not preserved in depictions or were reused, then this is likely to be lost to us. On reused stoppers, for example, see R. Thomas, 'Roman Vessel Stoppers', in D. Peacock, L. Blue, and J. Whitewright (eds), *Myos Hormos – Quseir al-Qadim: Roman and Islamic Ports on the Red Sea. Volume 2: Finds from the excavations 1999–2003* (Oxford, 2011), 11–34.

[13] For differentiation between and among categories of late Roman glass carving, see for instance H. G. Meredith, *Word Becomes Image: Openwork Vessels as a Reflection of Late Antique Transformation* (Oxford, 2015), 90.

[14] On work-habitation complexes, see for example late Roman Kom el-Dikka, Alexandria (Egypt) and early Byzantine Gortyn (Crete). Respectively, see M. Rodziewicz, *Les habitations romaines tardives d'Alexandrie à la lumière des fouilles polonaises à Kom el-Dikka*, *Alexandrie III* (Warsaw, 1984); E. Zanini, 'Lo scavo nel "quartiere bizantino" di Gortina: Il contesto metodologico dell'avvio di una ricerca', in A. Iacobini (ed.), *Bisanzio, la Grecia e l'Italia* (Rome, 2004), 145–59.

Figure 2. Thomas Panel, fragment of a glass *opus sectile* (cut work) wall decoration with a bearded face identified by the Greek inscription as Θομας (Thomas), likely from Egypt, *c.* 410 CE, overall length 790 mm, Corning, Corning Museum of Glass (86.1.1). Source: The Corning Museum of Glass.

LATE ROMAN GLASS PRODUCTION AS CROSS-CRAFT

The late Roman period witnessed an increasingly visible, public presence of craftworkers such as glassblowers in urban spaces, particularly widespread by the late sixth century and early seventh centuries.[15] However, depictions of either the production of raw materials or carving in any material in urban centres during this

[15] On the visibility of craftworkers and merchants, see E. Zanini, 'Artisans and Traders in Late Antiquity: Exploring the Limits of Archaeological Evidence', in W. Bowden, A. Gutteridge, and C. Machado (eds), *Social and Political Life in Late Antiquity* (Leiden and Boston, 2006), 373–411, esp. 396–404; H. G. Meredith, 'Making Anonymity Visible through the Use of Scale: Honoring the Conspicuously Absent with Laboring Bodies in 4th–8th century CE Construction Scenes', in K. Sessa and K. Uhalde (eds), *Scale and the Study of Late Antiquity: Collected Essays from the 14th Meeting of Shifting Frontiers* (Milan, 2023), 105–18. On late Roman familiarity with glassblowing in textual sources, see, for example, a Greek hexameter verse from a third century CE Oxyrhynchus fragment that describes glassblowing, E. Lobel, *The Oxyrhynchus Papyri* (London, 1983), 50: 57–9, no. 3536; E. M. Stern, 'Glass and Rock Crystal: A Multifaceted Relationship', *Journal of Roman Archaeology* 10 (1997), 192–206, esp. 206. See also H. J. Magoulias, 'Trades and Crafts in the Sixth and Seventh Centuries as Viewed in the Lives of the Saints,' *Byzantinoslavica* 37 (1976), 11–35, esp. 23–4.

time period are virtually non-existent. Such geographically restricted omissions further highlight a fundamental division between the three glass industries of raw material production, shaping via glassblowing, and carving.[16] Particularly around 300–800 CE, the manufacture of late Roman glassware called for a number of independent, sequential operations (*chaîne opératoire*).[17]

Despite appearing similar to other, largely transparent contemporaneous glass, Roman glass itself is not a single material. Glass is invariably produced with the same constituent parts of soda, lime, and silica. Historically, however, glass-makers in different epochs chose specific sources of soda, for instance, resulting in glass that was as different as silver from gold. The chemical composition of glassware nevertheless preserves evidence of its production. Glass itself, therefore, documents a combination of long-distance trade in ingredients such as natron, a native source of soda prevalent in the Wadi Natrun in Egypt, as well as variations resulting from locally sourced material such as sand.[18] Similar to petrographic analysis, these markers provide evidence concerning not only origins and patterns of long-distance trade, but also of localised additions and interactions between producers.[19]

Most likely due to the ingredients necessary to make glass, in the late Roman period primary production was restricted geographically to large production centres in the Levant and Egypt.[20] Long-distance transport was essential to move the raw material to producers not only throughout the Mediterranean but also to North Africa, India, the Caucasus, and as far east as China. In contrast to earlier localised manufacture in glass, the scale of glass making increased dramatically after *c.* 50 BCE/50 CE as a result of the invention of glassblowing that revolutionised Roman glass production, as will be further discussed below.[21] Two reasons for such radical growth in glass production concern primary and

[16] Part of what differentiates Roman glass production from that of earlier periods is the incredible scale possible due to the shift in raw materials from plant ash to natron (which could be collected on an industrial scale from Wadi Natrun, Egypt) and the invention of glassblowing around the mid-first century CE. The picture is very different for glass produced before the late Roman period, for example in the Late Bronze Age and Islamic period. However, the Romans continue the model of importing raw glass to work locally. See for instance J. Henderson, *Ancient Glass: An Interdisciplinary Exploration* (Cambridge, 2013).

[17] On the *chaîne opératoire* and late Roman glass carving in particular, see Meredith 'Unfinished *Chaîne opératoire*' (with bibliography). The production of glassware in the Roman period is in part defined by fundamental differences in production from both the preceding (*c.* 1600 to 1000 BCE) and succeeding periods (800–1500 CE), see Rehren '3,000 Years of Glassmaking,' 2021.

[18] For instance, see M.-D. Nenna, 'Primary Glass Workshops in Graeco-Roman Egypt: Preliminary Report on the Excavations on the Site of Beni Salama, Wadi Natrun (2003, 2005–9)', in I. Freestone, J. Bailey, and C. M. Jackson (eds.), *Glass in the Roman World* (Oxford, 2015), 1–22.

[19] For pioneering work, see I. C. Freestone, M. Ponting, and M. J. Hughes. 'The Origins of Byzantine Glass from Maroni Petrera, Cyprus', *Archaeometry* 44 (2002), 257–72.

[20] Pliny, *Historia Naturalis* 36.65.190–2, ed. D.E. Eichholz, *Pliny. Natural History, Volume X: Books 36–37*, Cambridge, MA., 1962. On Pliny's story about the origins of hot glass, see ibid. 36.65.26.

[21] On late Bronze Age glass production see Rehren '3,000 Years of Glassmaking,' 2021.

secondary production. First, a characteristic of Roman glassware is the innovative use of the mineral natron in the composition of glasses from this period.[22] The Wadi Natrun in Egypt was for the first time exploited as a rich and available source of natron for glass making. Second, and resulting in a phenomenal change in secondary production, was the invention of glassblowing around the mid-first century CE. This technological change allowed for glass working on an unprecedented scale from this point to the present day. By the sixth century CE, craftworkers and merchants moved to urban centres, resulting in a visible presence perhaps for the first time.[23] Whereas glassmakers involved in the production of raw glass were somewhat isolated and remained largely invisible (that is, not chosen to be portrayed as such on contemporaneous material culture), glassblowers in particular were represented from first century CE clay lamps to second/third century sarcophagi. This suggests the secondary producers were a more familiar sight. Such centralisation may have contributed to inter-industry relations.

Primary Production in Glass

Like surviving fragmentary and finished glass pieces, a dismantled completed firings and failures provide documentary evidence of primary production rarely found in written sources. Concerning what occurred in practice, the site of Bet Eli'ezer, Israel, in particular, provides evidence with which to reconstruct a rectangular Roman glass making furnace.[24] Measuring approximately 4 × 2 m, the furnace was designed for a single firing which might take 10–30 days to reach an estimated 1,100 degrees Centigrade. A single firing would likely produce around five to ten tonnes of raw glass. After the furnace cooled, the roof and walls were dismantled in order to extract the contents. Furnaces like these are found on the Levantine coast and in Egypt, including a well-known failed attempt which left eight tonnes of raw glass *in situ*.[25] The newly made block of glass was then broken up into smaller pieces as a finished product for sale and sold by weight.[26]

[22] In contrast to the plant ash used in Bronze Age glass, see Rehren '3,000 Years of Glassmaking,' 2021.

[23] For a discussion of this sixth century shift with respect to artisans and traders, see Zanini, 'Artisans and Traders in Late Antiquity', 373–411; L. Lavan, 'From *Polis* to *Emporion*? Retail and Regulation in the Late Antique City', in C. Morrisson (ed.), *Trade and Markets in Byzantium* (Dumbarton Oaks, 2012), 329–372. See also L. Lavan, *Public Space in the Late Antique City*, 2 vols (Leiden, 2020).

[24] Y. Gorin-Rosen, 'Hadera, Bet Eli'ezer,' *Excavations and Surveys in Israel* 13 (1995), 42–3.

[25] Despite consistent recycling practices in antiquity, presumably it was considered a better use of resources to abandon rather than to break up the failed firing. See R. H. Brill, 'A great glass slab from ancient Galilee', *Archaeology* 20 (1967), 89–95; I. C. Freestone and Y. Gorin-Rosen, 'The Great Glass Slab at Bet She'arim, Israel: an early Islamic glassmaking experiment?', *Journal of Glass Studies* 41 (1999), 105–16.

[26] On independent late Roman trade in recycled glass (as at Sardis), see above n. 11. On evidence of interactions among engravers in the form of reuse, see the discussion below.

Chunks of raw glass were shipped, for example in amphorae transport vessels, to be remelted in secondary workshops throughout the Mediterranean.[27]

Textual evidence confirms what is found in archaeological sources concerning trade involving at least two independent stages of glass production.[28] However, sometimes written evidence fills in gaps in the archaeological evidence concerning the primary stage of production. The chapter on glass in Diocletian's 301 CE *Edict of Maximum Prices* (16.1-4) differentiates between raw glass, vessels, window glass, and one other unidentifiable type of glassware.[29] Due to the inclusion of two 'colours' in the *Edict*, it suggests that both kinds of raw glass were widely available in the Mediterranean for purchase. Raw glass and cups each have two entries distinguishing between the more expensive price for Alexandrian glass (*vitri Alexandrini*) as opposed to the cheaper price for Judaean greenish glass (*vitri Iudaicis virdis*). Judaean glass refers to common blue-green coloured glass, which results from the minerals in local sand.[30] In contrast, Alexandrian glass refers to decolourised glass that appears colourless. The additional labour and resources involved in adding manganese to decolourise Alexandrian glass would have likely resulted in nearly doubled costs for the raw material. Similarly, worked perhaps free blown decolourised cups cost one-third more than Judaean greenish glass. It is noteworthy that, according to the *Edict*, trade in decolourised glass was available as part of primary as opposed to secondary production. Although it is widely understood that glass workers could and did add colourants to raw glass before blowing, the *Edict* indicates that at least two grades of raw glass were available as part of primary production. This suggests that there may have been firings making several tonnes of either Alexandrian or Judaean glass for long-distance trade.

Secondary Production in Glass

In direct contrast to geographically limited late Roman production in raw glass, knowledge of glass working appears to have been widespread, accounting for

[27] R. H. Brill, 'Scientific Investigations of the Jalame Glass and Related Finds', in G. Davidson Weinberg (ed.), *Excavations at Jalame: Site of a Glass Factory in Late Roman Palestine* (Columbia, MO., 1988), 257–83, esp. 283, note 37.

[28] For example, in the Babylonian Talmud (Shabbath 154b) concerning Sabbath rules for a merchant, *c.* the third century CE Rabbi Huna differentiates between unloading glass from a donkey laden with raw glass or finished, trans. G. D. Weinberg (ed.), *Excavations at Jalame: Site of a Glass Factory in Late Roman Palestine* (Columbia, MO., 1988), 25, note 2.

[29] Hereafter referred to as the *Edict*. On the surviving Greek and Latin versions of the glass chapter, see in particular H. G. Meredith, *Word Becomes Image: Open-work Vessels as a Reflection of Late Antique Transformation* (Oxford, 2015), 15–19, with bibliography. On mosaic tesserae as the unidentified glass category, see E. M. Stern, 'Roman Glassblowing in a Cultural Context', *American Journal of Archaeology* 103 (1999), 441–84, esp. 466.

[30] On Judaean glass, see Josephus *The Jewish War* II.189–91. See also, D. Barag, 'Recent Important Epigraphic Discoveries Related to the History of Glassmaking in the Roman Period', *Annales du 10^{e} Congrès de l'Association Internationale pour l'Histoire du Verre, 1985* (1987), 109–16, esp. 115.

'flourishing provincial production'.[31] Diagnostic evidence for furnaces used in the production of free blown glass, as opposed to raw glass, includes debris such as misshapen and cracked glass fragments, trails, and other discarded material and is found throughout the late Roman Empire and beyond.[32] Large quantities of newly made glass, recycled glass, or both were distributed widely both locally and long-distance.

It is likely that the only conceivable use for broken or waste glass was as a raw material to be remelted for reuse. Therefore the market for raw glass must have been limited to glass producers. For example, what appears to be a handbook by an anonymous Alexandrian dated to the late first century distinguishes between ὕελος ἀργή (unworked glass) (*Periplus Maris Erythraei*[33] 49.23, 56.19), ὑαλᾶ σκεύη (glass vessels) (*PME* 39.9), λιθίας ὑαλῆς πλείονα γένη (*PME* 6.2.25-26, 17.15-16) and ὑαλῆ λιθία σύμμικτος (*PME* 7.16) (several kinds of coloured glass).[34] These divisions indicate trade in finished products at two stages of glass production for domestic consumption and overseas production.[35] By the eighth century, the *Compositiones variae*, perhaps the earliest technical manual for craftworkers, included how to prepare coloured glass mosaics.[36] The 'recipes' are largely partial, demonstrating that considerable skill and training were necessary in order to follow the limited guidelines provided.[37] Despite a dearth of written accounts about workers, the small number of surviving technical treatises by merchants and producers that reference specialised production and trade in raw materials contrast markedly with technical guidance for secondary producers. Whereas the *PME*, as a merchant's guide, lists categories of cargo, guides for producers offer instructions for those already familiar with glassmaking (presumably at least an apprentice in a guild). The clear difference between lists of commercial cargo representing a range of in-process to finished glasswork (from coloured – likely raw glass – to unworked glass and vessels) as opposed to recipes therefore points to craftworkers and merchants with distinct knowledge bases engaged in inter-industry relations.

[31] M. Sternini, *La fenice di sabbia. Storia e tecnologia del vetro antico* (Bari, 1995), 137–200.

[32] On waste produced from Roman glass furnaces, see in particular C. Höpken, B. Birkenhagen, and M. Brüggler (eds), *Roman Glass Furnaces* (Schiffweiler, 2021).

[33] Hereafter *PME*.

[34] See also Meredith, *Word Becomes Image*, 14–15.

[35] On primary and secondary production in glass, see especially M.-D. Nenna, M. Picon, and M. Vichy, 'Ateliers primaires et secondaires en Égypte à l'époque gréco-romaine', in M.-D. Nenna (ed.), *La Route du Verre: Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Âge* (Lyon, 2000), 97–112.

[36] On recipes for making glass mosaics, both glass pastes and metal leaf tesserae, see A. Caffaro, *Scrivere in oro. Ricettari medievali d'arte e artigianato (secoli IX–XI). Codici di Lucca e Ivrea* (Naples, 2003), no. 14, 64–5; nos. 15 and 16, 66–7; T. Burns, Compositiones Variae*: A Late Eighth-century Artists' Technical Treatise* (London, 2017), 94–5, 109–10.

[37] On technical treatises and reconstruction, see, for example, P. H. Smith, 'In the Workshop of History: Making, Writing, and Meaning', *West 86th: A Journal of Decorative Arts, Design History, and Material Culture* 19, 1 (Spring-Summer 2012), 4–31.

During the watershed sixth and seventh centuries in the Eastern Mediterranean, archaeological spaces of secondary production displayed craft-work for sale and artisans in the process of producing such work. The glass-blowing furnaces used in secondary production suggest a somewhat typical late Roman spatial layout for permanent working-shops in urban centres. Although there is a great deal of variation among craft worksites in the Roman period in the Eastern Mediterranean in particular, a relatively large number of excavated worksites for a variety of media from the late Roman period provide a recurring or model architectural 'type' of two or more adjoining cellular rooms used as a space for producers to work, store, and potentially advertise and sell their wares to customers, sometimes with a connected courtyard work area.[38]

An example of three adjacent and connected areas is known at Bet She'an (Roman Scythopolis), Israel, in what has been identified as a *c.* sixth century production-retail site in the city centre. The three rooms, likely workspaces, include a central room, courtyard, and storeroom.[39] The central room was the main room used in glassblowing and includes the glassblowing furnace. Raw glass, presumably warming in order to be ready for use, was found next to the furnace. Similarly, raw glass was stored on shelves along the walls for subsequent use. Evidence of annealing and slow cooling was found right next to the furnace in the form of complete vessels encased in large quantities of olive pits.[40] It is believed that their heat-insulating properties made them suitable for the protracted cooling required to prevent cracking.[41] The concentration of olive pits are yet more evidence of secondary industries in perishable materials.

To the south was the courtyard. It was found with construction materials (stone and mud) ready to repair and rebuild the furnace. To the north of the central room was the storeroom that housed the same construction materials. The walls of the storeroom were lined with shelves filled with complete vessels.

[38] For instance, on the exceptionally preserved late Roman 'Sculptor's Workshop' at Aphrodisias in Caria (Turkey) specialising in marble portraits and mythological statues, see J. Van Voorhis, *The Sculptor's Workshop* (Wiesbaden, 2018).

[39] On the glass workshop at Bet She'an, see in particular Y. Gorin-Rosen, 'Glass Workshop in The Bet She'an Excavation Project 1992–1994', in G. Mazor and R. Bar-Nathan (eds), *Excavations and Surveys in Israel 17* (Jerusalem, 1998), 27–9. On the shops more broadly, see especially, E. Khamis, 'The Shops of Scythopolis in Context', in L. Lavan, E. Swift, and T. Putzeys (eds), *Objects in Context, Objects in Use: Material Spatiality in Late Antiquity* (Leiden, 2007), 440–72.

[40] See E. Rowan, 'Olive Oil Pressing Waste as a Fuel Source in Antiquity', *American Journal of Archaeology* 119/4 (2015), 465–82.

[41] For *comparanda*, see in particular A. Fischer, 'Glass Production Activities as Practised at Sepphoris, Israel (37 BC–AD 1516)', *Journal of Archaeological Science* 26 (1999), 893–905; Rowan, *Olive oil pressing waste*, 475; G. H. Barfod, I. C. Freestone, A. Lichtenberger, R. Raja, and H. Schwarzer, 'Geochemistry of Byzantine and Early Islamic glass from Jerash, Jordan: Typology, Recycling, and Provenance', *Geoarchaeology* 33, 1 (2018), 1–18.

Therefore, the storeroom could have served as a place to sort orders or as a viewing space for customers.[42] The urban location and access along the Street of the Monuments via a portico suggest a retail function in addition to a productive one.[43]

Archaeological sites with evidence of secondary glass production seldom have carved glass. When they do, engraving is often minimal.[44] Although it is plausible that glassblowers may have also been trained as engravers (perhaps in areas without a carving or finishing centre in a variety of materials) producing very small quantities of glass ranging from slightly abraded or etched glass to extensively carved sculptural objects, evidence of carved glassware suggests an independent industry with craftworkers trained in this distinct skill set producing and selling in larger quantities.

Tertiary Production in Glass

Although it is widely acknowledged that primary and secondary Roman glass production were entirely separate industries, the evidence for carving as independent localised tertiary production remains overlooked. This is due in large part to an absence of furnaces in cold-worked carving, and as a result there are no clear infrastructural remains with which to identify this subtractive process.[45] Moreover, tertiary production is more challenging to reconstruct archaeologically if, for example, domestic spaces were used for multiple functions including as cold-working sites.[46]

The process of finishing late Roman objects is little understood. Due to a paucity of evidence, finishing or completion is seldom discussed with reference to Roman objects. The skill sets integral to carving, whether in chalcedony, glass, ivory, silver, or other materials, all make use of a shared cold-working technique. Instead of approaching late Roman industries as material-based, as the example of 'glass' implies, it is plausible that finishing, for instance, was organised to profit from such skills.

[42] On city traffic in the early imperial period, R. Laurence, 'City Traffic and the Archaeology of Roman Streets', in D. Mertens (ed.), *Stadtverkehr in der antiken Welt. Internationales Kolloquium zur 175-Jahrfeier des Deutschen Archäologischen Instituts Rom* (Rome, 2008), 87–106. On underlying political motivations, see also, R. Burns, *Origins of the Colonnaded Streets in the Cities of the Roman East* (Oxford, 2017).

[43] For an example of glass retail (recycling) without production at the Byzantine shops at Sardis, see above n. 11.

[44] For instance, G. D. Weinberg and S. M. Goldstein, 'The Glass Vessels', in G. D. Weinberg (ed.), *Excavations at Jalame: Site of a Glass Factory in Late Roman Palestine* (Columbia, MO, 1988), 38–102.

[45] For a corrective, see Meredith, *Word Becomes Image*, 12–14, esp. figs. E, F and G. See also Meredith 'Unfinished *Chaîne opératoire*'.

[46] For example, on debris what was likely a domestic site for carving ivory and bone, see St. Clair, *Carving as Craft*.

EVIDENCE OF LATE ROMAN CARVING AND CARVERS

Concerning our primary interest of inter-industry relations, we will consider evidence of the engravers themselves, carving and finishing as cross-craft, cold-working production sites, and extensive carving in vessels made using a shared technique in different materials, all before turning to how the above offers evidence of interactions among tertiary craft producers.

Specialised Engravers in Multiple Materials

Specialised job titles for craftworkers and merchants survive, particularly in the Eastern Roman Empire. Kai Ruffing, among others, has shown that there are myriad specialised job titles found in Greek papyri and other written sources in the Eastern Mediterranean in particular.[47] Focusing on first to seventh century CE Greek papyri and inscriptions, Ruffing amassed a corpus of over 800 titles and concluded that most occupational titles are by types of goods or raw materials (such as textiles, foodstuffs, metal, wood, and so on) and that titles by separate functions within an activity are rare.[48] Ruffing later argued that the prevalence of professional titles in various crafts and trades alone is not evidence for 'extravagant' specialisation.[49] Therefore, late Roman terms for occupational specialisation, or a lack thereof, may raise more questions than answers. Moreover, Cameron Hawkins's subcontracting model of the urban economy would account for specialisation and inter-industry relations as part of professional networks.[50] Thereby, working in sequence, an engraver could potentially specialise in a process, such as carving in glass or carving in a range of materials, in sequence. Either possibility fits the data for late antiquity. Evidence concerning specialisation as glassmakers involved in primary production, glassworkers in secondary production, and engravers (such as *diatretarii*) survives in the form of epigraphic sources.[51]

[47] In particular, see K. Ruffing, *Die berufliche Spezialisierung in Handel und Handwerk: Untersuchungen zu ihrer Entwicklung und zu ihren Bedlingungen in der römischen Kaiserzeit im östlichen Mittelmeerraum auf der Grundlage griechischer Inschriften und Papyri*, 2 vols. (Rahden, 2008).

[48] Ruffing notes that several job titles are synonyms suggesting linguistic distinctions rather than specialisation, and that some may have been part-time occupations resulting in the problem of comparisons. Ruffing *Die berufliche Spezialisierung*. On the Latin occupational terms, for example, see S. R. Joshel, *Work, Identity, and Legal Status at Rome: A Study of the Occupational Inscriptions* (Norman, OK and London, 1992).

[49] K. Ruffing, 'Driving Forces for Specialization: Market, Location Factors, Productivity Improvements', in A. Wilson and M. Flohr (eds), *Urban Craftsmen and Traders in the Roman World* (Oxford, 2016), 115–28, esp. 117. On specialisation, for instance, see R. K. Flad and Z. X. Hruby (eds), *Rethinking Craft Specialization in Complex Societies: Analyses of the Social Meaning of Production* (Arlington, VA, 2007).

[50] On finishing trades in particular, see Hawkins, *Manufacturing*, esp. 178 and 180.

[51] See M. Trowbridge, *Philological Studies in Ancient Glass*, University of Illinois Studies in Language and Literature (Urbana, IL, 1930). On *diatretarii*, see Meredith, *Word Becomes Image*,

There is evidence from legal sources indicating a clear separation among these occupations between secondary producers working in glass and engravers that worked in glass and possibly also in other materials. This suggests a perceived division based on distinguishable skill sets. The *Codex Theodosianus* sheds light on what is known about carving as a profession. A fourth century CE law includes a list of trades exempted from public services (*Codex Theodosianus* 13.4.2). This law confirms that engravers (*diatretarii*) were in fact differentiated from glass workers (*vitrearii*), stonecutters, and workers in ivory, underscoring a legal distinction in late Roman civil society. The list of appended occupations concerned does not, however, restrict an engravers' artistic output by material.[52] In contrast to secondary producers restricted to the medium of glass, there is no clear evidence that *diatretarii* refers exclusively to carving in a single medium or even that carving was necessarily in glass. It appears that as a result of retrieval bias scholars have equated glass vessels possessing a carved cage network almost exclusively with the work of *diatretarii*.[53] There is thus no real basis upon which to conclude that products of *diatretarii* were limited to 'carved glassware' alone. Instead, especially when considering this evidence together with the glass chapter in Diocletian's *Edict of Maximum Prices*, a general division between hot-working and cold-working is more likely what occurred in practice.

Instead of asking if workshops worked in more than one material, a more fruitful question may be *when* did they. To clarify, I am not arguing that all workshops produced goods in more than one medium. An excellent example to the contrary is the 'Sculptor's workshop' at Aphrodisias in Turkey. Evidence here clearly points to late Roman sculptural production exclusively in marble until the fourth century. Moreover, evidence of what is likely a secondary glass furnace from around the fourth to sixth centuries was found in another area of the city.[54] Specialisation here likely meant this workshop repeatedly produced mythological figures or portraits – all executed in marble.[55] The large-scale marble sculpture produced here may represent a different model of production, in part due to the figural subject matter and in contrast to small-scale luxury objects.[56] Despite

esp. 42–5 with bibliography. There is also the possibility that there was at least one additional 'glass' industry, namely independent recycling. On an example at Sardis, see above n. 11.

[52] For a parallel phenomenon concerning silver production, see D. E. Strong, *Greek and Roman Gold and Silver Plate* (London, 1966), 18.

[53] For a list of dozens of terms used for vessels in the early third century CE, see Athenaeus, *Deipnosophists* XI, ed. Ch.B. Gulick, *Athenaeus: The Deipnosophists*, London and New York, 1927.

[54] R. R. R. Smith and C. Ratté, 'Archaeological Research at Aphrodisias in Caria, 1996', *American Journal of Archaeology* 102 (1998), 225–50, esp. 238.

[55] This building has been identified as a workshop largely due to excavated evidence documenting ephemeral processes such as training apprentices, demonstration pieces, in-process revisions, and versions of the same subject in different sizes, Van Voorhis 2018. See also E. Stewart, E. Harris, and D. Lewis (eds), *Skilled Labour and Professionalism in Ancient Greece and Rome* (Cambridge, 2020).

[56] The tools used for sculpture in the round may have been different from those used to produce smaller sculptures. If true, then this could have discouraged cross-craft if this meant that distinct tools required different skills. However, it seems more likely that tools may have varied in size, for

examples like these to the contrary, overall the evidence suggests that we cannot presume that all workshops, or even most involved in carving portable objects, were necessarily restricted to one material.

Late Roman Architectural Evidence of Cold-working Sites

This paper has thus far outlined evidence demonstrating that late Roman production in 'glass' was divided into at least three industries, two of which have been well-known for some time largely because these industries centre around the presence of a furnace, providing a straightforward diagnostic means of identification in archaeological excavations.

In contrast, the third kind of 'glass' production is cold-worked.[57] A reappraisal of the handful of cold-working sites dedicated to carving, concentrated in the late Roman period, along with an examination of a core late Roman case study of extensively carved vessels produced in a range of materials (where some individual objects incorporate more than one material), demonstrate at least collaborative finishing if not knowledge of multiple media. Cold-working thus also did not need to be – nor does it appear to have been – exclusively material-specific.[58] This indicates that carving and/or finishing required technical knowledge that may be more fruitfully approached as skill-based and almost certainly cross-craft.

Indirect evidence of cross-media production exists in bone and ivory carving. At Palatine East in Rome, for example, more than 1,500 fragments of carved bone and ivory were found together in a dump likely related to domestic production. Archer St. Clair Harvey concluded that the same saws, chisels, and lathes were used here to carve both ivory and bone: 'in many cases the two materials were used interchangeably, often in combination with each other, and that the same artists worked indifferently in both materials, probably together rather than in independent workshops'.[59] The evidence at Palatine East demonstrates cross-media carving production in other materials indicating a precedent in Late Roman carving, specifically ivory and bone carving performed side-by-side.

example, but represent the same or at least a similar skill set. On tools used in marble carving, see 'The Art of Making in Antiquity: Stoneworking in the Roman World', https://artofmaking.ac.uk/explore/tools/, accessed April 4, 2024.

[57] For example, at least one ceramic version of a gold-glass vessel survives, with a clear potential for more, see a mid-fourth century CE glazed earthenware bowl with Saints Peter and Paul, 85 x 140 x 133 mm, New York, Metropolitan Museum of Art, Fletcher Fund (52.25.1), https://www.metmuseum.org/art/collection/search/468386 (accessed April 4, 2024). Additionally, approximately 25% (23 of 92) openwork vessels are known in materials other than glass, such as precious stone or metal, Meredith, *Word Becomes Image*, fig. C. See discussion of openwork vessels below.

[58] For example, on discarded worked bone and ivory mixed together in a spoil heap, see St. Clair, *Carving as Craft*.

[59] A. St. Clair Harvey, 'Carving in the Center: Evidence for an Urban Workshop on the Palatine Hill in Rome', in G. Buhl, A. Cutler, and A. Effenberger (eds), *Spätantike und byzantinische Elfenbeinbildwerke im Diskurs* (Wiesbaden, 2008), 249–70, esp. 259–60. See also, St. Clair, *Carving as Craft*, 15–37.

If not all carving sites operated in more than one material, then this again raises questions concerning the conditions for cross-craft media production. If there were already clear divisions between independent stages of production and trade, such as hot- vs. cold-working in glass, then it may have been more likely that cold-worked carving would occur in a space with specialists who were working in a range of materials. It is therefore important to approach Late Roman working sites and commercial shops not only along material lines but also based on processes, such as engraving.

In light of excavated evidence of cross-media production in carved bone and ivory, it is worth revisiting a carving complex found at Kom el-Dikka in Alexandria, Egypt. Although there is no evidence of carved glass vessels (at this house, at least), glass cold-working occurred in what has been identified as a cold-working/finishing room at what appears to be a carving/finishing-habitation complex.[60] While late Roman Kom el-Dikka has been discussed largely with respect to its Christian community, archaeological excavations have uncovered a network of houses set up for craftwork in a range of materials.[61] These arrangements suggest a nuanced understanding of cross-craft carving or finishing in permanent cellular rooms.[62] Similar processes, and presumably similar tools, were used in the different materials for the shared technique of carving as part of finishing.[63]

Excavations here provide evidence of varied industrial and commercial activity. In particular, in the sixth-century House D there are four rooms of special interest, two of which are cold-working sites, likely for carving/finishing (fig. 3).[64] Each of the working areas and commercial rooms all access a central

[60] For mould-blown decorated glassware from Kom el-Dikka, Alexandria (Egypt), see R. Kucharczyk, 'Glass Vessels Decorated with Christian Symbols from Alexandria', *Études et Travaux* 25 (2012), 149–158. For later engraved glasswork from this site, see R. Kucharczyk, 'Islamic Scratch-Engraved Glass from Alexandria (Kom el-Dikka)', *Journal of Glass Studies* 51 (2009), 40–52; R. Kucharczyk, 'A Fragment of Dichroic Glass from Alexandria', *Journal of Glass Studies* 56 (2014), 29–35; R. Kucharczyk, 'Two Fragments of Early Islamic Cameo Glass from Alexandria', *Journal of Glass Studies* 61 (2019), 1–12. For a seventh century CE craft-habitation community see for example Gortyn (Crete), Zanini, 'Lo scavo nel "quartiere bizantino" di Gortina', 145–59.

[61] Such as the function of the courtyard in House D serving as a private oratory, see C. Haas, *Alexandria in Late Antiquity: Topography and Social Conflict* (London, 1997), 173–214, esp. 202.

[62] Material divisions were most likely primarily for the purposes of sorting and recycling materials. On recycling, see M. Ponting and D. Levene, '"Recycling economies, when efficient, are by their nature invisible." A first century Jewish recycling economy', in M. J. Geller (ed.), *The Archaeology and Material Culture of the Babylonian Talmud* (Boston, 2015), 36–65; Duckworth and Wilson *Recycling and Reuse*.

[63] On tools as evidence of cross-craft relations, see E. M. Stern, 'Interaction between Glassworkers and Ceramicists', in P. McCray (ed.), *The Prehistory & History of Glassmaking Technology, Ceramics and Civilization* (Westerville, OH, 1997), 183–204.

[64] Haas, *Alexandria in Late Antiquity*, plan 2.

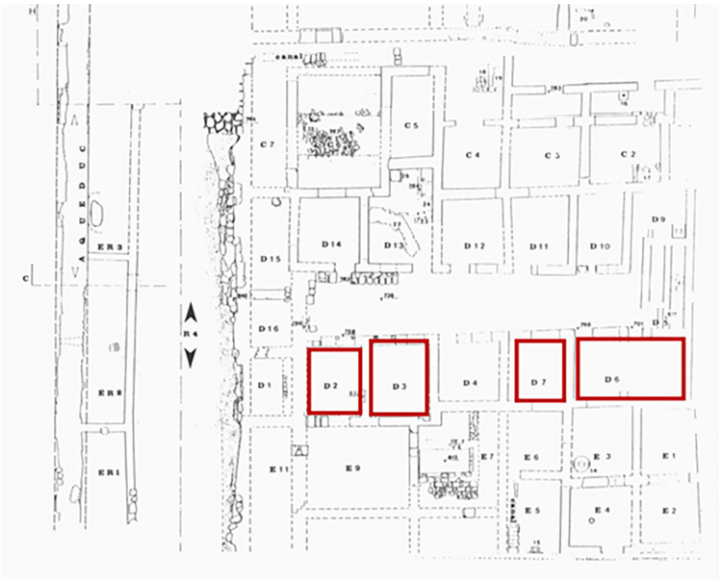

Figure 3. Plan of House D, at Kom el-Dikka, Alexandria, Egypt. Room functions identified of special interest include showroom (room D2), workshop in semi-precious gems (room D3), finish workshop for glassware (room D7), office (room D6). Source: Haas 1997, plan 2.

courtyard indicating a co-operative space.[65] Near the street is a retail display area, essentially a showroom, and at the back there is a room that has been identified as an office, perhaps for an owner or manager.[66] In between are two rooms, each dedicated to carving in a different material.[67] In a working area demonstrating in-process work on semi-precious gems, granite anvils tools and several pieces of rock crystal in various stages of production have been found (fig. 4).[68] To the east, another room has been identified as a finishing workshop for glassware. Pieces of glass found in D7 include glass beads (fig. 5),

[65] See the courtyard used for marble carving at Aphrodisias (Turkey), Van Voorhis, *Sculptor's Workshop* and at Kom el-Dikka, Alexandria (Egypt). See also above n. 61.

[66] The part of the room that interests us has been identified as a place of work and accounting for the following reasons: D6 is the largest room in this wing (5.15 x 2.90 m); two entrances lead to this room from a communal courtyard; this room was decorated with a mosaic floor, yellow-brown painted walls; and a desk and shelves were attached to the walls. In addition to varied finds in another part of the room, those related to production include fragments of rock crystal, unspecified unfinished glass 'products' and glass beads, small bronze coins (diam. 7–10 mm), and a lock, see M. Rodziewicz, *Les habitations romaines tardives d'Alexandrie: à la lumière des fouilles polonaises à Kôm el-Dikka* (Warsau, 1984), 87–93, esp. 87, 93.

[67] Both rooms are no larger than 3.40 × 2.90 m with walls preserved up to around 2.95 m high, Rodziewicz, *Les habitations romaines tardives d'Alexandrie*.

[68] See rock crystal production waste and semi-finished products from the soil of workshop number 1, Rodziewicz, *Les habitations romaines tardives d'Alexandrie*, fig. 273.

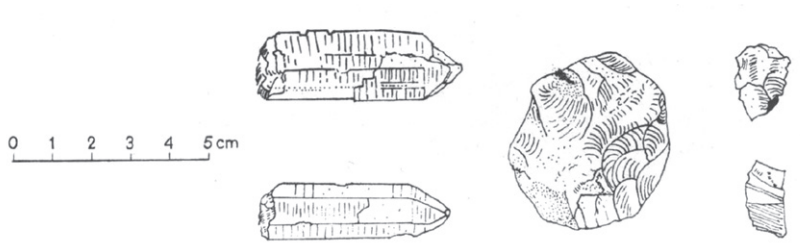

Figure 4. House D, Kom el-Dikka, Alexandria, Egypt. Fragments of rock crystal from room D3. Source: Rodziewicz 1984, fig. 73.

Figure 5. House D, Kom el-Dikka, Alexandria, Egypt. Glass beads from room D7. Source: Rodziewicz 1984, fig. 83.

with tools for glass beads in another house.[69] Moreover, there is no evidence of any hot-working in this complex. A furnace, likely for shaping glass, was found in a workshop across the road.[70] This means that at this site there were different areas for working the same material with what appear to be independent secondary (glassblowing) and tertiary production (carving) in glass. As part of a network of producers in related but distinct carving/finishing industries, this complex both

[69] House F (room F5), see Rodziewicz, *Les habitations romaines tardives d'Alexandrie*, 242.

[70] Rodziewicz, *Les habitations romaines tardives d'Alexandrie*, 241, for example, suggests that millefiori glass was produced at Kom el-Dikka and used for inlay. This points to further craft interconnections concerning late Roman producers at Kom el-Dikka.

maintained material divisions (such as a room dedicated to glass production independent from another room dedicated to the working of rock crystal) yet simultaneously brought producers using similar production processes together, likely co-ordinating them as part of a cross-media cold-working complex. Moreover, this evidence further reinforces divisions specified in economic sources by supporting a physical division in production, likely hot- vs. cold-working.

Late Roman Vessel Carving Techniques in Multiple Materials

While excavated evidence of in-process carving is scarce, it appears to be concentrated in the fourth to sixth centuries CE. Taking the example of openwork vessels (that is, two-layered vessels connected by a network of horizontal glass bridges), portable vessels carved using this particular technique can be used to detect interactions between and among late Roman tertiary producers.[71] Although glass vessels comprise a majority of this vessel type, they were also made exclusively in precious stones (such as agate, chalcedony, marble or rock crystal) or in metal (in particular, bronze, gold, or silver).[72] The corpus reveals evidence of late Roman production for these functional vessels identified for drinking, as well as lamps, largesse, and libation vessels.[73] Regardless of the material or function, they are identifiable based on their openwork carving technique.

Despite limited extant evidence concerning openworked vessels in stone, it appears that finishing similarly often meant the addition of a metal collar and/or suspension rings.[74] This composite vessel type in particular demonstrates that the finishing of metal openwork vessels necessitated collaboration or trade – at the very least co-ordination – among metal workers and glassblowers.[75] The metal workers would produce the metal of the required composition,[76] shape the material, and then finally engraving it, while the glassworkers would prepare a characteristic cobalt blue liner.[77] If a metal collar or suspension chains were

[71] For example, see the Lycurgus Cup, image of Dionysos, as the dichroic glass openwork vessel changes from pea green to wine red. Nearly complete vessel with post-Roman metal mounts; imagery also includes King Lycurgus, Pan, a panther, satyr, and maenad; c. fourth century CE, ht. with metal rim 165 mm, diam. outside metal rim 132 mm, inside metal rim 122 mm, wall thickness not reported. London, British Museum (1958,1202.1), https://www.britishmuseum.org/collection/object/H_1958-1202-1 (accessed April 4, 2024); Meredith, *Word Becomes Image*, fig. 80; Meredith, 'Unfinished *Chaîne opératoire*', 119–39. Similarly, gold-glass with evidence of painting appears to have been roughly contemporaneous with glass production, see Walker *Saints and Salvation*. On openwork vessels, in particular, see Meredith, *Word Becomes Image*; D. Whitehouse, W. Gudenrath, and P. Roberts, *Cage Cups: Late Roman Luxury Glasses* (Corning, 2015).

[72] Meredith, *Word Becomes Image*, 1–8, fig. C.

[73] Meredith, *Word Becomes Image*, esp. 65–71, fig. GG.

[74] For instance, see a rock crystal lamp, Meredith, *Word Becomes Image*, figs. 51.1–1.5.

[75] See Meredith, *Word Becomes Image*, fig. J.

[76] On a 95% silver composition for Sion Treasure lamps, see Meredith, *Word Becomes Image*, figs. 69–76.

[77] See Meredith, *Word Becomes Image*, 19, fig. J. On glass liners, see Meredith, *Word Becomes Image*, figs. 69–76, and 78.1–8.4.

Figure 6. Nearly complete decolourised, transparent colourless glass lamp with original copper alloy collar, hook, loop, and looped elements; *c.* 300 CE, ht. glass vessel 71 mm, ht. metal collar 5 mm, hook and loop 170 mm, rim diam. glass 121–2 mm, rim diam. copper alloy collar 110 mm, wall thickness glass not reported, wall thickness of copper alloy collar 1 mm. Corning, Corning Museum of Glass (87.1.1). Source: Meredith, *Word Becomes Image*, figs. 88.1–88.6, at 88.5.

needed for a glass openwork vessel (such as fig. 6), then the sequence of production suggests that such vessel production went back and forth between metal and glass producers following a subcontracting model. Even if, for example, glassworkers purchased a 'finished' carved metal openwork vessel in order to subsequently construct a glass liner, once the glass component was complete the composite vessel presumably would need to go back to a metalworker to add metal suspension chains.

Carving in late first to mid-sixth century CE glass openwork vessels reveals empire-wide standardisation in the geometric cage network towards the base. Such consistent patterns are found on vessels from a wide geographic range.[78] A

[78] For instance, H. G. Meredith, 'Evaluating the Movement of Open-work Glassware in Late Antiquity', in M. Mundell Mango (ed.), *Byzantine Trade, 4th–12th Centuries The Archaeology of Local, Regional and International Exchange Papers of the 38th Annual Spring Symposium of Byzantine Studies* (Aldershot, 2009), 191–7.

single, unvaried pattern repeated by rows of circles on these vessels strongly suggest standardisation. Regardless of the number of rows of circles higher up the walls, the same range of geometric patterns is found on the bottom of all glass openwork vessels.[79] Correlated to the vessel's shape, the circular elements that occupy the final row on bell-shaped vessels are always larger than those of any other row. The penultimate row of geometric cage networks typically contain twice as many circular elements as the antepenultimate row.

This degree of consistency is important because it supports the interpretation that engravers – over a period of several centuries – adhered to a centralised model. Based on the sequence of production, it is likely that engravers would have begun carving a network of interconnected circles from the bottom up, since this is where the regularity is observed. This suggests that this practice may have been taught in tertiary workshops. Despite gaps in our knowledge of tertiary production in glass workshops, surviving evidence of glass carving supports a model in which engravers across media worked closely in one complex.

Standardisation does need not be considered in opposition to variation. Whereas standardisation is most often limited to the penultimate and ultimate rows of this design element, colour combinations among geometric cages differ, as does the frequency of cage networks alone or in combination with an inscription, imagery, or ovolo frieze. As Vince Van Thienen has argued concerning the production of crossbow brooches, specifically with respect to debates concerning either standardised military production or regional variations, there is evidence to suggest that in the fourth century CE especially certain features may have been uniform to be recognisable yet with scope for expression and variability within localised decorative elements.[80] This may also have been true of late Roman openwork vessels.

Complete objects like this fourth century CE glass lamp with an original metal fitting (fig. 6) demonstrate finishing involving more than one material demonstrating multi-craft production. While there is no written evidence concerning the manufacture of such extensively carved vessels nor are worksites known, two likely but opposing possibilities exist concerning production. The first possibility

[79] For example, see an entirely decolourised, transparent colourless glass openwork vessel with an extensive geometric pattern on the vessel's exterior from Niederemmel (Kr. Bernkastel-Wittlich), Germany; second third of fourth century CE, ht. 180 mm, rim diam. 155 mm, wall thickness 2 mm, Trier, Rheinisches Landesmuseum (1950.15), see Meredith, *Word Becomes Image*, figs. 27.2, 27.4. See also a decolourised, transparent colourless glass openwork vessel with a translucent emerald green Latin inscription, BIBE VIVAS MVLTIS ANNIS (*'Drink! May you live for many years'*), and extensive geometric pattern (upper opaque pale yellow horizontal band with light cobalt blue below) on the vessel's exterior from near Novara, Italy; *c.* first third to second half of the fourth century CE, ht. *c.* 120–121 mm, ht. letters 14 mm, rim diam. *c.* 121–5 mm, wall thickness not reported, see Meredith, *Word Becomes Image*, figs. 43.2, 43.3.

[80] V. Van Thienen, 'State Control, Regionality or Guidelines? The Production of the Crossbow Brooch', in S. Hoss (ed.), *The Production of Military Equipment - Fabricae, Private Production and More, Panel 9.1, Archaeology and Economy in the Ancient World 48* (Heidelberg, 2021), 47–57.

Figure 7. View from beneath the two filed sections of the ovolo band from a nearly complete decolourised, transparent colourless glass lamp with original copper alloy collar, hook, loop, and looped elements (fig. 6); *c.* 300 CE, ht. glass vessel 71 mm, ht. metal collar 5 mm, hook and loop 170 mm, rim diam. glass 121–2 mm, rim diam. copper alloy collar 110 mm, wall thickness glass not reported, wall thickness of copper alloy collar 1 mm. Corning, Corning Museum of Glass (87.1.1). Source: Meredith, *Word Becomes Image*, figs. 88.1–88.6, at 88.4.

is that a glass engraver carved the glass parts followed by the sale of the carved piece to a metal worker to complete the object for use. This would thereby indicate 'vertical' specialisation, with separate skills and tasks associated with making a single object. The traditional 'one material' paradigm tends to treat production in a single medium as a monolithic and exclusive category. Although plausible for utilitarian vessels without the optional third stage of carving that characterises luxury glassware, this model ignores evidence of multi-craft carving/finishing collectives found in the archaeological record from the sixth and seventh centuries. However, collaboration among material specialists is suggested in particular because two sections from this vessel's ovolo frieze sections were filed in antiquity (likely by a specialist trained in glass cutting after the extensive carving involved) (fig. 7). Filing appears to have been required to make space for the metal collar's closing mechanism (fig. 8).[81]

[81] The two ovolo frieze sections that were removed were presumably meant to accommodate the curved nail that fastens the collar (fig. 8). The two filed sections (fig. 7) are only visible today because the curved nail used to fasten the collar was moved post-production, Meredith, *Word Becomes Image*, figs. 88.1–8.6.

Figure 8. Detail of the curved nail that fastens the copper alloy collar from a nearly complete decolourised, transparent colourless glass lamp with original copper alloy collar, hook, loop, and looped elements (fig. 6); *c.* 300 CE, ht. glass vessel 71 mm, ht. metal collar 5 mm, hook and loop 170 mm, rim diam. glass 121–2 mm, rim diam. copper alloy collar 110 mm, wall thickness glass not reported, wall thickness of copper alloy collar 1 mm. Corning, Corning Museum of Glass (87.1.1). Source: Meredith, *Word Becomes* Image, figs. 88.1–88.6, at 88.3.

The second possibility, which more likely explains high-end production in openwork vessels and other cross-craft objects, is an engraver working as part of a collective of engravers trained in a range of materials, possibly with a professional network nearby (such as the Kom el-Dikka model with a glass-blower and other secondary worksites across the road). The engraver carved the glass (or metal or stone) vessel, perhaps also finishing the vessel by adding metal mounts or subcontracted the metal additions rather than selling an unfinished piece.[82] The second model is more attractive for the late Roman luxury carving in our openwork vessel case study. This collaborative model fits the sixth and seventh century urban craft-habitation communities elsewhere, such as in Gortyn (Crete), and explains the artefactual evidence – suggesting closely working together with specialists, whether or not in other materials, in other processes – and the likely possibility that an artisan worked in more than one material to finish an object.

It is plausible that metal fittings were purchased and attached in a glass workshop, but logistically the model of a 'finishing centre', presumably with subcontracting, is more likely. This is due to the degree of specialisation exhibited by the presence of independent but related primary and secondary glass producers together in Palatine East in Rome (Italy) and Kom el-Dikka in Alexandria with what appears to be largely interchangeable engravers working in adjacent spaces (most likely with an eye towards recycling materials rather than fundamental material divisions in terms of skill).

The sequence of production for openwork vessels made entirely of glass suggests inter-industry relations among four different types of producers: glass makers, glass workers, engravers, and metal producers.[83] First, decolourised

[82] On subcontracting networks, Hawkins states that rather than a single physical location of production, '[t]he locus of production that unites the various specialists…is the neighborhood rather than the workshop', Hawkins, *Manufacturing*, 180.

[83] See Meredith, *Word Becomes Image*, figs. J and N.

glass was produced by glass makers. Second, if particular colours or colour combinations were called for, then colourants were added to the fabric (as discussed below) by glass workers who also shaped vessels and added any coloured glass in horizontal registers, for example, for inscriptions. Third, engravers worked in cold-working worksites to carve two layers from one layer, preserving horizontal glass bridges. Fourth, intact vessels suggest that final assembly occurred with the addition of metal fittings. Four distinct specialisations are therefore suggested involving not only different 'glass' industries but also different materials, including metals.

Late Roman Dichroic Glass

A noteworthy example of a colour combination resulting from material added to the glass fabric is dichroic glass. To create dichroic glass, minute quantities of gold and silver are intentionally added to the fabric, most likely during the melting phase of glass.[84] Only a small number of Roman period dichroic glass vessels survive. By adding these precious metals to the fabric of the glass the aim was to transform the colour of a finished vessel in use. In dichroic glass openworked vessels, an entire vessel appears one colour in transmitted light and another colour in reflected light. This colour-changing property means that when light passes through the object it appears transformed, as if by magic.[85] In practice, the functional basis for this visual trick suggests that when empty a vessel might appear the colour of unripe grapes, like the *Lycurgus Cup*, currently in the British Museum, and when filled with wine the vessel would be transformed to the colour of ripe grapes matching its contents. Dichroic glass is extremely rare in antiquity.[86] This rare chemical composition, with the resulting variations in the colour combinations produced, is largely known and restricted to the late Roman period and these elaborately carved openwork vessels. While dichroic glass itself suggests collaborative production (between producers of raw glass and metal, as well as between glass vessel producers and engravers), we now turn to more direct evidence of interactions between tertiary producers via recycled glass.

[84] As part of the colouring process of glass, working metal scraps or powder were added to crucibles during the melting stages of glass in first to fourth century CE suburban Aquileia, see F. Di Turo, et al., 'Chemical Analysis and Computed Tomography of Metallic Inclusions in Roman Glass to Unveil Ancient Coloring Methods', *Scientific Reports* 11, no. 11187 (2021), 1–12, esp. 9.

[85] On a *c.* second century CE description of a similar trick and, in the story at least, identified as rock crystal, see Achilles, Tatius *Leucippe and Clitophon*, 3.3.

[86] See above n. 71. On dichroic glass in the late Roman period, Meredith, *Word Becomes Image*, figs. I.1–I.2.

Interactions among Tertiary Craft Producers

Little evidence remains regarding quotidian interactions between producers, whether working in the same or different materials. However, extensively cut glass with rare and distinctive colourants offers evidence of associations among tertiary producers – and specifically interactions between and among raw glass production, shaping, engraving, and the craftworkers involved. Concerning the artefactual material, shipwrecks provide evidence of careful sorting by colour expressly for export markets, most likely not to contaminate colours intended for reuse. Although unusual, extensively cut glass with rare and distinctive colourants document what appears to be a local trade network among tertiary producers such as those working in the openwork technique, *opus sectile*, and mosaics.

In Egypt, there likely is evidence of strategic recycling among high end producers working with cut glass. An example of a glass *opus sectile* (that is, cut work) wall decoration from approximately 410 CE is a fragment depicting a bearded face in profile identified by a Greek inscription as Θομας, Thomas (fig. 2). The crucial part here is that the pinkish skin colour, unusual in antiquity, used for Thomas's face is recycled dichroic glass – and was most likely sourced from openwork vessel producers.[87] Openwork vessels with inscriptions date from approximately the late third to mid-sixth centuries CE. This evidence indicates that recycling between (or among) engravers (tertiary producers) in glass was purposefully designed for a specific and limited professional network.

Akin to long-distance trade in raw glass evident since at least the first century CE, glass routinely travelled to local producers. Furthermore, secondary production in glass is characterised by widespread provincial production. In contrast, however, as an essentially optional addition to luxury carved objects, tertiary production in glass appears to have been geographically restricted, resulting in what might be described as series or localised types of carved glassware with standardised elements.[88] As has been shown, such uniformity may be understood as selective standardisation (perhaps contributing to the recognisability of a particular series or vessel type) and simultaneous variation within a limited repertoire of design elements.[89] This does not mean that extensive carving in glassware could not occur independently or removed from secondary producers, but the zenith in carved luxury objects, particularly portable ones during this era, represents a time in which urban craft communities shared resources. Importantly, this is not just as part of cross-craft professional networks

[87] R. H. Brill and D. Whitehouse, 'The Thomas Panel', *Journal of Glass Studies* 30 (1988), 34–50, esp. 41.

[88] For a few late Roman glass series, see Meredith, 'Unfinished *Chaîne opératoire*'.

[89] On the limited design elements found throughout the corpus of openwork vessels, Meredith, *Word Becomes Image*, 46–71.

organised around shared materials, as has previously been known (for example, at the marble Sculptor's Workshop at Aphrodisias), but also around techniques and processes (that is, carving/finishing). The artefactual evidence and written sources confirm this.

Evidence from architecture, objects, as well as economic, legal, and other written sources all indicate that glass production consisted of at least three separate spheres of production. Approaching the varied stages of production in glass as cross-craft processes – rather than as a monolithic material – is crucial to properly comprehending production as a multi-industry whole, potentially comprised of fundamentally related and interconnected parts. Moreover, this contributes to approaching carving as a technique or process rather than exclusively as material-specific.

CONCLUSION

The model of urban and specialised collaboration among glass producers suggested in this paper represents the interdependence required of inter-industry relations – that is, cross-craft – in terms not only of resources but fundamentally of skills. As I have argued, archaeological and economic evidence for late Roman luxury glassware strongly points to glass production as comprised of two hot-working stages and one separate cold-working industry. There is evidence for cross-craft relations between or among these related but separate industries. Raw glass was made in specific geographic areas producing large quantities for trade throughout the Mediterranean and beyond, perhaps initiating a model of specialisation fundamental to 'glass' production. As secondary production on display in urban centres, glassblowing was the most visible of the three kinds of glass production discussed. The textual, archaeological, and artefactual evidence, particularly for the carving and finishing of portable luxury objects as part of multi-craft relations, opens new vistas for scholars of late Roman craft production and the urban economy. The processes associated with cross-craft are reflective of important aspects of artistic and economic life in late Roman and early Byzantine society and are crucial to understanding the craftworkers themselves.[90] They were not just working with one material but multiple materials – and within complex material and social realities. By considering carving and finishing techniques not as material-specific but as technique-specific, the methodology and insights from this fresh perspective have the potential to contribute a broader and more nuanced understanding of the complexities of the late Antique craft industry.

[90] On late Roman craftspeople and carved glassware, see for instance H. G. Meredith 'Looking for – and Finding? – Workshop Makers' Marks on Late Roman Diatreta', *The Journal of Glass Studies* 66 (forthcoming); H. G. Meredith *The Unknown Maker: Anonymous Roman Glass Artisans and their Legacy* (Cambridge, in preparation).

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