Anchoring Science and Technology in Greco-Roman Antiquity

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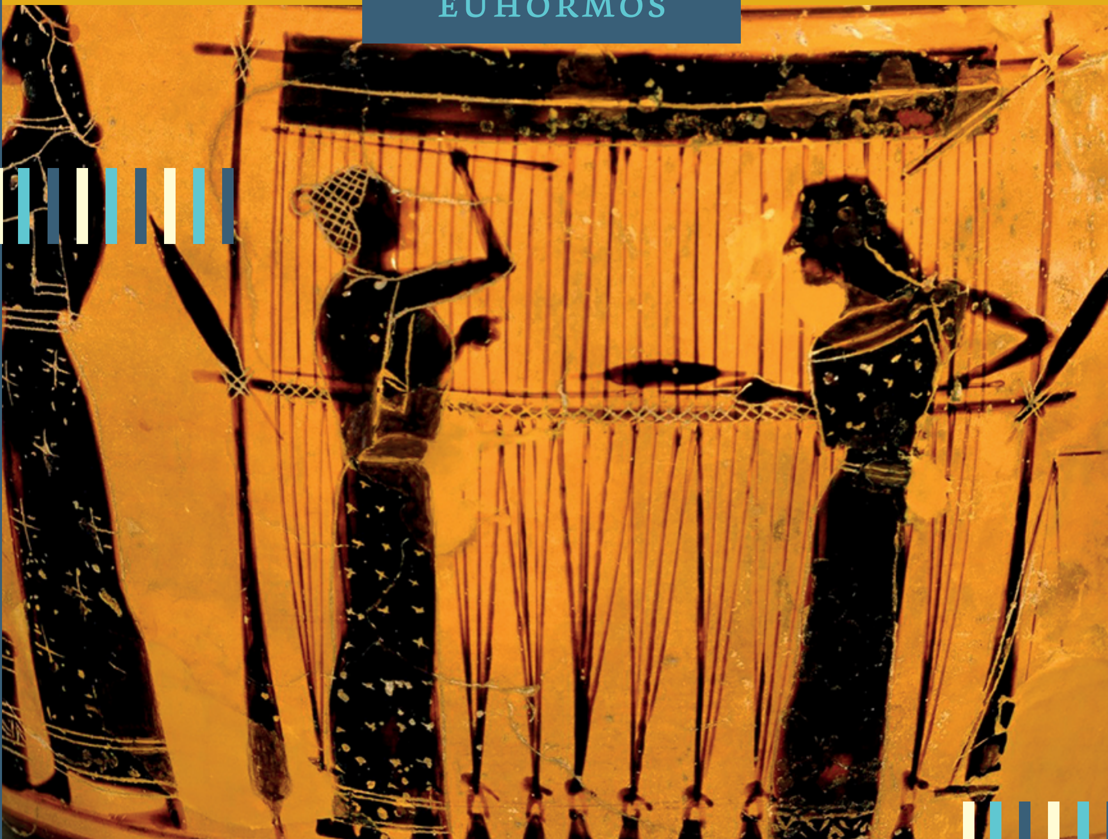

Edited by

Miko Flohr, Stephan Mols, and Teun Tieleman

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GRECO-ROMAN STUDIES IN ANCHORING INNOVATION

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Foreword

EUHORMOS is an international book series intended for monographs and collective volumes on Greco-Roman Antiquity. Specifically, we welcome for publication manuscripts related to the concept of 'anchoring innovation' by classical scholars of all disciplines from all over the world. Books in this series will be published as much as possible in Open Access. EUHORMOS is one of the results financed by the Dutch so-called Gravitation Grant (2017), awarded to a consortium of scholars from OIKOS, the National Research School in Classical Studies. See https://anchoringinnovation.nl/, where we also list earlier results from this research programme.

The ancient world saw many examples of change and innovations. The unique accessibility of materials from and about this period in the ancient Mediterranean frequently makes it possible to analyze successful and unsuccessful 'anchoring' of change: the various ways in which 'the new' could (or could not) be connected to and embedded in what was already deemed familiar. 'New' and 'old' are mostly not used as objective labels, but also a matter of the perception, framing, and valuation by relevant social groups and actors. 'The new' is not restricted to the technical or scientific domains, but can also include the 'new information' imparted by speakers through linguistic anchoring strategies; innovations in literature and the arts; political, social, cultural, legal, military, or economic innovation; and new developments in material culture.

The name 'Euhormos' itself is well-anchored. It is the Homeric term for a harbor 'in which the anchoring is good', although the careful reader will notice that danger is never far away. This dynamic nature of 'anchoring' and the risks involved in it are embraced by our research team as part of this title. For now though we will focus on its auspicious aspect, since we are looking forward to affording 'good anchorage' to studies contributing to a better understanding of 'anchoring innovation' in Greco-Roman Antiquity.

Ineke Sluiter
Academic Director
Leiden
On behalf of the Governing Board of the Anchoring Innovation Programme

Figures

CHAPTER 1

Anchoring, Science and Technology in Greco-Roman Antiquity—an Introduction

Miko Flohr, Teun Tieleman, and Stephan Mols

1 Innovation beyond Modernity

> In der Tat stand die Technik nicht so im Mittelpunkt der antiken Zivilisation, wie dies heutzutage der Fall ist.[1]

> The use of hydraulic technology in Roman mining of the first and second centuries AD remained unsurpassed again until the nineteenth century.[2]

For long, the shadow of (European) modernity loomed large over scholarship on innovation in science and technology in Greco-Roman antiquity.[3] Assessments came in two flavours: one group of scholars believed that the Greco-Roman world was *not* unlike the modern world in the ways in which it made progress in science and technology, and would be inclined to argue that the overall level of achievement was high, given the pre-modern context; a second school of thought tended to emphasize that antiquity was *very much* unlike modernity in both the nature and extent of scientific and technological progress; scholars subscribing to the latter idea would often stress the failure of Greco-Roman societies to innovate, and the lack of progress, which they would describe as 'stagnation'. The traditional figurehead of this school was Moses Finley.[4] While these modernizers and primitivists differed profoundly in their views on innovation, science and technology in the Ancient Mediterranean, both groups have essentially embraced European modernity as their leading analytical yardstick, evaluating ancient developments and achievements against the European scientific and technological revolutions of the seventeenth, eighteenth and nineteenth centuries—the common use of terms like

1 Diels 1920, 40.
2 Wilson 2002, 31.
3 See also, quite explicitly, Pleket 1967, 1.
4 Finley 1965.

'pre-modern' and 'pre-industrial' in scholarship on Greco-Roman economies is, in that sense, something of a giveaway.[5]

The intellectual limitations of this (essentially historicist) approach are obvious, as is the implicit Eurocentrism.[6] Modernity, of course, never was a foreseeable or intended outcome of history, and it cannot be the yardstick against which the classical world, in whichever sense, can be measured.[7] It is inaccurate to think of Greece and Rome as 'pre-modern' societies: they should simply be seen as 'not modern'—like the vast majority of human societies in world history—and if there is any historically meaningful yardstick against which Greco-Roman science and technology can be reliably measured, it comes from that large reservoir of non-modern societies.[8] More fundamentally, however, it may be questioned whether competitive comparisons, with their natural emphasis on (eventual) achievements, really should be our leading perspective on histories of science and technology in past societies. One thing that too often gets obscured in historicist arguments about 'how far they got' are the much more fundamental questions of how they got there, and how that interfered with society at large.[9] Put more bluntly: the looming shadow of modernity has often reduced Greco-Roman technology and, partially, science to a proxy of economic growth and civilizational progress, whereas, in Greco-Roman historical reality, 'the technological' and 'the scientific' were complex, variegated and discursive fields of practice with profound economic, social and cultural meaning. While many scholars are aware of this, historicist perspectives remain influential, particularly in the study of ancient technology.

This edited volume approaches science and technology in Greco-Roman antiquity by privileging practice and process over achievement. It does so by explicitly centering the notion of 'anchoring', and by exploring how this concept can add a new dimension to scholarly debates about Greek, Hellenistic and Roman science and technology. 'Anchoring', which we will introduce in some detail in section 3 of this introduction, emerged in the 2010s as the central focus of a nation-wide research effort by classicists, archaeologists and ancient historians in the Netherlands, and the conference from which this volume originates was part of this collective effort.[10] In its most basic meaning, 'anchoring'

5 See e.g. frequent occurrences in Scheidel 2012; Temin 2013; Terpstra 2019.

6 See on these issues, in general, Chakrabarty 2000; Goody 2006.

7 Cf. Greene 1993, 44. "The Industrial Revolution only happened once, initially in Britain and then in parts of Europe, and can therefore hardly be considered to be a 'normal' path of economic development."

8 As, e.g. attempted by Terpstra 2020. On science see Lloyd 2006.

9 See, the overviews of technological achievements in e.g. Mokyr 1990; Headrick 2009.

10 See esp. Sluiter 2017.

presupposes that in order for new ideas and practices to stick and succeed, they somehow need to be connected to ideas and practices that are already part of the shared common ground. Thus, a key aspect of 'anchoring' is that it does precisely what past scholarship on ancient science and technology has often not done: it shifts focus from the question *what* to the question *how*, and thus, to the ways in which humans—individuals and groups—approached, understood and produced science and technology. The concept of anchoring invites scholars to ask questions about how certain technologies and insights became part of the shared cultural vocabulary of communities in the Greco-Roman world, starting from the idea that it is not necessarily self-evident that new ideas and practices emerged to be picked up and stick around—as is attested by a range of ideas and practices that appeared but then disappeared and never became truly anchored in mainstream scientific or technological practice. Examples include early experiments with anatomical research in Ptolemaic Alexandria, and the use of brick in first century BCE Pompeii.[11]

2 Debating Ancient Science and Technology

Science and technology are concepts that emerged long after Greco-Roman antiquity, even though they have an etymology rooted in the classical tradition; they have strong implicit connotations in our modern world. The question whether there was such a thing as 'science' or 'technology' in antiquity has been vehemently debated in the twentieth century, but this debate has fallen silent without reaching a universally accepted conclusion.[12] In this volume, we use the terms 'science' and 'technology' as convenient, modern labels, but in full recognition of the fact that in antiquity there never existed unifying conceptions that were co-extensive with these terms.[13] Ancient terminology was different in nature. One can think for instance, of the study of the external world in the context of what was called 'natural philosophy' or, in Aristotle's case, 'theoretical philosophy'; one can also think of the Greek term τέχνη, which may refer to crafts and skills such as carpentry, but also to medicine and what we today call 'applied sciences'. Given this difference between ancient and modern ways of thinking, this volume adopts a pragmatic approach, and it coheres around a set of practices in the sphere of what *we* would call science and technology, including the collection and organization of knowledge,

11 Flohr, this volume.
12 Cf Brooke 1993.
13 See Lloyd 2004.

prediction and causal explanation, but also the control of natural phenomena and the exploitation of knowledge for human ends, that is, practical applications and social roles. Indeed, the social and cultural embeddedness of 'scientific' and 'technological' practices is a recurring theme in this volume. By using terms like 'science' and 'technology' in this pragmatic way, our volume aligns with modern historical scholarship.[14]

Science and technology have a long history in Greco-Roman scholarship, stretching back into the nineteenth century, and materialized in large quantities of handbooks, volumes, monographs, and journal articles. Discourse on both science and technology is rooted in a variety of disciplines, including philology, history and archaeology, and some debates, particularly in the study of ancient technology, have been energized by these disciplinary divides. For instance, ancient historians traditionally were (and to some extent remain) more pessimistic about Greco-Roman technological progress than archaeologists; even in the current century, the optimism of archaeologists like Wilson and Greene contrasts sharply with the pessimism of ancient historians like Scheidel and, recently, Terpstra.[15] As is well-known, for most of the twentieth century, the dominant view in scholarship was that progress was stagnant, and that this was due to a cultural blockage.[16] As the most prominent champion of this idea, Moses Finley, argued, this blockage was rooted in ancient attitudes towards economic growth and productivity, which were of minor importance to those who controlled the means of production—the land-owning elite. In this view, ancient technology and science were means to satisfy curiosity rather than means to make life better: 'the aim of ancient science … was to know, not to do'.[17] This view, in which there was very little technological development and an almost complete separation of scientific theory and everyday practice, has little support nowadays, and particularly since the turn of the millennium scholars leave more room for technological progress and practical applications of theoretical knowledge.[18]

This more optimistic attitude towards the role and history of ancient science and technology came with an increased scholarly interest in the issue, but this did not immediately lead to a thematic engagement with actual processes of innovation. Partially, this may be due to the fact that scholars have

14 For a full discussion of the issues involved see e.g. Lloyd 2014 and the useful observations made by Taub and Jones 2018, 2.
15 Cf. Greene 2000; Wilson 2002; Scheidel 2009; Terpstra 2020.
16 See the appendix by Meeusen, this volume.
17 Finley 1965, 32.
18 Esp. Greene 2000; Wilson 2002; Cuomo 2007; Flohr 2016.

traditionally focused on particular subfields of technological and scientific practice—one specific craft, one type of innovation, one scientific discipline. This approach has lost some of its attraction in recent years, but it still is a force to be reckoned with, as is reflected in the structure of the many handbooks that have been produced since the turn of the millennium, and which exert considerable influence on the scholarly community. Almost without exception, these handbooks have been carved up in chapters devoted to individual fields of scientific and technological practice. Thus, Oleson's ground-breaking *Oxford Handbook of Engineering and Technology in the Greek and Roman World* has chapters highlighting the different kinds of productive technologies—textile, leather, glass.[19] Similarly, Irby's *Companion to Science, Technology and Medicine* includes chapters a wide range of practices and disciplines—zoology, botany, meteorology.[20] The first volume of the *Cambridge History of Science* by Alexander Jones and Liba Taub, has chapters on topics like, e.g., Babylonian mathematics, Egyptian Medicine, Greco-Roman astronomy and astrology.[21] While many of the individual chapters in these handbooks do explore the historical dynamics of change and innovation, sometimes to great detail, their disciplinary focus offers only limited space for thematic and conceptual reflection on the ways in which science and technology can develop across fields of practice. This volume starts from the idea that the concept of 'anchoring' offers a way to do precisely this: the chapters of this volume also concern different fields of science and technology but their collective focus on how new ideas and practices became anchored in what was already there centralizes the how and why of innovation in ancient science and technology.

We are in good company. In recent years, scholars of Greco-Roman antiquity have begun to address processes of knowledge production and innovation more explicitly and thematically, partially inspired by developments in other disciplines, such as prehistoric archaeology, ethnoarchaeology and anthropology, as well as sociology and innovation studies. This is particularly true in the study of technological change in the production of ceramics and glass. Kevin Greene's 2007 article on lead-glazed Hellenistic pottery offered a theory-rich close reading of one (non-canonical) innovation in consumer ceramics, and advocated an approach to innovation that was imaginative of individual agency and decision-making.[22] More recently, Astrid van Oyen's work on Gaulish *terra sigillata* offered an approach to emergence, development and

19 Oleson 2008.
20 Irby 2016.
21 Jones and Taub 2018.
22 Greene 2007.

transmission of craft knowledge and skills among potters that integrated theoretical insights from Science and Technology Studies and Actor-Network Theory.[23] In the study of glass technology, Katherine Larsson has recently offered a detailed, theoretically informed, microhistory of the emergence and diffusion of glass-blowing based on an anthropological approach to innovation.[24] The study of Greco-Roman science has developed according to a slightly different rhythm, but it too has, since the 2010s, seen a clearly increased interest in, particularly, the socio-political circumstances behind the production and accumulation of knowledge. Thus, Marquis Berry's 2015 study of Hellenistic Science at court sketched how Hellenistic courts facilitated the emergence of certain types of 'scientific' approaches and texts.[25] In recent years, the emergence of libraries in the Hellenistic and Roman period and their role in scientific practice has been critically revaluated by a number of scholars.[26] A key practice in ancient scientific discourse—encyclopedic writing—has also been more systematically engaged with.[27] Thus, since the turn of the millennium, the people, processes and networks through which technological practices and scientific knowledge emerged and spread have become increasingly central to scholarship on science and technology in Greco-Roman antiquity. Through its focus on the concept of 'anchoring', the present volume builds upon this development.

3 Anchoring, Innovation, Science and Technology

The concept of anchoring has its intellectual roots in insights from social psychology, behavioral economy and science and technology studies, and it was adapted by Ineke Sluiter to unite a range of parallel concepts in several branches of the humanities, including linguistics, literature studies, and history.[28] Anchoring is a phenomenon that should be thought of as operating on the level of human cognition; its foundational idea is that the human brain, to structurally embrace new ideas and practices, needs to be able to permanently connect it to knowledge or skills that already are familiar. Thus defined, anchoring works across fields of practice. As Sluiter highlighted, 'anchoring'

23 Van Oyen 2016.
24 Larson 2019, citing e.g. Spratt 1982; Knappett 2016.
25 Berrey 2017.
26 E.g. König et al. 2013; Johnstone 2014.
27 König and Woolf 2013.
28 Sluiter 2017, 33.

can be used to understand the *corvus*, a successful invention that allowed the Romans, then inexperienced fighters at sea, to fight the Carthaginians on their own terms during the naval battles that decided the first Punic War. Similarly, the Roman transition to authoritarian rule under Augustus was made palatable for key groups in Roman society because of its anchoring in established and Republican traditions: this 'made the new situation acceptable as a form of adapted tradition, rather than forced innovation'.[29] The body of scholarship is quickly expanding: a volume edited by Roald Dijkstra has shown how the notion of anchoring can add new dimensions to the cultural history of the apostle Peter between the first century CE and Late Antiquity; a volume on 'aetiological thinking' by Antje Wessels and Jacqueline Klooster has explored how, in literature, politics and religion aetiological narratives and often invented origins were used to anchor innovations in traditions.[30]

As a concept, anchoring is inextricably linked to 'the new', and, thus, to innovation. In line with developments in Science and Technology Studies since the 1980s, anchoring centralizes the human factor: processes of innovation are, often, shaped not so much by intrinsic potentialities of new ideas and practices, but by how these interfere with the skills, ideas, ambitions and priorities of people involved. Processes of anchoring and innovation therefore cannot be understood without engaging with the people involved—the 'relevant social group'—and their material and conceptual lifeworlds. These, of course, tend to be locally and socially specific, and are always historically rooted. As already suggested by the examples presented in the preceding paragraph, the actual anchoring of new practices and ideas, thus, can only be studied through carefully contextualized microhistories that give pride of place to individuals and groups in their everyday social, economic and physical environment at their particular moment in time.

Through its roots in Science and Technology Studies, the notion of anchoring has an obvious relevance for the study of innovation in ancient science and technology. A good example of what a sensitivity to processes of 'anchoring' may add in this respect concerns the fate of Mago's Punic treatise on agriculture after the fall of Carthage as recounted by Pliny. Pliny describes how the Romans, as they were destroying Carthage in 146 BCE, donated the Carthaginian libraries to local rulers in Africa, with the sole exception of Mago's work, which the senate ordered to be translated into Latin, 'even though', as Pliny explicitly remarks, Cato had already produced his treatise

29 Hekster 2020, 102.

30 Dijkstra 2020; Wessels and Klooster 2022. See also Klooster and Kuin 2020.

on agriculture.[31] The story has puzzled modern scholars: why was this work, more than the others, so important to the Roman senate? Why was it decided to add Mago's treatise to the Roman stock of agricultural knowledge? Some have suggested that the story was (partially) invented at a later moment.[32] While this cannot be excluded, the idea of 'anchoring' does offer a historical rationale for Pliny's narrative: As Carthage and Corinth were being sacked and looted, Roman senators were in the process of translating the enormous wealth they amassed through imperial conquest into large-scale landholdings in the Italian peninsula, and this revolutionary socioeconomic development had led Cato around 160 BCE to write his *De agri cultura*, which, as Columella remarked 'first taught agriculture to speak Latin'.[33] Of course, the senate, as a group, had a structural interest in expanding their agricultural knowledge, but perhaps more importantly, Cato's writings also had given them a template of how this might be done—through texts. Thus, one can argue that, by the mid-140s BCE, the ongoing emergence of large-scale landholding, and very existence of a work like *De agri cultura* offered readily available anchoring points for the idea that it might make sense to have Mago's treatise brought to Rome and translated into Latin. Moreover, subsequently, once the text had been translated into Latin, the idea—true or not—that its first translation into Latin had been ordered by the Senate only two decades after Cato's work had been published became an anchoring point in itself: as Pliny's text showcases, it could be invoked to highlight the traditional authority of Mago's text.

The example of Mago also highlights another aspect of anchoring that is central to this volume: ideas and practices that came to be anchored in local assemblages of technology and science were not always *strictu sensu* new inventions. Many, in fact, may have existed for quite some time, and simply had begun to circulate through the social, political and economic networks that connected communities in the Greek, Hellenistic and Roman Mediterranean, encountering new groups of potential users on the go. In understanding developments in science and technology—and in studying the anchoring of scientific ideas and technological practices—circulation should be considered as relevant as invention. This is of course true for many cultural fields of practice—if we can think of Greco-Roman visual (or literary) culture in terms of *koine*, the same is true for technology and science: the totality of ideas and practices that were circulating in supra-local networks can be seen

31 Plin. *NH* 18.5: 'cum iam M. Cato praecepta condidisset'.

32 E.g. Erskine 2013, 117–8.

33 Colum. *RR* 1.1.12: 'qui eam latine loqui primus instituit'.

as constituting a technological or scientific *koine*.[34] This *koine* functioned as a universalized cultural archive that could particularize into locally or regionally specific technoscapes and sciencescapes.[35] In this context, one could argue that one key anchoring practice often was, quite simply, 'translation'—of a text, from a language of circulation (e.g. Greek) to the preferred language of a relevant social group (e.g. Latin), or of a technique, from the material reality in a location where it is already anchored, to that in a location where it is being introduced. In the increasingly globalized, but culturally still rather fragmented world of Greco-Roman antiquity, quite a lot of anchoring is likely to have been taking place at the interface of local and global science- and technoscapes, and understanding how this worked of course is an essential part of the history of science and technology in the Greco-Roman world.[36] We suggest that this makes 'anchoring' a natural part of the conceptual toolkit associated with the idea of 'glocalization', which is increasingly seen as a key phenomenon in the study of ancient culture, including technology and science.[37]

4 The Contents of This Volume

The seventeen chapters that follow this introduction explore the intersection between anchoring, technology and science in the Greco-Roman world from a variety of angles, and through a variety of approaches. As our intellectual agenda lies with exploring the heuristic potential of 'anchoring' for the study of Greek and Roman science and technology, we have included papers focusing on a variety of places and periods. Additionally, some chapters are primarily text-oriented; others are mostly oriented towards material culture; some combine several categories of evidence. We have divided the book into four thematic sections, focusing on, respectively, the concept of anchoring, innovation and knowledge circulation, technology and change, and anchoring and science.

34 On the notion of *koine*, and the associated processes of universalisation and particularisation see Versluys 2015, 154–5.

35 On the concept of *technoscape* see also Appadurai 1990, 297–8. Appadurai uses the term on a global level, but his phrasing leaves room for local and regional *technoscapes* in the way Pitts and Versluys use *objectscapes*. Cf. Pitts and Versluys 2021, 367–8.

36 On the use of globalization in the context of antiquity see the essays in Pitts and Versluys 2015.

37 Cf. Witcher 2019, 643; González Montoya 2021. On glocalization see Roudometof 2016; Cobb 2022.

Section 1. The Idea of Anchoring

The chapters immediately following this introduction engage with the concept of anchoring on a conceptual and transhistorical level. Thus, the chapter by James McAllister gives the notion of anchoring a deeper philosophical underpinning. Starting from Wilhelm Dilthey's distinction between 'natural' and 'mental' phenomena, McAllister argues that as an invention takes root in a community, it develops from a natural phenomenon, an 'outer experience', to a mental phenomenon, an 'inner experience', and it can do so because it can be easily linked to phenomena that have already been internalized, prior to the moment in which an invention first appears. If McAllister offers a rationale of what anchoring *does*, the subsequent chapters by Bijker and Daston sketch ways to operationalize anchoring as a research tool. Chapter 3 by Wiebe Bijker starts from the close relation between the concept of anchoring and the social construction of technology-framework (SCOT). This relation was already highlighted by Sluiter in her 2017 article, but it is discussed here at greater length and to greater detail.[38] Bijker argues how concepts from the SCOT-toolkit (such as 'stabilization', 'closure', and 'technological frame') make it easier to study processes of anchoring in practice. The subsequent chapter by Lorraine Daston explores the conceptual ecosystem of technological development beyond innovation. She argues that, in Early Modern Europe, key drivers of technological refinement were emulation—the desire to make something a little bit better than had been done before—improvisation—the need to find ways to adapt existing practices to new contexts or materials—and artisanal virtuosity—the aim to display one's exceptional skill. Daston argues that these 'alternative values' to innovation reflect a world in which technological development often was collective, incremental and cumulative—and, thus, by its very nature, anchored in everyday knowledge and practice; Daston suggests that in this way, Early Modern Europe offers a model for understanding processes of technological refinement in antiquity. Finally, a chapter by Ineke Sluiter uses the socio-technical assemblage of the 'door', broadly defined, to explore the relations between anchoring and technology from three different angles: the image of 'automated' doors could be used to sketch the physical properties of the divine realm, where everything moves smoothly and effortlessly; the affordances of 'real' ancient doors could be used as an anchor point in narratives about access and control; modern 'revolving' doors, on the other hand, served as a (misleading) anchor point for understanding the theatrical

38 Sluiter 2017, 27.

device of the ekkuklêma. Sluiter's chapter aptly showcases the diverse ways in which 'anchoring' and 'technology' are intertwined.

Section II. Innovation and Knowledge Circulation

The second group of chapters addresses issues of innovation and knowledge circulation in the Greco-Roman world. Two chapters focus on architecture and building technology. Chapter 6 by Jean VandenBroeck-Parant offers a close-reading of the construction of the Theban treasury in Delphi, where use was made of a unique system with wooden frames to stabilize the foundations of the building, which was situated in a location where the threat of prolapse was real. VandenBroeck-Parant shows how this strategy for stabilization, while unique in itself, was in fact based on practices and knowledge that were well spread among builders in Classical Greece. What we are seeing, thus, is a particularization of ideas and practices from the universalized technoscape of the fifth century BCE Aegean. The subsequent chapter by Miko Flohr analyses the micro-historical contexts of three crucial steps in the development of building technology in late-Republican Italy—the invention of concrete, the emergence of standardized building materials, and the spread of brick. Studying these innovations in detail highlights how in each case, innovations did not appear ready-made at once, but proceeded in small steps, each anchored in the technological lifeworlds and socioeconomic ambitions and possibilities of specific social groups in specific localities.

Chapter 8 by Serena Conolly analyzes what could happen when innovations were unwelcome to those in power. Starting from the famous story about fate of the inventor of 'unbreakable glass', who was killed on the orders of Tiberius after presenting his invention to the emperor, Conolly highlights how innovations could be seen as a risk, rather than an asset, and what that could mean for the ways in which those in power responded to them.[39] Power dynamics could facilitate the spread of ideas and practices—but could also prevent them from sticking around. Finally, in a chapter focusing on papyrological evidence, Mark de Kreij uses social semiotics and SCOT to explore innovation in book rolls and codices in Roman Egypt. His analysis highlights how certain innovations can be linked to particular contexts—double-use book rolls emerged in the context of schooling; the city of Antinoupolis, newly founded in the second century CE, played a crucial role in the spread of the *codex*. Both examples highlight how innovations cannot be understood without understanding how they connected with a specific relevant social group in a specific location.

39 On this story see also Finley 1965; Wilson 2002; Flohr 2016.

Together, these four chapters show how local actors—builders, inventors, bookmakers—interacted with 'global' networks in which knowledge and practice circulated, and how they were integrating 'global' practices into local technoscapes—or, conversely, tried to feed local inventions into global networks of cultural exchange.

Section III. Technological Change

Five subsequent chapters focus on the role of anchoring in processes of technological change. Chapter 10, by Jill Baker, highlights how important it is to see developments in Greco-Roman technology against the background of earlier technological developments in bronze-age Mesopotamia and Egypt. Indeed, Baker suggests that these earlier innovations—e.g. in land-surveying, in mathematics, and in military technology formed the bedrock in which much later innovations of the ancient Mediterranean could be anchored.

The other chapters in this section address the challenges associated with technological change, and the ways in which anchoring strategies can alleviate these. The complexity of anchoring technological change is highlighted in the chapter by Maria Gerolemou, which analyzes a series of innovations in archery and artillery that ultimately led to torsion catapults in the fourth century BCE. While the military impact of hand-bows, belly bows and the torsion catapults is beyond reasonable doubt, each of these military technologies suffered from a bad press, because they were at odds with the ideal of manly virtue (*andreia*) that dominated Greek attitudes to warfare. Thus, cultural ideals were one area of concern when it came to technological change. Risk was another, and the chapter by Anna Soifer centralizes this issue when looking at the role of craftsmen in technological development. Analyzing the accumulating innovations in glass-blowing and *terra sigillata*, Soifer highlights how innovations involving the adoption of new techniques came with risks, and how anchoring new techniques in the pre-existing socio-technical lifeworld of craftsmen could help to mitigate perceived risk and facilitate the spread of innovations. Thus, the development of both glass-blowing and *terra sigillata* techniques was gradual, with small changes that connected well to existing practice. While step-by-step experiments in everyday craft practice offered one way to anchor technological innovation, Rabun Taylor explores another one: modeling. Close-reading Roman innovations in water-powered saw-milling, in dome-construction, and in the construction of siphons, Taylor argues that modelling—even though it has left very few traces in our evidence—played a key role in anchoring new technologies into a community of skeptical and risk-averse craftsmen. If chapter 12 and 13 focused experiments and modelling by craftsmen and builders, the fourteenth chapter, by Michiel Meeusen, explores a more playful way in which new technologies could be anchored in the hearts and minds of relevant social groups—by using them to display mythological narratives. Observing that many ancient inventors developed new devices with the specific purpose of evoking or alluding to myths, Meeusen argues that mythological narrative could build a conceptual bridge between inventors and their audience, which ultimately contributed to the normalization of their inventions.

What these chapters collectively highlight is that technological innovations—whether in weaponry, in crafts, in engineering, or in *automata*—can hardly be understood without understanding the actual socio-cultural constraints under which the people involved operated. Even when there were no prevalent cultural inhibitions against change, there could be strong social and economic incentives *not* to embrace innovations.

Section IV. Anchoring and Science

The final section explores ways of anchoring scientific knowledge. Chapter 15 and 16 are chronologically situated in Classical Greece. Marianne Hopman analyzes a long speech in Prometheus Bound, in which the protagonist predicts the future fate of Io, arguing that it is in fact full of Hippocratic references, and that it can be seen as a way by the fifth century BCE author of the tragedy to anchor the Hippocratic innovation of *prognosis* in the pre-existing phenomenon of prophetic speech, thus giving it an authority among Athenians that it did not yet have. The chapter by Giovani Fanfani, Ellen Harlizius-Klück and Annapurna Mamidipudi highlights how, in Greece, weaving, as an everyday practice, can be seen as a form of applied arithmetic: the production of geometrical patterns on the loom depended on a complex understanding of the dyadic logic of warp and weft. This made that weaving generated concepts of order that could be transferred to other fields of practice, and could inform innovation in several domains of thinking, including arithmetic, cosmology, musical terminology and metrical theory. Weaving, thus, became a powerful anchor for the cosmic and political order, and a starting point for mathematical thinking; ultimately, it stood at the basis of the Platonic separation of pure and applied knowledge.

The final two chapters are situated in the Roman imperial period. Courtney Robey explores anchoring strategies in Heron of Alexandria's *Metrica*, a text that incorporates elements from the Greek mathematical tradition as well as from Mesopotamian and Egyptian origin. Robey Distinguishes *cultural* anchoring—connecting Hero's argument to earlier mathematical traditions—from *cognitive* anchoring—linking new mathematical ideas into more familiar ones, and she argues that Heron uses a range of linguistic markers to produce these anchors. The chapter by Teun Tieleman discusses how the second century CE Roman medical author Galen uses references to the Hippocratic corpus to anchor medical innovation—even if this meant a substantial reinterpretation of Hippocratic texts. Using Hippocrates rather than more recent authors as a reference, Galen can authoritatively anchor ideas in the past without subscribing to one of the medical schools of more recent periods. Thus, Galen could present medicine as a unitary, rather than a divided science.

The picture that emerges from these chapters is that innovations in scientific knowledge could be anchored through invocations of cultural authority or through cognitive affinity: new ideas can to some extent be anchored by associating them with figures of authority in the scientific *koine* (such as, in the Roman Imperial period Hippocrates), but at a more complex, technical level, it may be more helpful to connect them to the nearest cognitive mooring point in the 'science-scape' that is broadly familiar to the intended audience—and this may include everyday practices like weaving.

5 Discussion

So, what does come out of all this? We would like to conclude this introduction by highlighting several more general points that, in our view, emerge from this volume.

First and foremost, as far as debates about ancient technology and science are concerned, the chapters of this volume, in our view, showcase how anchoring offers a key toolkit for the studying of developments in technology and science in their micro-historical context: starting from the idea that innovations will somehow need to be anchored in what is already there, leads to approaches to ancient science and technology that add a new (cognitive) dimension to scholarly discourse. Whether it is Greek architects designing a monument in a challenging location in Delphi, Roman colonists trying to make *opus reticulatum* with Pompeian grey lava, or Greek intellectuals introducing Hippocratic innovations, the micro-historical level to which anchoring transposes our approach leads to new insights—both on the level of individual cases, and on the level of scientific and technological innovation as a whole. Indeed, on closer, micro-historical inspection, many Greek and Roman innovations become much less radical than they may seem at first sight; almost universally, they turn out to consist of a series of smaller steps, often historically contingent or otherwise coincidental, involving tinkering, experimentation, or modelling. Anchoring, in reality, often means that big leaps become small steps—but at the same time, it connects those small steps much more directly to actual people—individuals and social groups—in their cognitive and material environment. This enriches the field of study, particularly in the light of the traditional emphasis of discourse on Greco-Roman achievement outlined at the start of this introduction: embracing an anchoring perspective, and the micro-historical perspective that comes with it, is one of several ways to remove modernity from the interpretative horizon, and to analyze ancient technological change and scientific development on its own terms.

Second, we believe that the chapters of this volume also make clear that Greek and Roman scientists and innovators could and did actively use strategies that resemble what we call 'anchoring' to link their ideas to a relevant social group—even if they themselves thought about what they did in rather different terms, and even if we cannot always trace back the conceptual tricks that they used to anchor the new in the familiar. Sometimes we can: going to the emperor to sell the invention of unbreakable glass is an anchoring strategy, even if it fails dramatically. Using mythological narratives as a vehicle for displaying technological ingenuity is a way to make *automata* meaningful for a non-specialist target-audience. Linking medical innovations to the authoritative figure of Hippocrates (even if he had nothing to do with them) is a way of connecting the new to the familiar. Thus, anchoring is not just a modern conceptual tool that enables us to look at antiquity (or other historical societies) in new ways—it also was, at least to some extent, a meaningful historical phenomenon in the development of Greco-Roman technology and science.

Finally, third, as far as the broader context of the Dutch anchoring innovation project is concerned, we believe that the essays in this volume offer a series of conceptual refinements and developments that take the idea of 'anchoring' somewhat beyond its original definition, and, thus, offer a range of anchoring points for future work, both within and beyond context of the anchoring innovation project. We particularly want to highlight three of these. First, as is highlighted by several chapters focusing on innovation in crafts and engineering, anchoring is not restricted to (explicit) imaginative cognition—it also may operate at the more implicit level of embodied skills and knowledge: the anchoring of an innovation may also, simply come down to its successful integration in the routinized set of bodily motions. Second, in several of the historical examples discussed in this volume 'anchoring events' take place at the interface of the local and the global, and thus should be seen in the sphere of glocalization—one can think of the Theban treasury at Delphi, the history of *opus reticulatum* and brick, and the use of papyrus in codices in Egypt. Finally, we feel that several of the examples discussed in this volume also highlight the central role of power and authority in processes of anchoring—either through the figure of the emperor, or through invoking traditions and individuals with a solid reputation in the relevant area of expertise. Power relations—real or imagined—are an essential element in anchoring, and they should play a central role in our explorations of anchoring processes.

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PART 1

Anchoring

CHAPTER 2

How the Romans Conceived Their Roads: Inner Experience in the Anchoring of Technological Innovation

James W. McAllister

1 Invention, Innovation, and Anchoring

The distinction between 'invention', the production of a new idea, object or practice, and 'innovation', the successful adoption and diffusion of something new, originated with Joseph A. Schumpeter in his studies of entrepreneurship in the 1930s.[1] An important question since then has been what factors determine whether an invention leads to innovation. One promising answer focuses on how well and in what ways potential users comprehend the new idea. The concept of anchoring is meant to capture this requirement. An invention has a higher chance of leading to innovation if the experience of using it recalls—or is anchored in—something known and familiar.

Here we focus on anchoring of technology. A paradigmatic illustration in modern times is Thomas A. Edison's work around 1880 to transform a device, the incandescent filament lamp, into the electric lighting system that took over the world. Edison's appeal to design elements that recalled gas lighting facilitated acceptance of the innovation.[2]

Technology in ancient Rome is another good source of case studies. Rome made many engineering and manufacturing innovations, including the road network, bridges and aqueducts, sewers, baths, concrete, the *codex* or bound book, and glass manufacturing techniques.[3] Indeed, the Romans saw themselves more as systematisers of inventions made by other Mediterranean peoples than as inventors in their own right, if we are to believe Pliny the Elder in *Naturalis Historia*, a compendium of Roman knowledge and achievements (first century CE).[4] The study of Roman technology, therefore, turns the spotlight on anchoring.

1 Parayil 1991, 80–83; Fagerberg 2013, 6–10.
2 Hargadon and Douglas 2001.
3 Flohr 2016.
4 Romani Mistretta 2018, 131.

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The concept of anchoring is still relatively underdeveloped, however. Ineke Sluiter, introducing the 'Anchoring Innovation' research agenda in classical studies, characterised the difference between invention and innovation as a 'human factor'. As Sluiter explained, 'Innovations may become acceptable, understandable, and desirable when relevant social groups can effectively integrate and accommodate them in their conceptual categories, values, beliefs and ambitions'.[5]

In this chapter, I offer a new philosophical account of the anchoring of technological innovations. This will draw on the work of Wilhelm Dilthey on natural and mental phenomena and how we apprehend them. I will support my account with evidence from Roman invention and innovation.

2 Dilthey on Inner and Outer Experience

Discussing the foundations of the *Naturwissenschaften* and *Geisteswissenschaften* in the 1890s, Dilthey took over a distinction formulated by Immanuel Kant between two categories of phenomena and the ways in which we apprehended them. *Naturerscheinungen* or natural phenomena, such as physical effects and processes, were grasped through sense perception, or what Kant called 'outer experience'. *Geistige Erscheinungen* or mental phenomena, which included human acts and artworks, were different. Their physical expressions were given in outer experience, but observers interpreted their meanings by linking them to what Kant called 'inner experience', or one's experience from within of one's own empirical-psychological states, including beliefs, intentions, and affects.

Dilthey elaborated on the ways in which we gained comprehension of phenomena of the two kinds. Since we were able to individuate natural phenomena purely by ostension in outer experience, according to Dilthey, picking out such a phenomenon did not depend on having achieved even a preliminary understanding of it. A scientific explanation of a phenomenon might come long after its discovery.

Things were otherwise for mental phenomena, Dilthey argued. Their meanings were partly constitutive of their identity, so it was impossible for us to individuate a mental phenomenon simply by ostension in outer experience: we needed first to grasp its meanings. When we individuated a mental phenomenon, therefore, it had already passed through inner experience. In that phase

5 Sluiter 2017, 21, 23.

we achieved an initial understanding of the phenomenon in common-sense terms. Subsequent scientific research might yield a more sophisticated comprehension of a mental phenomenon, of course; this had to maintain continuity with the initial common-sense understanding, however, or we would be unable to reidentify the phenomenon in experience.[6] As Dilthey wrote in 1894:

> The human sciences are distinguished from the natural sciences first of all in that the latter have for their object facts that are presented to consciousness as from outside—as phenomena and as given in isolation—while the objects of the former are given *originaliter* from within as real and as a living continuum or nexus. As a consequence there exists a system of nature for the physical and natural sciences only through inferential conclusions that supplement the data of experience by means of a combination of hypotheses. In the human sciences, by contrast, the continuum or nexus of psychic life is an original or basic given. Nature we explain, but psychic life we understand [Die Natur erklären wir, das Seelenleben verstehen wir].[7]

Let us consider a pair of illustrations. Take scientists studying a natural phenomenon, such as magnetism. They may individuate a magnetic effect in observational data, find it surprising, note that they lack an understanding of it, give it the status of explanandum, and subsequently strive to find a scientific explanation of it. This is a well-established empirical cycle in natural science. In his summary of Roman natural knowledge, for example, Pliny reported observational accounts of several notable magnetic phenomena while making clear that no explanation of them was available.[8]

Contrast this with a behaviour that Dilthey would classify as a mental phenomenon: gift-giving. What makes an object a gift is not any intrinsic properties of the object, but the intentions and meanings that giver and receiver ascribe to it. For this reason, ostension in observational data (as used to individuate natural phenomena) is incapable of identifying instances of gift-giving, distinguishing gifts of different types or demarcating gift-giving from other cases in which goods change hands. To do that, we need an initial common-sense understanding of the mental phenomenon of gift-giving, based largely on our own previous experiences of the phenomenon and what they meant to us.

6 Bransen 2001, 16167–16168.
7 Dilthey [1894] 2010, 119.
8 Healy 1999, 155–158.

This requirement holds both for participants in the practice of gift-giving and for scholars in human sciences studying this mental phenomenon. For example, the Romans distinguished gifts of two types, *dona* and *munera*. *Dona* included spontaneous gifts, such as those given at the beginning of a relationship, while *munera* were gifts considered socially obligatory, such as customary gifts on the occasion of festivals and recompense for services for which payment was not appropriate.[9] Before any scientific research project into Roman gift-giving can get under way, we must have an intuitive understanding of these social categories and their meanings to be able to distinguish instances of *donum* and *munus* in historical records.

The contrast between the ways in which natural and mental phenomena are individuated suggests that, whereas it is possible to encounter a natural phenomenon that no-one has observed previously, there are no completely novel mental phenomena to discover: we have seen all mental phenomena before, in one form or another. We identify a thing as a particular mental phenomenon largely on the basis of that prior acquaintance.

I suggest that Dilthey's account of natural and mental phenomena and their individuation offers a plausible way to underpin the concept of anchoring of technological innovations. The distinction between invention and innovation maps onto that between outer and inner experience, I hypothesise. On this view, the outcome of an act of invention is a natural phenomenon that we apprehend purely in outer experience. For this reason, an invention may strike viewers as irreducible to familiar categories. A successful innovation, by contrast, holds meaning for us and is apprehended partly via inner experience. This explains why a successful innovation will strike users as familiar in some respects: they are already acquainted with the mental phenomenon of which it partially consists. Anchoring, on this suggestion, involves turning a technology from a purely natural phenomenon into at least partly a mental phenomenon.

3 Inventions in Outer Experience

To show how this account helps us understand anchoring in technological innovation, let us trace the roles of outer and inner experience in the perception and reception of Roman inventions and innovations. I will contrast invention in this section with innovation in the next.

9 Hyland 2009, 25–28.

Hero of Alexandria, who lived in Roman Egypt in the first century CE, designed and manufactured many automata, which he described in his treatises, *Pneumatica* and *Automata*.[10] These automata were mechanical animations that appeared to move spontaneously: some depicted recognisable everyday or mythological scenes, such as a singing bird or Hercules' shooting an arrow at a dragon.[11] They were intended as wonders in temple rituals and theatre performances, evoking in viewers an experience of *thauma*, or astonishment and awe.[12] Hero's automata were powered by various component mechanisms, like the aeolipile ('ball of Aeolus'), a brass vessel fitted with transverse nozzles that spun on its axis when water inside was heated into steam.[13]

Crucial to the effectiveness of such wonders was that their movements should seem unexpected and inexplicable. Hero emphasised the importance of keeping the workings of his automata out of sight, withholding any sense of understanding or familiarity from the audience so as to heighten the effect of surprise and mystery. For example, Hero wrote that he made his automata too small to conceal a human operator, so as to deprive spectators of even that suggestion of intelligibility.[14] Hero, in other words, studiously avoided providing any anchoring for his automata: any semblance of familiarity to the viewer would have diminished their impact as spectacles.[15]

On this point, I depart from the interpretation that Michiel Meeusen offers later in this volume. Meeusen argues that mythology was an important resource for anchoring Roman technological applications. He gives Hero as an example: in Meeusen's view, Hero's depiction of familiar mythological characters and scenes in his automata was a way of providing anchoring for them, thus facilitating their acceptance and adoption.[16] I suggest that these visual references to the familiar cannot be regarded as anchoring, however, for two reasons. First, anchoring of an innovation usually hinges on recognisability of the means that are used to produce a new effect, not on recognisability of the effect. Anchoring of infrangible glass, for example, consists in the fact that, while it demonstrates a new property (infrangibility), it does so by means that appear familiar (it resembles ordinary glass). Second, anchoring is a demystifying technique that negates *thauma*. By contrast, it was important to Hero that the way in which his automata produced their effects remained obscure and enigmatic, in order

10 Murphy 1995; Sherwood et al. 2020, 76–82.
11 Steadman 2021, 111–131.
12 Tybjerg 2003; Berryman 2009, 50–53; Lightfoot 2021, 208–214.
13 Keyser 1992; Sherwood et al. 2020, 39–40.
14 Murphy 1995, 15.
15 Bosak-Schroeder 2016, 127–128.
16 Meeusen 2025.

to heighten their effectiveness as temple and theatre wonders. That is why his designs refrained from offering any clues to their functioning. In other words, Hero deliberately withheld anchoring from his automata. In turn, this helps explain why his automata and their mechanical components never caught on as innovations. The aeolipile, for example, clearly never progressed from invention to innovation: this application of steam power remained a one-off gadget, as G.E.R. Lloyd noted, leading to no further technical developments.[17]

In Dilthey's terminology, Hero's temple and theatre wonders, and more particularly components like the aeolipile, were good examples of natural phenomenon. They appeared to the observer in outer experience as surprising spectacles awaiting explanation. By contrast, they did not show up in inner experience: Hero's contemporaries had no pre-existing or common-sense understanding of these phenomena by which they could make sense of them.

Summarising, Hero's automata and mechanisms such as the aeolipile were novel natural phenomena that had no presence in viewers' inner experience. This meant that they could count on no familiarity. This, in turn, heightened their effectiveness—anchoring them would have been counterproductive. They emphatically remained inventions rather than innovations.

4 Innovation: Inner Experience

The role of common-sense understanding is otherwise for what Dilthey termed mental phenomena. The meanings of a mental phenomenon are central to its identity, so we cannot individuate such a phenomenon without relying on a preliminary, common-sense understanding of it. We gain this in inner experience, in which our beliefs, intentions, and affects come into play.

My contention is that successful Roman technological innovations amounted partly to such mental phenomena. Let us take roads as an example. Whereas the first paved roads in the Italian peninsula were Etruscan, the Romans made the *via publica* into a widely adopted innovation. Starting with the Appian Way linking Rome to Capua in the fourth century BCE, the network reached an extension of 120,000 kilometres by the late empire.[18]

Why did this innovation catch on so well in the Roman world? Saying that military commanders, administrators, and traders found roads useful does not fully answer this question, for not all useful inventions catch on. There were, I suggest, pre-existing intellectual conditions that made roads available to

17 Lloyd 1973, 106.
18 Chevallier 1997, 306.

Dilthey's inner experience. This meant that Romans already had, so to speak, an understanding of roads when they first saw them.

This prior understanding was rooted in the Roman notion of space. Pietro Janni, Kai Brodersen, and others have distinguished two conceptualisations of space: in terms of lines that pass through it, and in terms of areas that fill it.[19] They have argued that the former was more prominent than the latter in ancient—and especially in Roman—spatial cognition. Romans seem to have conceptualised space primarily by means of one-dimensional lines or routes traversing it. This is a hodological conception of space (from the Greek, *hodos*, road or path).

Evidence that the Romans held this conception comes from two main sources: aids to travellers and descriptions of the geography of a region. First, the Romans summarised practical geographical knowledge primarily in itineraries, ordered lists of places defining a route.[20] One example is the *Itinerarium Antonini*, a third-century CE guide for travellers that listed over 2000 places and their distances along over 225 routes across the empire. Scholars continue to debate the extent to which Romans made maps and even how broadly we should construe the category 'map' in the Roman world.[21] Nevertheless, it seems that the Romans made few cartographic representations of landscape of the sort that we take for granted today, and did not use these for travel.[22]

The hodological view of space is prominent in Roman geographical writing too. At the opening of *De Bello Gallico*, for instance, Julius Caesar gave an overview of the geography of Gaul. Caesar did not describe the spatial relationship of areas to one another, as a modern writer might. Instead, he listed the natural routes through Gaul consisting of the rivers Garonne, Marne, Seine, Rhone, and Rhine, and explained how they led to the territories of the *Belgae*, *Aquitani*, and *Galli*.[23] In a similar way, Pliny followed coastlines and rivers to structure the geographical survey of the known world in his *Naturalis Historia*.[24]

It is easy to see how this might have helped the innovation of roads catch on in the Roman world. Built roads were an embodiment of the itineraries in terms of which the Romans conceptualised space.[25] The identity of the phenomenon 'road' for Romans was determined partly by meanings attributed to it, namely its congruence with the hodological conception of space. Roads

19 Janni 1984; Brodersen 2003.
20 Salway 2007.
21 Riggsby 2019, 172–201.
22 Whittaker 2004, 63–87; Cioffi 2016.
23 Bertrand 1997; Krebs 2018, 96–102.
24 Murphy 2004, 133–148.
25 Kolb 2007; Carlà-Uhink 2022.

for the Romans were therefore, in Dilthey's terminology, not solely a natural phenomenon, but partly a mental phenomenon too: a Roman encountering a road for the first time would have recognised it from inner experience. This amounts to anchoring the technology in something familiar to its users, and distinguishes the road network as innovation from the aeolipile as invention.

5 Conclusions

Interpreting the anchoring of technological innovation in terms of Dilthey's inner and outer experience convincingly reconstructs, I believe, the human factor at the heart of this notion. Naturally, the proposal calls for further development and scrutiny. To begin with, we should look at philosophical traditions since Dilthey that, taking everyday life as the basis of experience, have developed the concept of inner experience in new ways. In the phenomenology of Edmund Husserl, for example, the *Lebenswelt* (lifeworld) was the domain of common sense or daily life, given to and taken for granted in our immediate experience prior to scientific knowledge.[26] Second, the proposal should be articulated and tested by reference to further examples of invention, innovation, and anchoring from both ancient Rome and other epochs. I necessarily postpone that work to future occasions.

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26 Smith 1995.

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CHAPTER 3

Anchoring Innovation as a Form of Social Construction of Technology

Wiebe E. Bijker

The concept of 'anchoring innovation' recognises that innovation does not always mean that the new is replacing the old, nor that innovation is only happening in technology, neither that it is value-neutral.[1] Typically, innovations need to be anchored in existing images, values and practices to make them acceptable, understandable and—I shall argue—even to make them working. Sluiter illustrates this with several examples. The Athenian *tetrachdrachm* showed a portrait of the goddess Athena and her sacred owl, thus anchoring this coin in a widely shared notion of the divine protector of the city. A second example was the innovation on the Roman ships that fought the Carthaginians in the first Punic war (264–241 BCE). A boarding ladder was invented to allow Roman seamen (or, rather, soldiers) to get onto Carthaginian ships and thus turn the sea battle into a man-to-man fight on deck. This innovation consisted of a *corvus* ('crow') with *harpago* ('gripper') that fixed the ladder onto the deck of the enemy's ship, anchoring the innovation in the image of a crow grabbing a prey with his claw and in the common practice of walking a ladder.

The idea of anchoring innovation, however, seems to go against the standard view of innovation as a technical process that always results in something new, produces progress and typically moves in a linear development from invention to innovation, to diffusion and distribution, to wide-spread adoption. The Athenian *tetrachdrachm* was just another coin, not something particularly novel. The *corvus*, mounted on the masts of the Roman ships, must have looked a rather silly contraption in the eyes of experienced sea men and it certainly did not make the ships sail better. I shall discuss how anchoring innovation is indeed at odds with a standard view of innovation, but well in line with recent studies of innovation and technology-society relationships as these have been done since the 1980s. I shall show how the concept of anchoring innovation is rooted in a social-constructivist understanding of technology.[2]

1 Sluiter 2017.

2 This should not come as a surprise since the Anchoring Innovation program explicitly drew on the Social Construction of Technology approach in its initial formulations.

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1 The Social Construction of Technology (SCOT)

The Social Construction of Technology (SCOT) approach studies the development of artefacts and engines as resulting from social processes.[3] A starting point for SCOT was the critique of technological determinism. Technological determinism comprises two basic claims: (a) technology develops autonomously, and (b) technology determines societal development. These claims were criticised as being intellectually impoverished and politically debilitating. Technological determinism involves a poor research strategy, it was argued, since it entails a teleological, linear, and one-dimensional view of technological development that could be shown to be empirically false. In addition, technological determinism is politically debilitating because it suggests that the paths taken by technological development are inevitable (because autonomous), thus making social and political debate on technology a futile endeavour. To bolster this critique, it was necessary to show that the development, stabilization and even the working of technologies are socially constructed, with the emphasis on *social*.

I can summarize the SCOT research heuristics as a three-step process. Key concepts in the first step are 'relevant social group' and 'interpretive flexibility'. An artifact is described through the eyes of relevant social groups: groups that are somehow relevant for understanding the artifact and its role in society. Relevant social groups consist of actors who all refer to the artifact in the same way. Let me illustrate this with the example of the invention of the modern bicycle—then (in the 1880s) called 'safety bicycle.' Bicycle producers, young athletic users of the high-wheeled 'Ordinary Bicycle', women cyclists, and anti-cyclists—each of these groups described the Ordinary in the 1870s in their own way. Because looking at an artifact through the eyes of different relevant social groups produces different descriptions—and so, in a sense, different artifacts hidden within that one thing of metal, rubber and wood—the researcher is able to demonstrate the 'interpretive flexibility' of the artifact. Though it is common to speak of one artifact, in practice there are many. The Ordinary, for example, was an 'unsafe machine' in the eyes of women, but a 'macho machine' in the eyes of the young male Ordinary users. For the typical woman of the era, the bicycle was a machine on which your skirt got entangled in the spokes and from which you frequently made a steep fall; for the 'young man of means and nerve' riding the bicycle was a way to exercise and impress people (including young ladies!).

3 For a comprehensive introduction, see Bijker 2015. For SCOT in the broader context of science and technology studies, see Bijker, Hughes and Pinch 1987.

In the second step, the researcher follows how interpretive flexibility diminishes over time, as some artifacts gain dominance over others and meanings of different artefacts converge, and in the end one artifact results from this process of social construction. Here, key concepts are 'closure' and 'stabilization'. Both concepts are meant to describe the outcome of the process of social construction. 'Stabilization' stresses process: a process of social construction can take several years in which the degree of stabilization slowly increases up to the result of closure. In the case of the bicycle, the 'unsafe bicycle' became dominant over the macho bicycle and thus opened the way for alternative designs that addressed the risk of riding that high-wheeled Ordinary—leading to the low-wheeled bicycle with a chain drive on the rear wheel, then generally called the 'safety bicycle.'

In SCOT's third step, these processes of stabilization are analysed and explained by interpreting them within a broader theoretical framework. The explanation seeks to answer why a given social-construction process follows one course rather than another. The central concept here is 'technological frame'. A technological frame structures the interactions among the members of a relevant social group and shapes their thinking and acting. It is similar to Kuhn's concept of 'paradigm', but with one important difference: 'technological frame' is a concept that applies to all kinds of relevant social groups, while Kuhn intended 'paradigm' exclusively for scientific communities. A technological frame is built up when interaction 'around' an artifact begins. In this way, existing practice guides future practice, though without logical determination. Typically, a person will be included in more than one social group, and her/his thinking and interacting will thus also be guided by more than one technological frame. One important element in the technological frame of women, in the history of the bicycle, was their wish to become more independent and free to move around—these were also the years leading up to the suffragette movement. That made them into an important relevant social group in the social construction of the safety bicycle. In the technological frame of the relevant social group of 'men of means and nerve', who rode the 'Macho bicycle', a preference for high-speed riding was important. And when the low-wheeled safety bicycle proved to be very fast with its air tyres and chain drive, they also were won over. Thus a detailed analysis of the technological frames of the relevant social groups can offer an explanation of how the social construction of the safety bicycle happened.

This three-step research process thus amounts to: (a) a sociological-historical description of an artifact through the eyes of all relevant social groups, which results in demonstrating the artefact's interpretive flexibility, (b) tracing the artifact's social construction by following its diminishing interpretative flexibility and gradual stabilisation, and (c) explanation of this social-construction process by using the technological frames of relevant social groups.

2 SCOT Illustrated by Maria Gerolemou's and Anna Soifer's Chapters

I shall illustrate the Social Construction of Technology by drawing on the fascinating studies of innovation in bows and torsion artillery devices by Maria Gerolemou and glass blowing and *terra sigillata* by Anna Soifer.[4] Since I am not a scholar of Greco-Roman antiquity, let alone a researcher of war engines or ceramics, my claims necessarily must remain modest: I merely aim to illustrate SCOT, not to improve upon the innovation studies by Gerolemou and Soifer. Hopefully I am not misreading their cases and apologize in advance if it turns out that I have done so.

My reading of the war engines case is that there are several relevant social groups, though Gerolemou does not use that term. First there are the warriors, who use a variety of fighting devices—from their bare hands to swords and spears, to bows and torsion-driven catapults. I want to emphasise that the choice of relevant social groups is done by the analyst and not dictated by the empirical material. Depending on the research question, it may be enough to consider all warriors as one relevant social group, or the analyst could choose to distinguish fighters with speers and swords (anachronistically: the infantry) from fighters with engines that allow doing harm at a distance (artillery). My impression is that Gerolemou considers one single relevant social group of warriors. I am curious how the story would unfold when two relevant social groups are distinguished: the first of spear and sword fighters, and the second of archers and catapult users. In the first relevant social group—let me call this the 'hand-fighters relevant social group'—the emphasis probably is on *andreia*, courage, conceived as a virtue you can only show in man-to-man combat. Would it be possible that within the second—let's call that the 'archers relevant social group'—emphasis is put on 'the knowledge, skill and technique of the archer', presenting the fighter as 'not a slave to his weapon, unlike the hoplite to his spear, but the one who wisely and skilfully guides it'?[5]

Distinguishing these two relevant social groups allows me to demonstrate the interpretative flexibility of the *gastraphetês* (belly bow): rather than one, there are two belly bows. In the eyes of the hand-fighters relevant social group,

4 Gerolemou, this volume; Soifer, this volume.
5 Gerolemou, this volume, 170, citing the *Odyssey* and *Heracles*.

the *gastraphetês* is a 'coward engine'; through the eyes of the archers relevant social group, we see another *gastraphetês*: the 'clever bow.' The question thus becomes: which of the two artefacts—the 'coward engine' or the 'clever bow'—will become dominant and stabilize? That is partly an empirical question: what do archival and archaeological data show? And it is partly a theoretical question: can we explain why either the 'coward engine' or the 'clever bow' has stabilized? My impression from reading Gerolemou's chapter is that the 'clever bow' has stabilized; but why did this happen? The other artefact, the 'coward engine', seems to have the support of Homeros and Euripides, and thus perhaps of the general public too. That is quite a formidable support! Gerolomou argues that it is the 'bodily character' (my words) of the belly bow that makes the 'clever bow' win over the 'coward engine': 'By including the body and muscles of the warrior in its operation and description, the belly bow seems to nourish the belief that he could win a battle in collaboration with his weapon and not because the superior weapon wins the fight for him.'[6] In other words, the 'clever bow' became anchored in the values of *andreia* and man-to-man fighting, thus beating the 'coward engine' on his own terms. I would not be surprised if the enhanced action-at-a-distance of the 'clever bow' also played a role, but I do not know the historical evidence well enough. And that is important: it is not enough that *we* think that shooting farther is an asset—to explain technological development, we must have evidence that the contemporaneous actors saw it like that.

So, demonstrating the interpretative flexibility of an artefact sets the agenda (how did the interpretative flexibility diminish, which artefact became dominant, how did the innovation come about, why did it happen like this?) for empirical and theoretical research. The empirical question is answered by tracing how various relevant social groups talk about and use the artefact. The theoretical question is answered by describing a 'technological frame' for each relevant social group. Technological frame is an analyst's concept, not an actor's concept: a particular technological frame is formulated (or hypothesised or conjectured) by the researcher to make sense of the interactions that she observes in that particular relevant social group. Let me illustrate this with Anne Soifer's study of the innovations in *terra sigillata* and glass blowing.

The first point to observe about the concept 'technological frame', is that it is intended to describe the thinking and interacting of *all* relevant social groups and not only inventors or engineers. This is in line with Soifer's focus on the 'lived experience' of innovations and her recognition that it is Roman

6 Geroulemou, this volume, 173.

craftspeople who made the innovation, rather than some single inventor. When describing the technological frame of a specific group of craftspeople, one should include a 'combination of numerous factors, including, but not limited to, other actors involved, social, political, and economic contexts, and the physical materials and objects implicated in the process'.[7] The technological frame thus describes 'what is known, established, trusted, familiar, culturally acceptable, or reliable, thereby influencing the decision-making process and encouraging participation in innovation'.[8] More detailed analysis of the archaeological evidence, for example of the Jerusalem glass craftspeople in the mid-first century BCE, then provides more details such as their techniques, tools and knowledge to fold flat pieces of glass, then stretch to create small glass rods and inflate these with air to create tubes.

Research on the social construction of technology in the nineteenth and twentieth century suggests that different groups of glass workers—in different locations and at different times—would add new elements to their technological frame and thus be able to do new things with the glass—in other words: innovate. Soifer does not explicitly identify relevant social groups, but I think that they can be found in her account of the ceramicists, when realizing that the different locations and time periods that she uses to tell her *terra sigillata* story, effectively produce different relevant social groups. First, there are the Etruscan potters making the fine bucchero, with knowledge, skills and technologies to make a black gloss and fine creamware. Then there were the Greek ceramicists of red- and black-figure fineware. And finally, there are the craftsmen in Arezzo (Arretium) around 30 BCE, who produced *terra sigillata*. This illustrates an important finding of SCOT research: that an innovation is not made at one moment and then diffuses more or less unchanging through society, as for example Rogers suggests.[9] Instead, with every new group that engages with the technology, new elements are added—the innovation process never stops and all relevant social groups add to it. So, if I may disagree slightly with one small point that Soifer makes, I would not say that 'while the technique changed over time as it was adopted in different regions of the Roman empire and in some versions, its methods are not fully understood'.[10] Instead, I would stress that all relevant social groups worked with their own versions and understood their own methods as fully as necessary to craft their ceramics. Stating that a group 'does not yet fully understand' builds on the assumption that *we* (as twenty-first century researchers) have absolute and

7 Soifer, this volume, 181.
8 Soifer, this volume, 181.
9 Rogers 1962.
10 Soifer, this volume, 187.

final knowledge to calibrate and characterize the knowledge and techniques of historical actors as being partial and not-yet-complete. SCOT's heuristics to study technology development as a social construction is meant to avoid that kind of teleological and anachronistic historiography. And this pertains to contemporaneous studies of different knowledge and innovation systems too. That is why the Anchoring Innovation project co-funded a conference in India with handloom weavers and other craftspeople to study anchoring innovation in handloom weaving.[11] Handloom weaving is often considered as outdated, to be substituted by mechanised weaving looms or at least to be museumised. Annapurna Mamidipudi showed that also in these supposedly outdated communities of craftspeople, much innovation is going on.[12] Even more striking: handloom weavers initially were offended when they heard Mamidipudi's characterization of their practice as innovative—they associate innovation with computers and biotechnology, while they see their work cherishing tradition. Once they understood our reasoning, they recognized that they were indeed adapting their knowledge, tools and designs to changing circumstances (we called that innovation), while at the same time anchoring their work in the Indian saree tradition.[13]

3 Conclusion

An important insight that is captured by the idea of anchoring innovation, is that innovations typically are rooted in the past—in other artefacts, and in materials, knowledge, practices, language, values. That insight is important because it refutes the standard image of technology innovations. That standard image depicts innovations as brand-new, thereby obscuring insight in how these innovations could come about. SCOT further details that insight. Technological frames specify how the past shapes the thinking and interacting within relevant social groups and thus details the anchoring mechanisms.

The second important insight offered by the idea of anchoring innovation is that innovation is not done by single inventors but is the outcome of multifaceted processes in society. SCOT details this by the concepts of relevant social group and its technological frame. This focus on social processes rather than single inventors seems particularly important for studies of innovation in Greco-Roman antiquity, when sources are less likely to identify individual engineers but where clever use of archaeological and written sources can

11 Flohr 2019.
12 Mamidipudi 2016.
13 Mamidipudi and Bijker 2018.

identify such social processes—as Soifer and Gerolomou demonstrate. (But SCOT maintains that this applies always and everywhere—all technologies are socially constructed, from the *terra sigillata* to the handloom, from the *corvus cum harpago* to autonomous military drones.)

Thirdly, innovation is not a purely technical thing. As the various studies in this book show, innovation typically happens in all sectors of society—literature, politics, town planning, theatre, music, war fare, etc. But also the seemingly technical innovations can only be understood by taking into account a broad range of non-technical aspects: the aesthetics of the new *terra sigillata*, the availability of enough wood to fire the high-temperature kilns, or the values of *andreia* in Greek society. Even the well-working of an engine is not a matter of physics, chemistry and economics only. The Macho bicycle worked well during a short period and for a particular group; without changing anything in the 'thing' itself, it became working less well when the social construction of the safety bicycle proceeded as an alternative. As Ineke Sluiter summarizes: 'Innovations may become acceptable, understandable, and desirable when relevant social groups can effectively integrate and accommodate them in their conceptual categories, values, beliefs and ambitions.'[14]

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14 Sluiter 2017, 23.

CHAPTER 4

Beyond Innovation: Early Modern European Technological Values

Lorraine Daston

1 Introduction: Novelty as Nuisance or Worse

The insight that informs this volume is that there is nothing self-evident about the connection between 'new' and 'improved', despite the advertising jingle and the relentless hype about innovation in every realm from scholarly grant proposals to laundry detergent. On the contrary, historically speaking, the association has rather been not 'new and improved' but 'new and untested and potentially disastrous—or at very least, inconvenient'—as anyone who has ever been forced to update a perfectly satisfactory computer program knows. As this volume's theme of 'Anchoring Technology' underscores, new technologies have historically been anchored in existing social and material contexts, not presented as radical ruptures with all that came before.[1]

There are good reasons for this: every technology exists within a finely calibrated ecosystem of human customs and material infrastructure. Just as in natural ecosystems, the sudden introduction of a new species can have disastrous knock-on effects. Abrupt change can rip apart delicate webs of interdependence, whether these concern symbiotic relationships among species, global just-in-time supply networks, or horse-drawn city traffic before the advent of bicycles. This is why anchoring remains essential even in cultures that glorify innovation, the more radical the better. For example, even the much-touted 'disruptive' technology of driverless cars is anchored in current automobile design, extant highway systems, and entrenched human habits. I will therefore not focus on innovation but rather on three alternative values in the history of technology: improvisation, emulation, and virtuosity. My examples will be drawn mostly from early modern Europe, but I suspect that these values already in the sixteenth and seventeenth century boasted a long historical lineage and that they are to some extent still relevant.

1 Sluiter 2017.

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2 Emulation

Circa 1600 Philip Galle of Antwerp published a series of 20 images designed by Jan van der Straet and engraved by Jan Collaert I. The collection was entitled *Nova Reperta*, or 'New Discoveries', and these give a fair idea of what a well-informed European of the time thought were the cutting-edge novelties of the era. Not all were what we would call technology: the discovery of the Americas featured prominently on the frontispiece (fig. 4.1). But many were, including the three inventions singled out by Girolamo Cardano, Francis Bacon, and other early modern *novatores* as proof that the moderns had surpassed the ancients, at least in the mechanical arts: gunpowder, the printing press, and the magnetic compass.

However, the 'nova' in the title *Nova Reperta* did not mean 'new' in the breaking-news sense of the modern word 'innovation'. Many of the inventions and discoveries (two ideas still conflated *c.*1600[2]) were centuries old, like water

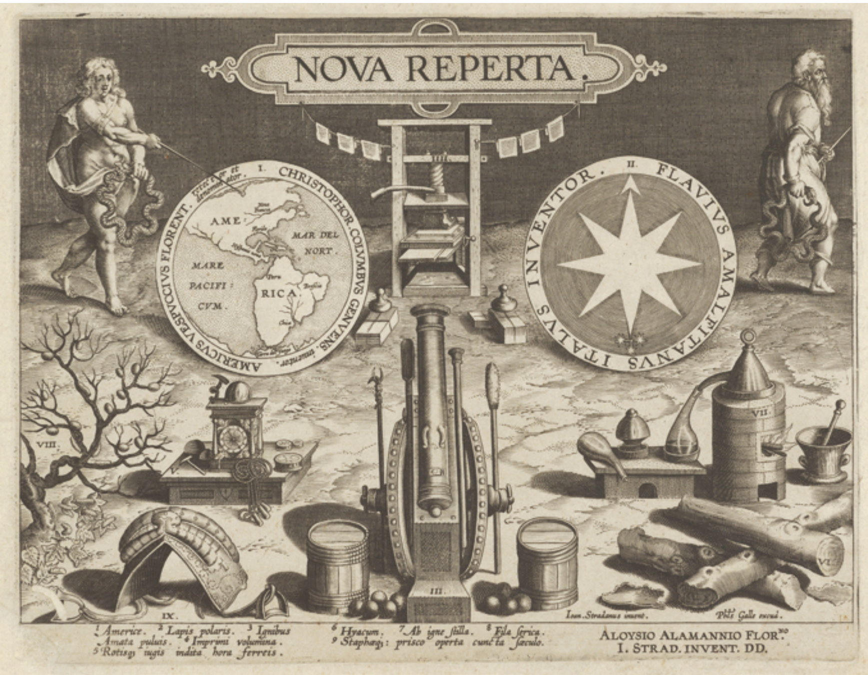

FIGURE 4.1 Frontispiece, Jan van der Straet, *Nova reperta* (*c.*1600), engraved by Theodor Galle
PHOTO: THE METROPOLITAN MUSEUM OF ART, NEW YORK. PUBLIC DOMAIN

2 "Invention", *Oxford English Dictionary Online* 2021.

FIGURE 4.2 Book Printing, Jan van der Straet, *Nova reperta* (*c.*1600), engraved by Theodor Galle
PHOTO: THE METROPOLITAN MUSEUM OF ART, NEW YORK. PUBLIC DOMAIN

mills. Others were not so much isolated inventions, much less datable inventions made by an identifiable person, as they were long production processes, like silk manufacture. Even the plates that commemorated a relatively new invention ('new' here meaning less than 300 years old) are group portraits showing a division of multi-staged labor (fig. 4.2).[3] The one signed invention, the magnetic compass attributed to Flavio Gioja of Amalfi (see fig. 4.1), dates back to the early fourteenth century.

Although the *Nova Reperta* is often presented as an early witness of pride in modern technological innovation, its underlying assumptions about what innovation is seem anything but modern. There is no sharp distinction between inventions like gunpowder and discoveries like the Americas; 'new' can mean anything from yesterday to 500 years ago; the invention in question is more a process than a thing in most cases, involving many stages and many people; as a result, there is rarely a single inventor. Instead, innovation

3 Stijnman 2017.

itself is a slow, incremental process in which workers are constantly tweaking and adjusting prototypes to make them more efficient or multi-purpose or easier to use. This process was called 'emulation', which was distinct from both imitation and innovation.[4] Between the extremes of slavish copying of old designs and the introduction of radical new ones, artisans took a proven device and the work process associated with it and made small improvements, which were in turn emulated by others. This is a process as old as Hesiod's good kind of *eris* ('rivalry', 'competition') in the *Works and Days*[5] and as new as Adam Smith's description of worker ingenuity in the pin factory in the *Wealth of Nations* (1776).[6] It is competitive but not necessarily individualized; ingenious, but rarely disruptive. When Francis Bacon in the *Novum organum* (1620) contrasted the progressive mechanical arts with the stagnant sciences, this was what he meant by progress: slow, incremental, cumulative but in the end remarkable.[7]

3 Improvisation

My second early modern category, improvisation, is closely related to the first. The fact that the mechanical arts could be described as 'arts' rather than as unskilled labor indicated that they were governed by principles that could be taught. However, because the mechanicals arts involved the imposition of form upon recalcitrant matter, artisans were constantly having to adjust their rules to the peculiarities of their materials: the carpenter who had to work around the knotty grain of this piece of wood; the tailor who had to modify a pattern for this bolt of unusually fine-spun silk; the apothecary who had to substitute a different ingredient for a spice that could not be found; the dyer who had to make do with a woad plant that did not deliver the desired shade of blue. As in the case of medicine, which had to deal with the infinite variety of human bodily complexions, the mechanical arts were constantly adjusting to the infinite vagaries of matter. Recipes and the so-called books of secrets warned users that the instructions and ingredients given should not be followed slavishly: everything from water to the potency of healing herbs varied locally and had to be adjusted accordingly.

4 Jones 2016, 140–144, 200–210.
5 Hesiod 2009, 71–72.
6 Smith 1986, 114–115.
7 Bacon 1828, 225.

The variability of matter was usually regarded as a nuisance, but it was also the occasion for productive novelty. The medieval *experimentum*, or trial, was a test of some new ingredient or process, not an experiment that probed into hidden causes, and experiments were of necessity being constantly conducted in artisan's workshops and also in households. Generations of women might keep, annotate, and hand down recipes for everything from eye ointment to puddings to cosmetics, each new owner adding her notes about successful improvisations to the original recipe.[8] Like emulation, improvisation was incremental, cumulative, and anonymous, but it was also constant and serendipitous. Every workshop, every kitchen was willy-nilly a laboratory, like it or not.[9] When dedicated laboratories started to appear in the late seventeenth century, it is no accident that their equipment of stills, hot fires, and cooking ware was borrowed directly from the kitchen and apothecary shop.

4 Virtuosity

The third and last of the alternative early modern values to technological innovation was virtuosity. Because of the growing prestige of the fine arts of painting and sculpture and the concomitant cult of individual artists from the fifteenth century onwards, virtuosity is often narrowly associated with the tradition of mimesis, in a lineage stretching back to Pliny's story of the competition between the ancient Greek painters Zeuxis and Parrhasius.[10] The trompe l'oeil still life is a tribute to the continued vitality of artistic virtuosity as illusionist imitation.

However, there was also a tradition of virtuosity in the early modern mechanical arts that was not so narrowly defined by mimesis. In contrast to the highly mimetic automata of the eighteenth century, like Jacques de Vaucanson's duck that quacked, swam, ate, and defecated,[11] the virtuoso automata of the sixteenth century were more likely to be works of elaborate clockwork, like the 1574 astronomical clock at Strasbourg with its sophisticated astronomical calendar clockwork tracking the motions of the planets and eclipses, its carillon that played six tunes as well as a golden cock that crowed every day at noon.[12] Or a work of artisanal virtuosity could display supreme mastery of form over

8 Leong 2018.
9 Smith 2013.
10 Pliny the Elder 2003, 308–311.
11 Riskin 2003.
12 Cahn 1979, 91.

FIGURE 4.3 Ivory frigate by Jacob Zeller (1620)
COURTESY OF THE GRÜNES GEWÖLBE, STAATLICHE KUNSTSAMMLUNGEN, DRESDEN

recalcitrant matter, like this delicate frigate crafted of hard brittle ivory as a showpiece for the *Wunderkammer* of the Saxon kings (fig. 4.3).

Virtuosity aimed to inspire wonder at the maker's extraordinary skill, not necessarily at novelty and very rarely at utility. The astronomical clock could tell time, but that was the least of its attractions. These were objects meant to be displayed to an admiring audience, not to make work easier or more efficient, to cure diseases, or win wars. They did serve political purposes: the princely *Wunderkammer* was regularly enlisted to impress and over-awe visiting dignitaries, the prince basking in the reflected wondrousness of his collection.[13] Yet here too improvisation and emulation were at work—the rivalry of Zeuxis and Parrhasius was emblematic of the rivalry among master craftsmen to outdo one another. Here novelty was the byproduct of competition—things never before imagined or achieved, a perfection that challenged all rivals.

5 Conclusion: Novelty for Its Own Sake

These early modern alternative values to innovation were embedded in a system of labor organization centered on the workshop, in an understanding of technology as a multi-stage process rather than as a product, and in an Aristotelian philosophy of form and matter that recognized variability as a fact of life. Within this system, inventors might be individualized (this was especially the case with works of virtuosity) but by and large the processes of innovation were as collective as they were incremental and cumulative. Although many of the resulting technologies were ultimately as disruptive as anything Silicon Valley has thrown at us—just think of the printing press—they did not explode upon the scene like stellar novae in the heavens. And almost none were celebrated because they were new: the "nova" in *Nova Reperta* refers to anything that happened since Antiquity.

The only early modern technology that did celebrate novelty for its own sake was the one most reviled, then as now: fashion. Then as now the St. Vitus' dance of febrile innovation in dress was grudgingly tolerated for its economic benefits. But then as now fashion exposes the shadow side of innovation: pure novelty for its own sake, as short-lived as surprise.

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13 Daston and Park 1998, 265–276.

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CHAPTER 5

Ancient Greek Doors and Their Humans

Ineke Sluiter

1 Introduction

The long history of human technological invention is at the same time a history of human-thing interactions, meaning-making, and symbolism. The use of doors to separate outside from inside, to provide entries and exits, to exclude and to welcome, is a case in point (see fig. 5.1).[1] There can be no doubt that doors constitute a security-enhancing and protective technology, especially given their frequent accoutrements of bolts, locks, and keys.[2] Even if we think we are just looking at doors from the point of view of (technical) 'design', we need to acknowledge their intended use by and effect on humans, including such implied values as safety or coercion. Donald Norman, who elaborated the concept of 'affordances' coined by James Gibson, was intrigued by the problems doors could pose for people, given the common absence of any clear clues to anyone trying to get through one, on whether they would need to push, pull, or slide.[3] Doors engage us in a physical interaction of relevance to anyone interested in embodied cognition. 'Every morning, a door stands in my way', says Ruth Bielfeldt in a well-known paper on 'material things that

1 Oakley 2020, 8, on scenes of daily life on Athenian vases: 'Doors are a common architectural element shown, and a single one often serves two functions, as the place of departure and as the place to be entered'. Figure 5.1 is his figure 1.2 (2020, 9).

2 See Diels 1920 on ancient Greek doors and locks; Haddad 2016 on the evolution of door-locking mechanisms in the S.E. Mediterranean. In the 'Swallow Song' (*PMG* 848, 14–16), children who are trick-and-treating threaten to steal the door itself (or, alternatively, the doorpost, or the woman of the house; she's not that big, they think they can carry her off easily; —this is the domain of comic hyperbole) (ἢ τὰν θύραν φέρωμες ἢ τὸ ὑπέρθυρον / ἢ τὰν γυναῖκα τὰν ἔσω καθημέναν· / μικρὰ μέν ἐστι, ῥᾳδίως νιν οἴσομες). See Griffith 2000, who notes 15-cent.-BCE legal texts from the Hurrian city of Nuzi that actually contain provisions against the stealing of doors.

3 Gibson 1966 and especially 1979 ('The affordances of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or for ill' (1979, 127). Norman was interested in particular in potential for action: 2002, viii; see also 2002, 9–10 about affordances of doors (i.e., the properties determining how they can be used; their potential for doing things with and to them); 2002, 87–92 about 'the problem with doors'; for a more recent discussion and application of the concept, see Levine 2015, 6–11 (I'm grateful to Matthew Ward for this reference).

FIGURE 5.1 (Attic red-figure chous) 'reveler, pounding door as woman with lamp inside apprehensively waits', ca. 430–420 BCE, NY, Metrop. Museum of Archeology, 37.11.19 Fletcher fund (in the public domain)

engage people in a physical way and, in doing so, prompt them to reflect on the bodily conditions of human perception, existence, and history'.[4] Restricting ourselves to a technical understanding of how ancient doors were constructed and used would deprive us of important insights into their entanglement with

4 Bielfeldt 2018, 420–421.

their human surroundings, the social construction of their meaning, and their role in the cultural imagination.

From the earliest Greek poetry that has come down to us, we find doors in very different contexts: an innovative and imaginative kind of door is ascribed to the divine realm in the *Iliad*, different types of doors unexpectedly form back-ground support for the narrative trajectory of the *Odyssey*, and in the Greek theatre, something rather resembling a revolving door might have been in use (or not, as it will turn out). In this chapter, I will be discussing these three case-studies, purposely highly different in nature (sections 2–4), with a particular focus on meaning-making, on the affordances of doors, and on the ways in which the familiar phenomenon of the prototypical door, which had been available for a long time, 'anchors' various innovations in the symbolic realm.

The use of the concept of 'anchoring' for this particular piece of technology shows that this chapter positions itself in the ambit of 'science, technology, and society' studies, and the 'social construction of technology' (SCOT), with its emphasis on the entanglement of humans, social structures, and things.[5] The concept of 'anchoring' has four major components: it is based on the assumption that in order to absorb whatever strikes us as '*new*' (1), we must be able cognitively to anchor, i.e., *connect* (2) it to something *familiar* (3), and this is studied on the level of *relevant social groups* (4).[6] We can be more precise about the 'familiar': this refers to what is in the 'common ground' of the communicative situation, 'the sum of [two or more people's] mutual, common, or joint knowledge, beliefs, and suppositions'.[7] Common ground encompasses 'cultural common ground' (culturally shared information), and 'personal common ground', information shared by some individuals. 'Cultural common ground' is the relevant form in this chapter. Everything that is part of the shared and remembered past is part of the cultural common ground and therefore suitable as an anchoring ground for new ideas or inventions. But it is also possible to use analogies to other domains of one's contemporary society in order to anchor something new, e.g., when defining a 'drone' (the new thing) as a 'flying computer' (where 'computer' functions as the anchor).[8] Anchoring is dynamic: something that initially may have required a familiar analogue itself, can later on provide conceptual stability to newer phenomena. That is why the prototypical doors mentioned above can function as the anchoring

5 SCOT goes back to the fundamental paper by Pinch and Bijker 1984. See also Bijker 1995.
6 See Sluiter 2017.
7 Clark 1996, 93; see Sluiter 2021, 244 with the other literature cited there.
8 Sluiter 2021, 248.

backdrop to more imaginative and innovative uses: they are the regular and familiar ones that most easily come to mind as the best example of a door.

2 Divine Doors: Automation

In the *Iliad*, we encounter the first automatic doors in the history of Western-European literature. When Hera and Athena decide to take action and help the embattled Greeks, Athena dons her armour, and Hebe prepares their flaming chariot and harnesses a team of horses. Hera takes the reins, cracks the whip, and the doors of heaven open spontaneously to let them through.

> And of their own accord (automatically) the gates of heaven bellowed,
> The gates kept by the Horai,
> To whom great heaven and Olympus are entrusted,
> To either open the dense clouds or close them.
>
> αὐτόμαται δὲ πύλαι μύκον οὐρανοῦ, ἃς ἔχον Ὧραι,
> τῇς ἐπιτέτραπται μέγας οὐρανὸς Οὔλυμπός τε,
> ἠμὲν ἀνακλῖναι πυκινὸν νέφος ἠδ᾽ ἐπιθεῖναι.
> *Il.* 5.749–751

There is some (quite forgivable) unclearness in this text about the exact location of the doors. Mount Olympus and heaven are sometimes (as here) equated, sometimes not quite, when one is halfway the other.[9] In this case, the goddesses are finding Zeus after their ascent to the highest point of the Olympus, preceding their descent to Troy, i.e., they are driving *in* before driving *out*.[10] This is not science fiction (in the sense that the narrator would be imagining something that could one day be available to humans).[11] This is the cultural imagination hard at work in shaping the divine realm, where gates

9 That the terms refer to the same location here is clear from the hendiadys in 5.750, marked by τε. On this issue, cf. Sale 1984.

10 Mendelsohn 2015, 1 has noticed the ambiguity and speaks about going 'in or out', further pointing out that Homer seems to be anticipating the automatic garage doors by over two millennia; see Mayor 2018, 134. I thank Prof. Irene de Jong for discussing the spatial arrangements in this passage with me.

11 See Berryman 2003, 351f. and 356 on the distance separating mythological accounts from 'entertain[ing] the idea that automata could be constructed by technological means' and on 'imagination divorced from interaction with real technology'.

consist of clouds that can be opened and closed. The goddesses pass these doors in their chariot.

How do we know, apart from the fact that we are told? The strongest anchoring feature of this passage is the sound made by the gates when they open: they groan or creak. This is not to be taken as a sign of a poorly performing Olympic maintenance department, it simply means that the door is indeed opening, or even: that the door is actually there. Creaking is a general feature of ancient doors, and the poet can use it in this passage, consciously or not, to alert us to a virtually invisible presence.[12] Sometimes Homeric doors bellow like a bull.[13] In ancient comedy, reporting that one hears the door is used invariably to call attention to the fact that it is opening and a character is about to enter the stage.[14] In Euripides' tragedy *Hercules Furens*, Megara relates how her children were missing their famous father, and her tell-tale example is that whenever the doors were creaking, everyone would jump up and rush to see whether it might be him.[15] And in a famous Athenian court case (dating to the fourth cent. BCE), the husband of an adulterous woman realizes with hindsight that the creaking of his door in the middle of the night meant his wife had gone out for a secret rendezvous, although she had offered a different explanation at the time.[16]

Imagining the possible is always anchored in the actual.[17] In this case, the imaginative and creative idea of automatic doors is anchored in a form of sensory feedback familiar from the daily world of the Greeks.[18] Noiselessness does not come into it; a noiseless door simply does not meet the standard of identity for a humanly understandable door yet. And this door is ultimately there for

12 Norman 2002 (1988), 102–104 on 'using sound for visibility': 'Sometimes things can't be made visible. Enter sound: sound can provide information available in no other way'.

13 *Od.* 21.48–49 τὰ δ' ἀνέβραχεν ἠΰτε ταῦρος/ … τόσ' ἔβραχε καλὰ θύρετρα ('they bellowed like a bull … that is how loudly the beautiful doors bellowed'. The verb μύκον used in our passage (*Il.* 5.749) is also a term for the lowing of cows. Elsewhere, it is the divine weight of Athena that makes a human chariot groan loudly (*Il.* 5.838–839).

14 See, e.g., Ar. *Eq.* 1326 καὶ γὰρ ἀνοιγνυμένων ψόφος ἤδη τῶν προπυλαίων ('for I can already hear the outer door opening'; *Ran.* 605 ὡς ἀκούω τῆς θύρας καὶ δὴ ψόφον ('for, look, I can hear the creaking of the door'); Men. *Pk.* 316 ἀλλὰ τὴν θύραν ψοφεῖ τις ἐξιών ('but someone is coming out, they are making a noise at the door'); *Fr.* 860–861 l. 2 ἐψόφηκεν ἡ θύρα, τίς οὑξιών; ('the door creaked, who is coming out?');

15 Eur. *HF* 77–78 ὅταν / πύλαι ψοφῶσι, πᾶς ἀνίστησιν πόδα.

16 Lys. 1.14 ἐρομένου δέ μου τί αἱ θύραι νύκτωρ ψοφοῖεν, ἔφασκε … ('when I asked why the door creaked in the night, she said …' (that she needed to go to the neighbours in order to relight a lamp that had gone out)).

17 See Sluiter and Versluys 2022.

18 This is, of course, to be distinguished from the poetic trope of the 'speaking door', for which see Wessels 2024.

the enjoyment of humans. There is another sensory and embodied anchoring effect in the reference to the concrete actions of opening and closing the door, on two levels. First, such action words have a role in enactive cognition and they make the story more immersive.[19] And, secondly, this opening and closing of the cloud-gates may be anchored in the experience of the seasonal visibility or obscurity of Mount Olympus, for the Horai are also the embodiment of the seasons. Here, too, there is a hidden human perspective, for it is primarily human beholders who look up to heaven through the clouds.

The automatic doors of the Olympus belong in a discourse about the divine, where everything is golden, and every action is performed effortlessly and easily (ῥᾳδίως). The automatic doors separate the human and divine worlds. And they creak open, for they are doors, however fictive. This, then, is anchored imagination, not so much of future-oriented technology, but of the world of the gods and how we can represent it as and for mortal people.

The connection between the divine and automatically opening doors would become a staple of Greek cultural common ground. An ancient commentator on the *Iliad* passage understood the phenomenon as a way to indicate the prestige of the goddesses.[20] The spontaneous opening even of human doors could itself be part of an epiphany, a sign that the gods were miraculously present.[21] In the *Iliad*, an example is Achilles' immediate understanding of the fact that Priam must have had a divine escort when he came to see him: otherwise he could have never got through the quite impressive doors on his shelter.[22] We find similar points in Euripides' *Bacchae*, and in Hellenistic poets, such as Theocritus and Callimachus. As Heather White puts it: 'every Hellenistic reader knew that doors unfailingly and automatically opened whenever a god (or goddess) was near them'.[23]

19 See Grethlein and Huitink 2017.

20 Σ bT on *Il.* 5.749b ἐμφαίνεται δὲ καὶ τὸ ἀξίωμα τῶν θεῶν, εἴγε ἑκοῦσαι αἱ πύλαι εἴκουσιν αὐταῖς.

21 Documented extensively in Weinreich 1929.

22 *Il.* 24.566–567; as the audience of this scene, we know that Achilles' surmise is correct. In 24.446 Hermes had opened the doors to the Greek camp, and in 24.448–457 there is an elaborate description of the doors to Achilles' abode, which only Achilles could open by himself, whereas that would otherwise require three men, cf. Lynn-George 1988, 234–236; 1996, 11–13; Hermes, of course, opens them without a problem. Cf. *Od.* 6.18–20.

23 White 1977, 136 on Theoc. *Id.* 24.15–16, where Hera's snakes have no trouble entering Heracles' bedroom; see further Williams 1977; McKay 1967 on Callimachus' *Hymn to Apollo* 1–7. He lists (1967, 188) the words used to indicate such spontaneous openings and their uncanny nature: αὐτός, αὐτόματος; εὐθύς, ἐξαπίνης. On earlier texts, see Verdenius 1977 on Parmenides B1, 17–18 (the Doors of Night and Day, which need unlocking); Eur. *Ba.* 447f. on the miraculous liberation of the captive Bacchants: αὐτόματα δ' αὐταῖς δεσμὰ

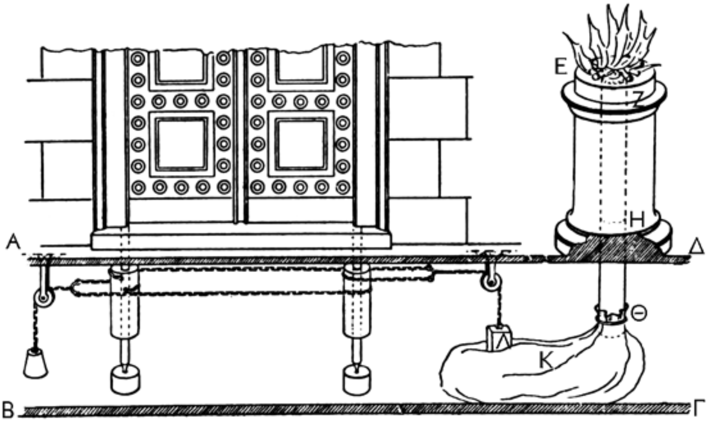

FIGURE 5.2 Illustrating Hero's design for an automatically opening door; Bur 2016 (her figure 20, adapted from Schmidt 1899, 181, his figure 40)

Some eight centuries after the *Iliad*, Hero of Alexandria (first century CE) used contemporary technology to create a working version of an 'automatic door'.[24] In his handbook on *Pneumatics*, there are two sets of building instructions (see fig. 5.2, for a reconstruction on the basis of one set). Hero describes the temple doors he designed as follows: 'When a sacrifice is being burned, the doors open automatically (αὐτομάτως ἀνοίγεσθαι) and when the sacrifice is extinguished, they close again'.[25] There is no doubt that the technological understanding going into these and other devices is advanced. Hero's device involves the expansion of heated air, and a whole system of weights, chains, and pulleys (in one of the two designs, he also uses water power). This has led to a long-standing debate, for which I refer to the introduction to this volume, about a presumed 'blocage': the question of what obstacles prevented ancient technology, which was simply there and available, from being used more widely and productively, especially in an economic/industrial way.[26] This idea has now been largely discredited because it imports a certain normative idea

διελύθη ποδῶν / κλῇδές τ' ἀνῆκαν θύρετρ' ἄνευ θνητῆς χερός ('the chains on their feet came loose spontaneously, and the bolts opened the door without human hand').

24 Michiel Meeusen also discusses the *Iliad* passage and Hero's design in his unpublished 2020 paper, and equally emphasizes its situatedness 'in cultural and social webs of history'. I thank him for sharing the preprint with me.

25 Hero *Pneum.* 1.38–39 Schmidt.

26 Asper 2013, 412; Bur 2016, chapter 1, describing the debate in the sixties and seventies of the last century between Finley 1963 ('blocage'), and the counter arguments by Edelstein 1967 and Dodds 1973. See also Greene 2000.

about what technology *should* be for (economic growth), without taking into account relevant ancient contexts of use. Given the theoretical framework of this chapter, we are clearly more in sympathy with attempts to understand the socio-technical ensembles we discern in classical antiquity 'on their terms'.[27]

Tatiana Bur, for instance, explains the human context against which we should read this Heronic project. Hero's automatically opening temple doors are part of a *miniature* version of a temple complex, to be put inside a real temple and to be activated there. The background is thus one of creating a sacred environment and an atmosphere of religious wonder and awe (θαῦμα).[28] Multiple scholars have argued that doors and thresholds structure the way we experience spaces, that they are the markers of significant moments of transition, and that this is true in particular for sacred thresholds.[29] The symbolic value of doors, again especially in a religious context, has long been recognized. In 1911, Ogle provided an inventory of superstitions connected with the threshold and the door. Among other things, the threshold is where spirits gather, and in the comic playwright Menander a character swears 'by the door'.[30]

Hero's opening doors are a symbolic representation, but also an enactment through mechanical means of a theophany: they represent the gods' actual presence and their willingness to accept the sacrifice. His *model* of an automatic door does not function as a door, and it does not anticipate an automatic door that human beings might want to use, one that opens on anyone's approach: no one exits or enters the temple, but an open door is a welcoming gesture with which the god shows acceptance of the sacrifice.[31] Technology is anchored and embedded in religion here, and in a long cultural tradition, going back all the way to Homer's *Iliad*.

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27 See particularly Flohr 2016.

28 For Hero's striving after the effect of *thauma*, see Tybjerg 2003. For *thauma*/wonder in Hellenistic poetry and art, see Zanker 2004. On creating a sacred environment, see Miles 2016.

29 See, e.g., Van Opstall 2018 with bibliography.

30 Ogle 1911, 251 on superstitions connected with the threshold; 1911, 261 on thresholds as the locus of prophetic inspiration; 1911, 262 as the place where spirits gather; 1911, 264 on swearing by the door in Menander (*fragm.* 801 Kock).

31 See Versluys and Woolf 2021, 215–219 on the affordances of objects, and the way in which new objects and materials change religious practices. *Automata* are one of their cases in point.

3 Doors and Narrative in the *Odyssey*

3.1 *Hospitality*

It is well-known that the theme of *xenia* or hospitality permeates the *Odyssey*.[32] In practical terms, one could rephrase this as a pervasive interest in who gets the right to enter and who is kept out, who is admitted and kept inside with rather too much enthusiasm, who is locked inside and not allowed to leave. The theme is sounded right from the first book, when Athena arrives in the form of Mentes, and waits patiently on the threshold of the court, at the outer doors (ἐπὶ προθύροις), which is the right thing for a guest to do. Telemachus is annoyed when he notices him and realizes that a stranger has been kept waiting at the door.[33] The corollary to a guest waiting at the door is the effort of the host to make him welcome straightaway.

Lateiner formulates this theme in terms of 'proxemics' (the symbolic use of space), and states that '[t]he *Odyssey* deploys space and the control of delimited territory as a semiotic code that shapes its plot' (1992, 137). For us, the important thing to note is obviously the role of doors in this context, as a logical anchor in the cultural common ground. In that sense, it is significant that the ultimate transgressor of hospitality, the Cyclops, uses the monstrous boulder serving as the door to his cave not just to keep his sheep inside, but also Odysseus and his crew.[34] The rock is called θυρεός (door stone) or simply πέτρη 'rock'), which he can 'close' (ἐπέθηκε, the normal term for closing a door). It would take twenty-two four-wheeled wagons to move it. Odysseus realizes there is no way for him and his men to dislodge it; they have to trick the Cyclops himself into doing so.[35] The material arrangements in the Cyclops' cave underline how far from the civilized world they have come.

The problem at Circe's residence is almost the opposite. Her hospitality extends rather beyond what would be desirable from the point of view of her guest, although it starts misleadingly well with some prompt door-opening. The group of explorers Odysseus has sent ahead, stand at the outer doors (ἐν προθύροισι) and hear the goddess sing inside. They call out, she immediately

32 See Reece 1993.

33 Athena ἐπὶ προθύροις, *Od.* 1.103; Telemachus realizing the lack of proper hospitality, 1.119–120; on the whole scene, see Mari 2016; Lateiner 1992, 142.

34 Notice that the cave is open when Odysseus and his men arrive. They are themselves transgressors here when they simply go inside to take a look (*Od.* 9.218).

35 *Od.* 9.240–243 αὐτὰρ ἔπειτ' *ἐπέθηκε θυρεὸν μέγαν* ὑψόσ' ἀείρας, / ὄβριμον· οὐκ ἂν τόν γε δύω καὶ εἴκοσ' ἄμαξαι, / ἐσθλαί, τετράκυκλοι, ἀπ' οὔδεος ὀχλίσσειαν· / τόσσην ἠλίβατον *πέτρην ἐπέθηκε θύρῃσιν*. Odysseus' realization of the problem, 9.304; opening by the Cyclops himself, 9.416.

opens the door and invites them in.[36] Eurylochus is suspicious and hangs back, but the others go inside where they are offered seats, food, and drink—with an admixture of drugs—and are promptly changed into swine.[37]

At the royal palace of the Phaeacians, Odysseus stands at the threshold,[38] from which he (like Athena arriving in Ithaca) can observe the incredible riches of the whole estate. This includes golden gates with silver doorposts, and gold and silver dogs as guardians.[39] However, when he has observed the whole lay-out of the place, Odysseus can simply step over the threshold and go inside to find the King and Queen; Athena has helpfully covered him in a fog that makes him invisible. Alcinous' palace is the opposite extreme of the cave of the Cyclops, and this includes their respective doors: the presence of doors is to be expected, their respective nature is new information, and their detailed description supports the story line.[40]

3.2 *Doors and Action*

Doors and their affordances are a material and meaningful anchor for representing the structure of space and issues of access and control. It should perhaps not come as a surprise then that when Odysseus finally finds himself back home and gets ready to kill the suitors, the action-packed drama is bound up, not just with endless killing, but, precisely, with doors and the actions they afford.

When planning his revenge, Odysseus has given instructions to remove all weapons from the hall, and Eurycleia locks them away with her key (19.30). There is an elaborate description of the doors to the special room that Penelope opens (while they creak loudly) with a key in order to take Odysseus' bow to

36 *Od.* 10.230 ἡ δ' αἶψ' ἐξελθοῦσα θύρας ὤϊξε φαεινάς.

37 *Od.* 10.220–240; the scene, including the opening of the doors, is repeated in Eurylochus' report, 10.256; 10.312 Circe opens the door to Odysseus himself; 10.389 she opens the door to the pig-sty in order to set the men-turned-swine free. Hers is the largest number of door openings in the *Apologoi*.

38 Thresholds are always important marked points of transition in Odysseus' journey (cf. De Jong 2001 on *Od.* 17.339–341, where Odysseus enters his own palace for the first time; she also refers to the episode in the land of the Phaeacians, and to *Od.* 10.62–63, in the land of the Aeolians.

39 Cf. Goldhill 1988, 11 for the role of guardian dogs, and the echo between this scene and the encounter with Odysseus' old dog Argos in Ithaca. I thank Matthew Ward for this reference and the observation in the previous note.

40 Golden doors, *Od.* 7.88; stepping over the threshold, 7.135. No mention is made of 'opening' the doors. However, Odysseus' sudden appearance, which must have resembled a theophany, puts everyone present in a state of *thauma* (7.145). On Odysseus' entry and the role of the Queen in this scene, see Wohl 1993.

the suitors for the contest she has devised (21.42–50). Odysseus makes himself known to the cowherd and the swineherd right outside the doors of the megaron (21.190) and explains his plan: it involves closing doors (κληῖσαι μεγάροιο θύρας, 21.236) so that none of the suitors can escape. The doors of the court must also be closed and locked (21.240–241). All these plans involving action with doors are executed in rapid succession: the swineherd orders Eurycleia to close the door of the megaron (21.381–382) and that is what she does (21.387). Philoetius closes the door of the court and ties the doors shut (21.389–391). Only then does Odysseus take his masterful turn in the bow contest.

Then it is time for the revenge itself: with a leap Odysseus takes up a strategic position on the threshold (ἆλτο δ' ἐπὶ μέγαν οὐδόν, 22.2), which gives him control over the entrance/exit, and makes his first kill.[41] The suitors realize they can only escape by dislodging Odysseus from his position at the door.[42] Telemachus is dispatched to fetch more weapons: he must hurry, for Odysseus realizes that all by himself he can only hold that crucial door for so long.[43] Telemachus returns quickly, and they arm themselves. Just in time, Odysseus realizes there is also a backdoor that needs to be watched and he dispatches the swineherd to do so. Just in time, since one of the suitors also realizes its existence, but it's too late: that door can easily be defended by one man. However, what's worse is that Telemachus turns out to have forgotten to close the door to the room where all the armour is stored, thus enabling the dangerous situation in which the suitors now also have weapons. Telemachus has to issue emergency orders to remedy the issue of access.[44]

Clearly, there is a lot of door drama going on here, based on a shared realization of characters and audience of the importance of control over entrances,

41 Book 22 is a very good example of immersive story-telling; our enactive cognition is triggered by the action words, many of which also involve doors. See Grethlein and Huitink 2017 (and p. 52 above).

42 Speech by Eurymachus, *Od.* 22.75–76: 'let's all together go for him, to see whether we can thrust him away from the threshold and the doors' (ἐπὶ δ' αὐτῷ πάντες ἔχωμεν / ἀθρόοι, εἴ κέ μιν οὐδοῦ ἀπώσομεν ἠδὲ θυράων). This is put into practice by Amphinomos, who attacks 'to see whether Odysseus would give way to him away from the doors' (22.91 εἴ πώς οἱ εἴξειε θυράων).

43 *Od.* 22.106–107, Odysseus speaking: 'Run and fetch them while I still have arrows to defend myself, that they don't thrust me from the doors, for I'm by myself' (οἶσε θέων ἧός μοι ἀμύνεσθαι πάρ' ὀϊστοί, / μή μ' ἀποκινήσωσι θυράων μοῦνον ἐόντα).

44 The backdoor (ὀρσοθύρη), *Od.* 22.126–130; suitors discussing its possible use, 22.131–138. Suitors getting access to weapons, 22.139–146; Telemachus acknowledging he left the door ajar, 22.153–156 (θαλάμοιο θύρην πυκινῶς ἀραρυῖαν / κάλλιπον ἀγκλίνας); ordering to close it, 22.157 (ἀλλ' ἴθι, δῖ' Εὔμαιε, θύρην ἐπίθες θαλάμοιο). The door is closed properly at 22.201. The story would be helpful to any parent yelling 'close the door' at a teenager.

access, exits, escapes. Doors serve as anchors of the narrative action by virtue of their role in establishing who controls space and through the actions they afford.[45] Affordances of doors are in the communicative common ground.

4 A Disappearing Revolving Door: the *Ekkuklêma* in the Greek Theater

My final case study involves a comparison between a modern and an ancient structure, illustrating how new types of doors are (only) conceived in specific socio-cultural circumstances. It also demonstrates how our own familiarity with such structures can provide a false anchor in how we perceive and interpret structures from classical antiquity. I am speaking of the mechanical device of the *ekkuklêma* or 'roller-outer' used in Athenian theatrical productions and of the modern 'revolving door'. I will resume an earlier discussion here, but add an important recent insight that demonstrates the relevance of considering technology in its sociocultural context, as a socio-technical ensemble or assemblage.[46]

Conventionally, in a Greek tragedy, performed in the context of a religious festival, certain actions would not be shown on stage, but were imagined as having happened off-stage or inside the palace or house represented by the stage building, for instance murders or suicides. If one wanted to show the *result* of such actions to the audience, one used this device.[47] It was a wheeled platform on which whatever needed displaying to the audience could be arranged back-stage and then wheeled out in a straight motion. However, an alternative form, in which the platform would be a revolving one, has also been widely accepted as a possibility (see fig. 5.3). While there are clear differences with revolving doors (in particular the platform itself), the reconstructed technical plan also shows striking similarities (see fig. 5.4). In thinking about sociotechnical assemblages, I used this similarity for a thought experiment, to discuss the question of whether the Greeks had actually invented the revolving door, rather than the man who was given a place in the Inventors Hall of Fame

45 The situation of the suitors, held captive in the hall, brings back echoes of the situation in the Cyclops' cave, with Odysseus unexpectedly cast in the role of the Cyclops (see Brelinski 2015). A similar reversal is brought out by the fisherman simile, where Odysseus takes the role of Scylla (see Sluiter 2014).

46 Sluiter 2017, 24–27.

47 The contraption could also be used self-referentially and metatheatrically in comedies (see Casanova 1997 for an extensive discussion of all the available evidence).

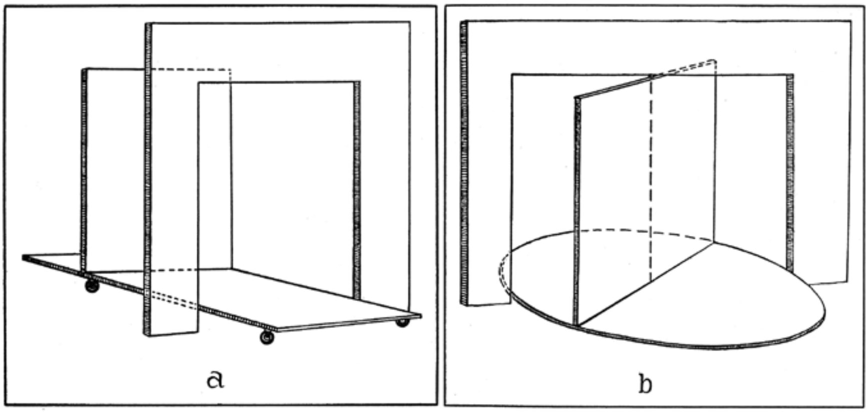

FIGURE 5.3 Two reconstructions of the ekkuklêma; 'revolving' type on the right (after A.C. Mahr, New York 1938, *Origin of the Greek Tragic Form*. New York 1938, fig. 27a–b)

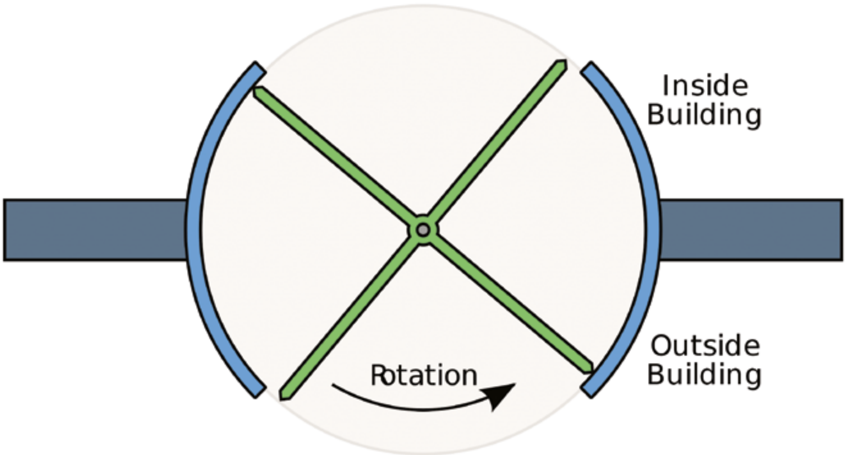

FIGURE 5.4 Design of revolving door (cf. Sluiter 2017, fig. 5b; source: Wikimedia, Life of Riley. Revolving door Plan View. CC-BY-SA 3.0)

for it, Theophilus Van Kannel (fig. 5.5). The (still correct) answer I provided at the time was a resounding 'no'.

The invention of the revolving door in late-19th-century Chicago belongs in the context of a highly specific 'sociotechnical assemblage'.[48] Department stores were invented, with frequent comings and goings of clients. They were

48 Jarrahi and Sawyer 2019.

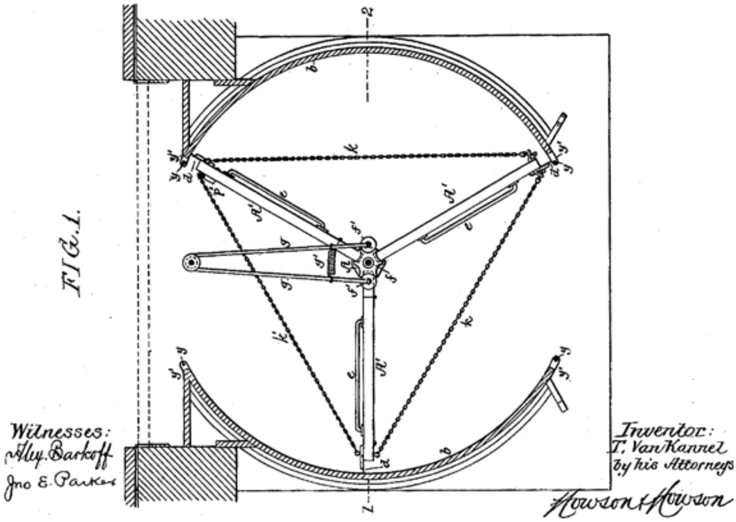

FIGURE 5.5 Patent drawing of the revolving door by Theophilus Van Kannel (Augustus 1888)

located in high-rise buildings, skyscrapers, with elevators that created a piston effect: air would be pushed down and out, and this meant that regular 'swinging' doors would be pushed open every time. And Chicago is cold. In Athens on the other hand, the recent invention of the theatre needed a very different thing, a contraption one could use to show the inside of a building to the audience in the theatre. The *ekkuklêma* simply never was intended or conceptualized as a technology for entering or exiting a building. It is not a door and is never called one; neither is it a failed innovation just because it did not evolve into a revolving door. Technology must be interpreted in its proper context of use.

There is reason however, to be suspicious even of this line of argument, since it still assumes that the 'revolving' reconstruction was an option (even dismissing the notion of 'door'), while it never discussed how the *ekkuklêma* itself might have been anchored in its ancient context of use. The 'revolving' interpretation was based on several ancient texts that talked about this piece of theatre equipment 'being turned' (*strephesthai*). Since this tied in with a known object in the modern world (the revolving door), at least a vestigial form of teleology (and unwarranted modern anchoring) may have influenced interpreters, emphatically including the present author (I take the blame for having made the comparison with the revolving door explicit, but the familiarity of the revolving door may have made the 'revolving' construction an obvious possibility, and it may have prevented scholars from raising objections to it).

FIGURE 5.6 Modern reconstruction of a *stropheion* (Casanova 2017, 9)

However, in a recent paper, Casanova (2017) studied the working of the *ekkuklêma* afresh, revisiting and reinterpreting all the relevant ancient texts.[49] In Casanova's view, these texts refer to a technique that was already well established in this period, the use of a winch or windlass, a στροφεῖον, operated by turning its barrel by means of a crank (in circular motions), pulling tight the ropes attached to the wheeled platform, and thus moving it forward (for a modern example, see fig. 5.6). While several texts do speak about the *ekkuklêma* 'being rotated (or turned) out' (always in the passive mood), this should be understood as meaning that the platform was set in motion by rotating the crank on the *stropheion*.[50] One very attractive aspect of this proposition, is that it comes with an immediate understanding of how well-anchored the

49 I thank Janric van Rookhuijzen for bringing this paper to my attention.

50 See Casanova 2017, 10 for the point that the term *ekkuklêma* itself does not imply a rotating motion either: the *kukl-* part refers to the fact that is was set 'on wheels'; it is a machine on wheels that can move something 'out' (i.e. on stage). One illustrative text discussed (2017, 15) is a scholion on Clem. Alex. *Protrept.* 2.12.1: ἐγκύκλημα ἐκάλουν σκεῦός τι ὑπότροχον ἐκτὸς τῆς σκηνῆς, *οὗ στρεφομένου* ἐδόκει τὰ εἴσω τοῖς ἔξω φανερὰ γίνεσθαι ('they call "*ekkuklêma*" [Casanova demonstrates that the spelling variant can be ignored] a machine on wheels, positioned outside of the theatre building; when it is turned out [by turning the *stropheion*], what is inside [i.e. backstage] is made visible to those outside [i.e., the theatre audience].

ekkuklêma must have been for the theatre technicians: the *stropheion* was used in the context of building, transporting heavy weights, and for ships.[51] It was simply reappropriated in a different (and new) domain: that of the theatre.

5 Conclusion

As we have seen, even a technical object as (relatively) simple as a door is best studied as part of a socio-technical assemblage. Doors can represent values (such as safety and security), they structure spaces, and entering or exiting them constitute meaningful moments of transition. Whoever controls the door can keep things and people inside or out. Opening doors and closing them, or forgetting to close them, can initiate various types of narrative scenarios.

Imagining the divine realm and human interactions with the gods can use the familiar furniture of human life as a form of anchoring. The innovative automatic doors of Olympus are anchored for a human audience in a familiar property characteristic of all doors: the noise they produce. The technical realization by Hero of miniature temple doors that apparently open spontaneously (although of course in fact there is a mechanical explanation) belongs in a context of producing a sacred environment characterized by awe and wonder. The anchoring is religious, and of course there is the cultural common ground of Homer.

In the *Odyssey*, the different uses made of doors serve to emphasize and make concrete and palpable the stories about failed, excessive, or successful execution of *xenia*-scenarios. We also saw how in the action-packed and exciting scene of the killing of the suitors, doors function as useful anchors because of their familiar affordances: the audience will immediately grasp their importance in gaining or preventing access and control, and realize the potentially dramatic consequences of leaving doors open when you shouldn't.

Finally, the only too familiar modern phenomenon of a revolving door may have stood in the way of a correct understanding of an ancient piece of theatre equipment. While the *ekkuklêma* was certainly new in the context of the theatre, it was most likely anchored in a familiar machine for moving heavy weights (in this case a wheeled platform). The *ekkuklêma* was anchored in more than one way then, for different groups. Firstly, for the Athenian citizens who

51 Casanova 2017, 9 collects the evidence for the use of these techniques, including Hdt. 7.36 on the construction of the ship-bridge over the Hellespont.

constituted the audience in the theatre, there must have been widely *shared values* about what could be shown in performance on stage, and in particular, what actions of violence or bloodshed should not be shown in a theatric festival dedicated to a god. At the same time, there was a *theatrical need* (maybe primarily for the author) to let the audience at least see the results of actions that had taken place off-stage; this would have corresponded to a shared desire in the audience. And finally, for the technical crew, the *technical realization and operation* of the *ekkuklêma* would have been straightforward and easily manageable because it was based on a technique that had long been available. This, then, is another example of the importance of the socio-technical assemblage: possibly wrongly (anachronistically) anchored by and for modern scholars, perfectly anchored in its own context.

Acknowledgements

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PART 2

Innovation

CHAPTER 6

The Reinforcement System of the Theban Treasury in Delphi

Jean Vanden Broeck-Parant

1 Introduction

The Theban Treasury was built in the fourth century BCE in the sanctuary of Apollo at Delphi. Upon excavation, a curious reinforcement system was found in its foundations that has sparked discussion throughout the last century. It consists of channels cut across foundation courses, which accommodated frames reinforcing the structure. This specific arrangement seems to be unprecedented and does not find any direct parallel in the Greek world in that period. The apparent singularity of the frames of the Treasury, often underlined by the commentators, suggests that it was an innovation of the time. Perhaps because it was designed to respond to structural problems specific to the Theban Treasury, it was apparently not used again in later constructions, at least in this specific form.

This chapter looks at the notion of 'anchoring' through the lens of this specific feature of the Theban treasury at Delphi.[1] It starts with a brief description of the treasury and the structural problems that it faced due to its peculiar location. This is followed by a thorough overview of the scholarly discussion on the reinforcement system found in the foundations of the treasury. I then give new arguments for the identification of the material used to fill the channels and address the question of their structural role, using parallels from various periods. Drawing on these observations, I finally discuss the context in which the frames were conceived, in an effort to position this innovation (if it indeed was one) in its technical and cultural background. By doing so, I show how this seemingly unique device was, in fact, anchored in a long tradition of craftsmanship.

1 Sluiter 2017.

DOI:10.1163/9789004714915_007

2 The Theban Treasury in the Sanctuary of Apollo in Delphi

The Treasury of the Thebans was erected in or shortly after 371 BCE, funded by the spoils of the battle of Leuktra.[2] It was located in the south part of the sanctuary of Apollo, close to the southwestern entrance. The building was facing west and was the first monument one could see on their right-hand side upon entering the sanctuary from that entrance. One of the largest treasuries of Delphi (12.33 × 7.22 m), it was a Doric building with a sober aspect and limited decoration, in line with fourth-century architectural developments of the Doric order. The elevation was made exclusively of a local, greyish limestone from the Profitis Ilias quarries, while poros was used for the foundations. Instead of having the usual distyle in antis plan with two columns in between anta walls in the front, the façade consisted of a plain wall pierced only by a door and by a small rectangular window on top of it. Inside, the space was divided between a pronaos and a cella. The krepis, made of three levels, rested on three courses of foundations, which were themselves laid on top of a footing course.[3]

The Treasury was so close to the south end of the sanctuary that it was actually resting on and overhanging the south peribolos wall, at a height of about four metres above the level of the road below. The exact way in which the building was articulated with the wall is difficult to determine because much of this part of the wall had collapsed leaving only parts of the northern foundations in situ at the time of its discovery. The southwestern part of the peribolos wall had been destroyed before the erection of the Treasury. Indeed, the Theban monument was located within a portion of the wall that had been remade, probably at the same time that the Treasury was built. This new section was constructed at least in part with poros blocks from the sixth-century Alcmeonid temple of Apollo, which had been destroyed in or around 373 BCE.[4] As A. Jacquemin and D. Laroche have put it, it is as if the peribolos wall had

2 Paus. 10.11.5. Diodorus speaks of a *naos* dedicated by the Thebans from the Phokian spoils (Diod. 17.10.5). While some consider that he was referring to the treasury and attributed it to the wrong period and occasion (Bommelaer and Laroche 2015, 156), others, like Dinsmoor (1912, 452) have suggested that Diodorus indeed referred to the Treasury of the Thebans and that his account was right, which implied that it must have been built after 346 BCE and the end of the Third Sacred War. P.J. Rhodes (2019, 52) thought that it is unlikely since, although Thebes was on the 'winning side', it was exhausted at the time.

3 The description of the building is based on the monograph of the Theban Treasury by J.-P. Michaud (1973) and the article by A. Jacquemin and D. Laroche (2012, 106–114).

4 See Rougemont 2013, n. 14, on the date of 373 BCE.

been replaced, in this area, by the foundations of a building.[5] The peculiar location of the Treasury, dictated in part by the lack of space in the sanctuary and in part by the desire of the Thebans to take a prominent position,[6] created several structural challenges for its builders. Not only did they have to deal with the steeply sloping terrain, but they also had to preserve the building from earthquakes and landslides, which were not uncommon in the region. It seems they designed the foundations of the treasury in response to these threats, and they probably did so with the recent catastrophe of the 370s in mind.[7]

3 The Channels in the Foundations: Description and Historiography

The poros foundations of the treasury consisted of three courses of ashlar. Some of the blocks of these foundations present, on their bedding surface, a single cut for a channel running from one end of the block to the other. The channels were cut at a distance of about 0.5 m from the outer ledge and their section is 7.5 cm deep and 10 cm wide. At least one corner block, still in situ, has two channel cuts crossing at an angle. Therefore, although not all foundation blocks are preserved, it is safe to say that the channels ran on all four sides of the two upper foundation courses (fig. 6.1). Hence, these channels evidently served to accommodate bars made of another material than stone.

The unusual character of these grooves has attracted much interest from scholars since the time of their discovery. Karo was, in 1910, the first scholar to comment on the channels and their function; he imagined that they had hosted 'pipes' ('tuyaux') made of lead, but could not fathom the function of such pipes.[8] The subsequent year, Bourguet relayed the observations made by Replat, who pointed out the crossings of the channels at the angle blocks and imagined that the grooves, instead of lead pipes, had contained wooden beams, and that these had been intended to increase the overall stability of the construction.[9] In the same year, the German scholar Pomtow published a similar interpretation, adding that the wooden beams ran along all four sides of the two upper courses of the foundations. He based this comment on the

5 Jacquemin and Laroche 2012, 111.
6 On the political and ideological implications of the location of the Theban Treasury, see Jacquemin and Laroche 2012, 111; Scott 2017.
7 Thély 2016, 251–255. Perrier 2021: 64–65.
8 Karo 1910, 190 n. 1.
9 Bourguet 1911, 160.

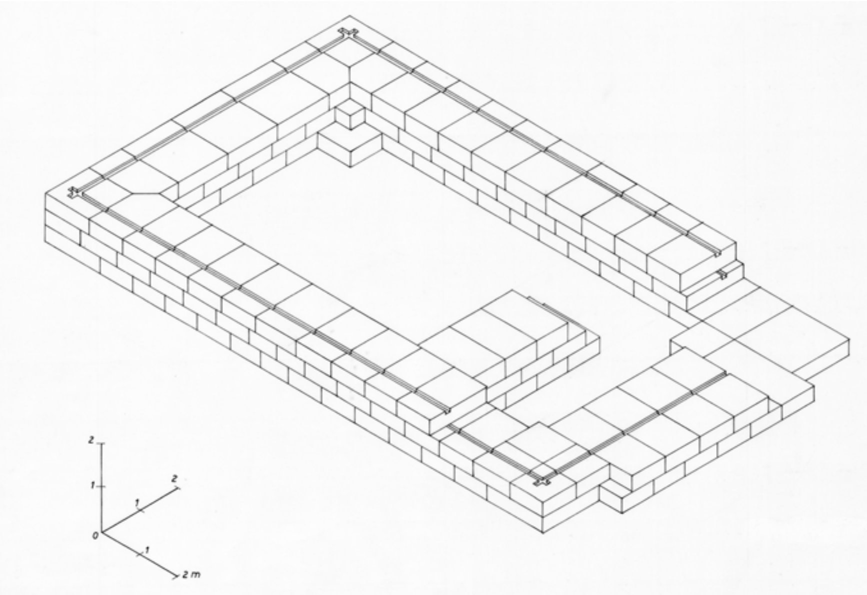

FIGURE 6.1 Axonometry of the foundations of the Theban Treasury (Michaud 1973, pl. 61 EFA/J. Blécon, 1970)

crucial information, found by Bulle, that a corner block of the krepis bore a faint imprint of the beams on its resting surface.[10]

In 1912, Dinsmoor discarded the ideas that these grooves had been used for wooden beams, arguing, conversely, in favour of iron bars. Dinsmoor's argument was based on the assumption that wood was not resistant enough for the intended purposes of the bars: wooden beams of 12.5 m long and 8 cm thick, he thought, could not have sustained such pressure. Furthermore, he pointed out that the angle blocks with the imprints on their resting surfaces presented dowel holes located in the area of the imprints, meaning that these blocks were dowelled not to the upper blocks of the foundations but, rather, directly to the frame. Dinsmoor claimed that such a system was not possible with wooden beams but he did not go any further in explaining why. Finally, his argumentation rested on two alleged structural uses of iron at the Propylaia at Athens and at the Olympieion of Acragas.[11] In a 1922 article on the use of iron reinforcements in Greek construction, Dinsmoor reiterated his idea that the groove had hosted an iron girdle, although he admitted that nothing remained of the bars. He also insisted that the fact that the limestone walls were dowelled to the

10 Pomtow 1911, 1613–1615.
11 Dinsmoor 1912, 454–455.

bar proved that it was made of iron, again without being any more specific in his arguments.[12]

The 1922 article by Dinsmoor remains often cited today and was an authority for at least several decades, to the point that two major twentieth century handbooks of Greek architecture, by Orlandos and by Martin respectively, retained the idea that the foundations of the Theban treasury were held together by an iron girdle in the foundations.[13] However, as these handbooks were being published, some scholars were expressing doubts about Dinsmoor's interpretation and, more generally, about the actual usefulness of iron reinforcements. In a mostly overlooked 1957 paper, Hamilton, an engineer interested in civil engineering history, reviewed the examples of structural iron discussed by Dinsmoor and questioned the idea that iron bars would have been of massive, solid construction.[14] He stressed three weaknesses in Dinsmoor's argumentation: first, the absence of any remains of iron apart from iron dust; second, the fact that these iron structures had not shattered the stone blocks when rusting away; third, the fact that such massive forgings required either an impressive labour force or an advanced technology for which no compelling evidence has survived. These are *ab silentio* arguments, but they do highlight the fragility of Dinsmoor's interpretation.

In 1973, in his monograph on the Treasury of the Thebans, Michaud offered the alternative possibility that the grooves had contained a wooden girdle. His arguments were as follows. First, iron bars would have been covered with lead, but no trace of lead or oxidation remains. Second, the other examples used by Dinsmoor to support his theory pertain to very different parts of the buildings, and in no case to the foundations. Third, the making and adjustment of such iron bars, with several mortises at the angles for vertical dowellings, required considerable means and advanced metallurgy techniques that are not inconceivable for the Propyleia of Athens but seem out of proportions in the case of the Theban Treasury.[15] Contrary to Dinsmoor, Michaud did not see any problem of dowelling the blocks of the lowest krepis course to wooden beams.[16]

12 Dinsmoor 1922, 149–150.

13 Orlandos 1958, 20–21 (= Orlandos 1966, 112–113); Martin 1965, 157–158.

14 Hamilton 1957, 33–37. Instead of solid sections of iron, Hamilton suggested that the beams could have been formed of long flats nailed to a wooden core or riveted together.

15 Michaud 1973, 24–25.

16 Michaud 1973, 25 n. 1, 34. In his review of Michaud's book, Miller (1975) regrets that he did not discuss the problem of dowelling the euthynteria blocks (here understood as the lowest course of the krepis) in the wooden beams. However, Michaud simply did not consider it a problem (25 n. 1: 'rien n'empêchait cependant de sceller sur le bois tous les blocs courants de l'euthyntéria').

The French scholar also briefly discussed the function of the frames. He discarded water torrents as the risk having prompted the system because it would have made the foundations dangerously interconnected. According to him, the two main factors that had to be taken into account were earthquakes and differential settlements; the purpose of the frame was to limit the damage caused by these two factors. He did not, however, discuss the structural mechanics in detail.

Since then, the frames of the Theban Treasury have been mentioned on several occasions. In her handbook on Greek architecture, Hellmann reproduced Michaud's reconstruction drawing of the foundations of the treasury but only referred, although cautiously, to the theory that the beams were made of iron.[17] Jacquemin and Laroche, on the contrary, endorsed Michaud's interpretation in their recent reappraisal of the treasury.[18] Finally, Thély suggested that the main reason for implementing the frames was the risk of landslides, which could be triggered by both earthquakes and water torrents.[19]

4 Iron or Wood? The Material Used to Fill the Channels

Iron is technically stronger than wood, with better tensile, compression and shear strengths.[20] However, several arguments further support Michaud's interpretation of the frame as wooden beams. The first is in line with his claim that there was no trace of lead or oxidation in the channels. Lead is often missing from mortises that used to contain it and have been exposed, intentionally or not, in the course of the history of buildings. This metal can be recycled very easily and scavengers have little hesitated to scrape it off whenever they had the occasion to. The operation of removing the lead, however, rarely (if ever) goes without deteriorating the edges of the mortises. Such scars are visible on many ancient monuments.[21] They are absent, however, from the channels of the Theban Treasury, which supports the idea that lead, and therefore also iron, were not used in this case.

Another point that needs to be considered is the question of feasibility. This issue has only been touched upon briefly by Hamilton (see above). One problem in particular seems not have been asked, perhaps because it was deemed

17 Hellmann 2002, 109.
18 Jacquemin and Laroche 2012, 111.
19 Thély 2016, 255.
20 Wright 2005, 12.
21 Bernard 2009.

to be obvious: was each of the four beams made of a single piece of material, or of several assembled pieces? The question is all the more important when it is considered that the long beams were about 12.6 metres long. Arguably, single-piece beams would have been preferable, for structural reasons. Iron bars would have had to be assembled in one way or the other, as there was no way to produce a wrought iron bar of this length in one go; cast-iron technology, even if it existed at the time, was not nearly as advanced as to produce 12.6-meter long bars. Several iron bars, therefore, would have had to be riveted or welded to one another. Single timber elements of that size, however, were not exceptional. Structural wooden beams and masts regularly exceeded that length in antiquity.[22] And while there are many recorded examples of long timbers, no clear evidence—whether archaeological or literary—survives of very long iron rods.

Finally, the issue of the costs, even if difficult to address, must be taken into account. Treister has gathered various fourth-century price records for iron clamps and dowels and suggested that because such objects were relatively simple to manufacture, the price of iron itself must have been only slightly lower.[23] Particularly relevant is the price per talent as recorded in the building account of the Thymele in Epidauros.[24] The figure is quite consistent over time, as it is comprised between 14 dr. 4 ob. and 15 dr.[25] from years 11 to 20 of the construction, i.e. between 366 and 357 BCE, a date probably close to that of the Theban Treasury.[26] On the basis of these figures, on the one hand, and of the volume comprised by the channels (about 0.6 m^3) and, therefore, the weight of iron necessary to fill them (about 4.6 T), on the other hand, the price of iron can be estimated at 2139 dr.[27]

It is impossible to say for certain what type of wood would have been used in the foundations of the Theban Treasury, but we can make an educated guess based on the length of the longest beams (about 12.6 m) and their structural role. Three types of wood can be considered good candidates: pine, fir, and cypress. Pine and fir were considered the most suitable types of wood for

22 Meiggs 1982, passim.
23 Treister 1996, 250.
24 Prignitz 2014 inscr. nr 2 = *IG* IV^2 103.
25 Mathé 2016, 248 fig. 3; Prignitz 2022, 410.
26 According to the chronology by Prignitz 2014, 104–105; see also Prignitz 2022, 412. Mathé (2017, 138–139) advocates a more traditional dating of the Thymele around 360–320 BCE.
27 It should be noted that the prices for dowels and clamps are significantly higher in other buildings of Epidauros (around 1 dr. per mina), but all these constructions can be dated to the later part of the fourth century BCE (see Prignitz 2022, 410). Prices in Delphi in the second half of the fourth century BCE vary considerably; see Mathé 2016, 248 fig. 4.

construction in the ancient Mediterranean. Cypress was deemed to be one of the most durable types of wood and was used in temples mostly for doors and special features. Meiggs has shown, however, that it was likely used for roofing as well in some cases and, therefore, it is possible that it was used in the channels of the Treasury of the Thebans.[28]

As noted by Meiggs, the documentation on timber prices is often frustrating. Most of the time, only the length of the purchased timber is indicated in the accounts, while the species is rarely specified.[29] In short, we usually do not have nearly enough information to draw good estimate figures. However, in our case we are lucky enough to have some recorded figures for the purchase of cypress logs in 336/5 by the *naopoioi*, the building commissioners in charge of the Temple of Apollo at Delphi.[30] While no measurement is recorded, these logs must have been for the main beams of the temple's roof, with a length of about 12 metres. The average price per log was 132 dr.[31]

Considering how thin the sections of the foundation beams were, it can be assumed that one log represented enough material to make all four beams. In terms of raw material price, 132 dr. is more than ten times cheaper than our estimate for the price of iron, and it was perhaps much less, if pine or fir was used rather than cypress. Of course, one needs to add transportation costs on sea and on land (about 80–90 dr. per log in the case of the beams for the temple of Apollo),[32] with the additional difficulty of having to carry a long log of 13 metres or more from the port of Kirra all the way up to the sanctuary of Apollo. However, the log could have come from much closer, which would have arguably reduced the overall price.

Finally, there is the question of the cost of manufacturing of the beams. Whether they were made of wood or of iron, it is difficult to estimate such a cost, not only because it is a unique system but also because we have very few accurate prices recorded for wood- and ironworking. In the case of woodworking, a contemporary parallel is found in the building account of the Temple of Asklepios of Epidauros, where it is recorded that a craftsman took up to work on the roof truss for 490 dr.[33] Of course, the frames of the Theban Treasury were a whole different kind of work, but it is hard to imagine that their installation would have cost more than that. As for iron, any attempt at getting broad estimates for the cost of manufacturing bars made of that metal is even riskier,

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28 Meiggs 1982, 200.
29 Meiggs 1982, 362–370.
30 *CID* II, 60.
31 Amandry and Hansen 2010, 445.
32 Amandry and Hansen 2010, 445.
33 Prignitz 2014 inscr. nr 1, l. 40–41 = *IG* IV^2 102, l. 42–43.

since the only known examples of structural iron (except clamps and dowels) that we know of are only recorded as negative traces in architectural remains. It is, however, worth reminding here the (arguably) rather limited capacities of the ancient Greek furnaces and the important amount of coal or firewood necessary to operate them. Clearly, from the perspective of the costs, the advantage must have been to timber over iron. However it is difficult to evaluate the cost of manufacturing the bars with iron, and whether cost would have been a deterrent for the Thebans, who benefitted from the spoils of Leuktra.

Overall, even if the use of iron cannot be discarded altogether, wood must be the preferred hypothesis: not only does it fit better with the archaeological remains, but it was also cheaper and much easier to work to the desired form than iron.

5 The Function of the Frames

In order to understand the structural function of the beams, two important elements must be taken into account. The first one is that, seen from the south, the foundations were at a height of about four metres from the ground. The second element is that the south part of the foundations were embedded in a portion of the peribolos wall that was essentially a retaining wall and had to withstand lateral forces (from the point of view of the Treasury) caused by the pressure of the soils. From a structural standpoint, therefore, the frames should not be considered so much as a reinforcement of the foundations (in the sense of layers of stone buried in the ground) as a reinforcement of a retaining wall where it was most vulnerable, i.e. most likely to open. This effect would have only been reinforced by the presence of a heavy structure (the south wall of the treasury) above this part of the wall.

A common solution in Greek architecture was the use of buttresses to help the retaining wall support the pressure exerted by the soils. Such buttresses were common from the end of the classical period. Examples include the fourth-century BCE retaining wall of the treasuries in Olympia, and later, in Messene, for the *skenotheke*.[34] In Delphi, buttresses are found in several monuments, but they are usually reversed buttresses located at the back of the walls, and served to secure the retaining walls into the soils.[35] Interestingly enough, in the case of the Theban Treasury, the builders also chose to resort to a hidden reinforcement system.

34 Egglezos 2019. Yoshitake 2021, 524–525, with references to other examples.

35 Bommelaer 1993, 44; Perrier 2021: 64–65.

Stability issues due to lateral thrusts are encountered in other parts of constructions. In buildings with a pitched roof, the main walls have to sustain the lateral thrust of the roof. In Greek temple architecture, two main types of roofing are attested that each deal with this issue in a different way. The first type is the post-and-lintel system. Here, a series of props counter the forces exerted by the ridge beam and the rafters, thus pulling the rafters inwards instead of outwards. The second type is the truss. Here, a tie beam connects the outer ends of the rafters to cancel the lateral thrust that they exert on the top of the walls.[36]

In the latter case, the tie beams usually do not exert any particular effect on the walls themselves, apart from a vertical load, as the truss is simply placed on top of the architraves without being connected to them. There are some cases in Greek architecture, however, where the tie beams were clamped to their support, thus effectively connecting parallel walls or colonnades to one another. Such was the case in the later third century BCE stoa of Attalos in Delphi, where the tie beams ensured the structural cohesion of the back wall and the front colonnade. Roux explained this unusual (though not unparalleled) system by the fact that the stoa was built on an artificial terrace and thus was exposed to landslide risks.[37] Roux mentioned two other examples of such a system in Delphi—at the Portico of the Aetolians and the East Building on the terrace of Attalos—and the 'Salle Hypostyle' in Delos, where the 'centrifugal' force exerted on the supports by the exceptionally large roof could explain the dowelling of beams on the supports of the 'lantern feature' in the centre of the building.

Comparable systems of tie beams were used in the Medieval period in order to prevent or contain lateral thrusts exerted by vaults and domes on their supports. These reinforcements, consisting of beams traditionally made of wood and, later, of iron, acted as girdles preventing the walls and pillars from being pushed outward. It seems that such systems could be found all over Europe during the Medieval period.[38] There are many examples, in Byzantine constructions, of horizontal wooden reinforcements of that sort. Choisy gave some examples of tie beams in vaults of the Byzantine period, whether in churches or in monumental cisterns.[39] These tie beams were often exposed and were either connected to wooden beams concealed in the masonry, or formed a

36 Hodge 1960, 35–44; Klein 1998, 335–339.

37 Roux 1987, 69–71.

38 Epaud 2008; Bella 2012. According to Viollet-le-Duc (1859, 397), the Merovingians and the Carolingians regularly used wooden beams concealed into the masonry.

39 Choisy 1883, 117–122.

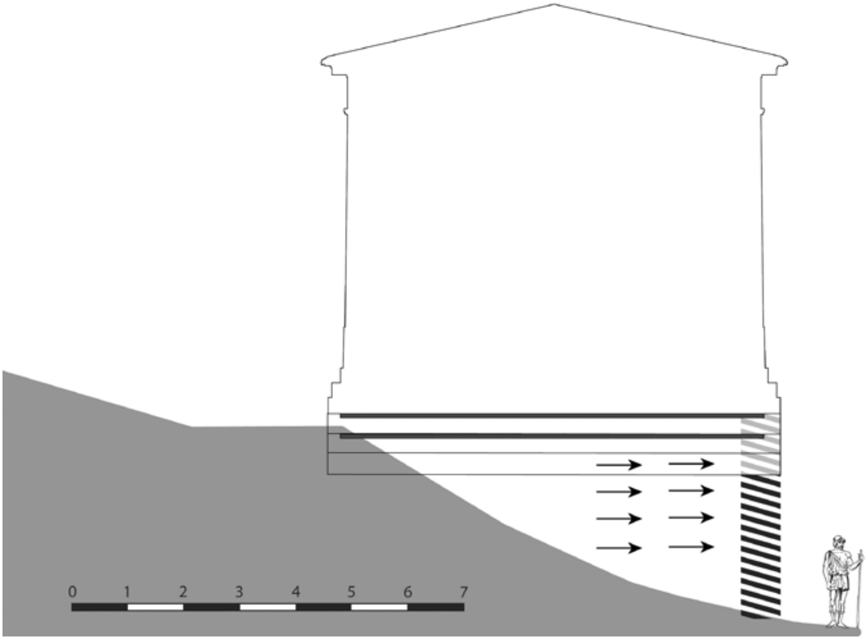

FIGURE 6.2 Schematic view, from the west, of the Treasury of the Thebans, and its location on the terrace, with the three courses of the foundations and the frames. After Didier Laroche (Jacquemin and Laroche 2012, 110 fig. 12)

network of exposed tie beams all acting together to contain lateral thrusts on the pillars. They were usually assembled with the saddle joint technique, as were the framings of the Theban Treasury.[40] In modern architectural restoration, tie beams are still used as ways of reinforcing vaulted structures.

These parallels further the analysis of the frames of the Treasury of the Thebans. As suggested by Michaud, differential settlements and earthquakes were the main threats to the integrity of the building. To these two factors one should add the lateral thrust induced by the soil mass on the south part of the foundations, which, in combination with the vertical load of the building itself, pushed the structure outward and downward. The frames tied the south part of the foundations to the northern part, which, as a consequence, was much less subjected to lateral thrusts and was thus much more stable. In this way, the lateral thrust exerted on the south part of the foundations remained contained, and the whole structure was better secured into the terrace itself (fig. 6.2). The system of grooves was thus fulfilling the role of buttresses, which

40 See Koumantos 2016; Ousterhout 2019, 397–398.

could not be used in this location, as a road ran down immediately below.[41] This solution was perhaps the best one that the builders of the Treasury could have come up with to deal with all of the potential risks all at once.

6 The Frames of the Theban Treasury and Greek Building Practice

While some have described the framing system found in the Theban Treasury as simply unique,[42] others have sought possible parallels, in Delphi and elsewhere. Partida found a similar system in an oikos near the theatre in Delphi.[43] She also compared the channels of the Treasury of the Thebans with the grooves cut across the blocks of a platform at the harbour of Anthedon on Euboea.[44] The channels in this platform do have a similar cross-section to the one of the Theban Treasury (about 11 cm wide and 8 cm deep). However, while there was a groove running parallel to the course and across the blocks, other grooves were cut transversely, and do not appear to have connected blocks together. Rather, they ran through the whole wall, from one end to the other. Rolfe, who first observed these structures thought that they could have been used to fasten blocks of the upper course or, more probably, that they were meant to allow seawater to run off.[45] However, the latter interpretation is hard to reconcile with the fact that some of these grooves did not lead outside of the structure, as was noted by Schläger, Blackman and Schäfer. They also ruled out the idea that these grooves were intended for ventilation because their cross-section was too small for such a function. Most importantly for the present argument, they discarded the possibility that the channels were filled with wooden inlays. According to them, a wooden framing would not have been sufficient to protect the structures against breakage. Furthermore, the shape of the channels, with varying width, was not suitable for wood. The decisive argument is that the wooden inlays would have been exposed to waves,

41 See Jacquemin and Laroche 2012, 111.

42 Michaud 1973, 24: 'une particularité intéressante (…) dont il n'existe, à notre connaissance, aucun équivalent dans l'architecture grecque'.

43 Partida 2000, 192–198; Partida 2017, 242–243. She does not discuss it in detail and does not specify which oikos. In the oikos *SD* 531, mortises were found, probably for the fixation of a wooden sheathing inside the building (Pouilloux 1960, 100; Bommelaer and Laroche 2015, 251). Their shape and purpose, therefore, differ from those of the channels of the Theban Treasury.

44 Partida 2000, 537.

45 Rolfe 1890, 102.

thus alternating between dry and wet states. Instead, Schläger, Blackman and Schäfer suggested that the channels were filled with mortar.[46]

Jacquemin and Laroche have pointed out that the rabbets documented by G. Roux on wall blocks of the stoa of Attalos in Delphi probably accommodated wooden beams, which served a similar function to the ones in the Theban Treasury—ensuring the cohesion of the blocks.[47] The interpretation and the comparison are persuasive, but some differences must be pointed out. First, the grooves of the stoa look quite different from the ones in the treasury. In the latter, the channels were completely concealed into the masonry, had the same depth on all sides and ran parallel to the foundation courses. In the case of the stoa of Attalos, some grooves ran parallel to the courses while others were cut transversally through the wall. The transversal grooves were shallower than the longitudinal ones, and the latter were not concealed, since they were cut along the outer edge of the blocks.[48] Furthermore, there is no indication that the frames of perpendicular walls were solidly attached to one another at the angles. While the frames must have had a reinforcement function, as perhaps attested by the deeper cuts in the middle course of the walls,[49] they served a different structural purpose. Indeed, in contrast with the Theban Treasury, which had to deal with important lateral thrusts combined with a dangerous position, the stoa only had to retain soils up to a certain height on its lateral walls; the back wall did not have a retaining function, which was fulfilled by an actual retaining wall.[50] A space was left between the two parallel walls, mainly to allow for the evacuation of water behind the stoa.

It is worth noting that most of the parallels mentioned so far are later than the Theban Treasury. They show that it was not as isolated a case as it appears at first sight, but they fail to explain the background and the origins of the framing used in the foundations of the building. While it can hardly be disputed that it constituted an innovation, it certainly did not appear out of the blue. In fact, it can be connected to a long tradition of craftsmanship and engineering.

Buildings made entirely or mostly of wood from the Greek world have left very few, if any direct traces, simply because very little organic material is preserved. As a result, and despite the input of textual evidence, the techniques of

46 Schläger, Blackman, Schäfer 1968, 66–68.

47 Jacquemin and Laroche 1992, 244. Roux (1987, 52, 72–73) interpreted it as a unique and sophisticated system for fixing wooden panels to the walls.

48 See Roux 1987, pl. 39.

49 Roux 1987, 66.

50 On the west side, the 'Terrace of Neoptolemos' covered the wall up to about 4.3 metres. On the east side, the slope was rising to reach about 4 metres high at the level of the back wall of the stoa.

timber construction are much less well known than stone building techniques. Indirect evidence must be used instead. 'Petrified' forms of wooden architecture, although quite distant from their original source of inspiration, can be found in Greek temples and in the Lycian 'house-tombs'. Timber elements have also sometimes left negative traces in the stone or brick structures that supported them.

Timber reinforcements have been used since at least the fifth millennium BCE. They have been recorded in the Bronze Age in Anatolia, in Minoan Crete and in Mycenaean constructions.[51] They were still widely used in the Byzantine period and in Medieval Europe, and can still be found today in traditional domestic buildings.[52] The structural purposes of the uses of timber reinforcements, however, can vary considerably. I have already mentioned that they could be used against differential settlements or the opening of supports. They could also prevent the buckling and deformation of the walls, especially when made of mudbrick. In seismic regions and in military buildings, horizontal timbers could limit the spread of sapping effect. It also made portions of walls easier to repair. The third century BCE engineer Philo of Byzantium advised inserting oak beams in defensive walls and towers, so that they could be repaired more efficiently in case *lithoboloi* caused some damage.[53] Such wooden inserts are perhaps mentioned as 'ἐνδέσμοι' in a late fourth-century inscription pertaining to the restoration of the circuit wall of Athens.[54] The same word appears in an architectural context in an inscription concerning the foundations of the prostoon of the Eleusinian Telesterion (ca. 342 BCE),[55] but it is not certain what specific architectural element it referred to, or if this element was even made of wood.[56]

From this brief summary, it is clear that at the time of the construction of the Theban Treasury, there was a long tradition of the use of wood as a structural component of buildings. There is little direct evidence for the assemblage techniques of timber in construction at that time. However, preserved elements of furniture and especially shipwrecks show that a large array of techniques (including the tenon-and-mortise technique) were known in the

51 See, for Minoan domestic architecture, Pomadère and Hilbert 2019; for Minoan palatial architecture, Devolder 2019; and for Mycenaean walls, Rougier-Blanc 2019 (all in the same dossier of issue 110 of *Pallas*).

52 See Wilcox 1981, with many examples (mostly from the Medieval period).

53 *Compendium of Mechanics* 5, A 13.

54 *IG* II^2 463, l. 50: [ξυλίνου]ς ἐνδέσμου[ς].

55 *I. Eleusis* 151, l. 23–24, 27.

56 Davis 1930, 15, Jeppesen 1958, 139–143: stone elements; *contra* Hellmann 1992, 86 n. 16: 'chaînage en bois'.

fourth century BCE.[57] Furthermore, stone monuments displaying so-called petrified carpentry can give a glimpse at the techniques used for assembling timbers. Lycian funerary architecture shows, for instance, that the saddle joint was known and widely used in construction in Anatolia in the classical period and probably earlier.[58] This is further supported by channels documented on blocks found in Xanthos and in the neighbouring Letoon, in Lycia. The channels cross at the angles in a similar way to the channels of the Theban Treasury, and it has been suggested that they served to accommodate and support wooden structures, with saddle joints at the corners (which would explain that the cuttings extend further than their intersection).[59] Furthermore, literary sources, in particular Theophrastos' *Enquiry into Plants*, show that at the time of the construction of the Theban Treasury, the Greeks had acquired a thorough empirical knowledge of the properties of the various types of wood and their best use according to various factors such as durability, flexibility and strength.[60]

Structural issues, whether caused by sloping or uneven ground or by earthquakes, were well known to the Greek builders and architects by that time. Famous examples include the second Heraion of Samos, the foundations of which were laid on a one-meter layer of sand and a layer of limestone sherds.[61] The sixth-century Artemision at Ephesos was built on a marshy area; to prevent the effects of humidity and perhaps also to 'isolate' the foundations at the base, a layer of coal was laid under the foundations.[62] Later, at Bassai, the temple of Apollo was constructed in a way that increased its resilience to earthquakes: the peristyle and the sekos were structurally independent from one another, the foundations were not attached vertically to the upper platform, and the mortises for the rafters of the roof were cut in a dovetail shape, in order to allow the roof to twist slightly without breaking in case of an earthquake.[63] Finally, from the classical period onwards, clamps and dowels were more and more frequent, in order to ensure the unity of the structures. These clamps and dowels were usually embedded in lead, arguably allowing a certain flexibility of the buildings.

57 Barletta 2009.
58 On the Lycian tombs see Kjeldsen and Zahle 1975 (349, fig. 27: chronology table).
59 Cavalier 2002.
60 The fifth book of the *Enquiry into Plants* is dedicated to timber and its various uses. Theophrastos was, however, a pioneer, and sometimes inherited assumptions 'which interfere with his scientific approach' (Meiggs 1982, 17–19).
61 Kienast 1991.
62 Plin. *HN* 36.95; Diog. Laert. 2.103; Vetters 1988, 86.
63 Cooper 1996, 143–144.

In short, at the time when the Theban Treasury was built, its builders could draw upon long traditions of woodworking and of dealing with the threat of instability. Far from an improvised solution, therefore, the frames of the foundations must be considered a targeted response to specific structural problems, infused with a long accumulated technological know-how. That being said, it is difficult to trace a direct 'line of descent' for the use of this particular system. This difficulty might be due, as already discussed, to the scarcity of archaeological remains of structural timbers. It may also be due to the fact that the frames of the Theban Treasury were an actual novelty. The question then becomes: who or what could have possibly inspired such an innovative system?

As a working hypothesis, it can be argued that the frames of the Theban Treasury owe part of their design and conception to roof trusses and the work of carpenters. As already discussed, the frames of the foundations work, at least in part, as tie beams, in a way reminiscent of tie beams in a roof truss. While it was earlier thought that the truss was not discovered before the Hellenistic period, there is substantial evidence supporting the idea that it was already used in Sicily in the middle of the sixth century BCE.[64] This innovation was not widely adopted in the Greek Mainland in the classical period, and the Parthenon, for instance, does not show any evidence of a truss, despite having a wide cella span. Nonetheless, the basic principles presiding to the tie beams of a roof truss, and to tie beams in general, were known. As noted by Lamouille, triangulated structures were necessary for objects as varied as ships, cart wheels and cranes, and were thus known from early times.[65] Therefore, craftsmanship traditions possessed by carpenters and, more generally, woodworkers might have inspired the system found in the Theban Treasury. This is all the more probable if, as Feyel has shown, most craftsmen seem to have specialized in a type of material, rather than specific tasks. Particularly in the case of wood, epigraphic evidence from the Hellenistic period shows that a woodworker could produce a diverse range of wooden objects.[66] In view of the above, it is possible, if not likely that the device of the Theban Treasury was anchored in woodcarving traditions and, more specifically, in carpentry practices.

64 Hodge 1960, 35–44 (with earlier references); Klein 1998.
65 Lamouille 2019.
66 Feyel 2006, 382–384.

7 Conclusions

In this chapter I have discussed the rationale behind a quite unusual feature in the design of the Theban Treasury at Delphi. As I have argued, for economic and technical reasons, the channels are likely to have contained frames of wood rather than one of iron. As for the functions of these frames, comparative evidence suggests that they were meant to counter not only differential settlements and the effects of earthquakes, but also, at a more mundane level, the displacement of the stone courses under the combined action of lateral thrusts induced by the artificial terrace and of the vertical load of the building itself. Such a closer look at the stability issues that the device was designed to counter, combined with the acknowledgement that such issues existed and were dealt with in all periods of history, allows one to shift the point of view, from a focus on otherness to an emphasis on similarity and connectedness.

This analysis has shown how the concept of anchoring, and the underlying idea that all innovations are embedded into tradition to various extents, encourage us to seek the wider cultural and technological contexts of innovations that would otherwise seem, at first, completely isolated. Thus, although the precise genealogy of the frame of the Theban Treasury cannot be determined at this stage, one can reconstruct the context that made its invention possible. While the system was certainly designed to meet a particular set of locally specific constraints and therefore appears as rather unique and new, its shape, function and technical details largely fit into the craftsmanship and engineering practices of its time. As Sluiter and Versluys have stated, "imagining the possible takes its starting point from a particular sociohistorical context filled with peoples, things, and ideas".[67] Similarly, the builders of the Theban Treasury had access to a web of knowledge and practices from which they were able to draw their inspiration for its reinforcement device.

Abbreviations

CID II Bousquet 1989.

IG IV^2 Hiller von Gaertringen, F., *Inscriptiones Graecae, IV. Inscriptiones Argolidis. 2nd edn. Fasc. 1, Inscriptiones Epidauri*, Berlin, 1929.

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67 Sluiter and Versluys 2020, 99.

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CHAPTER 7

From Ashlar to Brick: Anchoring and Innovation in Roman Building Practice

Miko Flohr

1 Introduction

In the early fourth century BCE, after the city had been sacked by the Gauls, the Romans decided to build a new city wall around their city. The project was spectacular in its scale, but conventional in building practice: the so-called Servian Wall was made by stacking carefully cut blocks of yellow tuff quarried in the Tiber Valley a few kilometres upstream of the city (fig. 7.1).[1] A similar technique, with comparable materials, had already been used in the podium of the temple of Iuppiter on the Capitol, in the late sixth century BCE, and the two early fourth century BCE temples in the sacred area of Sant'Omobono between the forum and the Tiber were built in the same way.[2] Indeed, throughout most of the Republican period, ashlar of locally quarried stone continued to dominate monumental public architecture in Rome, and the Italian peninsula.[3] Yet when about 660 years later, in the late third century CE, a second, much longer, wall circuit was built, it looked completely different: the walls constructed during the short reign of emperor Aurelian consisted of a concrete core faced with bricks—a technique allowing for a much quicker and more cost-effective construction process (fig. 7.2). Nevertheless, as had been the case with the Servian wall, the materials and techniques used in the project were part and parcel of local construction practice at the time: in and around the Roman Metropolis fully brick-faced concrete had been the default technique for public construction since the early second century CE, and it would remain so after the construction of the Aurelian Walls, throughout the late third and fourth centuries CE.

1 On the construction of the walls see now Bernard 2018, 75–117.

2 On the temple of Iuppiter Capitolinus (made of locally sourced tuff), cf. Jackson and Marra 2006, 426. On the temples in the sacred area of Sant'Omobono see Bernard 2018, 31; Arnhold 2020, 162–164.

3 Though not without technological change. Cf. Bernard 2018, 193–227.

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FIGURE 7.1 Remains of Rome's Mid-republican wall circuit on the Esquiline
PHOTO: LALUPA / WIKIMEDIA COMMONS

FIGURE 7.2 Rome, section of the Aurelian wall near Porta Metronia
PHOTO: LPLT / WIKIMEDIA COMMONS

The conservatism that connects these two projects is as significant as the gap in technical practice that separates them. The former illustrates how, in general, the circumstances under which larger-scale pre-modern construction took place were not conducive to innovation. In the Greco-Roman Mediterranean, larger-scale construction projects primarily served the social and political ambitions of individuals and communities, creating an extra incentive to make projects risk-averse: buildings needed to be finished, preferably more-or-less as they had been planned, and they would need to remain stable and safe afterwards.[4] The best way to keep such projects manageable is to start from practices firmly established in the local community. Failure was not without consequences: Pliny's letter to Trajan about the problems surrounding the construction of the theatre and baths at Nicaea in Bithynia highlights the realities of the structural and financial risks involved in case of errors.[5] It is not surprising that both wall circuits of Rome were built with well-established techniques, and with familiar building materials of which there was an ample supply in the direct hinterland of the city. Indeed, it is rather more remarkable that in a context in which there were strong logistical and economic incentives for conservatism, there was, in the long run, so much innovation that both wall circuits in terms of building materials and techniques have almost nothing in common.

This chapter starts from the idea that Roman innovations in building practice are a good starting point for exploring the potential of 'anchoring' in the context of ancient technological history: if building practice was, as a rule, conservative and risk-averse, innovations in materials and techniques probably could succeed much more easily if they could be connected to existing skills and routines: the 'anchoring' of innovations in established practice could be of critical importance for their adoption. Exploring the contexts and ways in which successful innovations in Roman construction technique were or became 'anchored' can thus add to our understanding of the evolution of practices in Roman building industry, and, thus, to the study of innovation and change in Greco-Roman technical practice. At the same time, it can also enrich our understanding of 'anchoring' as a heuristic tool. 'Anchoring' has, thus far, been used primarily in isolated contexts, and mostly on the basis of examples derived from the literary sources: the *guttae* in Doric temple architecture were explicitly anchored by Vitruvius in earlier wood-based construction practice; the *corvus* with which the Romans were able to beat the Carthaginians at sea

4 See also VandenBroeck-Parant, this volume.
5 Plin. *Ep*. 48.

was discussed by Polybius as a solution to one specific military problem.[6] Similarly, the anchoring strategies of Roman emperors are discussed by Roman authors in rather explicit terms, or are explicitly represented on visual culture.[7] Yet what happens to 'anchoring' if it is transposed to an area of practice for which the leading body of evidence is material and non-iconographic? Can anchoring flourish as an analytical tool beyond the textual record, and if so, what changes? And what happens to anchoring when it is applied not to sweeping, stand-alone innovations but to the smaller, often inter-connected changes in everyday practice? To explore these issues, the following pages will analyse three inter-related developments that have often been seen as critical steps in the history of Roman building practice: the emergence of concrete in the second century BCE, the development of *opus reticulatum* in the early first century BCE, and the appearance of brick in the Augustan and Early Imperial period.

2 Anchoring and Innovation in Ancient Technological History

The history of innovation in everyday technical practice in the Greco-Roman world has been debated throughout the nineteenth and twentieth centuries, but emphasis was long more on the resulting technological proficiency than on the actual processes of innovation.[8] In recent years, Greek and Roman archaeologists have increasingly begun to explore the anatomy of innovation to greater detail, starting from anthropological approaches to processes of 'making' and the embodied nature of craft skills.[9] Many have studied technological developments in ceramics production, particularly in the production of refined, decorated table wares, such as the Hellenistic, mould-made 'Megarian' bowls, Late Hellenistic and early Roman lead-glazed pottery, and Roman Terra Sigillata.[10] The invention and spread of transparent, blown glass, which had a profound impact on Roman material culture in the early imperial period, has also been debated intensively.[11] There is an emerging consensus among Greek and Roman archaeologists that these processes of innovation were uneven, slow and unpredictable: even a 'revolutionary' development like the

6 For these examples see Sluiter 2017, 26–29.
7 Hekster 2020.
8 See esp. Finley 1965; Greene 2000; Flohr 2016.
9 E.g. Sennett 2008; Marchand 2009; Ingold 2013.
10 Relevant studies include Rotroff 2006; Greene 2007; Van Oyen 2016.
11 See esp. Stern 1999; Larson 2019.

emergence of glass-blowing in practice can be divided into several smaller steps, and involved substantial trial and error. Thus, while the first experiments with blown glass can be dated to the first century BCE, the technology only was stabilized and standardised over the course of the first century CE.[12] Processes of innovation also were often local in nature—the spread of glass-blowing over the Roman empire in the first century CE was exceptional in its speed and its geographical reach, but quickly led to the establishment of a range of local and regional traditions. High-quality *terra sigillata* pottery was consumed in many places shortly after it had emerged, but its production long remained restricted to a limited number of production centres, which were not only clusters of production capacity, but also centres of skills and knowledge.[13]

The emerging consensus on these micro-histories of innovation in Greco-Roman antiquity connects well to the theoretically more refined work of pre-historical archaeologists. For instance, analyzing the uneven diffusion of the potter's wheel in the Bronze Age Mediterranean, Carl Knappett has argued that we should abandon sweeping, macroevolutionary interpretations of innovation and diffusion and 'turn to microevolutionary processes for explanation', advocating an emphasis on craft learning and technological traditions in local contexts.[14] Catherine Frieman's recent monograph on the archaeology of innovation, which covers all of human history, elaborates this point: as creativity is 'socially structured' and 'framed by human relations', innovation is

> a social process in which individual acts of creation emerge from histories of practice, collaboration, iteration, and experimentation that implicate a web of relations among people, things, ideas and practices.[15]

The step from this focus on the social construction of innovation on the micro-scale to the idea of 'anchoring' as defined by Sluiter is not big. In both cases, thinking about innovation is firmly anchored at the micro-level of actual decision-making processes by individuals and groups, and closely associated with the Social Construction of Technology-framework (SCOT) developed by Pinch and Bijker.[16]

12 Larson 2019.

13 Including particularly Arezzo, La Graufesenque, and Lezoux. See Van Oyen 2016.

14 Knappett 2016, 106. See also Knappett and Van der Leeuw 2014.

15 Frieman 2021, 187.

16 Sluiter 2017, 27; Frieman 2021, 50–53. See esp. Pinch and Bijker 1984; Bijker 1997. See also Bijker, this volume.

In the study of Roman building practice, the micro-scale, localized perspective on innovation has been less well-developed. Scholarship has traditionally focused on a limited number of places, particularly Rome and Pompeii, and has taken these to be normative. For Rome, discourse has long been dominated by the work of Marion Blake and Giuseppe Lugli.[17] At Pompeii, the leading framework for the development of local building techniques long rested upon the work of August Mau and, later, Roger Carrington.[18] These frameworks have been modified and refined over the course of the last decades: Filippo Coarelli studied the origins of *opus reticulatum* in the city of Rome in the late Republican period; Mario Torelli analyzed the subsequent spread of the technique through Late Republican Italy; Kees Peterse modelled the history of the limestone-framework technique in Samnite Pompeii.[19] The work of Lynne Lancaster and Janet DeLaine has further developed our understanding of imperial period building technology at Rome and Ostia.[20] Many of these contributions discuss the contexts and meaning of innovations, but most have a limited focus on the processes of change themselves. In recent years, scholars have become a bit more sensitive to these issues: Marcello Mogetta connected the emergence of concrete in Rome and Pompeii to a boom in the construction of large-scale elite houses: through these building projects, concrete was established as a building technique in these cities; Mogetta's approach, while mostly interested in reconstructing the chronologies of changing practice, recognized the localized nature of change, and its socially constructed nature, and emphasized the differences in practice within the Italian peninsula.[21] Starting from a mostly theoretical agenda, Astrid van Oyen has explored how concrete, as a material, did not emerge as a ready-made category, but 'developed along a trajectory of redefinition, categorisation, and differentiation', though, unfortunately, the actual historical details of this development remain underdefined, and the social contexts in which redefinitions, categorisations and differentiations took place stay mostly out of the picture.[22] In a recent article, the present author has explored the geographical relation between innovation in construction technology and the social heterogeneity that emerged, particularly in Italy, as a result of Roman imperial hegemony, in the last two centuries BCE, arguing that this created unprecedented conditions, particularly in and around Rome

17 Lugli 1957. See also Blake 1947; 1959; 1973.
18 Mau 1908; Carrington 1933.
19 Coarelli 1977; Torelli 1980; Peterse 1999.
20 DeLaine 2001; 2002; Lancaster 2005; DeLaine 2006; Lancaster 2008. See also, more in general Wilson 2006.
21 Mogetta 2015; 2016; 2021.
22 Van Oyen 2017, 146.

and the Bay of Naples, for technological innovation—including the innovations discussed in the following pages.[23] The present chapter builds upon this work, but it will dive a bit deeper into the local and socially contextualized micro-history of innovations.

3 From Blocks to Rubble: the Making of *opus incertum*

Concrete emerged when people began to build walls of which the loose parts—*caementa*—were held together not by their careful placement, but by a mortar that was sufficiently strong to keep them in place permanently. Mogetta has argued that in Rome, the earliest securely datable walls in concrete were built around the middle of the second century BCE, and not before, as was long believed; a wide distribution of the technique can be observed for the last quarter of the same century.[24] For Pompeii, he has dated the earliest buildings constructed with walls in *opus incertum* to around 150 BCE.[25] In both cases, Mogetta's work associates the earliest larger-scale application of concrete with the episodes of urban transformation and intense public and private building activity that characterized the latter half of the second century. These episodes followed, and can be linked to, Rome's spectacular expansion from a regional Italian power to a Mediterranean empire that culminated in the destruction of Corinth and Carthage in 146 BCE: on first sight, it would seem that it was the influx and redistribution of imperial wealth—and its translation into built property—that cemented the position of concrete in construction practice in Roman Italy.[26] However, reality was more complicated: concrete initially appeared as a local, or, at best, regional phenomenon. At Pompeii, the earliest applications of the technique can be found in the large elite houses of the mid-second century BCE, such as the House of the Faun (VI 12) and the *Insula Arriana Polliana* (VI 6). This led Mogetta to suggest that the emergence of concrete was somehow *related* to these new forms of architecture: the technique came with the design.[27] Yet at Paestum, Late Hellenistic elite houses were built with more traditional building techniques, even though they closely resembled the peristyle houses of Pompeii.[28] Paestum was constructed

23 Flohr 2023.
24 Mogetta 2015, 28–30.
25 Mogetta 2016, 66.
26 On the transformation of the Pompeian economy in the late second century BCE see Flohr 2019.
27 Mogetta 2016, 66–69.
28 On this point see, more elaborately, Flohr 2022, 163–164.

on a limestone plateau, and had no direct local access to volcanic sand, but the Bay of Naples is not far away: pozzolana could be shipped in without substantial transport costs. Moreover, the close resemblance in design between late Hellenistic houses in both cities suggests that Pompeii and Paestum participated in knowledge networks through which ideas about construction practice could easily have circulated between both places. Still, concrete was not adopted at Paestum in this period, and builders continued to work their materials with traditional techniques to construct the new peristyle houses.[29] Indeed, concrete became first successful in regions that not only saw significant building activity in the later second century BCE but also had direct, local access to substantial quantities of volcanic sand.[30] As the example of Paestum highlights, the technique did not immediately spread to regions where such sediments were not naturally available.

At Pompeii, some developments in building practice that followed the introduction of concrete suggest why the technique could become successful in the city. At least initially, mortar was not used in all sections of the wall. In the second century BCE, it was only used in the main body of the walls, while corners and door-posts continued to be made of large blocks of stone stacked directly on top of each other without mortar. Only in the early first century BCE, local builders begin to construct mortared posts and quoins.[31] Moreover, it is clear that concrete at Pompeii first appeared in a context in which so-called 'Sarno Stone' was the traditional building material.[32] This porous travertine was won at some distance from the city, and it had been the leading building material in the city from the fourth century BCE onwards. However, the introduction of concrete went hand in hand with the partial replacement of Sarno Stone with a locally available volcanic stone known among Pompeian scholars as 'Grey Lava' (fig. 7.3).[33] This material was less easy to cut to a regular shape than Sarno Stone, but with good-quality mortar that did not matter so much, and it was much cheaper, as it could be brought to the construction site without any meaningful transport costs. While Grey Lava had not been used at Pompeii before the mid-second century BCE, it had become the most important building material by the early first century BCE. Thus, one reason that concrete, once adopted, could become a success at Pompeii lied in the possibilities it

29 It is worth pointing out that this way of adopting 'new' peristyle architecture with 'traditional' local techniques is a form of anchoring *par excellence*.

30 See also Mogetta 2019 for the situation in early second century BCE Cosa.

31 See e.g. Flohr 2005, 40.

32 Mau 1908 and Carrington 1933 named the oldest phase of Pompeii after this material.

33 Mogetta 2016.

FIGURE 7.3 Pompeii, VII 4, 31. Wall in *opus incertum* of grey lava with door posts in Sarno stone
PHOTO: MIKO FLOHR

offered for the construction of longer wall-sections with cheaper building materials—alongside Grey Lava, early concrete walls also used substantial amounts of recycled Sarno Stone.[34] This incentive was lacking at Paestum, where building materials could already be won more or less on site, and the adoption of concrete would not have made any financial difference to builders.

Before concrete, the dominant building technique at Pompeii was the so-called 'Limestone Framework' technique (fig. 7.4). Walls constructed in this technique typically were held together by pillars consisting of large blocks of Sarno Stone stacked alternatingly upright and horizontally; the space between these pillars was filled by carefully stacked smaller blocks of Sarno Stone, held together by mortar, initially clay-based, later increasingly lime-based.[35] The most thorough study of the technique, by Kees Peterse, sketched a roughly linear evolution of the technique, culminating in *opus incertum*: initially, the pillars were close together, and the blocks of stone between the pillars were regular in shape; as the mortar became stronger, stones became less regular, and the pillars became fewer in number: the distance between them

34 Cf. Flohr in press.
35 Mogetta 2019, 242.

FIGURE 7.4 Pompeii, VII 3, 13. Wall in limestone-framework technique
PHOTO: MIKO FLOHR

increased.[36] Eventually, the pillars lost their function—and disappeared. This model was rejected by Mogetta, who argued that in many cases, differences in the execution of the technique could easily be ascribed to a variety of factors, such as the function of a wall within a building—carrying walls required a different execution than non-carrying walls—and differences in economic power—wealthier people building a home could afford better techniques than poorer people.[37] Yet while the evolution of Pompeian Limestone Framework as a building technique may have been somewhat less linear than Peterse believed, his model should not be cast away too easily. Peterse distinguished three varieties of the technique (A, B, and C). While buildings with the A and B variant were clustered close to the city center, the buildings with the (later) C variant can be found over the entire urban area, suggesting that the city in which they were built was larger than the city in which the earlier variants were used.[38] Furthermore, a chemical analysis of the mortars made clear that the mortar used in Type C walls contained more volcanic material than that in

36 Peterse 1999, 49–55.

37 Mogetta 2016, 48–55. See also Peterse 1999, 49–50 acknowledging the overlap between his type B and C.

38 Peterse 1999, 64–69.

walls of the other two types—even if there is still a significant difference with the levels of volcanic material found in the earliest Pompeian *opus incertum*.[39] It is possible that the development in reality was gradual, but that we simply lack the data due to the lower intensity of building activity in the first half of the second century BCE. It is also possible that there was a real innovative leap from 'late' Limestone Framework to 'early' *opus incertum*. Yet in both cases, the crucial point is that Pompeian builders had already begun to use locally available volcanic material in their mortar—and this had brought the innovation within the reach of everyday experimentation: it simply was a matter of finding the right mixture.

4 From *caementa* to *cubilia*: the Appearance of Standardized Building Materials

The appearance of concrete in Pompeii was thus well-anchored in preceding developments in local construction practice: it built upon an existing use of volcanic materials in mortars, facilitated by the easy availability of this material in the region. Rather than a revolution, the early history of concrete was a sequence of pretty small conceptual steps. The development towards *opus reticulatum* followed the introduction of *opus incertum* from the end of the second century BCE onwards. Unlike concrete, which could also be traced at Pompeii at an early moment, *opus reticulatum* seems to have been a local development of Roman metropolis. *Opus reticulatum* consists of small diamond-shaped blocks of natural stone with a flat surface that were placed in a regular, 'net-like' pattern (fig. 7.5). The development from *incertum* to *reticulatum* has generally been seen as gradual: over time, *caementa* became gradually more similar in size and shape, and they would increasingly be placed in a regular pattern, until, finally, a fully standardized and completely regular *opus reticulatum* emerged. Traditionally, archaeologists have referred to the intermediate stage between *opus incertum* and *opus reticulatum* as *opus quasi-reticulatum*, though the term is a modern invention.[40] The first more-or-less regular facings in this tradition can be found in the Horrea Galbana, constructed around 110 BCE; a fully developed form of *opus reticulatum* can first be found in the Theatre of Pompeius (55 BCE).[41]

39 Peterse 1999, 88–90.

40 On *opus quasi-reticulatum* see Blake 1947, 251–253; Lugli 1957, 501–505; Coarelli 1977, 10; Torelli 1980, 141.

41 Cf. Coarelli 1977, 15.

FIGURE 7.5 Ostia, *tabernae* I X 1 ('*Taberne Repubblicane*'). Late Republican *opus reticulatum* in tuff
PHOTO: MIKO FLOHR

According to Vitruvius, *opus reticulatum* had completely eclipsed *opus incertum* by the time he was writing, in the Augustan period:

> There are two kinds of walling; one like network, *opus reticulatum*, which all use now, and the old manner which is called *opus incertum*. Of these the *reticulatum* is more graceful, but it is likely to cause cracks because it has the beds and joints in every direction. … *opus incertum*, lying course above course and breaking joints, furnishes walling which is not pleasing but is stronger than the reticulatum.[42]

While aesthetics cannot credibly explain the gradual evolution from *opus incertum* to fully regular *opus reticulatum*, Vitruvius is probably right about the aesthetic value ascribed to *opus reticulatum* in his time, and in his assessment that the technique was vulnerable: the long, straight joints running up and down the wall facing were prone to cracking.[43] His text, however, is of

42 Vitr. 2.8.1. Translation Granger 1931, 111.

43 For this reason, the use of *opus reticulatum* in the early imperial period has increasingly become restricted to panels surrounded by bands of *opus latericium*.

little help in reconstructing why *opus reticulatum* became successful. Scholars have argued that the key advantage of the technique was that it allowed for a higher speed of construction on site: the *cubilia* of *opus reticulatum* were identical in size and thus could be much more easily put into place, whereas the traditional facings of irregular *caementa*—*opus incertum*—took more time as workers needed to find the right piece for each place, place, and *caementa* may have needed ad hoc reworking.[44] However, as DeLaine has argued, arguments in favour of efficiency should not be overblown. Time won *on site* was lost in the preparation of the *cubilia*, which took considerable time, meaning that the overall costs for *reticulatum* could even be higher than for *opus incertum*.[45] Still, *reticulatum* offered some practical advantages. Laying standard-sized *cubilia* in a regular pattern required less skill and effort than selecting and shaping *opus incertum* rubble, making it possible to separate more complicated parts of the work flow—making the *cubilia*—from easier parts of the work flow. Similarly, the use of standardized building materials made it possible to separate the preparation of building materials from the construction of the walls in time and space. This helped: the building industry was characterized by significant seasonal differentiation, as concrete walls could not be constructed between November and March, and during the hottest part of the summer.[46] The production of *caementa*, however, could continue all year around. Using pre-fabricated *caementa* of standard size and shape made it possible to use the building season more effectively and to do more with the same number of people: workers could spend part of the year making *caementa*, and part of the year using them to construct walls.

In the context of second century BCE Rome, improving the division of labour made a lot of sense. At a macro-economic level, this has been recognized before, but scholars have not generally thought-through how this was supposed to work at the micro-level of strategic decision-making by individual entrepreneurs—and it is here that the innovations in practice that led to *opus reticulatum* would have been anchored.[47] The spectacular expansion of the

44 See esp. Rakob 1976; Coarelli 1977.

45 See esp. DeLaine 2001, 240–245.

46 Based on Front. *Aq.* 2.123: *Idoneum structurae tempus est a Kalendis Aprilibus in Kalendas Novembres ita ut optimum sit intermittere eam partem aestatis quae nimiis caloribus incandescit.* Cf. Blake 1947, 352; Van Oyen 2017, 139. Blake and Van Oyen also refer to the *Lex Puteolana parieti faciendo* (CIL 10, 1781), but the date of November 1st mentioned in this building contract specifies the planned completion date of the project, not some general rule about the building season. It does, however support the idea that there was a season for building in concrete that ended around the start of November.

47 See for macro-economic perspectives Coarelli 1977, 18; Torelli 1980, 156–158.

city, and the continuous construction of public infrastructure and civic monuments made sure that there was an endless sequence of building projects, and this led to the emergence of a more or less permanent building industry providing work to an increasingly large workforce. Seasonality, however, offered a challenge to entrepreneurs, as they needed many people to do the work during part of the year, and much fewer people in other parts of the year. Letting go and re-hiring wage labourers on a seasonal basis created an insecurity and unpredictability, particularly when workers would need to be skilled—if projects are many in number, and substantial in size, it would be attractive to retain at least part of the (skilled) work force throughout the year, to reduce excessive friction costs while re-hiring in spring. Moreover, in the context of Late-Republican Rome, building entrepreneurs could not only draw upon paid laborers, but also may have been able to use people they held as slaves. Particularly in the second half of the second century BCE, the Romans brought large numbers of enslaved people to Italy, and these disproportionally ended up in the possession of Rome's senatorial elite—which, indeed, was disproportionally involved in construction activity in and around the quickly expanding Roman metropolis.[48] Construction workers held as slaves, of course, would be available throughout the year, but there would be limited work for them in the winter. Separating the construction of the walls from the preparation of the building materials could solve this people problem both for entrepreneurs relying on hired labour, and for those relying on people held as slaves. If the costs of building were for a large part determined by labour, this created a meaningful competitive advantage. Thus, once some builders in Rome came up with this idea, others would have had a strong incentive to follow suit—otherwise, they would be unable to perform at the same level as their competitors.[49]

Changing the logistics of the construction process, and improving the division of labour set in motion a development towards *caementa* that were more alike in size and shape, but this did not automatically lead to the strictly regular *opus reticulatum* of the late Republic and the Early Imperial period. In that sense, it is misleading to refer to walls with regularized *caementa* as *opus quasi reticulatum*: the term suggests builders were mimicking a technique that did not yet exist, nor was on their mental horizon.[50] 'True' *opus*

48 The role of slavery was suggested by Coarelli 1977, 18; Torelli 1980, 156. See also Mogetta 2015, 5. On the increase of slavery in Rome over the second and first centuries BCE see Scheidel 2005, 75–79.

49 On the importance of labour costs see DeLaine 2001.

50 For a critique of the label '*quasi-reticulatum*' see Coarelli 1977, 10.

reticulatum differs from what preceded it in one very fundamental way: its *cubilia* were mass-produced to have exactly the same dimensions. This was done not through cutting, but through sawing them to shape.[51] The arrival of mass-produced *cubilia* and of truly regularized *opus reticulatum*, thus, must be seen as a separate innovation: it was preceded by and dependent upon the development towards regularized *caementa*, but did not directly follow from it. The separation of materials preparation and wall construction did offer an anchor that allowed for the quick integration of mass-produced *cubilia* once someone had come up with the idea, but this still leaves open the question of how this idea came about. While direct evidence is lacking, it would seem that standardized *cubilia* were produced with the aid of a long stone-saw, which made it possible to saw a larger number of them at the same time. This suggests that they may first have appeared in the context of quarrying, where larger stone-saws were already being used to cut larger blocks of ashlar. In this scenario, *cubilia* would be mass-produced in quarries before being transported to the building site. This would make perfect sense: from the Late Republic onwards, quarries increasingly became involved in further processing excavated blocks of stone.[52] Producing *cubilia* in quarries would have the advantage that places and installations to do this sawing in an efficient way could develop a (semi-)permanent form, further streamlining the process; additionally, transporting *cubilia* rather than large blocks of tuff limited the risk of damage during transport.

5 From Stone-Faced to Brick-Faced Concrete: the Emergence of *opus latericium*

The emergence of *opus latericium* is dependent on the appearance of, first, concrete and, then, standardized building materials, but it made use of a material that had been around for quite some time: fired brick had emerged as a building material in the early third century BCE on Sicily and in Magna Graecia.[53] In Roman construction practice, fired brick appeared much later, first in loose architectural elements, such as columns, and then in quoins, door posts, and relieving arches; later, brick began to be used in bands throughout the entire

51 DeLaine 2001, 241.

52 See on quarrying practices esp. Trimble 2011, 67–77. Trimble focuses on marble quarries, but her work, in highlighting the complexity of operations done at these quarries, suggests a model for other quarries as well.

53 Östborn and Gerding 2015, 317.

wall, often in combination with *opus reticulatum*; full *opus latericium* entirely made of brick, appeared yet later again. Its early use in corners, door-posts and relieving arches suggests that brick could offer additional strength compared to alternatives of natural stone; its use in combination with *opus reticulatum* seems to address the shortcomings of this technique noticed by Vitruvius.

The oldest known examples of brick-faced concrete can be found in Pompeii—in the Odeon and the Forum Baths, which were constructed by urban magistrates in the decade following the establishment of a Roman colony in the city in 80 BCE (fig. 7.6). These buildings had walls with a semi-regularized *opus incertum* facing of grey lava, but corners and door posts were faced with brick.[54] This combination of materials and techniques is specific to these early colonial construction projects at Pompeii: they had not been used earlier, and would rarely be used afterwards. The Pompeian amphitheatre, built in the same period, had walls in a similar *opus incertum*, but with *opus vittatum* of stone instead of brick on the edges. No contemporary parallels for this use of brick are known elsewhere in Italy.[55] Perhaps, the choices made in the construction of these buildings reflect the specific social and political circumstances in Early Colonial Pompeii: the magistrates leading the Roman colony were outsiders to the region, and seem to have relied on their own networks to recruit the architects and builders for these projects. They were well-equipped to do so: Quinctius Valgus, one of the *magistri quinquennales* involved in the construction of the Odeon and the Amphitheatre, belonged to the circle around Sulla, and was involved in building projects in at least two other cities elsewhere in Italy.[56] It seems that the people he and his colleague brought in simply started from their usual way of working, and adapted it to Pompeii. Thus, following contemporary practice, they built in *opus incertum* with prepared, regularized *caementa*, using the most easily available local building material—grey lava. However, unlike the tuffs and limestones that could be used elsewhere in Italy, Pompeian grey lava could not be easily shaped in any regular form. Thus, the wall-facing looked more irregular than it did in other places, and a solution was needed for corners and door-posts, for which grey lava was not suitable. It is in this context that, in the case of the Odeon and the Forum baths, a choice for fired brick was made. Yet the brick did not stick: after

54 The facing is sometimes described as *opus quasi-reticulatum* (e.g. Lugli 1957, 498).

55 Adam (1994, 131) notices similarities with the Augustan (?) amphitheatre in Cassino, and the catalogue of Welch (2007, 189–252) makes clear that there were many parallels for the use of semi-regularized *opus incertum* resembling *opus reticulatum* in late-Republican amphitheatres, but there are no parallels for the use of bricks. For theatres see Sear 2006, 119–195.

56 Santangelo 2007, 72–73.

FIGURE 7.6 Pompeii, Odeon: early colonial *opus incertum* with grey lava and brick
PHOTO: MIKO FLOHR

these early colonial construction projects, Pompeii's new Roman elite seems to have adopted the traditional regional building materials.[57] First century BCE second style wall-decorations in Pompeii are generally associated with corners and door posts of *opus vittatum* in tuff or Sarno Stone.[58]

In Rome, the situation was similar: despite the famous Suetonian saying that Augustus left 'in marble what he had found in brick', there was hardly any brick in Rome in 27 BCE.[59] Late Republican architecture in the city almost

57 This is exemplified by the tomb of M. Porcius outside Porta Ercolano, who had been involved in the construction of the odeon and the amphitheatre, but was buried in a tomb of Nocera tuff and travertine. See for this tomb Kockel 1984, 53–57. There may have been some continuity: some tombs in the Via Nocera necropolis use a construction technique similar to the Odeon and the Forum Baths (cf. D'Ambrosio and De Caro 1983, 4EN, 6EN, 10EN); D'Ambrosio and De Caro date these tombs to the Augustan period, but they may well have been constructed in the preceding decades.

58 As e.g. in the Villa dei Misteri (Maiuri 1937), in the House of the Labyrinth (VI 11, 8–10, Strocka 1992) and in rooms 11–13 off the east side of the peristyle of VI 8, 20–21.2 (personal Observation). On the second style see Heinrich 2002.

59 Suet. *Aug.* 28.3: *marmoream se relinquere, quam latericiam accepisset*. Suetonius clearly misinterpreted the story, and re-anchored it in the building practice of his own age; Dio used slightly more neutral terms: 'τὴν Ῥώμην γηίνην παραλαβὼν λιθίνην ὑμῖν καταλείπω' (56.30: 'I found Rome made of earth, and left it to you made of stone'), adding that

FIGURE 7.7 Pompeii, Temple of Fortuna Augusta
PHOTO: MIKO FLOHR

completely depended on tuff, and used either ashlar or concrete with a facing in *opus reticulatum* combined with corners and door posts of *opus vittatum* in the same material.[60] Public architecture of the Augustan period continued in this vein, with a clear preference for ashlar. It is in the private architecture of the metropolitan elite—in houses and tombs—that brick first began to appear. Indeed, one of the earliest uses of brick in Rome is—perhaps somewhat ironically—in the House of Augustus on the Palatine; the first public building in Rome to use brick-faced concrete is the theatre of Marcellus, where it can be found in the inner concrete vaults.[61] In Pompeii, brick was used in the door posts of the Temple of Fortuna Augusta, which was constructed around 3 BCE or a little later (fig. 7.7), and in the Augustan reconstruction of the theatre by Holconius Rufus, where it was used for the facing of the *scenae frons*.[62] After the Augustan period, brick became a more common building material in

Augustus was not literally referring to the architecture of the city, but rather to the robustness of the state.

60 See esp. Lugli 1957, 505–506.

61 For an overview see Lugli 1957, 588. On the house of Augustus on the Palatine see Gallocchio 2019. On the theatre of Marcellus see Buonfiglio 2016.

62 On the Temple of Fortuna Augusta see Van Andringa 2009, 56–59. On the theatre of Pompeii see Johannowsky 2000, 20.

Rome and Pompeii, but not overwhelmingly so. In Pompeii, most brick-faced walls are associated with the 60s and 70s CE, when large parts of the city were reconstructed after earthquake damage.[63] In Rome and Ostia, brick only became dominant in the (very) late first century CE.[64] In many places in the peninsula, and indeed elsewhere in the Roman world, brick-faced concrete would always remain, at best, a secondary building technique, even if it was occasionally used.[65]

It is not hard to see why the application of brick in actual building projects in many places remained limited: brick required a dedicated industry that needed investment in specialized equipment and access to raw clay. This was not uncomplicated: raw clay could be won in many places, but it would often be found in locations that could also be used for agriculture—meaning that land owners would have to weigh their priorities. In many places, agriculture may often have been more rewarding than clay extraction. Thus, if good-quality building stone was locally available, this might often have been the more straightforward option for urban builders. Economically, brick particularly would come into the picture when elite land owners developed a direct interest in urban construction—because they were personally involved in big public construction projects, or in urban property investment, and because such initiatives were financially or socially rewarding. The Roman metropolis, and its booming property economy of the later first and second centuries CE was one obvious context where brick production became feasible; Pompeii in the period following the seismic upheavals of the early 60s CE was another; large-scale public building projects—such as the Baths of Caracalla and the Aurelian walls—also offered circumstances that could justify dedicated investment in brick production. In most places in the Roman world, these conditions were never met on a structural basis. By consequence, in many places, quarried stone remained the preferred building material throughout the imperial

63 See e.g. Fröhlich 1993, 157; Wallat 1993, 356.

64 For Rome, the Neronian fire of 64 CE has sometimes been seen as a watershed (Cf. MacDonald 1982, 30; Van Oyen 2017, 145), but besides imperial building projects, including the *Domus Aurea*, the Neronian Nymphaeum and the aqueduct branch to the Caelian hill, there are relatively few buildings in plain *opus latericium* that can be dated to the years immediately following the disaster, while there is considerable evidence for *opus latericium* in earlier Julio-Claudian projects, such as the *Castra Praetoria* (Lugli 1957, 590), and the Neronian Baths of 62 CE (Lugli 1957, 595). See also Blake 1959, 11.

65 At Paestum, for instance, brick was used in a reconstruction phase of the amphitheatre, in the 'basilica', in some *tabernae* and in imperial-period bathing installations, but never consistently: brick was clearly 'anchored' in the local building repertoire, but it was only used under certain circumstances, in particular construction projects.

period, even though, in many places, it seems clear that brick was well-known as a possible building material.

6 Discussion

The introduction of concrete, the development of *opus reticulatum* and the appearance of brick were three of the defining changes in Roman (metropolitan) building practice that paved the way from the ashlar of the Servian walls to the *opus latericium* of the Aurelian walls. In line with recent discourse on innovation in archaeology, analysing the coming about of these changes at a micro-level highlights first and foremost their gradual character: each of these changes gradually 'conquered' building practice, starting either from the corners of the walls, or from the centre, or being achieved through a number of subsequent steps. Moreover, it also makes clear that local circumstances played a key role in the uptake of innovations: for concrete, this was not only the availability, in certain locations, of volcanic ash, but also the increased range of materials that could be used in wall facings held together by strong mortar, which could—locally—lower construction costs. The regularization of *caementa* and the emergence of *opus reticulatum* were facilitated by the benefits of separating materials preparation from construction. This was caused by the seasonal limits imposed to the erection of walls of concrete in the context of large-scale urban construction in the Roman metropolis. For the use of brick, there is the growth of a large-scale brick industry in a limited number of places with sustained high levels of larger scale construction activity—again, the city of Rome played a key role. More importantly, however, in all three cases, the social and economic limits to the diffusion of the innovation appeared as pronounced as the eventual impact these new techniques would have in some places.

The role of using 'anchoring' in this analysis has been to direct the enquiry towards the actual introduction of practices into the technical vocabulary of builders, to extend it beyond the empirical questions of where and when into the hermeneutics of why and how. The result is a history of innovation and change that, compared to earlier discourse, is more sensitive to everyday practices, and to decision-making processes 'on the ground'. It has also resulted in a narrative that evokes a more fragmented picture of innovation than regular discourse on the history of Roman concrete has done: instead of a progressive sequence from the first experiments with pozzolana to the *opus latericium* of imperial and Late antique Rome, what emerges is rather a gradual diversification of the amount of options available to the people involved in construction. This change of perspective is extremely meaningful: earlier approaches have primarily looked at the evolution of building technology in hindsight—starting from the materials and techniques used in the Baths of Caracalla or the Pantheon in Rome. From such a perspective, inevitably a simplified genealogy emerges that suggests a gradual, but ultimately linear development towards a pre-defined end point.[66] Conversely, analyzing the individual contexts in which innovations became anchored, and the decisions taken (and not taken) at those moments, generates a much more diverse, much more complex picture—and one that is much more intimately connected to local urban histories of practice. Ultimately, this allows for a much more complete understanding of the chronological and geographical diversity of Roman construction practice than the genealogies of Roman concrete that have dominated discourse on Roman building technology, and it makes it possible to de-center and contextualize the spectacular, but outrageous developments of building practice in and around the Roman metropolis.

Finally, it could be argued that the argument made in this chapter differs from most earlier approaches to anchoring in two meaningful ways. The first is that the actual processes of anchoring have mostly remained implicit: rather than anchoring strategies, this chapter has essentially discussed processes and circumstances of 'becoming anchored'. The second difference is that the episodes of anchoring in the evolution of building techniques were not simply isolated instances of adopted innovation, but rather specific moments in much longer trajectories of change. As such, they were not only responsive to what preceded, but also shaped the possibilities in what was to come. I would suggest that both points enrich the conceptual anatomy of 'anchoring'. The first highlights the distinction between the discursive practices that made that an innovation could 'stick', and the event of sticking itself: both can be referred to through 'anchoring', but they are different things that may need to be distinguished more sharply in anchoring literature: 'anchoring narratives' do not need to lead to 'anchoring events', while anchoring events can occur without explicit narratives.[67] The second point highlights the need to close-read anchoring narratives and anchoring events in their evolving historical context: anchoring a 'new' idea to something that already was there was not so much a matter of making a connection between two stably existing things, but rather of durably connecting an emerging phenomenon—e.g. brick—to an evolving

66 As most explicitly in Van Oyen 2017, 140–146.

67 On discursive practices connected to anchoring see Sluiter 2021. Hekster 2020, 104 touches upon, but ultimately evades this distinction in discussing the use of *spolia* in the Christian *basilicae* in Later Antiquity. These spolia may be seen as discursive—a strategy to make seem familiar what in fact was new—but they also may reflect that basilicae *had become anchored* in normal practice and *thus* could share in the visual language that had long been reserved for *fora*.

target—concrete—in one specific place at one specific moment. Anchoring happens between ideas and practices that are in flux, and an established connection affects both: after brick became anchored in concrete, not only the history of concrete changed, but also that of brick, which subsequently could be mass-produced for large-scale construction in *opus latericium*. Anchoring, thus, does not refer to a (desired) *end point*, but to a moment of transition; it creates new possibilities as much as that it realizes existing potential. The examples discussed in this chapter have also suggested that anchoring events not only (or even 'not so much') transform practice, but rather diversify: the result of an anchoring event often was an increase in the number of options available, and a multiplication of subsequent development trajectories.

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CHAPTER 8

Tiberius and the Threat of Innovation

Serena Connolly

1 Introduction

> But there was this craftsman who made a shallow glass bowl, which could not be broken. And so he was given an audience with Caesar with his gift. ⟨…⟩ then he had Caesar return it to him and threw it onto the ground. Caesar could not have been more terrified. But the craftsman picked up the bowl from the ground; it had been dented as if it were a bronze vase. Then he brought out a little hammer from his cloak and with effort did a good job of correcting it. Having done this, he thought that he had Jupiter by the balls; at any rate the emperor said to him afterwards: "No one else knows about this glass-making, do they?" And just look. After he said no, Caesar ordered his head taken off: because, you see, if the invention became known, gold would be worth dirt.[1]
>
> Fuit tamen faber qui fecit phialam vitream, quae non frangebatur. Admissus ergo Caesarem est cum suo munere. ⟨…⟩ deinde fecit reporrigere Caesarem et illam in pavimentum proiecit. Caesar non pote valdius quam expavit. At ille sustulit phialam de terra; collisa erat tamquam vasum aeneum. Deinde martiolum de sinu protulit et phialam otio belle correxit. Hoc facto putabat se coleum Iovis tenere, utique postquam ille dixit: 'Numquid alius scit hanc condituram vitreorum?' Vide modo. Postquam negavit, iussit illum Caesar decollari: quia enim, si scitum esset, aurum pro luto haberemus.[2]

A popular anecdote was told of a craftsman who, proud at his discovery of a glass that would not break, brought his invention, in the form of a bowl, to the emperor. Apparently full of confidence, the craftsman dropped it, as if by accident; when the bowl failed to break, the emperor was shocked. Admitting that he was the only person who knew how to produce the glass, the craftsman was

1 Petr. *Sat.* 51. All translations, unless otherwise specified, are my own.
2 I reproduce here the text of Schmeling 2020.

executed because an unbreakable glass, so we are told, would become more valuable than precious metal and could even render precious metal worthless.

Three versions of this anecdote—in Petronius, the Elder Pliny, and Cassius Dio—differ slightly in their details, but the basic elements of a craftsman, his unbreakable glass, and the emperor's horror at the invention, remain the same.[3] The anecdote provides a fictional example of Tiberius' well-attested cruelty, paranoia, and suspicion. It also offers an example of the typical tricky craftsman, who tries to outwit others, even emperors. But the anecdote has broader significance for the history of ancient Mediterranean innovation.

I shall argue in this paper that, first, it imagines the emperor as having to react to a threat posed by innovation, one with catastrophic economic consequences. Second, this imagined reaction stands in contrast to the responses of others, including emperors (most notably Nero), to other real innovations in glass technologies of the first century CE. In giving the impression that innovation comes with a sudden discovery by a lone genius, I argue finally that the anecdote suggests to us how some innovations may have been perceived: as happening in bursts, as anxiety-inducing, and as something risky that could or should be managed, or even obstructed. Such perceptions, which persist today, may contribute to the failures of some innovations.

2 The Threat of Unbreakable Glass

Innovation and the threat of economic catastrophe are at the centre of Pliny's version:

> They say that when Tiberius was emperor, after a craftsman had carried out investigations into producing a glass that would have the quality of pliancy, his entire workshop was destroyed so that the value of bronze, silver, and gold should not be dragged down, and the frequency with which this story was told was greater than its credibility.
>
> Ferunt Tiberio principe excogitato vitri temperamento, ut flexile esset, totam officinam artificis eius abolitam, ne aeris, argenti, auri metallis pretia detraherentur, eaque fama crebrior diu quam certior fuit.[4]

3 Isid. *Etym.* 16, 16.6 and John of Salisbury, *Policraticus* 4.5, both offer expansions of the version told in the *Satyrica*.

4 Plin. *HN* 36.195.

A craftsman has produced some sort of new glass, though its nature is unclear. Pliny refers to a glass that is flexible; both Petronius (see above) and Dio (below) describe the craftsman as dropping it and then fixing its dents to render it new again.[5] A flexible glass, which would have been unbreakable, is an improbable innovation: flexible glass is only a recent development, while a truly unbreakable glass remains an impossibility.[6]

The imagined innovation would have been a boon to glassmakers. As Anna Soifer discusses in this volume, although glassblowing could allow for recycling of materials, 40–45% of blown glass was still wasted. Further waste would have come from breakages during manufacture, packing, and transportation. A flexible or unbreakable glass would offset some of this loss, resulting in higher profits for manufacturers (as well as distributors). A non-frangible glass would have been a boon to consumers too: before telling his version of the anecdote, Petronius has Trimalchio state that he loves glass, except that it breaks. Yet Tiberius had the craftsman executed (according to Petronius and Dio) or his workshop destroyed (according to Pliny).

Pliny supplies a bare explanation for the emperor's response: bronze, silver, and gold (*aeris, argenti, auri metallis*) would have seen their values dragged down (*pretia detraherentur*). This scenario of the results of a popular glass is not so far-fetched. According to Pliny (*HN* 36.198–199), another type of glass had this effect: glass that is 'white and translucent, however, has the highest value, which is the closest in likeness to crystal. Its use in drinking vessels has displaced that of silver and gold'. But if the effect of the craftsman's innovation were simply to disrupt the luxury tableware market, it seems far-fetched even within this imagined scenario that Tiberius would respond with violence. Pliny's wording offers clues for a different motivation.

Pliny's collocation bronze, silver, gold (*aeris, argenti, auri*) was used in the title of officials who oversaw the mints, as Probus (*De notis iuris* 3.11.1) records

5 Stern 2007, 355–357, believes the stories are much-embellished accounts of molten blown glass that is dropped and reformed while still hot; see also Lattermann 2017, 2–3. Hammers and other tools could be used on molten glass and also on glass cameos or relief work; see McDermott 1962, 144–145.

6 Strings of a flexible glass are currently used in fibre-optic cables, and flexible glass sheets are being trialled for use in electronic consumer goods. The Prince Rupert's drop is unbreakable (provided its tail remains intact), though that is not what is being described in our ancient sources. Modern glass products marketed as unbreakable either comprise glass panels reinforced with a thermoplastic interlayer or are made not of glass, but a composite of polycarbonate, acrylic, and other plastics. A nearly unbreakable glass was developed in 2015, as reported in Rosales-Sosa et al. 2015, though Drahl 2015 cautions that 'according to their calculations, this glass performed about as well as a heavy duty commercial glass'.

in his expansion of the abbreviation *AAAFF*: *aere argento auro flando feriundo* ('the casting and striking of bronze, silver, gold').[7] The wording seems to be alluding to an economic motivation for Tiberius, though Pliny offers no contextual details. A possible, though highly speculative, context that could explain the threat Tiberius hoped to destroy is the financial crisis of 33 CE.

According to several ancient sources, 33 CE saw a confluence of severe economic problems, of which Tacitus (*Ann.* 6. 16–17) provides the fullest account:[8] 'a great force of accusers unleashed against those who were in the business of making money, through usury, in contravention of a law of the dictator Caesar'; in response, the emperor offered a grace period within which new and existing loan agreements had to be revised, in accordance with the law. But 'because of this, there was a shortage of cash, as everyone's debts were called in; and because so many people's property was subject to condemnation or auctioned off, the money realized was held by the imperial or public treasury'. The Senate, in response, required lenders to invest two-thirds of their capital in land. This measure had several results: first, lenders called in their debts, leaving borrowers in financial peril, many of whom lost properties; second, the real estate market was flooded with properties, which were bought up by former lenders, whose working capital was thereby redistributed and concentrated among a few purchasers (mostly other lenders and the government), thus reducing the extent of its circulation. 'The upheaval to assets plunged families' status and reputations downward, until the emperor brought relief by distributing one hundred million sesterces among the banks and by making available three-year, interest-free loans'.

Scholarly attempts to explain what exactly was happening during the crisis have been hampered by the nature of our ancient evidence, written as it was by historians, not economists, and by attempts, some of them anachronistic, to fit what little evidence we have into modern economic explanations.[9] Yet most

7 Cicero refers to the mint officials as 'the ones in charge of bronze, silver, gold' (*tresviri aere argento auro*, *Fam.* 7.13.2). Pliny and others also use the collocation in lists of precious metals that are worked into luxury objects: e.g., Cic. *Nat. D.* 2.151, Livy 45.33.5, Ov. *Am.* 3.8.37–38, Plin. *HN* 3.30 and 37.202, Pompon. 2.78, and Apul. *Met.* 11.10.6.

8 There are briefer accounts in Suet. *Tib.* 48 and Dio Cass. 58.21.4–6.

9 This is the complaint of Elliott 2015. Key scholarship on the crisis includes Frank 1935, Crawford 1970, Rodewald 1976, Lo Cascio 1981, Duncan-Jones 1994, 23–25, Hitchner 2009, 282–284, Schartmann 2012, and now especially Elliott 2020, 90–96. Some scholars situate accounts of the crisis in contemporary politics and downplay the notion that there was a monetary crisis, emphasizing instead confiscations of usurers' property and the role of informers. I follow Elliott 2020, who argues that there was a monetary crisis and that Tiberius' response was purposeful.

scholars agree, following our ancient sources, that there was a monetary crisis; that liquidity was constrained because too much cash was held in the treasury or by private individuals; and that in an attempt to end the crisis, Tiberius apparently released a large amount of metal currency to be used for loans.[10]

If we situate the anecdote in the context of the financial crisis, we might infer that it imagines Tiberius destroying the craftsman or his invention because a rush away from precious metal objects—both coins and luxury items—to an unbreakable glass might cause the value of metals to drop before he had time to draw on his reserves and inject cash into the economy. As a result, he would be unable to solve the crisis, and economic disaster might follow.

The early 30s were a period of economic concerns for Tiberius. Suetonius relates (*Tib*. 34) that Tiberius, 'complaining bitterly that the value of Corinthian-ware vases had skyrocketed and that three mullets had been sold for thirty thousand sesterces, decided that there should be a limit on household decoration and that market prices should be regulated annually, as the senate should see fit'. Velleius Paterculus, writing in 30 CE, refers (1.13.4) to the contemporary craze for Corinthian ware; the date is only three years before the financial crisis.

A mania for Corinthian ware and resulting high prices prompted Tiberius to act. The subsequent story of the new glass presents Tiberius as reacting to another technological innovation, for which there might be a similar mania and similarly high prices, along with an economically deleterious abandonment of precious metals.

Petronius' version of the story (*Sat*. 51), which is quoted at the top of this chapter, connects Tiberius' response to pricey Corinthian ware and his reaction to the craftsman's glass, further suggesting that they were roughly contemporary. Trimalchio, his freedman creation, has been showing off his wealth at a dinner party perhaps set in Tiberius' reign.[11] Pointing to a dish, he declares jokingly that he is the only owner of real Corinthian ware: after all, the person who made his dish is called Corinthus. He then tells everyone the supposed origin of Corinthian ware: at the fall of Troy, the trickster Hannibal gathered up all the bronze, gold, and silver sculptures and melted them down; the result was Corinthian bronze. Trimalchio then complains that metal smells; he would

10 Duncan-Jones 1994, 25, reports that coin output increased around 33 CE, probably in response to the financial crisis; Butcher and Ponting 2015, 184, are not persuaded.

11 Klebs 1893, 665–668, provides an early argument for setting the dramatic action of Trimalchio's dinner in the reign of Tiberius. Courtney 2001, 7–8, observes that Petronius may not be historically consistent: among the performers referred to by name during the dinner, at least one may have been active under Gaius. Such inconsistencies do not rule out a Tiberian setting.

prefer glass, except that it breaks, and his version of the anecdote of the new glass follows.[12]

The anecdote connects unbreakable glass by its properties and its imagined impacts to precious metals. At the same time, however, the anecdote may gain credibility in the mind of the reader thanks to contemporary developments in glass technology.

3 Innovations in Glass

Tiberius responded to the craftsman's presentation with violence, but other innovations in glass were being enthusiastically embraced, including by emperors. Improvements in glass production during the period from 50 BCE through the end of the first century CE saw an increase in the volume and geographical spread of glass production, which led to low prices.[13] Those prices may have been kept low by the material's frangibility, with metal still preferred for its durability. As Trimalchio asserts (*Sat.* 50): 'I love glass … except that it breaks, I would prefer it to gold; but at least it is cheap'. If Trimalchio's preferences are reflective of the time, an unbreakable glass would indeed have become more popular than precious metals.

Major developments in glass technology included glass or glass-like products that were more durable, of which Pliny has two examples. First, having just told of the craftsman's new glass, Pliny wonders rhetorically, 'what does it matter?' and goes on to relate (*HN* 36.195) that 'when Nero was emperor, a type of glass was found thanks to which two small beakers, which they call hard-as-stone (*petrotos*), could sell for six thousand sesterces'.[14] Tiberius' imagined destruction of the craftsman's facility would have been pointless: (apparently) unbreakable glass products would anyway be produced again.

12 Pliny (*HN* 34.3 and 34.6) does not discount the notion that Corinthian bronze originated in the Roman sack of Corinth in 146 BCE, as bronze, gold, and silver objects melted. On this story, see Darab 2003 and 2012. The same story appears in Flor. 1.32.6–7 (B.ii.16). Plutarch *Mor.* 395b offers several versions, but discredits them. See McDermott 1962, 146. The stories reflect contemporary confusion about definitions of Corinthian bronze, on which see Jacobson and Weitzman 1992.

13 See the helpful surveys in Tatton-Brown 1991, Stern 2002, and Prior 2015, 21–36. Strabo 16.2.25 claims glass bowls and drinking cups could be bought at Rome for a copper coin, though this is probably exaggeration.

14 Eggert 1991, 290, n. 39, and Hayward 2016, 94, dismiss the possibility of such a product. Trowbridge 1930, 166, suggests that *petrotos* may be interpreted as 'a name for certain cups which perhaps looked like rock crystal'.

Second, he claims (*HN* 31.40) 'the emperor Nero made this invention: boiling water and, in a glass, plunging it into snow and cooling it'. A regular glass that has been heated to a high temperature and then plunged into cold snow should undergo thermal shock and shatter.[15] But Nero had apparently found a glass—perhaps akin to a tempered or ceramic glass—that could withstand a sudden change in temperature.[16]

Among other developments, Nero is also said to have watched gladiatorial contests 'in an emerald' (*in smaragdo*, Plin. *HN* 37.64), which may have been a magnifying lens.[17] Similarly, the clear and colourless glass that had only recently been developed in Italy (Plin. *HN* 36.194) was being shaped into pebbles and filled with water to be used as magnification aids (Sen. *QNat.* 1.6.5).[18] Glass balls were also being used by doctors as burning glasses to aid in cauterizing (Plin. *HN* 37.28).[19] As early as Nero's reign, they may even have been used as luxury playthings;[20] their spherical shape will have mitigated their frangibility.

These innovations were the results of gradual and incremental developments in glass technology that were the product of work undertaken by various craftsmen across time and space, as Pliny's survey of glass makes clear.[21] By contrast, the unbreakable glass of the anecdote is the sudden and strange creation of a lone craftsman.

15 Plin. *HN* 36.199 attests to the problem; Martial 12.74 recommends using earthenware as a solution, though in one of his riddling *Apophoreta* (14.94), he had earlier referred to glass whose stone-hardness (*gemma*) is not shattered by scalding water.

16 The invention is discussed by Dalby 2001, 76, who understands boiled-then-chilled water not as a wasteful and pointless luxury, but as a technique for killing dangerous microbes; Woods 2009 suggests that taking chilled water was recognized as a health cure. Scant attention has been paid to the glass.

17 Bastomsky 1972. Krug 1987 thinks that the story is referring to a mirror; Plantzos 1997, 462, and Healy 1999, 147, believe that we have too little evidence to decide. Woods 2006 argues that Pliny misunderstood his Greek source: Nero did not use an emerald (*vel sim.*) as a mirror (κάτοπτρον), but rather was watching the games like a spy (κατόπτης).

18 More generally on ancient Mediterranean lenses, see Plantzos 1997.

19 As Krug 1987, 461, points out, Seneca believed that magnification was achieved thanks to the water, not the glass that surrounded it; Pliny (*HN* 36.199) perhaps believed this too.

20 *CIL* VI 9797 (= *CIL* VI 33815a = *ILS* 5173 = *CLE* 29), ll. 1–6. On extant glass balls, see McClellan 1985. Champlin 1985, however, reads the inscription as political allegory and doubts that such balls existed.

21 Plin. *HN* 36.192–199. On Pliny's treatment of glass manufacture in these sections of the *Natural History*, see Freestone 2008, especially 82–90.

4 The Lone Craftsman

All three versions of the anecdote present the new glass as having a single individual as its originator. The presentation is not unreasonable, as glass production took place on a small scale, and, as a result, a craftsman takes on considerable risk with any new product. This craftsman's secrecy—in Petronius' version, he has not told anyone else—might speak to his desire to maximize his gain from the technology. Yet the fact that he works alone contributes to the apparent suddenness and strangeness of his creation.

In Petronius' version of the anecdote, the craftsman is tricky: to advertise its infrangibility, when the glass is handed back to him by the emperor, he drops it, picks it up, and hammers it back into shape.[22] The display leaves the craftsman full of confidence. But then Tiberius asks him: 'No one else knows about your hardening of this glass, do they?' In the Latin, the question opens with *numquid*, a word used when a negative answer is anticipated.[23] The craftsman, presumably pleased that the innovation is his alone, delivers the expected answer and is beheaded: his cleverness has sealed his fate. Tiberius acts out of concern for the economy, but also from anger at the craftsman himself.[24]

In the third version of the anecdote, Cassius Dio also emphasizes the trickiness of the craftsman. At 57.21.5–6, we learn that a portico in Rome had begun to lean; an architect or inventor solved the problem. Tiberius was not grateful, as one might expect, but instead jealous. He made sure that the man's name was not made public, and although he gave the man money, he then expelled him from the city. The man later returned and sought to rehabilitate himself by impressing the emperor with an unbreakable glass (57.21.7):

> Sometime later, when the man approached him and begged for forgiveness, he let drop before him, deliberately so, some glass cup, and although it was dented in some way or broken, the man worked at it with his hands and forthwith showed it anew, whole again. Because of this, while he hoped to receive forgiveness, the emperor had him killed.

22 In the companion story that precedes, Hannibal is also a 'trickster and great rogue' (*vafer et magnus stelio*). The trickery of the craftsman in the story that follows was sufficiently important to Petronius to relate in his version that he made tricky Hannibal the discoverer of Corinthian bronze. Matusiak 2010 conveniently collects the ancient references to Hannibal's reputation for trickiness.

23 Pinkster 2015, 328–330.

24 Some scholars have alternatively located Tiberius' response in superstition: Borghini 1990 and Schmeling 2011, 212, claim that the craftsman has thwarted the bad luck believed to accompany broken glass.

> μετὰ δὲ ταῦτα προσελθόντος οἱ αὐτοῦ καὶ ἱκετείαν ποιουμένου, κἀν τούτῳ ποτήριόν τι ὑαλοῦν καταβαλόντος τε ἐξεπίτηδες καὶ θλασθέν πως ἢ συντριβὲν ταῖς τε χερσὶ διατρίψαντος καὶ ἄθραυστον παραχρῆμα ἀποφήναντος, ὡς καὶ συγγνώμης διὰ τοῦτο τευξομένου, καὶ ἀπέκτεινεν αὐτόν.

Dio's two stories—of the architect and the portico, and of the inventor and his unbreakable glass—were presumably originally separate, but became conflated, perhaps by Dio, perhaps by one of his sources. The conflation was made possible by the fact that the Greek ἀρχιτέκτων can be rendered not only architect, but also, thanks to its broad semantic range, as inventor, designer, or artificer.[25] The two stories are centred on a person solving a technological problem: righting a leaning portico and producing a glass that will not break.

At first sight, both stories contrast the powerless architect-inventor who does good and produces wonderous objects with the powerful emperor who is jealous, suspicious, and destructive. Yet the contrast is not so straightforward. The architect-inventor is also tricky: he begs for forgiveness, but then brings out the unbreakable glass cup and deliberately (ἐξεπίτηδες) throws it down to the ground. He works at the damaged cup with his hands rendering it again unblemished. His apparently marvellous abilities make him momentarily the superior of the two men; it is only with his death that power is restored back to its rightful holder, the emperor.[26]

Some ancient readers might have perceived the emperor's treatment of the craftsman as unfair, given the existence of the contemporary accounts of (nearly or apparently) unbreakable glass outlined above, which might have acted as horizontal anchors in the minds of those who knew them and encouraged a more positive response to the unbreakable glass.[27] Yet the craftsman apparently omitted any anchoring of his innovation and terrified the emperor; the result was the failure of his innovation.

5 Perceptions of Innovation

The anecdote constructs innovation as the work of a lone individual working in secrecy, a sudden leap forward (rather than gradual and incremental change),

25 *LSJ*, s.v. ἀρχιτέκτων, A2.

26 Murphy 2004, 201, notes that the anecdote presents Tiberius acting as 'the final arbiter of what was permitted to be known' in order to maintain order. This supplies a response to the query of Finley (1965, 41) as to why the craftsman sought imperial favour, rather than an inventor's support.

27 On anchoring, see Sluiter 2017.

a source of fear through its potential for disruption, and finally, something that can be stymied. Similar constructions of innovation are at play in stories of 'the improved product', first identified by Henrik Lassen.[28] He reports a salient example: tales circulated in the United States during the fuel crisis of the 1970s that lone inventors had independently redesigned cars to run with extraordinary fuel efficiency, even 85 km/l, which would have been a boon to drivers. The possibility of these marvellous cars has been debunked. But the untimely deaths of some of their inventors have fuelled claims that car manufacturers, the oil industry, and even perhaps the government were trying to keep these inventions a secret.[29] The reason, so it was believed, was that these parties were afraid the re-tooled cars would destroy the car industry, or perhaps even the economy, as their impact on gas consumption and tax revenues would be immense.[30] In the case of the unbreakable glass, the innovation is stymied by the emperor; the ultra-efficient cars were apparently thwarted by a mix of alleged powerful forces.

In the following stories, powerful individuals use violence to manage the spread of innovations that would benefit them if kept secret, but might prove not beneficial or even harmful if shared.[31] Ivan the Terrible blinded the architect of St Basil's cathedral, a structure of singular design, so that he might never produce anything similar.[32] Three stories are told of Haitian king Henri Christophe and his Citadelle Laferrière, an extraordinary structure built between 1805 and 1817 that seems to have employed leading defensive designs of the time. In the first, the architect was hurled to his death from the Citadel so that he might not reveal its design to others, including potential enemies; in the second, the architect was allowed to return home to his native France after the Citadelle was complete, but 'as his ship set sail from Cap Henri, Christophe launched a single cannonball from the Citadelle, which arced its 15-kilometer path to the harbor and struck the ship, killing all on board'; finally, upon its completion, German military engineers who had worked on the Citadelle

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28 Lassen 1995. Lassen's work is also discussed in Champlin 2008.

29 Crewdson 1978, Haitch 1979, and White 1995.

30 That outcome is improbable: it assumes that every car owner in the 1970s suddenly replaced their existing cars with new marvellously fuel-efficient models and, in so doing, cut their gas consumption by 90%. Similarly, in the anecdote about unbreakable glass, Romans would need to sell their precious metal decorative items and tableware, replacing them with unbreakable glass objects, or abandon purchasing them in sufficient numbers for metal currency to lose its value.

31 The stories are outlined in Crum 1952, 167.

32 See Perrie 1987, 96–97. In another version, Ivan blinds the architect of the fortress Ivangorod.

were imprisoned there so that they might not divulge the secrets of its construction and layout.[33] There are stories too of innovation that might pose a wider threat: for example, a man is recorded as having presented to Louis XV of France a recipe for Greek fire; the king, fearing the risks to mankind of such an invention, bought the man's silence and destroyed the recipe.[34]

6 Conclusion

The details of all the anecdotes presented in this paper are unlikely to be true, and they do not constitute a history of innovation.[35] But they do reflect what people have believed or feared a ruler might do or should do in response to innovation.[36] They also reflect the extent of the threat that people have believed innovation might pose. That belief continues today.[37] There are, for example, concerns about the installation of 5G wireless communication networks, with many countries claiming that the Chinese government will use networks that run on equipment manufactured by Chinese company Huawei for espionage. But individuals have also expressed fears that 5G networks will harm human health, and some even believe that they were responsible for or helped to spread the COVID-19 virus.[38]

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33 The details of the second and third stories come from Minosh 2018, 413, whose summary I quote. The identity of the architect, who was not named in official records, is uncertain; on the various suggestions, see Gharipour 2014 and Minosh 2018, 412, n. 12.

34 See Gillispie 1992, 52, who also notes (75, n. 34) that the story may be inaccurate: the inventor may simply have presented a recipe that would have been ineffective.

35 Saller 1980 argues that anecdotes contain little historically reliable information. MacMullen 1977, by contrast, argues more positively that anecdotes reveal to us the range of what might be possible, and Africa 1995 suggests that historians should not be too hasty to dismiss their veracity. The kernel of the story may have been true: Tiberius may indeed have been fearful of any disruption to his plans to protect the economy in the 30s CE, and developments in glass were challenging the popularity of precious metals in decorative applications. But the connection of the two elements, along with the craftsman's invention, was most likely fictitious.

36 Just as Tiberius had a reputation for being astute (on which see Champlin 2008), so according to Šubrt 2017, Petronius emphasizes Trimalchio as likewise savvy and able to understand the emperor's response.

37 Over the last forty years, research on the Social Construction of Technology (on which see especially Bijker et al. 2012) has explored popular misunderstandings of the processes and possibilities of innovation. These misunderstandings have persisted despite the efforts of those working in the field of Responsible Research and Innovation. On popular perceptions of the risks that may accompany innovation, see Roeser 2018.

38 See Destiny 2020 and Parveen and Waterson 2020.

The anecdote of Tiberius and the unbreakable glass entertains us as a story of imperial cruelty and as an amusing and fantastical interlude in the history of glass. But more importantly, as an example of a failed innovation, it complicates our understanding of Romans' perceptions of and responses to innovation: anchoring encouraged Romans to accept and adopt many innovations, as Anna Soifer's paper in this volume, for example, compellingly demonstrates; yet perceptions of their risks and anxieties about inventors' potential secrecy could counteract that encouragement. Finally, the anecdote also contributes to constructing a history of ancient Mediterranean technology more firmly embedded within political, economic, and social history.[39]

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39 For an example of such a history, see Flohr 2016.

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CHAPTER 9

Functional Innovation in Bookcraft in Roman Egypt

Mark de Kreij

1 Introduction

In the history of the Western book, the book roll, or *volumen*, has been drastically marginalised. An important reason for this is that the form is not familiar to us and, unlike for its successor the codex, we have few complete examples that we can explore with our own hands. When the use of the book roll in antiquity is discussed, we often come across impressionist descriptions like the following:

> reading the *volumen* in antiquity implied a continuous reading, involving the entire body because the reader had to hold the scroll with two hands, and this prevented the reader from writing while he or she read.[1]

The eminent book historian Roger Chartier goes on to say that 'we know that the codex (…) enabled practices previously impossible'. Both statements are presented as non-controversial, as clearly marked by 'we know that', and this adequately represents the common opinion among book historians at the moment.[2] My work on ancient books, both in the form of the book roll and the codex, has led me to start questioning these and other claims.[3] My main premise is that the book roll was a successful medium that was used and developed for centuries by countless (groups of) users. In order to challenge the prevalent narrative, my research starts from the papyrological data of book rolls and codices from the first to fourth centuries of our era, the period that saw the rise of the codex, the form that we now all associate with the word 'book'. The narrative that Chartier represents is a teleological one, considering the book roll solely as a deficient predecessor to the codex. The fact that the book roll was the main form of the book in the Eastern Mediterranean for

1 Chartier 2004: 151.
2 Compare for example Vandendorpe 2009 [1999]: 28–29.
3 I am not alone, but dissenting voices are few; see especially Mroczek 2011.

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around 3000 years, in combination with my experience of the multiformity of ancient book rolls, makes me hypothesise that Chartier's view is reductionist. I also wish to revisit the narrative of the emergence of the codex, which is often presented as a neat, linear development.[4] Anchoring Innovation provides the tools to throw new light on this crucial period in book history. In this chapter, I explore the development of the book in these centuries beginning from the actual material objects. I present an analysis of two data sets that both support and illustrate my point: one case of innovation in the medium of the book roll, and one local aspect of the innovative process that led to the codex.

2 Double-Use Rolls

In the course of editing a Homeric papyrus from the Yale collection, it emerged that what had seemed like documentary writing on the other side was in fact part of a word list to book 5 of the *Iliad*.[5] The handwriting on both sides is not the same, but roughly contemporary, and the contents of both texts are clearly connected. The text on the recto appears to contain a rather complex discussion about the armour of Achilles (referencing books 16 and 18 of the *Iliad*), which suggests that its users will have been advanced students of Homer. The word list on the other side gives quite simple prosaic equivalents of poetic words, which would have been of use to all readers of Homer, but especially relative beginners. By combining these two paraliterary texts on Homer's *Iliad*, whoever gave this book roll its current form made it relevant to a much wider range of readers. At the same time, they saved space and money by having multiple texts they needed copied onto the same roll.

At first sight, there are practical advantages to using both sides of the papyrus roll, and yet we do not often find it done. Even if both sides are written on, the original text tends to have become obsolete, so that the reverse side can be used for a new text. This tendency to avoid using both sides of the roll has to do with its physical limitations. At this point it will be useful to briefly introduce one of the methodological pillars of my approach: social semiotics. Social semiotics provides the tools to let objects speak about their social contexts, i.e. their creators and users, primarily. The framework provides the methodological tools to undertake a multimodal analysis of objects, which is particularly

4 Important publications are Turner 1977, Roberts and Skeat 1981, the contributions by Gascou and Van Haelst in Blanchard (ed.) 1989, and more recently in theological studies: Gamble 1990, Epp 1997, Stanton 2004, Meyer 2007, and Stanley 2016.

5 De Kreij and Colomo 2019.

valuable when studying text carriers. This holistic analysis takes into account textual, paratextual, and physical aspects of the text object under consideration. In this context, social semiotics introduced the term 'modal affordance', which refers to the fact that the physical shape of an object may determine (the limits of) its use.[6] Papyrus sheets are made from papyrus fibres overlapping in a vertical and a horizontal layer. The edges of each sheet are vulnerable, since the ends of the fibres are exposed there and may easily fray. The form of the book roll is ideal, because it reduces the most vulnerable parts of the book to four: top, bottom, beginning, and end. Since normally only beginning and end are handled, and these only rarely (since one normally holds the rolled up portions of the roll in either hand, not its very edges), the form makes sense with regard to the material. Since one unrolls the roll with one hand and rolls it up with the other, the back of the roll regularly passes through both hands. If it has writing on that side, this is likely to get smudged or abraded by handling it to read the other side. Therefore, although a papyrus roll *allows* writing on both sides, the nature of the medium does not invite it.

Nonetheless, in the case of the Yale Homer papyrus, both sides appear to have been in use at the same time. The question arose: is this a unique experiment, or an example of an as-yet unrecognised kind of book roll? Double-use book rolls are not a recognised type and as a result they are simply not visible in current online databases. Unsurprisingly, they are also overlooked in current literature, unlike the well-studied corpora of true opisthographs on the one hand, and re-used rolls on the other hand. Opisthographs are rolls used for the same text (or the same author) on both sides, written by the same hand. Re-used rolls are literary or documentary rolls of which the back is re-used for a different text, written by a different hand, and not in any way related to the text that was first written on the roll. In his recent article on 'book rolls with multiple texts', for example, Kaltsas only focuses on re-used rolls, and on those with multiple texts on the front.[7]

Since double-use rolls are invisible in the data, finding parallels of the Yale papyrus has been a painstaking process. The first step was to explore other Homeric papyri, which has yielded a significant number of parallels, where two sides of the same book roll were used for different kinds of Homeric scholarship. As more examples emerged, it became clear that the double-use roll is a technological innovation that requires an explanation.[8] On the one hand there are the advantages listed above, on the other hand there is the practical issue

6 See Jewitt and Henriksen 2016.
7 Kaltsas 2019.
8 For the examples we had found at the time, see De Kreij and Colomo 2019, 12–15.

of rolling and unrolling a book roll with writing on both sides. Their existence suggests that there was a social context in which the advantages of double-use rolls outweighed the disadvantages; we may pose the question: what 'people problem' was solved with this new form of a known technology?[9]

The dataset (so far) shows no geographical or chronological clustering: it consists of examples unearthed in Oxyrhynchus, Hermopolis, and Theadelphia, with dates ranging from the second century BCE to the fifth century CE.[10] As regards contents, however, a pattern does emerge: most examples can be linked with reasonable confidence to an educational or scholarly context. We find rolls with Homeric texts on both sides, like our Yale papyrus, but also examples with Homeric commentary on one side, and a grammatical schooltext on the other. There are summaries of Euripidean plays combined with Homeric commentary, as well as a more advanced text on medical science with medicine recipes on the back. The social group most likely to have been in charge of making these rolls—or causing them to be made—is that of school teachers and scholars, who were also the ones who made use of them. The other social group that used them is that of students at different stages of education.

The multimodal analysis of the objects, taking into account physical attributes as well as textual contents, has led us to a group of texts used by teachers and students. Which factors in this particular social context can explain the emergence of this technological innovation? On the basis of what we know about teachers in Roman Egypt, two factors that could be relevant are economy and efficiency. We know that teachers had limited means and that they rarely had designated teaching spaces.[11] By using both sides of a roll, the teacher could save money, but also space, making their materials easier to transport. The relationship between the texts on the two sides is different in each instance. In some cases the texts on different sides clearly cater to different educational levels, which could have a practical reason: one might use only the elementary side while teaching younger students, and only the more complicated text when teaching advanced students. After all, both sides could not be in use at the very same moment.

The corpus of double-use rolls is characterised by its random distribution across different times and places, which reflects what we know of the production of book rolls. Unlike books today, they were not centrally produced. One could buy a standard-length book roll in papyrus workshops, adjust its length

9 I borrow the expression from Sluiter 2016: 27.

10 Provenance of many literary and paraliterary papyri is unfortunately unknown, which also holds for a significant number of double-use rolls.

11 Cribiore 1996: 18.

as needed (by glueing on sheets or cutting the roll down), and have the desired text(s) copied from an original (often borrowed from friends or acquaintances). There were scribes who produced copies of certain works to be sold, but most copies appear to have been made on private initiative. By extension, there is no reason to assume that an innovation such as the double-use roll spread from one innovator across Egypt. Rather, different innovators, in similar contexts, pressed by similar concerns, took the same advantage of the medium of the book roll. It required no adaptation of the object, except to fill an empty space with writing, but it drastically altered its usefulness for the social groups involved. The innovation is firmly anchored in the particular requirements of one social and professional group. This conclusion anticipates to some extent the tenets of SCOT, the social construction of technology, that I introduce in more detail in my discussion of the next data set.[12]

3 Avant-Garde Antinoupolis?

The most drastic innovation in the Western history of the book is the transition from book roll to codex, which took place between the first and the fourth century CE. The exact path from book roll to codex is unclear, as many aspects of the development remain in shadows. One issue with existing explanations is the implicit aim to create a unified narrative that reduces the innovation to a single time and place.[13] Given the point I made above about the distributed production of books in antiquity, I propose that we attempt a different approach. Rather than search for a πρῶτος εὑρετής, we might accept that in the literary and material evidence we only catch glimpses of a development that cannot be reduced to one place, time, or individual. These isolated insights into the genesis of the codex as the new standard form of the book should not be regarded as pieces of some lost whole, but rather as evidence of the geographically and chronologically distributed nature of the innovation. I find it hard to believe that the codex spread out neatly in time and space like ripples in a pond from its central origin. Instead, I posit a messy process of innovations attempted at different times and in different places. Our evidence is much easier to explain if we accept this hypothesis, and in fact it allows us to

12 On SCOT see also Bijker, this volume.

13 Note the idea that Caesar invented the codex, see Roberts and Skeat 1983: 18.

pay due attention to local peculiarities. One such local outlier is the dataset from Antinoupolis.[14]

Antinoupolis was founded by Hadrian in 133 to honour his lover Antinous who had drowned in the Nile during a visit to Egypt a few years before. It was founded as a Greek polis, on a par with a relatively small number of other cities in the Egyptian chora, and must have attracted metropolitan immigrants as well as the rural people referred to on the famous Antinous Obelisk.[15] The remains of this sizeable city were originally excavated in the early 20th century, and its rubbish heaps yielded a respectable number of papyri. In recent decades, an Italian archaeological team has continued the excavations, adding some further papyrological finds. As Johnson, the editor of the first two volumes of the Antinoupolis Papyri, noted, the rubbish heaps in the city contained mostly late, Byzantine, material, and only a few mounds contained Roman material.[16] This may be due to the city's proximity to the river.

There are other peculiarities in the papyrological record from Antinoupolis, which have largely gone unnoticed. In a 1998 article, Menci notes the preponderance of parchment among the codex finds, but she fails to mention the fact that the codex *tout court* is surprisingly common among the Roman finds. In the period when the codex had been introduced, but was still the less common form of the book (second to fourth century CE), the Antinoupolis finds show a clear preference for the codex. The vast majority of Christian texts found anywhere in this period were written in codices, but in fact most of these Antinoupolite codices contain pagan literature or technical works.[17] In order to explain the possible significance of this statistical anomaly, I will return to the multimodal analysis from social semiotics introduced earlier in this chapter, and bring in the Social Construction of Technology (SCOT).

For the Antinoupolis papyri, the multimodal analysis allows us to identify not only the relatively high number of codices, but also the crucial fact that most are not Christian. Just as in the case of the double-use rolls, the concept of modal affordances is relevant to the issue of the innovation of the codex. Although some people have assumed that the first codices were made of papyrus, the physical attributes of papyrus make it unsuited to the medium of the codex.[18] If one uses papyrus sheets to create a codex, the vulnerable places

14 I first discussed this dataset in De Kreij 2021.
15 Grimm, Kessler, and Meyer 1994.
16 Johnson 1914: 178–180.
17 I gave the numbers in table 1 and 2 in De Kreij 2021, 278.
18 Stanton 2004: 178 and Meyer 2007: 302.

where the fibres are exposed and may unravel (see above) are suddenly multiplied, and moreover these very places, the edge of every page, are commonly handled. This does not mean that papyrus cannot be used to make codices, as clearly it has been; about half of the codices from the second to the fourth century CE are made of papyrus. In terms of affordances, however, the material papyrus is unlikely to have inspired the radically new form of the codex.

Parchment, conversely, is supremely suited to the codex form, and rather unsuited to that of the book roll. Unlike papyrus, its size is not naturally limited; animal hides allow for much larger areas of writing material, which have to be cut into strips to create a roll. For a codex, such a large surface area may be folded to create many pages, and cut afterwards. In other words, by its nature, papyrus invites the form of the roll, while parchment invites the form of the codex. This hypothesis has a number of implications that I will explore elsewhere, but for now we may focus on the Antinoupolis dataset. In order to complete my analysis of this evidence, we need a further theoretical component: the theory of innovation as conceived within SCOT.

According to SCOT, the (lack of) success of a technology is not based (primarily) on the intrinsic properties of the object, but on its place within society. The success of a technological innovation is not based on its inherent superiority, but on its social embedding, or anchoring. When discussing SCOT, scholars often refer to the completely non-linear acceptance of the bicycle as a new technology, but we may now also think of the electric vehicle, which had been feasible for decades and was attempted many times before it became accepted by the relevant social groups, leading to its eventual success.[19] It is my hypothesis that the codex took a similarly winding path, before it became the standard form of the book.

As for the Antinoupolis data set, a particular asset of this socio-technological analysis of innovation is its attention for the individual in the process. SCOT posits that the nature of an innovation is linked to the background of the innovator, which it puts in terms of *inclusion*. If an innovator is highly-trained in the relevant technology (e.g., book roll production), he is a high-inclusion actor, and his innovations are more likely to be incremental adaptations of the current standard. We may think, for example, of the double-use rolls discussed in the first half of the article. A drastic change, conversely, is typically conceived by an innovator who is a low-inclusion actor, such as a young professional, or an immigrant trained within a different culture.

19 Bijker 1995.

This brings us, finally, to the Antinoupolis codices. In this newly-founded city, we find many more codices dated between the second and fourth centuries, and in particular parchment codices, than in the rest of Egypt. Although the dataset as a whole is small, the same patterns emerge in the old and new excavations, and in the different locations where excavations have taken place, suggesting that it is roughly representative. As the Antinous Obelisk reports, the new city attracted immigrants from the Egyptian countryside, but it may well have been the destination of immigrants from Rome or the Near East.[20] It may be relevant that it was in these very years that Hadrian drove out the Jews from Judea, following the Bar Kokhba revolt.[21] Moroever, the only parchment book roll containing pagan literature (P.Ant. I 26, Xenophon, *Symposium*) found in Egypt, a medium much more common in the Near East, comes from Antinoupolis.[22]

Antinoupolis was a community created largely *ex nihilo*, and thereby to an extent an immigrant community. Among these immigrants there may have been book makers with low inclusion in Egyptian bookcraft, who brought their own ideas of the craft and introduced what must have seemed to the locals as a radical new form of the book. Alternatively, or additionally, the books' owners may have played a crucial role. The books under consideration all contain literary texts of reasonable quality or advanced technical or scholarly works. The intellectual contents and the high quality of the books is suggestive of the status of the individuals who owned them. They tell a story of an educated elite with a penchant for parchment codices at a time when nothing like this was happening elsewhere in Egypt. Their choice for this new medium may have been made in a metropolitan area like Rome, and they may have been the very people who were put in power of the new *polis* by the central administration. The high status and mobility of the administrative classes in the Roman empire made them the perfect carriers for spreading technological innovations.[23]

20 Grimm, Kessler, and Meyer 1994.

21 132–135/136 CE; see, e.g., Mor 2016. Hieronymus, *In Zachariam* III 11 reports 'old Jewish histories' stating that those Jews who could not be sold into slavery were transferred to Egypt to die there: *multa hominum millia venundata sint, et quae vendi non potuerint, translata in Aegyptum, et tam naufragio et fame, quam gentium caede truncata.*

22 See Nocchi Macedo 2016 on the parchment roll. There is one further fragment from Antinoupolis (P.Ant. II 72, Sophocles, *Electra*) which has sometimes been regarded as part of a roll, but Nocchi regards this as unlikely based on its late date (6th–7th century CE). BKT V.1 5, a 3rd-century CE fragment of *Iliad* 3 of unknown Egyptian provenance, may also be part of a roll, but this remains uncertain.

23 Rogers' theory of diffusion of innovations (Rogers 1962) enables us to track how and why the innovation spreads through the population. Rogers established that certain factors tend to motivate potential adopters to subscribe to the innovation; he distinguishes

The Antinoupolis codices show how a holistic study of already published material can reveal patterns that have hitherto gone unnoticed. Moreover, and more importantly, the application of the concepts from Anchoring Innovation, social semiotics, and SCOT allows us to create a model to explain the atypical pattern that emerges from the papyrological evidence.[24] This hypothetical model for Antinoupolis as one important node of innovation in the development of ancient writing technology in Egypt can only be improved or refuted by analysing further data.

4 A New Perspective

The two data sets presented above demonstrate the need for a new perspective on a comprehensive dataset of ancient book rolls and codices, and suggest an outline for future approaches. It will be hugely beneficial to combine the two theoretical frameworks discussed in this chapter, social semiotics and SCOT.

Social semiotics offers the methodology of the multimodal analysis. The study of the material aspects of books is normally called codicology, adapted to 'voluminology' by Johnson for his study of book rolls (*volumen* in Latin), but both can be subsumed under the term bibliology. A fully integrated multimodal analysis of ancient books allows us to infer information about producers, writers, and readers from the physical object that joined them. This kind of methodology has been widely applied in other fields, as well as to smaller ancient datasets,[25] but it has never been used to analyse a multiform body of papyrological evidence, nor in a study of technological innovation.[26] Once we have used the objects to learn about the social contexts they moved within, SCOT provides the framework to talk about the ancient book as a technology embedded in society. Innovations that we find in the material record can

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between innovators, early adopters, and laggards, among other groups. Individuals and groups in metropolitan areas, for example, are more likely to adopt an innovation. In addition, the innovation may have a symbolic value to a certain individual or group (also Eveland 1986). Finally, people in a position of power are more likely to adopt an innovation than those who have less power over their choices. This theory has obvious value for the question of the emergence and diffusion of the codex over the 2nd to 4th centuries, even considering the fact that our evidence is incomplete and fragmentary.

24 Rogers 1962 (see above, n. 22).

25 E.g., Cribiore 1996 and Johnson 2004.

26 See Corbellini (ed.) 2013 on religious mediaeval literature; Daybell and Gordon (eds) 2016 on early-modern letters; Mroczek 2011 on the Dead Sea scrolls; Sarri 2018 on ancient letters; Waal 2015 on cuneiform tablets.

then be studied not as isolated peculiarities, but as traces of a living, constantly evolving technology.

These developments are a crucial part of the history of the book; even if some innovations ultimately proved unsuccessful, we must remember that they *might* have been. Especially documentary, technical, and scholarly works have been ignored in the discussions of ancient bookcraft. In fact, exactly these kinds of texts can more easily be linked to specific professional or social groups (e.g. bureaucrats, scholars, socio-economic elite) than literary texts. The innovation potential of educational texts has already been illustrated by the case of the double-use rolls. Finally, every scribe who wrote literary book rolls probably spent some, if not most, of his time writing documents.[27] While they have never been included in this kind of study, these non-literary rolls have a unique potential to inform us about paths of innovation in bookcraft.

Arguably the largest open question of the history of the ancient book is that of the origin of the codex. The framework offered by SCOT suggests that rather than trying to pin down the innovation of the codex to a single point in time (now irretrievably lost to us), it makes more sense to study the physical evidence as snapshots from the long and winding road from book roll to codex. The discussion about the emergence of the codex has largely left behind functional arguments and data-led analysis, and focused on the question of early adoption among Christians. I hypothesise that the codex did not offer one particular advantage that made it supersede the book roll. The evidence suggests that the innovation cannot be traced to a single event, but that the parchment and papyrus codex were attempted at different times, in different places, before the form 'caught on': it was distributed innovation.[28]

This vexed question can benefit further from the perspective offered by Anchoring Innovation, itself in part aligned with SCOT.[29] Since at least part of the question concerns the adoption of a technological innovation by a religiously defined social group, it is exactly the kind of issue that Anchoring Innovation can help to illuminate. Unlike some other kinds of innovation and anchoring studied within the programme, innovation in bookcraft is difficult to study because (1) most innovations (except the obvious innovation of the codex) have not been properly identified because of a lack of big data research, and (2) the process of anchoring is not easily discernible in either the material

27 Messeri 2003.

28 The term, normally applied to modern innovations, was coined by Von Hippel 1988. The understanding of distributed innovation is now also used by companies as a strategy to kick-start innovation.

29 Sluiter 2016: 27.

or the literary sources. However, this chapter has hopefully begun to show a way in which this new "tool for thinking" may illuminate an age-old question in book history.

5 Postscript

In June of 2023, when this chapter had already taken its final form, the University Library of Graz published a story about the discovery of a 'codex' from the third century BCE in their collection.[30] The papyrus in question had been published as P.Hibeh I 113 by Grenfell and Hunt, a banker's account in two columns on the recto of a papyrus (TM 8242). The papyrus was later donated to Graz University, where it has the inventory number UBG Ms 1946.[31]

The exact nature of the fragment is currently being disputed; nonetheless, a few things are clear.

1. On one side of the papyrus sheet there are remains of two columns of writing with bottom margin still extant.
2. There are a number of apparently non-natural holes in the fragment.
3. On the back of the papyrus, the one now covered in gesso and paint from its re-use in mummy cartonnage, a small piece of twine is visible.
4. The shape of the fragment shows that it was folded along a vertical middle line, which is where we find the row of holes. The fact that the left half (of the back) shows gesso and paint, while the right only shows traces of gesso suggests that the fragment was folded up before it was added to the cartonnage.
5. There is no evidence of writing on the back of the papyrus.

In the news article published by Graz University, the conclusion is that 'it must have been part of a book in codex form'. Specifically, the story calls it 'a notebook recording tax accounts for beer and oil in Greek'. Let me say from the outset that I do not believe speaking of a codex is particularly helpful with reference to this object.

Soon after publication of the story, it became clear that the evidence might allow other conclusions, as experts from different fields weighed in. Zammit Lupi interprets the layout of the papyrus as two pages with a single column of writing in the middle of each, folded for its use in a 'notebook'. Alternatively,

30 See https://www.uni-graz.at/en/news/grazer-mumienbuch/, 22/06/2023; last consulted 26/06/2023.

31 Images and metadata available here: https://unipub.uni-graz.at/obvugrpapyri/content/titleinfo/7951240?lang=en.

these are simply two adjacent columns on a roll or a sheet, which was folded for its re-use in the cartonnage. If the former, we may wonder why a piece of thread from the 'codex' was left to mar the painting on the cartonnage. If the latter, then the holes and thread could be explained as a means to more firmly attach the fragment to the cartonnage.[32] This second option better fits what we know of papyri and their re-use in this period, but the position of the holes in relation to the fold line as well as the fine twine used complicate the picture.

The symmetry, the page-like lay-out of the two columns, and the position of the holes recalls the form of a bifolium in a codex. At the same time, the backs of these 'pages' show no signs of writing, so it would not have been a codex in the form that we know it. Moreover, even once the codex was the established form of the book, it was rarely used for documents such as accounts, and only at a very late stage.[33] If the holes and the thread do belong to this papyrus' life as a text carrier rather than its re-use as cartonnage, we may consider whether a number of documents had been sown together as an alternative to the *tomos sunkollesimos*, a book roll made of single documents pasted together, that became so popular in the Roman period.[34] In the latest publication, the holes and thread are interpreted by Zammit Lupi as remains of a tacket sealing of the folded document, which strikes me as a more convincing analysis.[35]

What I find most interesting in this discussion is the sharp reaction among scholars against the possibility of finding the codex form in the third century BCE. Although I do not believe the Graz fragment to come from a codex, it is completely plausible that someone experimented with a different way of organizing texts at any point before the codex became common in the material record. The title of the Graz article cited above asks 'Should the History of the Book be rewritten?' I believe it should be, but more thoroughly than the author of that article has in mind: we should not merely adjust the timeline, but it is time for a new approach to the development of the book roll and the innovation of the codex from the perspective of distributed innovation.

32 G. Schenke, on the Papyrology mailing list, 25/06/2023, with reference to Vandenbeusch, O'Flynn and Moreno 2021. Another possibility, raised by J.R. Morgan on the same mailing list on 23/06/2023, is that this was a reused contract that had originally been sown shut, a relatively common occurrence in Ptolemaic Egypt.

33 See Gascou 1989.

34 See Clarysse 2003 and De Kreij, Colomo, and Lui 2020: 23–26.

35 See Zammit Lupi *et al.* 2024. A co-authored full re-edition of the document, to which I have been asked to contribute, is forthcoming.

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PART 3

Technology

CHAPTER 10

Anchoring, Innovation, and Ancient Near Eastern Technology

Jill L. Baker

1 Introduction

"I think our need for it will build it for us," observed Plato in his *Republic*.[1] His insight into the seeds of invention and innovation is captured in the contemporary maxim 'necessity is the mother of invention.' This notion was enthusiastically embraced by my grandfather, who was an electrical engineer at Detroit Edison, a major utility company based in Detroit, Michigan, USA, in the early 1900s. Although an engineer, he was by instinct an innovator, and invented switches, relays, and various other components to enhance both efficiency and productivity. Decades later, my grandfather would proudly show me some of his inventions, explaining each one's purpose, demonstrating for me precisely how need inspires invention and innovation. Archaeology has taught me to appreciate that 'necessity' is informed by a variety of factors, ranging from simple curiosity to the threat of invading forces, climate change, economic cycles, cultic practices, megalomaniacs and their egos, and the desire to improve the quality of life.[2]

The processes of discovery, invention, and innovation are inextricably interwoven. Simply expressed, discovery is the process of finding, encountering, or observing something for the first time; invention is the process of creating something for the first time; and innovation is the process of changing or

1 Book II, 369c. Emlyn-Jones and Preddy 2013, 162–163.

2 Participation in this conference, *Anchoring Technology in Greco-Roman Antiquity*, has given me a fresh and expanded appreciation of how technological development is 'anchored' in established knowledge, tradition, and the familiar. It was an honor to have participated in the Anchoring Technology in Greco-Roman Antiquity conference, one of the best organized and most informative I have attended. I am grateful to André Lardinois, Stephan Mols, and Suzanne van de Liefvoort for so brilliantly coordinating it, particularly given the challenges of a global pandemic. I am equally grateful for their invitation to participate and for recognizing the ancient Near East in these discussions. I am grateful to Miko Flohr, Stephan Mols, Teun Tieleman and Suzanne van de Liefvoort for organizing the publication of the conference proceedings. I am grateful to J.H. Tidy for meticulously proof-reading my paper.

evolving something that already exists or developing new methods or ideas based on ones that already exist.[3] For the purpose of this chapter, 'invention' and 'innovation' are relevant as they relate to the theory of 'anchoring', or "the dynamic through which innovations are embedded in and attached to what is (perceived as) older, traditional, or known."; 'Anchors' are "the concrete phenomena or concepts that are perceived or experienced as the stable basis for innovation".[4]

Prior to learning about the theory of anchoring, it had been my practice to refer to the technologies of the ancient Near East as 'antecedents' to those of Greco-Roman antiquity.[5] The research, experimentation, and theorizing conducted by the Babylonians, Assyrians, Egyptians, Canaanites and Israelites allowed them to discover, invent, and innovate on a broad scale and establish a substantial pool of knowledge and resources upon which the Greeks and Romans could draw. The technologies and systems (mathematics, sciences, religions, etc.) of the ancient Near East were the technological ancestors, antecedents, or 'anchors,' of those that were advanced in Greco-Roman antiquity, and beyond, in new and creative ways. This chapter will discuss a selection of ancient Near Eastern technologies and explore how they served as 'anchors' for Greco-Roman innovations.

Many academic discussions of ancient technology focus on the ingenuity and achievements of the Graeco-Roman Mediterranean. Undoubtedly, this was a period of considerable scientific achievement, during which many theoretical, mathematical, scientific, and engineering concepts were developed or advanced. They were promoted by philosophers like Thales of Miletus (ca. 624–546 BCE), Anaximander of Miletus (610–546 BCE) and Pythagoras of Samos (570–495 BCE), while engineers including Archimedes of Syracuse (ca. 287–212 BCE) and Heron of Alexandria (ca. 10–70 CE), invented contraptions like the screw, organ, syringe, force pump, and the aeolipile, a precursor of the steam engine.[6] However, many of these achievements were based on an extensive body of knowledge established by even earlier civilizations in Mesopotamia, Egypt, and the Levant.

Herodotus (ca. 484–425 BCE) in his *Histories* describes numerous technological systems extant in Mesopotamia, Egypt, and the Levant, both contemporaneous and, more significantly, pre-dating his research and writing.[7] Similarly,

3 Merriam-Webster; Cambridge Dictionary.
4 Sluiter 2016, 32.
5 Baker 2019.
6 See also Sluiter, this volume.
7 Strassler 2007.

the Egyptian short-stories *The Journey of Wen-Amon to Phoenicia* (ca. 1100 BCE) and *The Story of Sinuhe* (ca. 1875/1800 BCE) describe the prosperous and sophisticated civilizations of the Egyptians, Phoenicians, and Canaanites and some of their contemporaneous technologies.[8] Yet, although it was truly a crucible of creative and innovative inquiry, inspired by the needs and demands of complex societies and historical events, the ancient Near East is frequently overlooked and undervalued as a cradle of science, mathematics, technology, literature, and art.

Archaeological remains, artistic representation, and textual evidence reveal the reservoir of knowledge and practices developed by these ancient civilizations. Notable examples include the libraries and archives found in the Hittite city of Hattusa (ca. 1900–1100 BCE); Ashurbanipal's (ca. 668–627 BCE) library at Nineveh (modern Mosul, Iraq); the Temple libraries at Nippur (ca. 2500 BCE), and Ebla (ca. 2500–2250 BCE); from Egypt, artwork and papyri have survived, including the Papyrus Rhind (ca. 1550 BCE), the Moscow Mathematical Papyrus (ca. 1850 BCE), and the Edwin Smith Papyrus (ca. 1600 BCE). It is not unreasonable to suppose that the Greek philosophers of the seventh century BCE, were well acquainted with the foundational knowledge and accomplishments of their predecessors and contemporaries in Egypt and Mesopotamia: Egyptian polymaths, such as Imhotep (ca. 2667–2600 BCE), Mesopotamian scholars including the astronomers Naby-akhkhe-eriba and Balasî, both *tupšars* (astronomers) to the Assyrian Kings Esarhaddon (r. 681–669 BCE) and Assurbanipal(r. 668–627 BCE), both from the seventh century BCE.[9] The work of these, and other, early polymaths, established a millennia-old database upon which later Greek philosophers would draw and build.

This chapter reviews technological innovation in the ancient Near East between the Early Bronze Age and the first millennium BCE. In particular, it discusses those technologies associated with a developed urban lifestyle and associated activities. From the Early Bronze Age onwards, sources reveal rapidly developing urban centres, with market places, temples, and civil and governmental administration. The sections that follow describe some of the technologies which ancient urbanites developed as solutions to their newfound dilemmas.[10] Rather than discussing the more traditional technologies, such as ceramics, metalworking, tools, and weapons, the following pages will

8 Wilson 1992, 25–29, 18–22.

9 Weiss 2020, 9–10.

10 To facilitate this discussion, 'technology' will be defined as "the practical application of knowledge, scientific or otherwise, to resolve a problem, achieve a goal, satisfy curiosity, make life easier or to accomplish change" (Baker 2019, 4). Adopting such a broad

highlight a range of less obvious innovations, focusing specifically on the topics of urban planning, domestic architecture, military technology and pyrotechnology. This approach will illustrate not only the breadth of knowledge, ingenuity, and inventiveness of Bronze and Iron Age communities in the ancient Near East, but also the impact that new technologies had on contemporaneous society and its capacity to resolve problems and improve standards of living.

2 Urban Planning and Surveying

During the Neolithic and Early Bronze Age period, urban centres emerged and expanded rapidly and city planning became a vital, though often overlooked, tool or technology in adapting to change. Given the challenges communal living presents for humankind, establishing guidelines, rules, and laws by which all must abide assisted in maintaining order and avoiding conflict. Urban planning facilitated the development of a structured environment by creating dedicated residential, business, industrial, administrative, and religious zones within the confines of a city.

Numerous sites provide early examples of city planning, including ‘Ain Ghazal, Çatal Hüyük, Sha’ar HaGolan, and Jericho in the Neolithic Period; Bet Yerah[11] and Tell el-Arad in the Early Bronze Age and Megiddo and Beersheba (Figure 10.1, 3) in the Late Bronze and Iron Ages in Israel;[12] in Egypt the workers’ villages of Giza (Fourth Dynasty), Kahun (Twelfth Dynasty) (Figure 10.1, 1), Deir el-Medina (Eighteenth to Twentieth Dynasties), and Tell el-Amarna (Eighteenth Dynasty) (Figure 10.1, 2); and in Mesopotamia by the cities of Ur, Babylon, and Nippur. Each of these cities had well-planned, organized streets, alleyways, and activity zones. While Hippodamus of Miletus is often described as the father of town planning and the inventor of the grid plan, these earlier examples indicate that both town planning and the gridiron system pre-dated his application of them in later Greek cities.[13] Hippodamus’ knowledge and usage of city planning, specifically the gridiron plan, was likely anchored in and influenced by earlier town planning in Mesopotamia and Egypt.

definition enables the inclusion of both a wide range of architecture, contraptions, mechanisms and conveniences, and a number of remarkable technologies from the ancient Near East.

11 Paz and Greenberg 2016.

12 Mazar 1990: 243–246, Herzog 1978.

13 Aristotle *Politics* 2.5.1 (1267b22), Simpson 1997, Humphrey *et al.* 2006, 435.

FIGURE 10.1 City Planning. 1) Workers' village of Kahun, ca. 1835 BCE. Adapted from Petrie 1891, Pl. XIV, PD-1923. 2) Workers' village at Tell el-Amarna, ca. 1353 BCE. Adapted from Woolley 1922, Pl. XVI, PD-1923. 3) Beer-Sheva, Stratum II, ca. 900–586 BCE (Z. Herzog 1993, 167)

Surveying techniques, which integrated geometry, mathematics, and a keen awareness of spatial dimensions, enabled the configuration of streets, building layouts, property boundaries, and farming plots in both the city and hinterland. In Egypt, for example, determining the boundaries for individually-owned farmland was particularly important both for calculating tax rates and re-establishing field boundaries following the annual inundation of the Nile. The worker's village of Kahun in Egypt, ca. 1850–1700 BCE (Figure 10.1, 1), offers one of the earliest and finest examples of the prominent role surveyors played in the layout of cities.[14] Kahun had a grid plan which included major and minor streets and established the size, shape and orientation of individual structures.[15]

Known as 'rope stretchers' and 'scribe[s] of the field,' Egyptian surveyors were members of the scribal class, indicating that they were well-educated members of Egypt's upper class.[16] Four Eighteenth Dynasty surveyors have been identified from their rock-cut tombs in the cemetery of Shaykh Abd al-Qurna, located in Thebes (Luxor).[17] The depiction of surveying activities on painted panels in their tombs confirms their identity as surveyors. Surveying in Egypt was conducted by stretching out rope, which could be as long as 100 cubits in length, knotted at cubit intervals. Other surveying tools included levelling instruments such as the A-frame and F-frame which were used with a plum bob to establish level surfaces; the cubit rod, set-square; and the *merkhet*

14 Mazzone 2017, Petrie 1891, 5–8.
15 Morris 1994, 29–30.
16 Lyons 1927, Paulson 2005.
17 Amenhotep-Sise (TT75), Khaemhet (TT57), Menna (TT69), and Djerserkereseneb (TT38).

(*mrḫt*), and the *gnomon*, which were used to establish the four cardinal points, orientation, and right angles. Greek and Roman architectural engineers would continue to use the *groma* and levelling instruments.[18]

Knowledge of geometry and mathematics in the ancient Near East is evidenced by a number of texts. One example is the Papyrus Rhind (ca. 1550 BCE), which discusses arithmetic and algebra problems, how to calculate volume and area using geometry, and problems related to pyramid angles.[19] Another relevant papyrus is the Moscow Mathematical Papyrus (ca. 1000 BCE) which discusses numerous problems of arithmetic, algebra, and geometry, including the volume and area of complex shapes.[20] Finally, numerous Babylonian cuneiform tablets, discuss arithmetic, geometry, fractions, algebra, cubic and quadratic equations and some discuss tables now referred to as Pythagorean triples.[21]

3 Domestic Architecture

Domestic dwellings in Mesopotamia, Canaan, and Egypt were constructed with a stone or mudbrick foundation and a mudbrick superstructure, covered with a thick lime plaster. Floors were either hard-packed dirt, plastered with thick lime, or paved with ceramic fragments, stone, or shell. Foundations and walls were built to adequately support multiple stories, usually two or three, and offer insulation against heat and cold.[22] Their architectural style typically comprised courtyard(s) and side rooms on the first floor, upper story rooms, work spaces, and both public and private areas. Courtyards were also used as workspaces and activity centres, while roofs frequently provided additional workspace and storage.

To combat the oppressive heat, engineers developed air cooling systems, known as *malqaf* in Arabic, or *baad gir* (*baud-geer*) in Persian, or 'wind catcher' in English. These were installed mainly in Egyptian and Mesopotamian homes. This ingenious cooling system incorporated a tower-like structure on the roof which was either square or rectangular in shape and could be uni-directional, bi-directional, or multi-directional. Because its purpose was to catch the wind, its angular shape was designed to create stronger air flow, and so the taller the

18 Paulson 2005, Lyons 1927, 135, Brock 2005, Lehner 1997, 210–215.
19 British Museum number 10058.
20 Barnard 2012, 1.
21 Most notably, Plimpton 322 (ca. 1800 BCE). Robson 2001, 2002.
22 Baker 2019, 82–95.

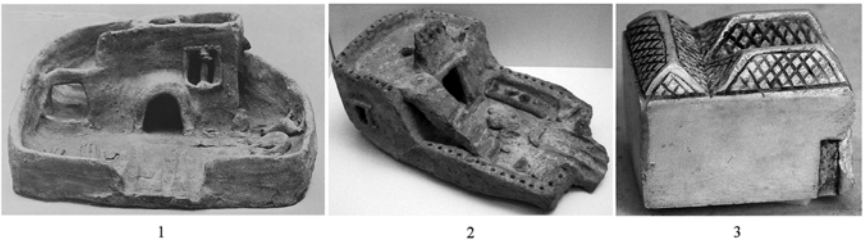


FIGURE 10.2 Wind Catcher. 1) Clay model of Egyptian house with wind catcher on roof, ca. 1850 BCE. British Museum EA 32610. Image adapted from Budge 1925, 467, Pl. III, PD-1923. 2) Clay model of Egyptian house with wind catcher on roof, ca. 2181–2055 BCE. Image: Keith Schengili-Roberts / Wikimedia. 3) Clay model of Egyptian house with wind catchers on roof. Early Dynastic Period, Abou Rawsh, near Cairo. Louvre, E 14698
IMAGE: WIKIMEDIA

malqaf the cooler and stronger the wind it would catch. Once trapped, the air was directed down into the house where it could be redirected either to pass over a pool of water in the courtyard, over the *qanat* (water canal under the house), through the depths of the cool earth, or simply to ventilate the house. The passage of cool air over water resulted in evaporation making the air even cooler. Whatever the preferred option, it proved to be an efficient and effective way to deliver cool, if not cold, air into and throughout the house, while also pushing out hot air.[23]

Clay house models found in tombs, called ‘soul houses’ or ‘spirit houses’ in Egypt and ‘spirit houses’ in Mesopotamia, provide striking examples of what ancient houses may have looked like.[24] Examples have been discovered in several locations in Egypt (Figure 10.2)[25] and in Babylon.[26] An additional example from Egypt, depicts a dwelling in the tomb of Neb-Ammun (thirteenth century BCE).[27] Each of these houses is represented with a wind catcher on the roof. So effective and efficient were ancient windcatchers, that this energy saving device to cool houses and buildings remains in use today in one of

23 Saadatian *et al.* 2011, Ford 2001, Mohamed 2010.
24 See on Egypt Budge 1925:466–468.
25 E.g. from Rifa in Egypt (Metropolitan Museum of Art, Accession Number 07.231.10; 13th Dynasty, ca. 1750–1700 BCE); Upper Egypt (British Museum Number EA32610; 12th Dynasty, ca. 1991–1778 BCE. Figure 2,1); and from the tomb of Abou Rawash, near Cairo (Louvre Accession Number E14698; Early Dynastic Period, ca. 3150–2686 BCE; Figure 2,3).
26 Rosicrucian Egyptian Museum, Catalog Number RC-2084.
27 Roaf 2005:1054, 2008, 2020.

the hottest climates on Earth, in Yazd province in Iran.[28] Steeped in tradition and efficiency, modern *malqaf* are anchored in ancient ones, which demonstrate the ancients' understanding of thermodynamics and evaporation and that dwellings and buildings can be successfully cooled without resorting to mechanical systems that use harsh chemicals.

4 Military Technology

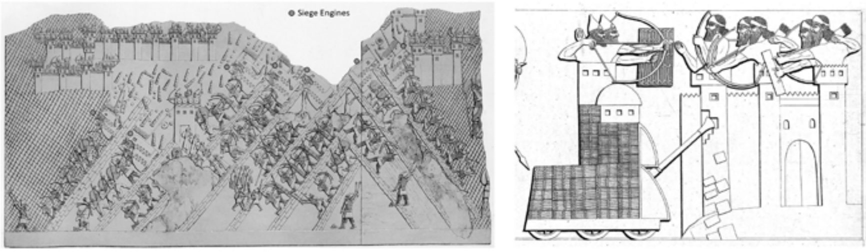
From the Early Bronze Age onward, Canaanite cities were encircled by fortification systems, in the form of walls, towers, and gates, to protect their urban centres and inhabitants from invading forces. The fortification systems of the Middle Bronze Age, however, were particularly impressive, innovative, and sophisticated.[29] These systems incorporated substantial stone foundations and mudbrick superstructures, including walls that could be up to 2.4 meters thick and watch towers and bastions that could measure between 5 × 10 meters to 26 × 26 meters.[30] During the Middle Bronze Age, city walls were supplemented by ramparts comprising giant earthen mounds abutting the exterior walls with a smaller counter-balance mound on the interior which prevented collapse.[31] Most ramparts employed a 30–40-degree slope which was often covered in loose rubble, rendering the surface 'slippery' and hampering an invader's ability to scale it. The ramparts were wide, ca. 25–40 meters, to prevent invaders from sapping or digging a tunnel under the wall to gain access inside the city. At the base of the rampart a wet or dry moat might be incorporated as a further barrier to invasion. Well-preserved examples of fortification systems with ramparts can be found in Israel at Ashkelon, Dan, Hazor, and Lachish. From the end of the Late Bronze Age and beginning of the Iron Age onward, newly constructed fortification systems either reused older ramparts, abandoned them completely, or established new ones. In these periods construction materials changed: while foundations continued to be made of stone, superstructures were constructed either entirely, or mostly, of hewn stones, referred to as ashlar blocks, which were largely uniform in size, with most sides dressed, with the remaining upper portions of the superstructure made either entirely of stone or partially of mudbrick.

28 Cf. Dehghani-sanij, Soltani, Raahemifar 2015, Pirhayati, Ainechi, Torkjazi, and Ashrafi 2013, Hedayat, Belmans, Ayatollahi, et al. 2015, Roaf 2020.

29 Mazar 1990: 198–208, Burke 2008.

30 Examples include Tell Beit Mirsim, Tel Zeror, and Gezer. Kempinski 1992.

31 Mazar 1990: 198–208, Burke 2008, Baker 2019, 95–97.



1 2

FIGURE 10.3 Assyrian Siege Engine. 1) Relief from the Palace of Nineveh of the 'Siege of Lachish', Israel, by Sennacherib, King of Assyria, Ca. 701 BCE (Layard 1853, Plate 21. PD-1923). 2) Relief of a siege engine from the Palace of Nimrud (Layard 1849, Plate 17, PD-1923)

Assyrian forces devised ways to breach substantial fortifications such as these. Preeminent among them was the armoured siege engine (Figure 3). Reliefs from the Palace of Nimrud during the reign of Tiglath-Plieser III (ca. 720–737 BCE) and panels portraying the 'Siege of Lachish' by Sennacherib, King of Assyria (ca. 701 BCE) illustrate battles waged between invading Assyrian forces and defending inhabitants.[32] The panels depict city walls, towers, gates and ramparts, weapons, battle tactics, and siege engines. The vehicles appear to be wheeled, having either four or six wheels, a battering ram(s), and they could be as tall as the city wall itself. The vehicle's superstructure was covered with protective wickerwork, wood, or rawhide, and outfitted with a fixed or movable battering ram. These armoured vehicles could accommodate a large number of troops and the height of the tower delivered them over the top of a city wall, while remaining relatively well protected.

Assyrian siege engines were precursors of the later *helepolis*, purportedly invented by Polyidus of Thessaly around 340 BCE and updated by Demetrious I of Macedon and Epimachus of Athens in 305 BCE,[33] but anchored in the example set by the Assyrians. The helepolis, of course, was a much improved and larger siege engine than those of the earlier Assyrians. To some extent, modern military tanks can be seen as incorporating elements of both the Assyrian siege engine and helepolis alike.

In order to remain undetected while crossing a body of water, such as a moat, or advance upon an island-city like Tyre, the Assyrians also developed an underwater breathing apparatus (Figure 10.4). Eighth century BCE reliefs from the Palace of Nimrud, depict military personnel, swimming unseen in

32 E.g. British Museum number 124906; Reg. No. 1856,0909.14.

33 Sekunda 1989, 133–134, Humphrey, Oleson, Sherwood 2006, 570–571, Baker 2019, 119–120.

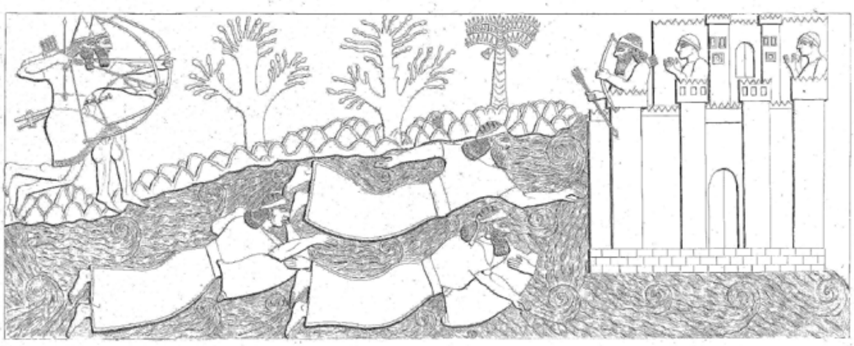


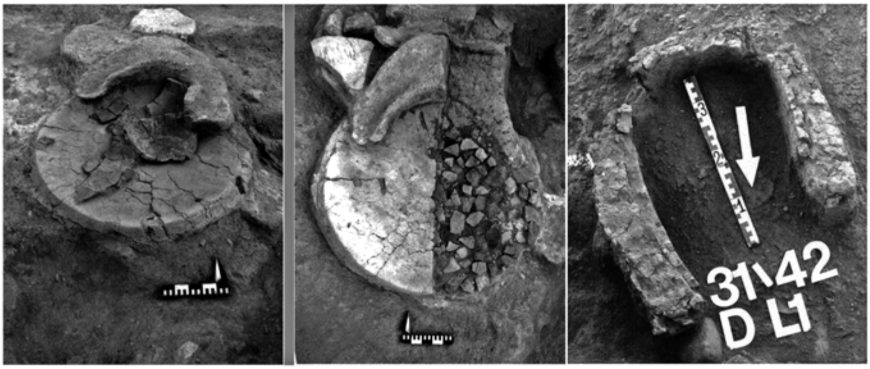
FIGURE 10.4 Assyrian soldiers (or fugitives) under fire while crossing a moat/river using inflated animal skins. From the Palace of Nimrud, ca. 850 BCE. Adapted from Layard 1849, Plate 33, PD-1923

water approaching a city.[34] The breathing apparatus was fabricated from animal skin, probably pig, with most of the skin sewn together and inflated with air, leaving one of the legs open to deliver air to the swimmer, functioning much like scuba-diving gear does today. Skins like these were also used as flotation devices, either for individuals or as pontoons to support rafts. Later, Aristotle described diving bells, inverted cauldrons inserted into the water so as to capture breathable air for a diver. These contraptions likely informed later underwater breathing machines such as those of Guglielmo de Lorena (1535), Nicholas Tarataglia (1551), Edward Bendall (1640), Edmond Halley (1691), Charles Spalding (1775), and Heny Fluess (1878).[35]

5 Cooking Technology

Most Bronze and Iron Age dwellings were equipped with a hearth. While they were the simplest and most affordable form of pyrotechnic installation, hearths were far from unsophisticated. In general, hearths were open and either round, ovoid, rectangular, or square in shape, measuring between 20 cm and 2.0 meters in diameter and 30–50 cm deep. To define and contain the burning area the perimeter was enclosed by non-flammable materials, such as rocks or bricks. The floor of a hearth was comprised of either a simple cleared surface, a shallow pit dug into the floor of a room, courtyard, or extra-mural open space, or a low mudbrick platform. Either the bare earth

34 Layard (1849) describes them as fugitives.
35 Bachrach 1998.



1 2

FIGURE 10.5 Hearth examples. 1–2) Type 4 hearths at Arslantepe, Turkey, period VI C (2700–2500 BCE). Adapted from Restelli 2015, 134, Fig. 4:2, 3. 2) Horse-shoe shaped hearth from Tell Arbid, H1 in Area D, Khabur ware period. Adapted from Smogorzewska 2012, 238, Fig. 13

formed the floor or it was coated with clay or mudbrick, above which a bed of river pebbles, stones, pottery sherds, or shells was carefully laid within the concave, semi-subterranean installation, and which basically acted as the heating element (Figure 10.5, 1).[36] The hearth's size, concave shape, and bedding material helped retain and radiate heat and enabled the user to create hot, warm, and tepid zones within the hearth. Fuel for the fire usually consisted of wood or dung, and possibly dry grasses to ignite it, and was laid on top of the bedding, which in turn protected the structure's sub-flooring and flooring. Research conducted at Tell es-Safi/Gath has been able to establish that in general, hearths could reach temperatures as high as 500–800 °C.[37] An example of a hearth from Arslantepe, in Eastern Turkey dating to the third and second millennium BCE, illustrates the shape and use of bedding materials (Figure 10.5, 2).[38] Some hearths were outfitted with a shelf or shoulder curving around part of the structure, which have been referred to as 'shoulder hearths,' as exemplified at Arslantepe (Figure 10.5, 1–2). The shoulder could be used as a warming feature while other pots cooked, and/or to rest cooking utensils when not in use. Examples of hearths with stone bedding were also found at Ashkelon, Tell es-Safi/Gath, and Chogha Mish.[39] Examples of rectangular

36 Black and Thoms 2014.

37 Gur-Arieh 2018, 67; Maeir 2015, 313–314.

38 Restelli 2015.

39 Ashkelon: Stager 2011, 25, 48; Tell es-Safi/Gath: Maeir and Hitchcock 2011. Chogha Mish: Alizadeh 2008, 33, 36, 37, 41, Pls. 7, 9, 15.

hearths were discovered at Tell Arbid in Northeast Syria from the Late Ninevite period.[40] The engineering of Bronze and Iron Age hearths, designed and built to achieve specific temperatures, capture and radiate heat, and create zones for direct and indirect cooking, demonstrated a keen understanding of thermodynamics. Hearths also provided a source of heat and were often centrally located in both domestic and public buildings, in multiple rooms of a single structure, and/or in courtyards, making use of adjacent flooring materials to radiate heat.[41]

As needs and life-styles changed, pyro-technology and cooking techniques adapted accordingly, particularly in urban settings, in which horse-shoe shaped hearths became extremely popular. This type of hearth was typically U-shaped, enclosed on three sides, with a wide, open front allowing access to the firebox (Figure 10.5, 3). Their construction could be as simple as three or four bricks situated directly on the floor.[42] More commonly, they were built on a low or raised platform made of stone and/or mudbrick, either set adjacent to or built into a wall or a niche.[43] Because of their configuration, horseshoe-shaped hearths created a hotter fire, directing heat upward to a pot or pan, so reducing the amount of fuel required to produce heat, and making them more efficient and economical than regular open hearths.[44]

Pyro-technology continued to develop to the extent that cooking installations began to resemble what we would recognize as modern stoves and cooking ranges. Ranges were used to supplement existing open hearths, horseshoe-shaped hearths, and ovens (though not discussed here), while each performed specific culinary tasks, demonstrating the significant strides made in pyro-technology. Archaeological excavation has identified two distinct types of stoves: linear and free-standing. Linear cooking ranges were typically bench-like structures affixed to a wall, with the cooktop above floor level, constructed of mudbrick, and covered with a thick white plaster (Figure 10.6, 1–2). Carved

40 Smogorzewska 2012, 236–237.

41 Smogorzewska 2012. Whether a hearth served for cooking or as a heating source may be determined by analyzing the debris in and around it. For example, if remains of flora and fauna are found in close proximity of a hearth, it indicates that most likely it was used for cooking.

42 For example at Tell Asmar, in the Northern Palace, Rooms E and F. Cf. Delougaz, Hill, and Lloyd 1967, Plate 76:B, C.

43 Platforms could be from a few centimeters high to approximately waist-height, as, for example, at Tell Arbid in northeast Syria, H14, Area D, during the Ninevite 5 period (ca. 2900–2600 BCE) in a dwelling quarter. Smogorzewska 2012, Figure 14.

44 Other examples include Nippur in the Enlil Temple, En Level III, Room 13, Phases Ia2 and 3 (McCown, Haines, and Hansen 1967, 15, Pl. 23A), Tell Asmar (Delougaz, Hill, and Lloyd 1967), Harappa (Meyer 2003), and at Ur (Woolley 1965).

FIGURE 10.6 Stoves. 1) Ebla, Royal Palace G. (ca. 2450–2300 BCE). Adapted from Peyronel, Vacca, Wachter-Starkady 2014, 17–18. 2) Ischali Kitîtum, room 1-Q.29 in Period IIB. Adapted from Hill and Jacobsen 1990, Pl. 18b. Free-standing cooking ranges. 3) Ishchali Kitîtum complex, Room 1-Q.29, Period III. Adapted from Hill and Jacobson 1990, Pl. 10b. 4) Abu Salabikh, Area E, Room 47. Adapted from Crawford 1981, 110, fig. 7

into the bench were multiple rounded, horseshoe-shaped openings, functioning as individual hearths or 'burners.' Each horseshoe-shaped burner stretched from floor level to the surface, with the lower portion operating as a firebox at floor level with a flue directing heat upward to the 'burner'. Large pots were set either directly into the coals, slightly above the coals on firedogs, or on top of a grill spanning the burner. A stove of this type was discovered in Palace G at Ebla (Figure 10.6, 1).[45] The stove in this kitchen boasted "eight plastered horseshoe-shaped hearths, set in a high bench with a plaster revetment built against the room's eastern wall".[46] Based on the height of these hearths, combined with fragments of globular, corrugated, and straight-rim jars found in and around four of the southernmost burners, it is thought that pots were inserted into the hearths and placed directly into the fire.[47] Based on flora analysis, it is speculated that this kitchen may have been producing medical remedies and/or substances for exotic, perhaps intoxicating, drinks used in ceremonies and rituals.[48] A similar linear stove installation was found at Ischali in the Kitîtum (Figure 10.6, 2).[49] This kitchen likely produced large quantities of food; in a later period, it was replaced with two free-standing ranges with multiple burners (Figure 10.6, 3).

Free-standing cooking ranges were set on solid, flat mudbrick bases, with mudbrick walls extending upward on three sides, enclosing most of the platform, leaving one short side open, and a hollow space in the middle (Figure 10.6, 3–4). The walls supported a mudbrick bench, with large holes on top functioning as burners. The hollow space below operated as the firebox with fires set below each burner. Pots and pans were likely set on top of a grate spanning each burner. These large stoves occupied the middle of a room, allowing cooks to access each burner from all sides of the installation. Examples of free-standing ranges include the "Oval Kitchen Stove" at Ishchali in the Kitùtum complex (Figure 10.6, 3),[50] which also demonstrates the transition from older to more innovative technology. Although the type of cooking apparatus changed, it remains evident that large quantities of people were serviced by this temple kitchen.[51] These cooking installations demonstrate ancient Near Eastern knowledge of thermodynamics and pyro-technology. Each apparatus cooked or boiled the cooking pot's contents differently based

45 In the so-called 'Special Kitchen,' Room L.2890, in Palace G, in proximity to the Court of Audience (ca. 2450–2300 BCE).

46 Peyronel, Vacca, Wachter-Starkady 2014, 17–18.

47 Graff 2012, 28, Mazzoni 1993.

48 Vacca, Peyronel, and Wachter-Sarkady 2017, Peyronel, Vacca, Wachter-Starkady 2014, 17–18.

49 Room 1-Q.29 in Period IIB, Hill and Jacobson 1990, 30–31, Fig. 11, Pl. 18b, Old Babylonian Period, ca. 1894–1595 BCE. Hill and Jacobson 1990, 7–75.

50 At Ishchali in the Kitùtum complex in Period III in room 1-Q.29. Hill and Jacobson 1990, 70, Pl. 10b.

51 Other examples have been found at Tell Asmar in the Private House Area, in the kitchen of the Arch House, room J 19:41, in Stratum Vc (Delougaz, Hill, and Lloyd 1967, 154–155, Pl. 67C) and at Abu Salabikh (F1 7515), in room 47, on the west side of court 71, in Iraq (Figure 10.6, 4).

on the desired food outcome. Nevertheless, each apparatus was anchored in several ways: in knowledge of thermodynamics, in pre-existing architecture of cooking apparatus, and in the need to cook food.

6 Discussion

The contraptions and systems referenced in this chapter, eclectic as they may be, represent a tiny fraction of the extensive scientific, mathematical, and engineering knowledge and acumen that peoples of the ancient Near East acquired and accumulated as a result of the theory, research, and development that established them. Separately and collectively, the examples discussed above illustrate not only breadth of knowledge, imagination, and ingenuity, but also the capacity to grasp and establish a wide range of engineering, scientific, and mathematical concepts and apply them to creating practical solutions while adapting to their physical and cultural environments as these evolved over time. The people of the ancient Near East demonstrated a remarkable capacity and ability to harness natural resources to produce energy for a variety of purposes, and a keen awareness and understanding of order and organization to promote economic wellbeing, public welfare, effective administration and good government. Their thirst for knowledge and boundless ingenuity testify to the unending quest for self-improvement and scientific advancement. Thus, establishing foundations and systems, anchors, on which future inventors and innovators could build.

If it is true that necessity sparks invention and innovation, what, then, inspires and informs the fabrication of new technologies, machines, and systems? The laws of physics, chemistry, science, and nature? Tradition and sociocultural norms? That which is familiar and therefore comfortable and easier to work with as a starting point? The evidence discussed in this chapter suggests that all of these serve as anchors for invention, development, and the manufacture of devices, machines, and systems; anchors that function as a foundation of established knowledge upon which and from which later ideas, improvements, and new innovations can be produced. For example, the conception for the Assyrian siege engine (Figure 10.3, above) was probably based on wagons. Wagons were four-wheeled vehicles used to transport bulky, heavy items and were pulled by oxen, donkeys, or horses. Wagons were used to carry harvested produce from field to barn for processing and from farm to market, for example. As the need arose for a siege engine, military engineers likely began with something familiar: the wagon (an 'anchor'), from which they developed an armoured vehicle for use in battle (the invention/innovation). The wheeled wagon was the 'anchor' for the siege engine that would allow the newly developed machine to move and transport the upper portion to the battle field. The innovative aspect of the siege engine was the superstructure built on top of the wagon, which accommodated weapons and soldiers, delivering them to a point of attack in battle in relative safety. Looking forward, the Assyrian siege engine informed the Greek *helepolis*, which informed siege towers of the Roman periods and Middle Ages, for example Leonardo da Vinci's fighting vehicle, which, in turn, informed the armoured tanks and vehicles that remain in use today. The Assyrian siege engine is but one example in which the anchoring aspect of invention/innovation can be observed.

The peoples of the ancient Near East left an invaluable legacy of knowledge and first principles on which succeeding generations could confidently build and reach out into the unknown. The continuity provided by anchoring coupled with the creative aspects of invention and innovation provided a comforting sense of connection to the past, and even the present, while at the same time propelling creativity into the future. Innovation that is connected with the past offers a familiar and relatively safe place from which to venture forth into the new and unknown. Familiarity and a sense of continuity which anchoring provides, makes innovation more easily acceptable and more easily integrated into the mainstream of society and culture. Each of the contraptions discussed above illustrate practical and theoretical anchors, foundations for later development, even when neglected or forgotten for centuries. If it were not for these vital first principles (anchors), Hellenistic philosophers and Roman engineers would have been starting from scratch and their contributions to civilization would have been less impactful. Innovation and technological advancement tend to be rooted in established knowledge; that is to say, by understanding the deep history of human technology, the ancient Assyrians, Babylonians, Egyptians, and Canaanites/Israelites are as relevant as the Greeks and Romans.

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CHAPTER 11

From Hand-Bow to Torsion Artillery Devices: Technological Innovation and the Human Factor

Maria Gerolemou

1 Introduction

This chapter explores technological innovation by discussing one case: the development from archery to artillery in the Greco-Roman world. Specifically, it examines the hand-bow (χειρουργικὸν τόξον), a well-known non-torsion mechanised bow called *gastraphetês* (belly bow), and two kinds of catapults that work with torsion; the *palintonos*, a double curved bow catapult which threw stones, and the *euthytonos*, a single curved bow catapult that shot arrows. The *gastraphetês* is described as an improvement of the hand-bow. It increases the range of the missiles not exclusively through muscular force.[1] In contrast to the hand and mechanised bow whose operation depends up to a certain degree on the human body and its muscles, the *palintonos* and *euthytonos* catapults are propelled through simple interactions, e.g. the pulling of a trigger, and by taking advantage the force of twisted ropes (τόνοι) made out of hair or sinew.[2] Both inventions are part of the general development of siege equipment under the auspices of the Dionysius the Elder (*c.*430–367 BCE), the tyrant of Syracuse, and the king Philip II of Macedon (382–336 BCE) during the fourth century BCE.[3]

Besides serving practical needs and aims (defence and victory), the successful adaptation of these artillery devices, similar to other technological innovations in the Greek and Roman world, depends on a variety of other things, chief among them, as we will see, up to which degree those are controllable by their human operator.[4] The successful diffusion of a new device is also inextricably linked to the manufacturer's incentives. Inventors of artillery devices seem to follow one implementation methodology: They employ a trial-and-error

1 See Hacker, 1968 37–38. Rihll 2007, *passim*.
2 Ctesibios' catapults were powered by air, and by metal (see Philo *Bel.* 77).
3 For discussion, see Bugh 2006 and Aristotle *Politics* 7.10.6; 8.
4 Cf. the case of medical machines and how physicians often feel anxious and unable to control them, and Gerolemou 2023.

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practice which, however, is not averse to a learning process based on observing the successful choices of previous engineers. This similarity and closeness of the new device with previous successfully tested engines creates a framework of familiarity which facilitates its adaptation.

Nevertheless, despite this strategy and its technological success, both non-torsion and torsion catapults represent innovations that, as we will see, were not powerful enough to redefine what their users valued most: *andreia* and *kleos*, courage and good reputation, depending on how and to what degree a warrior is involved in diminishing his enemies. This limitation did not necessarily impede their technological progress; artillery devices were successfully adapted and disseminated in Greco-Roman antiquity, securing victories while ensuring their users' safety. However, these devices do not seem have been influential enough to change societal expectations and martial behavior, even though they increased the chances for safety and victory. The enduring significance of sociocultural factors over technological advancements highlights the complex interplay between innovation and traditional martial values.

2 The Hand-Bow

The hand bow is a controversial weapon in Greek literature since it allegedly challenges the notion of *andreia*, bravery,[5] which in the archaic period is associated to the idea of close combat, masculinity, and nobleness.[6] A warrior devoid of martial courage is marked as unmasculine and unable to pursue personal glory that survives in the future even if the hero should fall in war. In support of this, modern scholars often quote the famous battle scene between Diomedes and Paris in *Il.* 11.379–95, where Diomedes wounded by Paris and his bow underlines the cowardice of the archer, whom he likens to a woman or a child. They also discuss Archilochus fr. 3 (West), often assumed to be referring to the Levantine war between Eretria and Chalcis,[7] which describes the archaic ideal of a hand-to-hand combat through the limited use of slings and bows and the praise of swords and spears:

5 On the concept of *andreia* see Sluiter and Rosen 2003, *passim*.

6 On cowardice as associated with the bow see *11*.385–95, Aeschylus *Persians* 147–9; cf. Aristophanes *Acharnians* 707 Thucydides 4.40 and Dunn 1996, 124; Kirkpatrick and Dunn 2002, 45. See further on that Lissarrague 1990, 97, 113f.; Cohen 1994, 696–715; D'Amato 2016, 803.

7 See, among others, Donlan 1970, 131–33, 135–136. But see Wheeler 1987, arguing against any connection between Archilochus fr 3 and the Levantine war dated ca. a generation before Archilochus.

> Not many bows will be stretched nor will there be numerous slings, whenever Ares brings together the press of battle on the plain; it will be the woeful work of swords. This is the warfare in which those spear-famed lords of Euboea are skilled (tr. by Gerber)

> οὔτοι πόλλ᾽ ἐπὶ τόξα τανύσσεται, οὐδὲ θαμειαὶ/ σφενδόναι, εὖτ᾽ ἂν δὴ μῶλον Ἄρης συνάγῃ/ ἐν πεδίῳ· ξιφέων δὲ πολύστονον ἔσσεται ἔργον·/ ταύτης γὰρ κεῖνοι δάμονές εἰσι μάχης/ δεσπόται Εὐβοίης δουρικλυτοί.

Support is also drawn from Euripides' play *Heracles* where the bow constitutes the basis for a discussion on cowardice as opposed to bravery, εὐψυχία. Specifically, at 140–203, Lycus argues that if Heracles is ever deprived of the bow, he will prove to be a coward. According to him, Heracles has never learned to face the spear in battle nor to use his bare hands to defeat the enemy, i.e. he could not win without his bow.[8] While the archaic agonistic ideal of close combat may seem incompatible with the use of the bow and distant battle, both Homer and Euripides highlight the skill, knowledge, and technique required by archers. For instance, in the *Odyssey*, Odysseus demonstrates his prowess in the bow contest (21.397–399). Similarly, in Euripides' Heracles, the use of a bow emphasizes the archer's expertise.[9] As I have argued elsewhere, in *Heracles*, Amphitryon defends his son's well-deserved reputation as the best of all men (183, ἄνδρ᾽ ἄριστον), exactly by exhibiting both the advantages of the bow and the technical skill required to wield it effectively.[10] He argues that this device gives the archer the chance to confront his enemy from a safe distance (170–194), and allows him to injure the enemy without being injured. It also provides him with a kind of autonomy: unlike the hoplite to his spear, the archer is not a slave to his weapon but the one who wisely and skilfully guides it. Moreover, as Amphitryon maintains, if a spear breaks, the soldier cannot defend himself, but if an arrow is lost, it can rapidly be replaced by countless other arrows (195). Both the arrows' replaceability and the fact that it's being overly controlled by the archer help eliminating the factor of chance (203, σώιζειν τὸ σῶμα, μὴ ᾽κ τύχης ὡρμισμένον). Hence, while for Lycus only a weapon

8 They also rely on Pausanias who states that archery is not a Greek custom (1.23.4, Ἕλλησιν ὅτι μὴ Κρησὶν οὐκ ἐπιχώριον ὂν τοξεύειν); see e.g. Snodgrass 1964, 156.

9 Moreover, the story of Philoctetes, Heracles' bow plays a significant role in the victory of the Greeks against the Trojans and Diodorus reports that Heracles was bestowed the bow by Apollo because of his *aretê* (4.14; 5.16).

10 Gerolemou 2022. Further on the importance of the bow in the play see Hamilton 1985; Padilla 1992.

that allows a face-to-face, close battle could be accepted as an aid towards the acquisition of bravery and *kleos*, for Amphitryon the technical advantages of a weapon and its skilful operation, in our case by the archer, is what makes a weapon and its user a successful team; the virtue of *andreia* is here being challenged or enhanced by the wisdom or skills of the user.

3 Non-Torsion Catapults: the Case of the Belly-Bow

I will now turn to the case of *gastraphetês* ('belly bow') which was invented sometime before 399 BCE.[11] Hero in his *Belopoeica* describes its earliest form: At paragraph 75 he gives us the reasons why suddenly people felt the need to revolutionise the traditional bow: 'Originally the construction of these engines developed from hand-bows (with engines he refers generally to artillery devices). As men were compelled to project by their means a somewhat larger missile and at greater range, they increased the size of the bows themselves and of their springs [...]. As a result, they (sc. springs) could hardly be persuaded to bend and required greater force than the pull exerted by the hand. Therefore, they devised something like this (sc. the *gastraphetês*)'.[12] What we learn from this passage is that the *gastraphetês* takes advantage of the design of the traditional bow, but apparently the device takes a step further and substitutes greatly for human arm and shoulder muscles in order to increase its impact and range.[13] Hero constructs here a narrative of progress in which the invention of *gastraphetês* follows a continuous line of development which starts with the previous invention of the hand bow. However, and while

11 See Campbell 2003, 3–4. But see also: Mardsen 1969. In chapter two he argues that *gastraphetês* was invented in 399 BCE. Rihll (2003) chapter two dismisses too the idea that this device might have existed prior to 399 BCE.

12 Translation by Marsden 1971. Τὴν μὲν οὖν ἀρχὴν ἤρξαντο γίνεσθαι τῶν προειρημένων ὀργάνων αἱ κατασκευαὶ ἀπὸ τῶν χειρουργικῶν τόξων· βιαζόμενοι γὰρ ἐξαποστέλλειν δι᾽ αὐτῶν μεῖζόν τι βέλος καὶ ἐπὶ πλείονα τόπον αὐτὰ μείζονα ἐποίουν καὶ τοὺς ἐν αὐτοῖς τόνους, λέγω δὴ τὰς ἐκ τῶν ἄκρων κάμψεις, τουτέστι τὰς [ἐκ] τῶν κεράτων σκληρότητας· ἐκ τούτου δὲ συνέβαινε, δυσπειθῶς καμπτομένων αὐτῶν, μείζονος δυνάμεως δεῖσθαι ἢ τῆς γιγνομένης ἀπὸ τῆς χειρὸς ἕλξεως. πρὸς δὴ τοῦτο ἐμηχανήσαντό τι τοιοῦτον.

13 As Rihll 2003, 52 puts it, two devices are required for the construction of a *gastraphetês* or generally a catapult: 'a mechanical device to take the place of the archer's arms, to draw back the bow, and another mechanical device to take the place of the archer's fingers, to hold and release the bowstring. A ratcheted stock and slider took the place of the archer's arms. The stock modelled the archer's bow arm, holding the bow firmly, and the slider moved backward and forward in the stock, modelling the archer's bowstring arm'.

he refers to the degree to which this is seen as better than the hand bow it replaces, he gives us no technological reason for why *gastraphetês* could not have been invented earlier.

While this kind of substitution for the archer's arms could have raised concerns similar to the ones we saw raised by Lycus with regard close vs distant combat, the experience-driven design of the device—it resembles a traditional bow—seems to have been intentionally adopted for the product's successful adaptation. Moreover, the device requires from the operator to use his entire body in order to bring the string against his 'belly' into the locking mechanism. This in combination with its name, *gastraphetês* (*gastêr*), belly bow, makes the device to look familiar:[14] the warrior's body collaborates with the weapon. Design and name of the *gastraphetês* seem to transfer some human qualities to the weapon with the purpose of shaping the user's behaviour towards it. In this way, the warrior develops a reciprocal relationship with his weapon, which allays potential fears that might be associated with the use of an advanced piece of technology. This relationship, however, is not based on true facts: While the use of the warrior's body applies force and is being involved in the stretching of the bowstring, what is decisive in this procedure are the design and operation of the pipe (σύριγξ), the slider (διώστρα), the groove (ἐπιτοξίτις), the block (χελώνιον), the claw (χείρ), the holders (κατοχεῖς), the withdrawal-rest (καταγωγίς) the arms (ἀγκῶνες) and the successful function of the trigger (σχαστηρία) which actuates the function of the belly bow by both securing and releasing the missiles.[15] In contrast to the traditional bow, made from wood, horn, sinew and glue, over which the archer has full control, the belly bow is the result of a mechanical design which involves the combining of the above components that serve a specific engineering task. Over this mechanical process which embraces the motion of distinguishable elements, the user of the belly bow cannot have full control. To be more precise, not even the engineer who designed it, could predict what could possibly go wrong. He can only learn from errors and improve the machine or guide its users how to operate it (see Hero *Bel.* 79).

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14 The ends of the bow are also called arms, ἀγκῶνες (Hero *Bel.* 78).

15 The tensile strength of a *gastraphetês* is significantly greater than that of a regular bow (and obviously of a bare hand) whose effective range is in the region of 150–200 yards, and Marsden 1969, 12 estimates an effective range of 200–250 yards for such a tension weapon. Biton in his *Construction of War Machines and Catapults* describes more advanced types of *gastraphetês* invented by Zopyrus who added two new elements: the winched pull-back system and the stand both necessary for bigger and heavier machines. See on that Marsden 1969, 13–14. and Campbell 2003, 6.

The novel technology of *gastraphetês* tries, nevertheless, to be consistent with the values and experiences of the warriors and society. By including the body and muscles of the warrior in its operation and description the belly bow seems to nourish the belief that he could win a battle in collaboration with his weapon and not because the superior weapon wins the fight for him. This idea is important for preserving core social values, such as *andreia*, as we saw in the previous section. Despite, however, the strategic design and presentation, the novel machine was viewed with suspicion at least in some parts of the Mediterranean.[16] This is what we learn from Plutarch at *Reg. et. Imp. Apophth.* 190D when he quotes the words of Archidamus III, the son of Agesilaus: when he saw a missile shot by a non-torsion catapult, which had been brought then for the first time from Sicily, he cried out 'Great Heavens! Man's courage is no more'.[17] His reaction underscores exactly the complex interplay between technological innovation in warfare and the prevailing cultural ideals of valor and heroism.

Because of the scarcity and sometime obscurity of sources, it is difficult to understand technological change in antiquity or better said to observe the stages through which an innovation goes until its final recognition and acceptance. Everett Rogers' *Diffusion of Innovations* (DOI) theory,[18] which explains how a new idea, behavior, or product is being adopted by the society, argues that some people or social groups are more apt to welcome an innovation than others. DOI theory differentiates between different types of adopters of an innovation: For instance, it identifies 1. The Innovators: These are people who want to be the first to try an innovation; 2. Early adopters who are very comfortable adopting new ideas; 3. Early Majority: these people need to see evidence that the innovation works before they adopt it; 4. Late Majority: these will only adopt an innovation after it has been tried by the majority; 5. Laggards: those who are very conservative and thus very sceptical of accepting and adapting new ideas in general. Although, it is particularly hard to apply this theory to ancient cultures where individuals, groups and their motives are difficult to identify, the anchoring innovation concept developed recently by the Dutch classicists focuses on innovation and change in antiquity and helps us understand the various social dynamics that could be involved in what is being described as technological innovation in classical antiquity. As Ineke

16 On a discussion on the relationship between *andreia*, catapults and social conservatism see Keyser 1994.

17 Marsden 1969, 65. Cf. the Gauls facing for the first time with Roman siege machinery, they surrendered without a fight (Caesar *Gallic War* 2.12, and 30–31); as cited by Rihll 2003, 115.

18 Roger 1962.

Sluiter describing the concept of 'anchoring innovation' puts it: '[i]nnovations may become acceptable, understandable, and desirable when relevant social groups can effectively integrate and accommodate them in their conceptual categories, values, beliefs and ambitions.'[19] Whereas Roger's idea of innovation depends on the compatibility or incompatibility of an innovation with values, memories, needs of the user, etc, the anchoring concept's key idea is 'societal negotiation', where innovation is integrated into the social group's existing beliefs and values. In the case of the catapults the 'human factor', that is the cooperation of the warrior's body with his weapons, is crucial for their successful diffusion. In the next artillery device that we are going to discuss in this chapter, that is, the torsion catapult, the warrior's body is involved even less in the process of 'harming' the enemy.

4 Torsion Catapults

I should now discuss the case of torsion catapults which by utilizing torsion with the help of a winch and more elastic materials (sinew and hair), they increase even more their power and range. Hero reports about this development at paragraph 81 of his *Belopoeica*: 'By means of the above-mentioned engine [i.e. the *gastraphetês*], of course, a larger missile could be projected at longer range. But they wished to increase both the size of the missile and the force of projection'.[20] That is why they proceed with designing torsion catapults. I will not discuss here separately the cases of *palintonos* and *euthytonos* catapults. It suffices to say that, according to our evidence, the use of torsion catapults dates to the second half of the fourth century BCE,[21] and the great impact force helped their spread. Philon in his *Bel.* 76 while describing Dionysius of Alexandria's repeating catapult, says the following: 'It fired, at the longest range, slightly more than one stade [i.e. 200 yards]. Such a neat

19 Sluiter 2017, 23. On the Anchoring Innovation Project see: https://anchoringinnovation.nl/.

20 Translated by Marsden 1971.

21 On that see Marsden 1969, 56–59; Keyser 1994, 38–53; Rihll 2003, 73–81; Campbell 2003, 8f. Pliny the Elder claims that one type of catapult was a Phoenicain invention (*HN* 8.20); but the scorpion was invented by Pisaeus son of Tyrrhenus. Diodorus reports that the catapult was invented under the patronage of Dionysus I in Syracuse, in 399 BCE. Specifically, he says that this device created great distress because it was a new invention (14.50.4, καὶ γὰρ κατάπληξιν εἶχε μεγάλην τοῦτο τὸ βέλος διὰ τὸ πρώτως εὑρεθῆναι κατ᾽ ἐκεῖνον τὸν καιρόν). Marsden 1971 and Marsden 1969, 49, 54–6, and Campbell 2003, 3–7 believe that Diodorus must be refereeing here to the invention of the *gastraphetês*.

arrangement is the design of the repeating catapult, embodying an ingenious and complex plan. Yet it has not found a noteworthy use. We must direct most of our research, as we have often insisted, to achieving long range and to tracking down the features of the engines which lead to power. By the means just mentioned, I see no advance made in these respects, but merely that several missiles, loaded simultaneously, are fired singly in rapid succession'.[22] Technical treatises present also technological failures of these devices. Similar to the *gastraphetês*, torsion artillery engines are improved through a trial-error procedure (what matters most here is the diameter of the spring cylinder), and in the end successfully adopted. As Philo puts it in his *Bel.* 50 by quoting Polycleitus, the sculptor: 'Perfection (τὸ εὖ) is achieved gradually (παρὰ μικρόν) in the course of many calculations (διὰ πολλῶν ἀριθμῶν)'.[23]

Nevertheless, and similar to the case of the belly bow, torsion artillery devices raise outside technical texts some criticism. This seems to be related to the fact that the engines' novel design (Philon *Bel.* 58, ἐξ ἀρχῆς ἐπινόησις) appears to cancel any relationship between the function of the device and the body of the warrior, and thus, threaten to turn the latter into a simple user or to a type of technologically enhanced warrior whose glory depends on various types of weapons, especially, on catapults. This is exactly what is being mocked by Mnesimachus, a Middle Comedy writer, with regard to Philip's the second use of artillery in his *Philip* fr. 7 (see especially, v. 10, καταπέλταισι δ' ἐστεφανώμεθα; see also Timokles, *Heroes* F12).[24] The fading away of the Greek idea of warfare depending on close battle, warriors' bodies and men's valour is being criticised by Polybius as well at 13.3 where the historian attacks Philip V and his military tactics and praises the Romans: here he describes the use of missiles as κακοπραγμοσύνη, treacherous dealing, and κακομηχανία, plotting mischiefs,

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22 Translated by Marsden 1971.

23 According to Frontinus, in his *Stratagems* (in the prologue of book three), engines of war in his era [first century CE] have long since reached their limits. Diodorus, on the other hand, describes Demetrios Poliorketes 'ready in invention and devising many things beyond the art of the master builders' (20.92.1–2, εὐμήχανος γὰρ ὢν καθ' ὑπερβολὴν ἐν ταῖς ἐπινοίαις καὶ πολλὰ παρὰ τὴν τῶν ἀρχιτεκτόνων τέχνην παρευρίσκων). Diodorus continues: 'For it was in his time [third century BCE] that greatest weapons were perfected and engines of all kinds far surpassing those that had existed among others; and this man launched the greatest ships after this siege, and after the death of his father' (20.92.5, ἐπὶ γὰρ τούτου βέλη τὰ μέγιστα συνετελέσθη καὶ μηχαναὶ παντοῖαι πολὺ τὰς παρὰ τοῖς ἄλλοις γενομένας ὑπεραίρουσαι; translated by Geer 1954).

24 As cited by Keyser 1994, 36. In contrast, Alexander's use of artillery is sometimes omitted by ancient authors in order to glorify Alexander by emphasising the difficulties of the battle (Keyser, 1994, 44–7).

in contrast to the tactics of open battle.[25] He continues by saying that for this reason, the ancients [ἀρχαῖοι] 'made a pact to use against each other neither secret missiles nor those discharged from a distance, and considered that it was only a hand-to-hand battle at close quarters which was truly decisive' [13.3.4–5, διὸ καὶ συνετίθεντο πρὸς σφᾶς μήτ᾽ ἀδήλοις βέλεσι μήθ᾽ ἑκηβόλοις χρήσασθαι κατ᾽ ἀλλήλων, μόνην δὲ τὴν ἐκ χειρὸς καὶ συστάδην γινομένην μάχην ἀληθινὴν ὑπελάμβανον εἶναι κρίσιν πραγμάτων]. 'But at the present they say it is a sign of poor generalship to do anything openly in war' [13.3.7, νῦν δὲ καὶ φαύλου φασὶν εἶναι στρατηγοῦ τὸ προφανῶς τι πράττειν τῶν πολεμικῶν].[26] Strabo also describes this ban of missiles which might be associated with a fourth-century military development but he is not referring to spears and bows (10.1.12). Everett L. Wheeler argues that Ephorus, who was the common source of Polybius' and Strabo's treaty prohibiting missiles, might have been thinking of fourth century BCE developments in large artillery.[27] In his own wording: Ephorus was no doubt aware of the new terrifying weapon of torsion artillery. 'For the first time in Greek warfare a man could be killed by a machine and not a warrior's prowess'.[28]

Clayton Christensen, who speaks of 'disruptive innovation fame',[29] and W. Chan Kim and Renée Mauborgne, the inventors of 'blue ocean strategy',[30] have shown that big changes in society and technology fundamentally challenge the conventional understanding of what is valuable. The investigation of new artillery devices shows a relationship between conservatism, associated with notions such as *andreia* and *kleos*, and technological accomplishment. The former does not cause technological stagnation—artillery devices are being successfully adapted and diffused in the Greco-Roman antiquity. However, they do not seem to influence values of society by changing expectations and realities.

5 Conclusion

In Greece and Rome like our contemporary world, technological innovation, in general, can be embraced and adopted or rejected depending on the ideas,

25 On Philip's the 5th war machines see also Polybius 5.99.7.
26 Translated by Paton 2011.
27 Wheeler 1987 *passim*. He also offers a review of past scholarship on the matter.
28 Wheeler 1987, 181.
29 Christensen, 1997.
30 Kim and Mauborgne, 2004.

beliefs and intentions of their users/perceivers. In ancient technical treatises novel artillery devices, for instance, are portrayed in a positive light and innovation here is inherently attached with the notion of progress. Other ancient authors describe the negative reactions of laymen to non-torsion and torsion artillery devices. As we learn from them, these devices bring with them changes that some people cannot identify with or that cause insecurity and resistance. The belly bow, for example, is successfully adopted because it is more effective than the hand bow and because this device has a friendly design, that is, one that is familiar and consequently simple for the user to work with. At the same time, however, this device creates negative impressions since it seems to challenge the notion of *andreia* which is inherently associated with the warrior's body.

The torsion catapult is a more complex device, and with an impact force and range greater than the one of the belly bow. This device eliminates the involvement of the warrior in battlefield completely and for this reason and, similar to the case of the belly bow, raises concerns about its effects associated with martial valour. Hence, sociocultural reasons, rather than solely technological or scientific ones, are also held responsible for the success or rejection of these devices. These reasons reflect both the intentions and anchoring strategies of the technicians as well as the ideological background or objectives of their recipients. While the rhetoric of the engineers surrounding these novel artillery devices does highlight risk as a central feature, this often is not translated into practice. That technological innovation comes with great risk, we learn only when we uncover the voices and fears of their users.

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CHAPTER 12

Risky Business: Anchoring Blown Glass and *terra sigillata* Production in the Face of Risk

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1 Introduction

Glassblowing, *terra sigillata*, hydraulic concrete, water-lifting devices—technological innovation had a tremendous impact on life in the Roman world, from contributing to the rise of a consumer culture, to facilitating maritime trade, to stimulating economic growth.[1] While the impacts of these and other technological innovations have been widely studied, considerably less attention has been given to *how* those innovations came to be and how that process was experienced in daily life.[2] Addressing the 'how' of innovation and its lived experience in the Roman world is therefore the underlying goal of this paper. To achieve that goal, the paper will examine the experience of the craftspeople involved in technological innovation, and specifically how new craft techniques were adopted, since the craftspeople themselves were essential agents in processes of innovation, and the new techniques were incorporated into their daily practice. Of the many possible factors that may have influenced the decision to innovate, the focus here will be on economic risk. Investment in new technologies incurs significant risks, both economic and otherwise, which must be deemed acceptable or worthwhile by those adopting them for innovation to proceed.[3] As such, considerations of risk would likely have been an important part of a craftsperson's experience of innovation. What would have made these risks acceptable? The concept of anchoring, or the act of grounding the new in the established or familiar, offers a way forward in attempting to understand the decisions that Roman craftspeople made when they chose to adopt new techniques and, more broadly, how innovation occurred despite the

1 Flohr 2016; Robinson et al. 2020; Wilson 2002.
2 Cf. Flohr 2020 for the need to address the 'how' question and the realm of everyday practice and experience; also Torrence and van der Leeuw 1989, 8 for a call to focus on 'what happened before' vs. 'what happened after'.
3 Spratt 1982; 1989; Larsson 2019, 15–16.

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inherent risks.[4] What factors could have acted as anchors, justifying the new techniques in the face of risk?

What follows will be an attempt to identify some of those factors. In order to do so, the paper will first look to archaeological and anthropological theory surrounding innovation to get a broad sense of what innovation is and how technological innovation, and the inherent risk, is experienced and managed by the craftspeople involved. The focus here will be on the perception of risk as key for understanding that experience. The paper will then turn to two case studies drawn from the Roman world—glassblowing and *terra sigillata* production—to identify the factors (anchors) that might have mitigated risk, or even simply the perception of it, enough to allow innovation to proceed. These case studies, based as they are in the material culture of glass and pottery production, will allow deeper insight into the daily practices and experiences of people—craftspeople—whose lives are not well-documented in the textual record.[5] The case studies demonstrate that technical, material, and knowledge-based anchors were likely important in decisions to adopt new craft techniques despite the economic risks, thus yielding insight into both the 'how' and the lived experience of the innovation process.

2 Experiencing Innovation

Understanding how craftspeople may have experienced innovation begins with the recognition that innovation is a process, one in which a new idea or discovery, such as a new craft technique, is implemented and spread through and between groups, resulting in more or less widespread adoption.[6] In other words, innovation is the process by which an invention, the in-the-moment discovery, comes to be widely used. This concept, while not necessarily highlighted by earlier scholarship on Roman technology,[7] is both explicitly acknowledged in the Anchoring Innovation project's framework and is supported by other anthropological and archaeological studies of innovation.[8] And while the latter have made an effort to delineate the various phases that comprise the process of innovation (e.g., discovery, invention, development, investment,

4 Sluiter 2017, 32.

5 Cf. Horden and Purcell 2000, 288 on the lack of written sources for the diffusion of new techniques.

6 Knappett 2011, 51; Torrence and van der Leeuw 1989, 3.

7 Although see Van Oyen 2020 for an explicit focus on the process of innovation in *terra sigillata* production.

8 Sluiter 2017, 21; Spratt 1982, 80; 1989, 246; Torrence and van der Leeuw 1989, 3.

adoption, production and distribution, obsolescence),[9] each of these vary in relevance depending on the specific case. This paper will therefore consider innovation more generally as the often lengthy process of the implementation, spread, and adoption of new ideas and technologies.

Recognizing innovation as a process further necessitates the recognition that it was a lived experience and that it is both possible and important to study the on-the-ground reality of innovation. Those involved in that process would have experienced innovation as part of their daily lives, an experience that could have been affected by any combination of numerous factors, including, but not limited to, other actors involved, social, political, and economic contexts, and the physical materials and objects implicated in the process. For craftspeople engaging in technological innovation, a large part of the experience would likely have been bound up in deciding whether or not to adopt the new technique in question. A wide array of factors could have influenced this decision, whether social/political (e.g. taboos, *habitus*, emulation, boundary negotiation, social networks, *etc.*), economic (e.g. investment, risk, *etc.*), technical (e.g. material properties, difficulty of techniques, *etc.*), or environmental (e.g. availability of raw materials, *etc.*).[10] It is among specific manifestations of these factors that we can expect to find the anchors that ground innovation and ease the decision to innovate. The anchors vary by situation but will be those factors that connect the new technique to what is known, established, trusted, familiar, culturally acceptable, or reliable, thereby influencing the decision-making process and encouraging participation in innovation.

Regarding economic factors and risk specifically, anthropological and ethnographic studies of technological innovation suggest that the *perception* of risk is the key element when deciding to adopt a new technique.[11] Thus, in searching for the anchors that facilitated the uptake of new techniques, it is necessary to look for factors that may have ameliorated perceived risk. As this is best done on a case-by-case basis, we turn to case studies of Roman period innovation to tease out some of the factors that could have mitigated perceived risk and thus acted as anchors in the adoption of new craft techniques: glassblowing and *terra sigillata* production.

On the surface, the case studies are quite different. Glassblowing is, and long has been, recognized as one of the most important inventions *and* innovations of the Roman world.[12] *Terra sigillata* is much less often discussed as

9 Spratt 1982, 80; 1989, 247.
10 Spratt 1989, 247; Lemonnier 1993; Knappett 1999; Gosselain 2010; Archibald 2013.
11 van der Leeuw 1989; Papousek 1989.
12 E.g. Finley 1965, 29.

an innovation, and even then the innovation tends to be organizational or aesthetic rather than technical.[13] Yet both required the adoption of new techniques and therefore came with risks. Both also flourished despite these risks and an investigation of the risk involved and how it (or the perception of it) may have been ameliorated reveals the existence of similar anchors in the innovation processes of both products.

3 Glassblowing

The history of glass production reaches back well before the Roman period to the first half of the second millennium BCE, at which time beads and small glass ornaments were produced in the Near East and Egypt.[14] The earliest glass vessels, produced in the Near East *c.*1500 BCE, were core-formed, using a technique closely related to bead production. Between the introduction of core-formed vessels and the earliest evidence for glassblowing there exists a span of nearly 1500 years. While new shaping techniques such as sagging over a mold were developed over time, prior to the adoption of glassblowing, none used air, and all employed heat-softened, rather than fully molten, glass.[15] Glassblowing was adopted in an incremental process between mid-first century BCE and mid-first century CE. The first indications of the use of inflation to work glass come from mid-first century BCE Jerusalem in the form of a deposit of glass waste.[16] The scraps demonstrate that the earliest inflation was not the same technique as that used just a century later throughout the Roman world, but rather consisted of short, hollow tubes sealed at one end and inflated with air. Only later were chunks of heat-softened glass blown with ceramic or iron blowpipes, and only in the mid to late first century CE was fully molten glass blown using a suite of tools and techniques, including the glassblowing furnace, iron blowpipe, and pontil technique for rim finishing, which had been developed over the course of the preceding century.[17] It is this mid to late first century CE form that is widely recognized as Roman glassblowing.

13 Greene 2000, 745; Jackson and Greene 2008; but see Cuomo di Caprio 2006, 299; 2007, 326, Flohr 2016, and Van Oyen 2020 for exceptions that view the production of *terra sigillata* as an innovative technique.

14 Stern 2008.

15 Stern 2008.

16 Israeli 1991; Israeli and Katsnelson 2006.

17 Stern 1999, 445–448; Greene 2008.

It was also at this time that glass recycling, in the form of fully melting down and reshaping glass fragments, became commonplace.[18]

The relatively rapid uptake of glassblowing in that hundred-year period would have incurred significant risk for those who adopted it, especially considering craftspeople had been successfully working glass using a variety of other techniques for over a millennium. Compared to earlier techniques, blowing with fully molten glass had much greater material costs. Approximately 40–45% of the glass used was lost during production, stuck to the walls of the crucible, and greater quantities of fuel were needed to maintain the 1050–1150 °C required to keep the glass in a molten state.[19] There would have been further risk in investing in new equipment such as closed furnaces and blowpipes, and in using the time and materials necessary to master a difficult technique that was in constant flux for over a century.[20] As Katherine Larsson notes, 'experience was a large investment and one that was not likely to be easily abandoned'.[21]

Despite these risks, glassblowing was adopted on a large scale, and two elements of that adoption process stand out as important for understanding how. First, as demonstrated by the history of glass working briefly outlined above, glassblowing developed gradually, and the development was characterized by small changes anchored in established techniques. Second, the physical properties of glass itself, and perhaps more importantly, knowledge of those physical properties, especially its ability to be fully melted and reshaped without significant loss in time or materials, would likely have helped to mitigate the perception of risk. As technical and material elements, these are undoubtedly not the only factors that impacted the decision to adopt glassblowing and helped anchor it. Yet, they were among the most salient factors with respect to glassworkers' daily practices, and therefore are important for understanding the experience of participating in the process of innovation. Thus, with full recognition that other factors (e.g. consumer demand) would also have influenced the perception of risk, we can proceed to explore both in greater detail in the archaeological record of Roman glassblowing.

Regarding anchoring in established techniques, as noted above, the earliest evidence of glass inflation comes from a deposit of glass fragments and production waste in Jerusalem, dated to the mid-first century BCE (fig. 12.1). The workshop from which the deposit came primarily produced cast glass bowls,

18 Keller 2005, 67.

19 Stern 1999, 451–452; Price 2005, 179.

20 Knappett 1999, 128.

21 2019, 11.

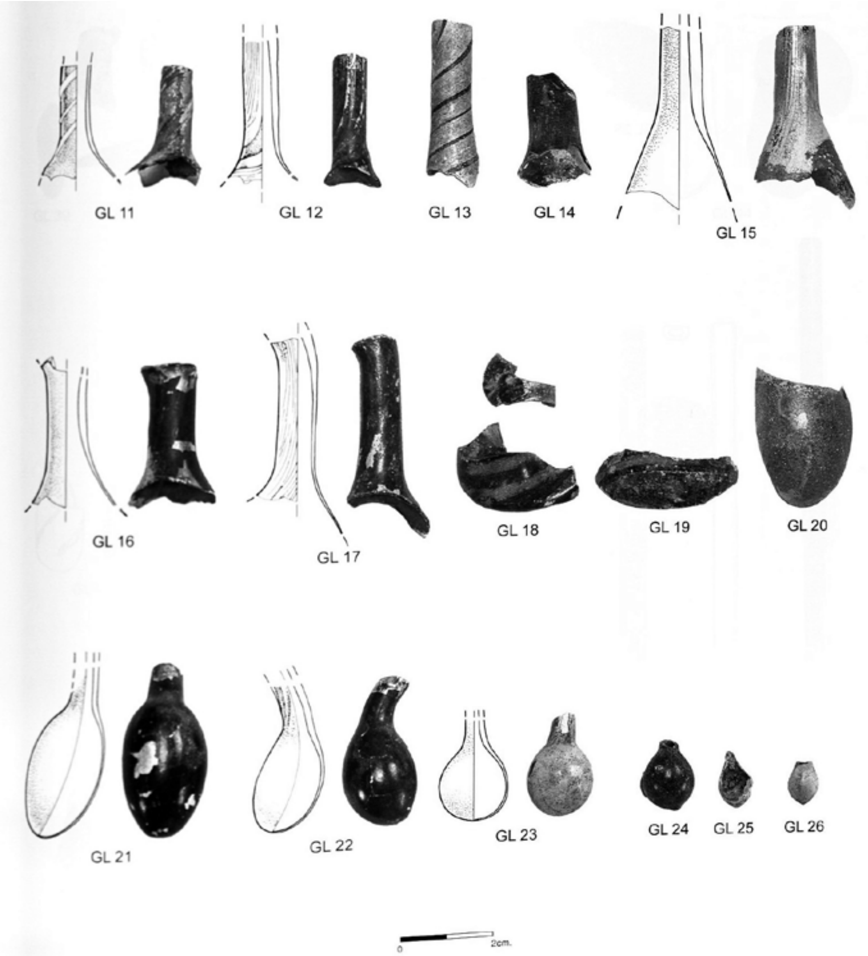

FIGURE 12.1 Waste from the production of inflated glass tubes, Jerusalem, mid-first century BCE (Israeli, Y. and N. Katsnelson, 'Refuse of a Glass Workshop of the Second Temple Period from Area J', in: H. Geva (ed.), *Jewish Quarter Excavations in the Old City of Jerusalem* vol. 3, Jerusalem 2006, pl. 21.1, courtesy of the Israel Exploration Society, Jerusalem)

but also made small objects, such as glass rods, and experimented with small vessels formed by inflating tubes of glass. The precise techniques used for the inflated vessels are not entirely evident from the production waste, but the excavators posit that the tubes were made by folding sheets of glass and stretching them with pincers. The tubes would then have been heated or pinched and folded to close one end, heated at the closed end, and inflated by blowing air into the open end.[22] This sequence of steps, provided it was the one used, is revealing, as it primarily employs techniques and tools that would already have been part of the glassworkers' daily practice. Flat pieces of glass were used for casting bowls, just as they would have been for forming the glass tubes, and the technique of stretching with pincers was used in creating the small glass rods as well as the tubes for inflating. It is conceivable, therefore, that the fact that inflation was the only significant new element in the multi-step production process would have lowered the perceived risk. Anchoring a new technique in established production techniques could thus have been one factor that facilitated the process of innovation, leading eventually to the widespread adoption of glassblowing.

This conjecture finds support in the development and uptake of another element of the glassblowing process—use of a blowpipe for inflation—which was first accomplished using pre-heated chunks of glass attached to the hot end of a ceramic or iron blowpipe. In this technique, referred to as 'chunk gathering', one or more chunks of raw glass are pre-heated to 500–600 °C, then attached to the tip of an even hotter blowpipe, heated to *c.*950 °C, and blown. Since the gathered glass is not molten, it is possible to blow multi-colored vessels in this manner, and it is precisely such bi-colored vessels that unambiguously attest to the use of the chunk-gathering technique in the early-mid first century CE.[23] The practice is known particularly from Avenches (Switzerland), where the remains of a glass production workshop in operation from *c.*40–70 CE yielded bi-colored crack-offs with rings of iron oxidation residue that could only be the result of chunk gathering and blowing with an iron blowpipe.[24] While production debris that is unequivocally a result of chunk-gathering is only known at Avenches, small vessels produced in this manner have been identified elsewhere, and Marianne Stern argues convincingly that chunk gathering was the first method of gathering used for blowing glass with a blowpipe.[25] This is perhaps not surprising, as the key concept of chunk gathering, namely that heated chunks of glass can fuse together, is central to techniques such as core-forming, which were already ancient in the first century CE. The primary difference lies in the method of creating a hollow interior: air as opposed to a sand

22 Israeli 1991; Israeli and Katsnelson 2006.

23 Stern 2012.

24 Amrein 2001, 95; Stern 2012; crack-offs are the pieces of glass that remain stuck to the blowpipe after the rest of the vessel is removed for various finishing processes (Stern 2012, n. 11).

25 Stern 2012.

core. The similarity of chunk gathering to established techniques, along with its reliability, would likely have facilitated the adoption of glassblowing with a blowpipe, aided also by that fact that it would not have required an increase in fuel used. As with the earliest inflation, it appears that anchoring a new technique in established ones may have been important for the progress of innovation as a factor that could have made the perception of risk acceptable to glassworkers.

Compared to chunk gathering, blowing fully molten glass has significantly greater material costs and, therefore, risks. More fuel is needed to reach the 1050–1150 °C required to melt glass, and a larger amount of glass is lost when it sticks to the walls of the crucible.[26] However, as noted by Larsson, fully melting glass allows for recycling, thus offsetting other economic risks (e.g. the need for more glass due to loss of material through mistakes), and perhaps lowering the overall perception of risk.[27] This idea draws support from the fact that cullet piles—deposits of glass production waste and broken glass objects—begin to appear in the archaeological record around the beginning of the Flavian period, or slightly before, roughly at the same time that objects blown from molten glass and literary mentions of melting glass appear.[28] Beyond offsetting the loss of glass when gathering molten glass from a crucible, the use of re-melted cullet may have lowered risk in other ways. On a purely technical front, mixing cullet with raw glass lowers the melting temperature of the material, which would, in turn, reduce the quantities of fuel required.[29] Learners' mistakes would also not have resulted in a net loss of costly raw material, only time. Thus, whether or not the factors associated with recycling materially lowered the risk of blowing molten glass, it is entirely conceivable that recycling could have reduced the perceived risk, which is key. Moreover, considering the excitement expressed in contemporary literature regarding the discovery of melting glass, it is quite likely that it was viewed with optimism and positively affected the perception of blowing molten glass and the risks inherent in its adoption.[30] Here then we have another possible anchor: knowledge of the physical properties of raw materials. Indeed, Stern proposes that the use of molten glass was borrowed by the glass vessel industry from the flat, architectural glass industry, which had been using it since the first half of the first

26 Stern 2012, 43–45.
27 2019, 16.
28 Stern 1999, 450–451; Keller 2005, 65–67; Price 2005, n. 5.
29 Keller 2005, 65.
30 Stern 1999, 450–451.

century BCE, suggesting that this particular material property of glass would have been known and trusted before its use in glassblowing.[31]

4 *Terra sigillata*

Much like the technique of blowing fully molten glass, the production of *terra sigillata*, the Roman fineware *par excellence*, was preceded by a history of continuity and change in pottery production and a gradual development and implementation across time and space. The ware, first produced in Arezzo (ancient Arretium) around 30 BCE, is part of an Italian fineware tradition that stretches back through black gloss and fine creamware to Etruscan bucchero and is also closely connected to the Greek tradition of highly purified finewares (e.g., red- and black-figure) and to the eastern sigillatas.[32] It displays significant continuities with these earlier wares, including purified clay, shaping techniques, similar forms, and, in some cases, surface treatment (slipping). However, it is set apart from its immediate predecessors, black gloss and Eastern Sigillata A by its red color and high gloss respectively.[33] The high gloss is the result of full sintering of the slip during firing, while the red color comes from firing in a fully oxidizing atmosphere.[34] Such results were achieved by means of a single phase, indirect firing process, in which the flames, smoke, and soot resulting from wood combustion were prevented from coming into direct contact with the vessels being fired, and the atmosphere of the kiln was never brought into reduction.[35]

Single phase, indirect firing was a new technique at the end of the first century BCE and was a source of novel risk in pottery production. While the technique changed over time as it was adopted in different regions of the Roman empire and in some versions its methods are not fully understood, all of its variations had the basics in common. Firing took place in a two-chamber, updraft kiln, with fuel and fire in the lower chamber (firebox) and ceramics stacked in the upper chamber (firing chamber). 'Single phase' indicates that an oxidizing

31 2012, 43.

32 Peacock 1982, 114–115; Heimann and Maggetti 2014, 192–193; Sciau et al. 2020.

33 Hayes 2008, 14.

34 Sintering is the fusion of the fine clay particles of the slip to create a glassy, non-porous surface (see Cuomo di Caprio 2007, 332–333; also called vitrification in some scholarship); an oxidizing atmosphere is oxygen-rich, while a reducing atmosphere is oxygen poor, both states affecting the nature of the iron oxides in the clay and thus the vessel's color.

35 Cuomo di Caprio 2006; 2007, 329; Leon et al. 2015, 658.

atmosphere was maintained in the kiln throughout the firing (in contrast to, for example, the three-phase oxidation-reduction-oxidation firing hypothesized to have been used for Athenian red-figure).[36] 'Indirect' refers to the fact that the ceramics did not come into contact with the hot air and combustion material emanating from the firebox but were rather fired through irradiation. However, how this was achieved differed over time and in some cases is not definitively known. The indirect component of the firing process is the key to making highly glossy, homogeneously red *terra sigillata* because it protects the vessels from contact with the reducing atmosphere or combustion materials that could turn the slip black, a color which would then be locked in when the slip sintered. It is also where a significant amount of the risk lies. Relying on irradiation for firing requires higher temperatures, using at least double the amount of fuel that direct firing processes do.[37] Changes in the structure of the kiln itself to facilitate indirect firing could have resulted in higher construction and maintenance costs. New kilns would likely have been required, as the higher temperature contrasts between interior and exterior put greater stress on the kiln structure, necessitating stronger walls than were needed in direct firing updraft kilns,[38] and new structural elements were necessary for protecting the vessels from combustion products. Moreover, certain versions of these elements, particularly the rectangular ducts that Cuomo di Caprio hypothesizes for Italian *terra sigillata*, were prone to cracking.[39] Any cracks would have needed immediate repair or else greatly increased the chance of misfiring due to the smoke and soot released into the firing chamber. There was no room for error, for if the slip turned black prior to sintering, it was not possible to re-oxidize the vessel.[40] Finally, as with glassblowing, the time taken and material wasted in learning to control the indirect firing process could certainly have been perceived as a significant risk.

Experimental production of *terra sigillata* at the site of Marzuolo in southern Tuscany from 30/20–10 BCE provides a rare glimpse of innovation in progress and thus an ideal opportunity to investigate what may have anchored it in the face of the risk described above. During this period, potters at Marzuolo produced a ware similar to standard Italian *terra sigillata* in its levigated nature, sintered slip, forms, and stamps, but deemed experimental by excavators

36 Walton et al. 2013 for the firing process of Athenian red-figure and possible complications to the basic three-stage process.

37 Cuomo di Caprio 2007, 332.

38 Cuomo di Caprio 2007, 332.

39 2007, 337–347.

40 Cuomo di Caprio 2006, 299.

due to the large percentage of misfired vessels (68.5%), slight presence of semi-sintered and non-slipped vessels, and low degree of standardization in forms.[41] Trial-and-error, particularly in attempts to control firing conditions, is visible in a number of forms. Three kilns belonging to this phase have been found at Marzuolo: two small, circular kilns and one larger rectangular kiln, none seemingly built at precisely the same time.[42] A number of the sherds display a dotted pattern, which the excavators suggest is the result of an unsuccessful attempt to use perforated terracotta plates (found in the same deposit as the experimental *terra sigillata*) as some form of kiln furniture to achieve indirect firing.[43] Fragments of *tubuli* (see below), possibly used to achieve indirect firing, were found in dumps and in association with the rectangular kiln.[44] Finally, archaeometric analyses and poorly fused slips indicate significant variation in firing atmosphere and temperature (although generally over 900 °C).[45] Combined, this evidence suggests multiple attempts to replicate the indirect firing technique used contemporaneously at Arezzo, not all of which were successful.[46]

The experimental production of *terra sigillata* at Marzuolo appears to have ceased after a decade or two, possibly, as recently suggested by Astrid Van Oyen, due to the inability of a small, independent production unit to scale up without external investment.[47] Whether the need for investment, inability to replicate the slips of standardized *terra sigillata*, or other circumstances caused the cessation of production, the nature of its brief existence suggests the influence of anchors similar to those present in glassblowing. The use of traditional updraft kilns with only slight additions (perforated saggars?) or modifications (*tubuli*?) suggests that the decision to attempt indirect firing and invest in the necessary infrastructure was anchored in well-established techniques. The basic procedures for constructing and firing such a kiln would already have been part of a potter's practice. The accumulated knowledge of

41 Vaccaro et al. 2017, 238.

42 Bowes et al. 2020, 280–281.

43 Vaccaro et al. 2017, 241.

44 Bowes et al. 2020, 281, 284.

45 Vaccaro et al. 2017, 254–56; Müller et al. 2019.

46 The technique used to achieve indirect firing at Arezzo and elsewhere in Italy is not yet fully understood.

47 Van Oyen 2020. There is slight evidence (the same fabrics discovered at nearby sites) that standard *terra sigillata* production may have directly followed the experimental phase, although much more evidence would be required for this to be conclusive (Bowes et al. 2020, 287). Whether this is the case or not, there was a break before *c.*50 CE when it is clear that new potters were active at Marzuolo using new clay sources (Van Oyen 2020).

the material properties of clay and slip—how they respond to oxidizing and reducing atmospheres, smoke, flames, and heat—built up over centuries of fineware production, could also, at least initially, have mitigated the perceived risk by providing reassurance that the technique would theoretically work. And while Marzuolo may be an anomaly in the visibility of the innovation process, such conclusions are in evidence at other *terra sigillata* production sites as well.

Mass production of *terra sigillata* at the renowned production site of La Graufesenque (France) is one such example. The site features the remains of a massive updraft kiln of the *fours à tubulures* type with an estimated capacity of 30,000 vessels (fig. 12.2).[48] This kiln type, one element in a suite of technological changes that occurred when the primary production of *terra sigillata* shifted from Italy to S. Gaul,[49] was constructed with cylindrical terracotta tubes (*tubuli*) running from holes in the perforated floor of the firing chamber, through its middle or up the sides, and out of the top of the kiln, with the intent of conducting the combustion products from the firebox to the kiln's exterior without letting them come into contact with the vessels being fired.[50] By the time the large kiln at La Graufesenque was in operation (*c.*80–120/130 CE), two-chambered, updraft kilns with a perforated floor between the chambers had long been used for pottery production in Gaul,[51] and indirect firing of some sort had been accomplished in Italy. The use of a common kiln type with the addition of structural elements (*tubuli*) that did little to alter the well-known design suggests again that the adoption of indirect firing was anchored in established techniques. And while the decision-making agency is not clear cut at a production site with the organizational complexity of La Graufesenque,[52] the anchor could have been effective for a craftsperson, with familiarity of practice lowering the perceived risk, or for a possible landowner or proprietor, who would not have been investing in entirely unproven infrastructure. This anchor moreover could have combined with knowledge of the material properties of clay to lower the perceived risk still further. Potters would have known from centuries of accumulated experience that higher temperatures produce glossy surfaces, but also lock in colors, and that contact with the air and materials produced in the firebox turns red ceramics black, and further that these were processes that could be relied on. Landowners or proprietors, without such knowledge themselves, would have been obliged

48 Vernhet 1981.
49 Leon et al. 2015.
50 Cuomo di Caprio 2007, 348–350.
51 Kern 2003.
52 Peacock 1982, 125–126.

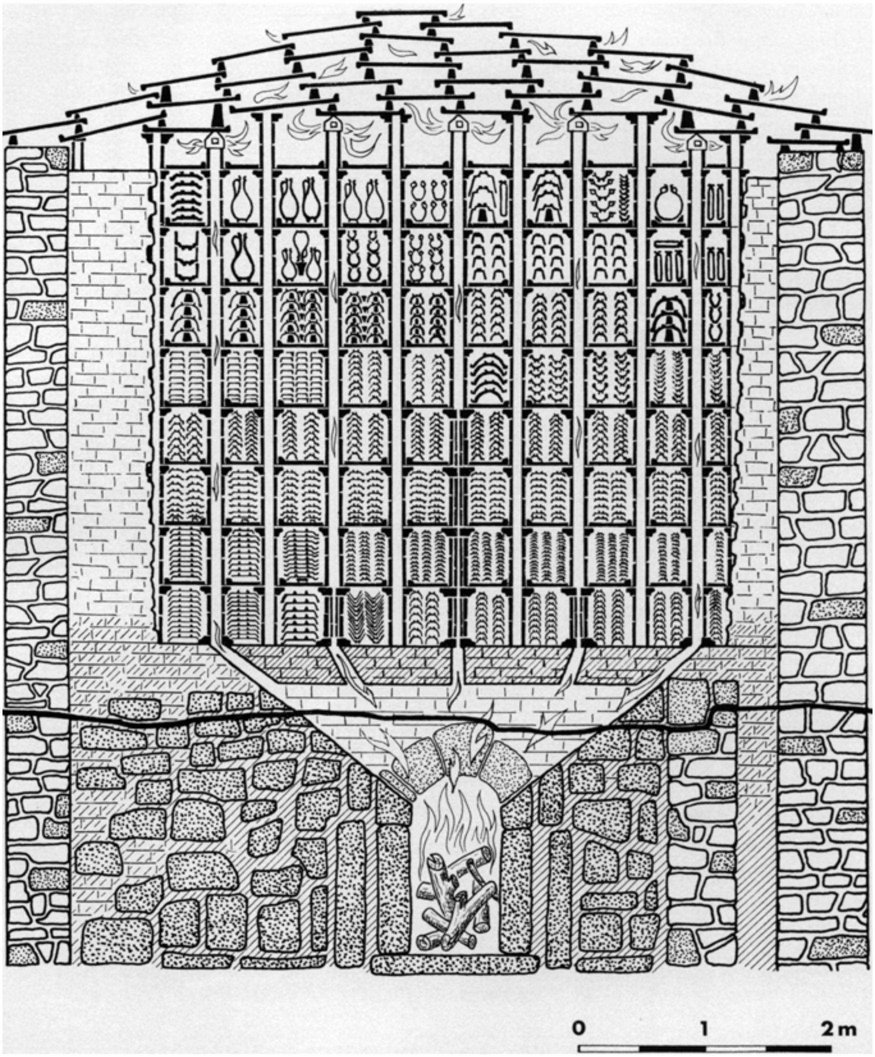

FIGURE 12.2 Reconstruction of the large *terra sigillata* kiln at La Graufesenque (Coupe théorique est-ouest du four chargé (le trait indique la limite des parties conservées): fig. 10 in Vernhet 1981, *Gallia* 39.1)

to trust in the knowledge of those they hired. That the type of kiln used at La Graufesenque has been found at *terra sigillata* production sites across France, as well as in Germany, Britain, and Spain attests to its widespread adoption, making it conceivable that established production techniques and knowledge of the material properties of clay did, in fact, act as anchors, rendering the technique of indirect firing familiar enough to be perceived as an acceptable risk.

Finally, while space precludes a thorough discussion of African Red Slip (ARS), the successor to Gaulish *terra sigillata*, the process and anchors described above seem to have been repeated in N. Africa. ARS was produced in the types of kilns previously employed in the region, with the sole addition of saggar boxes to protect the vessels and maintain a continuously oxidizing atmosphere,[53] suggesting, as above, that the use of established techniques and knowledge of the material properties of clay and slip functioned as anchors as potters continued to innovate and *terra sigillata* production continued to evolve.

5 Conclusions

While this paper has emphasized technical and material factors as anchors that likely facilitated the adoption of new techniques by Roman craftspeople and thus key parts of the lived experience of the innovation process, there were undoubtedly other factors at play. Indeed, social factors are also often critical in decisions to adopt new technologies.[54] The use of established techniques in conjunction with the innovative one(s) has a social dimension in fact, for it would have helped the new technique fit into both the extant technical system and cultural understandings of how things are done.[55] Demand too, driven by the values and habits of consumers would have played an important role. This is potentially in evidence at Marzuolo when, around 50 CE, *terra sigillata* began to be produced again, although by different individuals.[56] While the indirect firing technique was more established by this time, *terra sigillata* had also gained significantly in popularity, as witnessed by the spread of production to Gaul and exportation across the Roman empire. Marzuolo, moreover, was well-placed to be aware of and respond to increasing consumer demand, having become an inland trade center, engaged in distributing goods coming in from the coast to territories further inland.[57] These social factors almost certainly acted as anchors, lowering the perceived risk enough for potters to attempt indirect firing through knowledge that their products would sell.

Likewise, the availability of information regarding new techniques, as well as craftspeople to teach them, would have impacted decisions to participate in innovation. Knowledge regarding complex production practices

53 Cuomo di Caprio 2007, 351–352.
54 Lemonnier 1993, 5; this is the guiding principle behind theories of technological choice.
55 Lemonnier 1993, 12–14.
56 Vaccaro et al. 2017, 244.
57 Vaccaro et al. 2017, 252.

has a tendency to travel through robust social networks, particularly those that are relatively local and have high frequencies of interaction, due to the need for direct instruction.[58] Glassblowing would likely have been one such technique.[59] In the case of glassblowing, the existence of social networks of craftspeople participating in the process of innovation may have acted as anchors, the contact with knowledgeable people who were themselves adopting it reducing the perceived risk. Taking this further, the increasing integration of the Mediterranean and beyond fostered by the Roman empire would likely have facilitated the formation of these networks.[60]

Taking these considerations into account, it is evident that there is more work to be done in identifying the anchors that facilitated the adoption of new craft techniques, particularly those stemming from the social and cultural spheres, which would have formed much of the broader context of innovation. A wide range of factors (social, political, economic, technical, environmental) likely functioned together as anchors in any given innovation scenario, but their share of importance would have depended on the specific context of each individual situation.[61] The technical and material factors discussed here—largely established techniques used alongside a new one and knowledge of material properties—as the factors most immediately tied to the daily practice of craftspeople, may have been more relevant in a situation such as the experimental production of *terra sigillata* at Marzuolo where the full consequences of the use of a new technique were uncertain, than at one such as the mass production at La Graufesenque where the demand was already known to be high and the knowledge networks were more robust. However, while the degree of their importance may have differed between scenarios, these technical and material factors are visible in each of the situations examined here, thus yielding an answer, however partial to the dual questions of how technological innovation happened in the face of risk and what the experience of the innovation process was for artisans on the ground. As anchors, established techniques and knowledge of material properties would have grounded new and risky techniques in the familiar and reliable, mitigating the perceived risk and allowing craftspeople to incorporate those techniques into their practice until the technique became widespread.

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58 Archibald 2013; Knappett 2018; Archibald refers to these networks as 'innovative clusters', while Knappett discusses the 'wide bridges' needed for this type of knowledge transmission.

59 Archibald 2013, 29–30.

60 Flohr 2016.

61 Cf. Knappett 1999.

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CHAPTER 13

Models and Modeling in Roman Technology

Rabun Taylor

1 Introduction

This article investigates how modeling was used to facilitate technological processes in the ancient Greco-Roman world. *Modeling* is a loose term used here to encompass several related processes, all of which, in some fashion, project a desired outcome onto a current process through experiment, testing, simulation, or use of prototypes or proxies. Testing prototypes, running trials, and training for complex new procedures are second nature in the modern world, where venture capital, regulation, legal jeopardy, and market competition raise the stakes of success or failure. But how much, and to what ends, did ancient innovators do the same? If models there were, to what extent were they anchored in existing customs? And did such anchoring advance or retard their success?

I begin with a brief definition. Models are cognitive tools operating in real space that precede and facilitate a useful outcome but are to some degree inchoate. They are *not* to be understood principally as replicas, end products, or even specimens or templates.[1] They are instead critical components of certain kinds of knowledge production within artisan communities: tools of 'active learning' anchored in complex epistemic traditions of craftsmanship.

What do I mean by *anchored* here? In brief, a model must present, in manipulable form, a system following familiar schemata that the knowledge community understands and accepts—an industry standard, as it were. But the model also modifies or subverts the norm in some way that is not just whimsical or ingenious, but genuinely innovative. Innovation, rightly understood, can advance or diversify the industry standard—or, in rare cases, stand alone as a unique achievement.

1 This is not to exclude such roles from working models; as Mindrup (2019) argues for architectural models, the same object can serve a range of generative and representational functions. Specimens and templates were widely used in antiquity, but they served more to replicate fully resolved components of the design than to assist with functional or relational problems.

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In many categories of Greek and Roman technology evidence of modeling is hard to find.[2] Our ignorance may stem from ancient literary bias against technically oriented professions. Archaeology is not a satisfactory corrective for this bias; apart from exceedingly rare discoveries of scale models of buildings, it proves almost as opaque on this matter as literature and inscriptions. The disdain for such things in ancient literary discourse was not absolute, however, and neither is the silence. Plato and Aristotle acknowledged the *demiourgos* as a generator both of ideas and forms.[3] Vitruvius famously vaunts architectural drawings—*ichnographia, orthographia, scaenographia*—as essential tools in the architect's portfolio of skills.[4] Ancient authors and inscriptions refer to plans or models as tools for the architect.[5] But we need look no further than Frontinus to confront the intellectual headwinds that advocacy for the technical trades faced. The aristocratic political appointee to the water commission of the city of Rome, whose commentary on the aqueducts of Rome elucidates one of the most impressive demonstrations of large-scale systems management in antiquity, expressed naked contempt for the technicians and middle managers under his supervision. The methods and arts of these watermen, who earned direct mention only on account of their putative corruption, were of no further interest to him.[6] We consequently learn nothing from Frontinus about the *habitus* of these men and their profession. Yet he depended at every turn on their skill, experience, and judgment, and we can occasionally glimpse vestiges of their technological competence behind his words.[7] What we cannot see, however, is any evidence of modeling.[8] That is not because it was extraneous to the toolkit of the water engineer—I will argue below to the contrary—but because such matters were too far removed from the executive suite to merit attention.

That said, we must not presume that technologies advanced habitually by modeling. In agriculture, for example, we can easily envision prototypes

2 E.g., see Senseney (2011, 186–187) on the lack of evidence in the classical world for drawings in the generative process for machines.

3 Senseney (2011) argues at length, and rather persuasively, that Plato even derived his famous concept of the *idea* from the *realia* generated by craftsmen, and architects in particular.

4 Vitr. *Arch.* 1.2.

5 Coulton 1977, 55–59; Gros 1985; Haselberger 1997; Pensabene 1997; Wilson Jones 1999, 50–57; Taylor 2003, 27–36; Wesenberg 2007; Lohmann 2009; Senseney 2011; Stinson 2011, 420–423; Pierattini 2012; Corso 2016; Mindrup 2019, 76–79.

6 Front. *Aq.* 75–77, 112.

7 E.g., see Taylor 2000, 33–39, 2024, 152–157 for methods of measuring water volume.

8 The *formae ductuum* of the aqueducts that Frontinus claims to have prepared (*Aq.* 17) were maps of the existing system and played no role in design or construction.

heralding the wheeled plow or the front-loading harvester.[9] Crop development, however, or the domestication and breeding of animals, probably did not emerge from models—except, perhaps, in the widely applicable abstract sense that any new 'best practice' becomes a model to follow, so long as it makes sense economically or environmentally. But as I explained above, that isn't what I mean by a model at all. A model is a fallible companion along the journey of discovery, not a finished standard for the future.

In other categories we can envision elaborate modeling but the lack of confirming evidence severely hampers our capacity to understand it. Textile production, though often characterized as a deeply conservative (and thus *anchored*) craft in Greco-Roman antiquity, offered vast opportunities for tinkering and repertoire expanding. Even some traditional techniques were so intricate as to require memory aids. 'The Roman master weaver must have had the mental agility of a modern computer programmer, along with a prodigious memory'.[10] Such heavy mental tasks—comparable, perhaps, to monumental building—demanded cognitive aids distributed between the mind and the world. These may have conformed to some kind of 'niche construction' embedded in the creative process itself, by which complex task sequences could be schematized in space and time without recourse to models.[11] But in cases where true creativity was called for, for instance a new, non-traditional pattern, an unconventional weave, or an unfamiliar tailoring task—one thinks of the widespread textile production technique known as nålebinding, which in late-antique Egypt was adapted to challenging forms such as woolen socks with a toe divider—models would have been genuinely useful reference tools, both for masters and apprentices.[12]

We are somewhat better informed about certain crafts or industries associated either with capital investment or state sponsorship. At the highest level of patronage, we can cite the state-sponsored military engineering charrettes at Hellenistic Syracuse and Rhodes and the think-tank and testing facilities at the Mouseion of Alexandria under the Ptolemies, the latter evidently devoted to developing and improving machines for civil as well as military use.[13]

9 Forni 2006; White 1967, 157–173, who concludes that two types of *vallus* were in use.

10 Wild 2008, 473. Cf. Frieman 2021, 70–71.

11 Clark 2008, 61–68.

12 Here Plato's advice to practice a trade by using its materials, methods, and tools from childhood comes to mind: 'For anyone to become a good farmer or builder, the latter must play at building toy houses (παιδείων οἰκοδομημάτων παίζειν), and the former must play at farming; and those raising them must provide each with miniature tools, copies of real ones' (ὄργανα σμικρά, *Leg.* 643 b–c; my translation).

13 Lewis 1997; Wilson 2002; Cuomo 2007, 41–59.

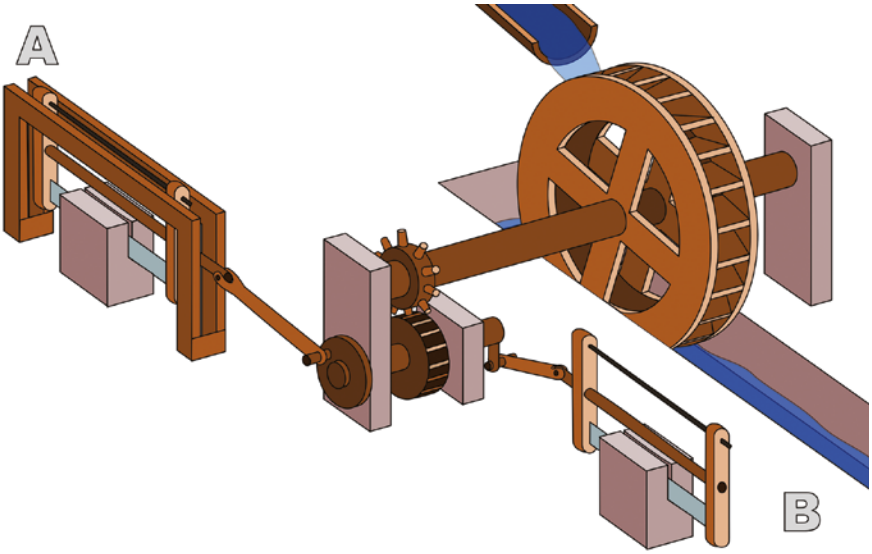

FIGURE 13.1 Reconstruction of the Hierapolis sawmill of Ammianos based on Ritti, Grewe, and Kessener (2007)
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Industrial research and development of a more entrepreneurial kind can be presumed—though not directly referenced in surviving ancient sources—in the successful speculative business initiatives of men like Licinius Murena, 'inventor' of maritime fish farms, and his contemporary Sergius Orata, who developed lucrative methods for oyster cultivation as well as thermal bathing.[14] Another notch or two down on the social scale, but also possibly working under the financial aegis of high-level sponsors, can be mentioned such men as the 'wheel-wizard' (*trochodedalos*) M. Aurelius Ammianos, who presents himself in an illustrated sarcophagus inscription as the inventor (or perhaps improver) of water-powered stone sawmills at Hierapolis (fig. 13.1).[15]

I will now present three case studies of modeling, each representing a high-profile category of Roman technology: the design of water-powered saws, the erection of a massive concrete vault, and aqueduct siphon construction. In each instance, though no model survives or is attested in surviving sources,

14 Fagan 1996; Yegül 2010, 80–86; Marzano 2015.

15 Ritti, Grewe, and Kessener 2007; Grewe 2008; Kessener 2010. On the social and economic conditions under which such investment might take place, see Erdkamp, Verhoeven, and Zuiderhoek 2020a, 2020b, and various articles in that volume.

I argue for the necessity of its existence and offer a feasible (if hypothetical) reconstruction of it. I then propose four principal motives for innovation in the Hellenistic and Roman world, all related to social or economic gain, and conclude with a reflection on the key relationship between technological progressivism, driven by these impulses, and forces of conservatism that might thwart it. Modeling, I contend, was one important means by which an innovation could take root within a professional community of cautious, even skeptical, artisans. This anchoring of the new in the soil of the past was necessary before the new could hope to thrive in the world at large.

2 The Case for Modeling Industrial Water-Powered Sawmills

A recent investigation of the impressions of pinewood on the slabs of lime deposits recovered from the aqueduct-powered flour mills at Barbegal near Arles has drawn attention to blade patterns from a vertical lumber saw (fig. 13.2).[16] This is an arresting detail. On the one hand, stone saws required *horizontal* action to retain the abrasive sand and water in the groove; thus Ammianos' unmanned buck saws at Hierapolis bit into the stone entirely under their own weight (see fig. 13.1). On the other hand, manual wood-sawing was done *diagonally*. Ripping large timbers lengthwise into boards was accomplished using a two-man saw angled through the log or beam, one man positioned atop the log and the other below.[17] The angle harnessed the saw's weight and momentum to maximize each stroke's bite against a fairly low contact interface. Positioning the saw vertically would minimize the interface even more, but the sawyers would then bear the saw's entire weight—and unproductively, as the weight gave no purchase to advance the cut longitudinally.[18] Everyone who has operated a handsaw understands that sawing at an angle is easier and more efficient.[19]

16 Sürmelihindi et al. 2019; Passchier et al. 2020.

17 Meiggs 1982, 348–349; Ulrich 2007, 45–50.

18 One Gallo-Roman representation of a two-man ripsaw in use, a tomb relief, does show the saw in a fully vertical position. But the representation is very crude, showing no handles or frame (Meiggs 1982, 348, fig. 14d). If it represents actual practice at all accurately, what it might suggest is that Gallo-Roman sawyers worked the saw *near vertical*, but not entirely so.

19 Presuming the board or log is not vertical or near-vertical. Given the mechanical challenges introduced by placing the wood vertically, even on a small scale, I have not considered it.

FIGURE 13.2 Fragment of calcium carbonate recovered from the grain mill at Barbegal, Musée de l'Arles antique
IMAGE: CEES PASSCHIER

From the traditional somatic perspective, then, the fully vertical mechanical solution devised at the sawmill serving Barbegal is downright counterintuitive. Yet it prevailed. It must, then, have developed from robust experimentation, which—among other things—would likely have ruled out an entirely mechanized process. Whereas a hand-powered saw blade moves with the cut, most shop-grade mechanical saw blades do not advance through the wood; the wood, propelled by a separate force, advances around the blade. The Roman vertical power saw would thus have required the horizontal log or beam to be pushed or pulled against it. Yet surely the prospect of harnessing water power to *propel* large logs and simultaneously *saw* them exceeded even the trochodaedalian wizardry of an Ammianos. The logs were probably advanced horizontally in a cradle using winches, weights, or animal power.

So why devise a vertical blade, rather than replicate the motion of the two-man saw? Simply put, because a mechanically powered ripsaw blade operates most efficiently along a short, fixed axis that encounters the least possible resistance. An angled saw would lengthen the axis of reciprocal motion and the contact interface, thus encountering greater frictional resistance.[20]

20 Resistance is a significant factor on a large scale, especially if we envision a multi-blade saw, like the four-bladed stone saw used at the late-antique Gerasa sawmill; see Seigne 2002, 2006; Grewe 2008, 434; Wilson 2020, 175.

Further, it might imperil the traction process by occupying overhead space needed for the men, animals, or mechanisms propelling the log forward.

To my knowledge, no comparable evidence exists elsewhere in the Roman world of a mechanized lumber mill. Barbegal, with its cascading, aqueduct-powered grain mills, thus stands in the vanguard of not one but *two* water-power technologies. While that seeming exclusivity may eventually be dispelled by further research (of the board impressions left in Roman concrete, for example), the fact remains that Barbegal/Arles was by any standard a magnet for machine technologies. All this experimentation required a laboratory of sorts where artisans could engage in something comparable to R&D but also transfer their ideas across industries. Evidently the lucrative milling industry at Arles made such a convergence possible.

Once a breakthrough core principle was launched—in the case of mechanical saws, it was the crankshaft, which converts rotary into linear reciprocal motion[21]—then the process of further experimentation could be managed with the kind of creative tinkering, or bricolage, that has always occupied artisans who work regularly with machines. Though it rarely resulted in historic breakthroughs, such tinkering produced genuine improvements that made sense within a local or regional framework even if they were rarely universally scalable. Tamara Lewit's systematic analysis of ancient Roman wine and oil press technology reviews the full range of known designs applied to this task across the Roman world.[22] She concludes that there was no revolution in press design during the Roman period: the lever-and-screw press, once deemed a transformative innovation that supplanted older weighted or winch systems on the force of its superior efficiency and productivity, was in the event taken up only sporadically, often for reasons of safety or convenience rather than profit—and after all is said and done, Roman screw presses prove no more efficient than their antecedents.[23] The application and refinement of a particular technology within a region often depended on available resources, both material and intellectual. If an artisan adept at a specialized skill was available, then the likelihood that it would be transferred across crafts or devices was greatly enhanced.[24]

21 Schiöler 2009.

22 Lewit 2020.

23 Lewit 2020, 333–339.

24 Mattingly 1996; Lewit 2020 326. In a similar vein, Janet DeLaine (2006, 248–249) observes that vernacular and imported technologies were used concurrently in the Roman imperial building industry. The situation was hardly different with technology devised under royal sponsorship—catapults and siege engines. Studying the dissemination of these devices, Serafina Cuomo (2007, 43–59) sees no technological revolution in effect but

3 Modeling Architectural Form, Structure, and Assembly: the Pantheon Dome

Surviving architectural scale models demonstrate quite literally that modeling existed in antiquity.[25] The evidence for prototypes, plans, scale models, and templates is decisive, but the application of models that advanced to a level one might call diagnostic or heuristic—e.g., 'test-drivable' prototypes of the sort that concerns me here—is patchy. Most known architectural miniatures seem to have been purely symbolic.[26] But one of them—a stone temple model from Niha in Lebanon—testifies directly to its use as a genuine prototype; alterations for the superstructure are inscribed directly on it (fig. 13.3a). Another, a miniature temple podium at Ostia, presents the builder or client with two alternative options for a columnar scheme around its stylobate. The single surviving tier of a stackable stone model of the Great Altar at Baalbek appears to have been a prototype, as it reflects the final structure in simplified form (fig. 13.3b).[27] Rather like Giuliano da Sangallo's 1489 wooden model of Palazzo Strozzi, it could be disassembled, floor by floor, for closer inspection.[28] Also like Giuliano's, this interior was unfinished, articulating the organization and geometry of the space. It is not a finalized blueprint intended as a guide for construction.[29] As a generative tool it seems to embody what cognitive scientists call an epistemic action, an indirect spatiotemporal route to completing a complex task aimed at increasing the mental capacity for accomplishing the task.[30] In cases where the task is unique and creative, as in monumental architecture, a model may itself evolve through several cycles of perception and action. Concerning Giuliano's three known wooden models of Palazzo Strozzi, which were partial or unfinished, 'it is more helpful to conceive of them as compositional studies or as a cluster of interrelated sketches for a design that

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rather a scattering of 'primitive' and more 'advanced' devices coexisting through the Hellenistic period, along with many hybrids.

25 Kalayan 1971; Will 1985; Haselberger 1997; Pensabene 1997; Wilson Jones 1997; 1999, 52–56; Taylor 2003, 32–36; Mindrup 2019, 74–82.

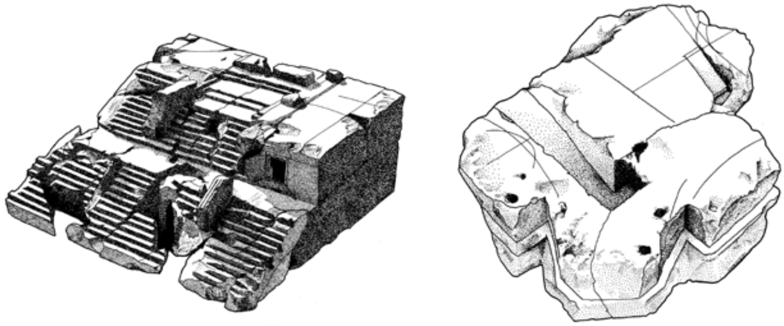
26 *Las casas del alma*; Maligorne 2010.

27 Taylor 2003, 32–36.

28 Lillie and Mussolin 2017.

29 This brings to mind the precepts of Vicenzo's Scamozzi's *The Mirror of Architecture* (1615): 'First, Let no man that intendeth to build, settle his fancy upon a Draught of the Work in Paper, how exactly soever measured or neatly set off in perspective, without a Model or Type of the whole Structure, and of every parcel or partition in Board or Wood. Next, That the said Model be as plain as may be without Colours or other beautifying, lest the Pleasure of the Eye preoccupate the Judgment' (trans. Fisher).

30 Kirsh and Maglio 1994; Clark and Chalmers 1998; Clark 2008, 70–81.



A B

FIGURE 13.3 Ancient Roman models of the temple of Niha and the Great Altar at Baalbek, Lebanon
DRAWINGS: RABUN TAYLOR

was still in the process of being developed'.[31] Indeed Manolis Korres, a great authority on the ancient building craft and the recent author of a monograph on the conception, design, and construction of the Odeion of Herodes Atticus in Athens, considers scale models so essential to the creative process through all stages of construction that he envisions a large shed housing them directly beside the building site.[32]

It is one thing to model architecture in order to master complex tasks of formal development; it is quite another to simulate a structure in full scale as a hedge against systemic failure. The frontiers of Roman innovation were clouded by cautionary tales of disaster. Technological failures appear rarely in the ancient record, but when they do, they are vivid, and tainted by reproof. The scandalous collapse of a wooden amphitheater at Fidenae, killing tens of thousands, tops the list of Roman engineering calamities both in terms of human cost and in the intensity of opprobrium aroused by the sponsor's corner-cutting and *sordida merces*.[33] As governor of Bithynia, Pliny lamented a series of architectural boondoggles and failures he had inherited, including an unfinished theater in Nicaea that was crumbling and sinking.[34] The initial failure of Claudius' drainage of the Fucine Lake before an expectant audience embarrassed the emperor and aroused accusations of incompetence and

31 Lillie and Mussolin 2017, 218.
32 Korres 2015.
33 Tac. *Ann.* 4.62–63; Suet. *Tib.* 40.
34 *Ep.* 10.39.

corruption.[35] In Mauretania, a tunneling project for an Antonine-era aqueduct to the city of Saldae went badly awry, necessitating the recall of its chief engineer, Nonius Datus, to correct the error.[36] In the latter two cases corrections were possible and the projects were brought to completion, though presumably not on budget. With such prospects of debacle in view, the technicians of Roman antiquity—and especially those engaged in ambitious, expensive, and prominent projects—would have hedged their bets through experiment and simulation. They would also have been particularly attentive to anchoring their innovations within design frameworks that were, in every way possible, time-tested and familiar to their workmen.

This kind of modeling, with its emphasis on engineering, structure, and process, differs fundamentally from the prior kind, though a uniquely complex and monumental undertaking may have involved both. In the case of the large Roman projects we have little direct evidence of the processes involved, but their very scale demanded testing. Simulations could be designed at partial or full scale; the latter was generally preferable, given that stresses and loads can only realistically be tested at full scale. A simulation was usually displaced from its intended location to a safe zone near the ground and away from danger. For buildings, two principal kinds of simulation model must have dominated—one testing structure, the other assembly. These models were not mutually exclusive, and to be truly effective they had to be adjustable, allowing for easy disassembly, tinkering, and reassembly.

Korres has recently envisioned, in splendid detail, a life-size *structural* model of one of the compound wooden trusses meant to span the colossal auditorium of the Odeion of Herodes Atticus.[37] The trusses' length, though extreme (the longest ones exceeded the diameter of the Pantheon!), was considered a matter of secondary concern so long as well-designed joints were properly locked in place to hold the wondrously long lower compound tie-beam in high tension; so Korres envisions the mechanical model as a single truss built to scale in terms of height and beam section, but not length[38] (fig. 13.4). This was decidedly not an assembly model. It did not help the builders devise, or even envision, the process by which each colossal truss would be assembled or put in place. The objective was to test the static and dynamic tolerances of its beams and joints under a full load (and then some), which was simulated by hanging weights. The test truss and its weights would have

35 Suet. *Claud.* 20, 21.6; Tac. *Ann.* 12.56–57; Dio 61.33.5; Leveau 1993.
36 *CIL* 8.2728; Cuomo 2011.
37 Korres 2015, 125–127.
38 Brokaert and Zuiderhoek 2015, 152–155.

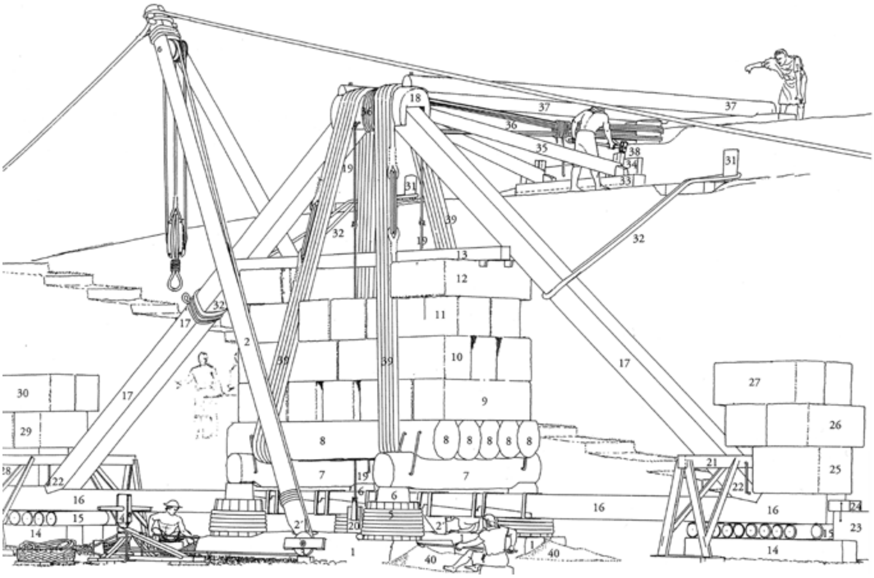


FIGURE 13.4 Hypothetical test model of a truss for the Odeion of Herodes Atticus
DRAWING BY MANOLIS KORRES. COURTESY OF MELISSA PUBLISHING HOUSE AND MANOLIS KORRES

been left in place for a year or more to permit the observation of cumulative deformations, wind tolerance, and so forth.

On a somewhat different note, I have proposed an *assembly* model for a flying centering scheme of the Pantheon.[39] The greatest logistical problems confronting this monument's construction lay not in testing the concrete dome's structure but in devising, assembling, and dismantling the wooden centering. Prototypes could have been assembled on a low drum, just high enough to test the lifting systems required to raise the wooden components into place. Such a model could also have served effectively to test the structural integrity of the centering under dome-like loads—though not of the dome itself. What has not been adequately appreciated is the extent to which sand, earth, or gravel could simulate the dome's weight upon this formwork. Once the convex wooden mold of the dome and its supporting frames had been refined to the builders' satisfaction and assembled in place, a series of low cylindrical retaining walls could be built atop it in tiers, like the outer walls of the Pantheon's 'step buttresses'. Contrived roughly in the manner of a rice paddy, each terrace could then be filled with, say, gravel, applied in amounts that simulated the

39 Taylor 2003, 190–211.

weight of the anticipated volume of concrete to be used on the final dome. Plumb bobs hung from the inner frames and suspended just a few centimeters above corresponding markings on the ground could serve as deformation gauges. Any movement observed during the process of application could be quickly counteracted by redistributing gravel. The knowledge gotten by this experiment could then be applied to the real dome—as could, almost in its entirety, the wooden centering itself and its bespoke lifting apparatus.[40] The simulation thus had the distinct advantage of blending into the final process.

4 Built-in Modeling: Aqueduct Siphons

But to what extent could simulation, or capacity for it, be *habitually* incorporated into the final product? Such a presumption seems to contradict my proposition above—that the model must stand apart from the final product. Yet nobody would deny that some experimentation was done in situ; indeed, it is hard to imagine any complex project in which situational improvisation was not called upon as a matter of necessity. One class of engineering projects in particular merged mechanical variability into its day-to-day functions: hydraulic infrastructure. Aqueducts and drains were designed to adapt to extremes of volume and flow according to the vagaries or cycles of rainfall. Aqueducts in particular were self-regulating. Their subsystems guaranteed that, by means of overflow tanks or spillways, intake volume would never exceed the offtake capacity—or, conversely, by means of dams or auxiliary reservoirs, the offtake would never run dry. Could this built-in capacity for variability, though, be marshaled to model certain components of the construction process itself?

Aqueduct subsystems such as inverted siphons, distribution tanks, and relieving tanks relied on their ability to maintain states of equilibrium under variable conditions.[41] Within limits, they could serve as their own seasonal or situational simulators and be tested and calibrated accordingly. Overflow mechanisms allayed the danger of filling open-flow systems to the bursting point. Auxiliary conduits could be opened or shut according to need. It is usually presumed that all this built-in pliancy was applicable only after the water

40 This simulation does not, however, help to model the essential process of dismantling the centering, to which I gave attention in my book (Taylor 2003, 209–211). It also exaggerates the liquidity of the 'concrete'—i.e., its tendency to be displaced by adding more material—since gravel does not harden into a rigid, lithic substance whereas concrete obviously does. Just as obviously, it is because of this fact that rehearsing disassembly of the centering under a load of gravel would be impossible.

41 Hodge 2002, 147–161, 215–245; Smith 2007a; Ortloff 2010, 278–295; Kessener 2016.

started flowing and therefore after the aqueduct's completion. In fact, the first condition need not be predicated on the second. To be sure, many aqueducts were built not from the top down but in discrete segments, perhaps with teams operating concurrently.[42] The archaeological evidence for this method, however, is confined to continuous downhill open-flow systems. Any system that included inverted siphons, I contend, needed hydraulic priming during construction.

Industry standards would have recommended some basic guidelines for siphon design within the system: a particular pipe diameter, a maximum depth for the viaduct (*venter*) along the valley bottom, and a provisional length-to-drop ratio, known as the hydraulic gradient, which probably constituted a simple relationship to the slope of the open-flow system upstream (say, 2 : 1—or, to use a common gradient, .30% : .15%). But all these variables needed to be perfectly intercalibrated to ensure exact equilibrium between water volume entering the siphon and exiting it. The industry standards, founded on best practices within the trade, offered no more than an approximation of real operating conditions. At least one of the variables had to be adjustable. End height was the most easily adjusted during construction, and the only way to do that was with a flow of water at high volume.

Compared to open-flow systems, pressure systems are clumsy at handling variability in water volume.[43] Yet because every extramural siphon had to handle all the aqueduct's deliverable water, it was forced to deal with this inconstancy. It could do so in three ways: by using a varying number of available pipes; by flowing at variable velocities under differing conditions; or by allowing constant overflow during times of high volume. The first option applies to the multi-pipe siphons in the West, such as those at Lyon, but it was unavailable to the single-pipe systems favored in the East.[44] The second option was feasible only if the siphon pipe started near the bottom of a relatively deep header tank, which when full to capacity would generate higher pressure and thus greater flow velocity.[45] Such an arrangement presumes a drop at the header end between open-flow intake and the pipe offtake. The first option operated within fairly limited parameters; as for the second, there is no evidence it was

42 Hodge 2002, 191–194.

43 Smith 2007a; 2007b.

44 Smith 2007a, 25. To enable quick responses to variable flow, all the pipes—including those that were shut off—would have been kept full of water at all times, given the dangers of water hammer, air entrainment, and air resistance when filling an empty siphon pipe quickly.

45 Smith 2007b, 240.

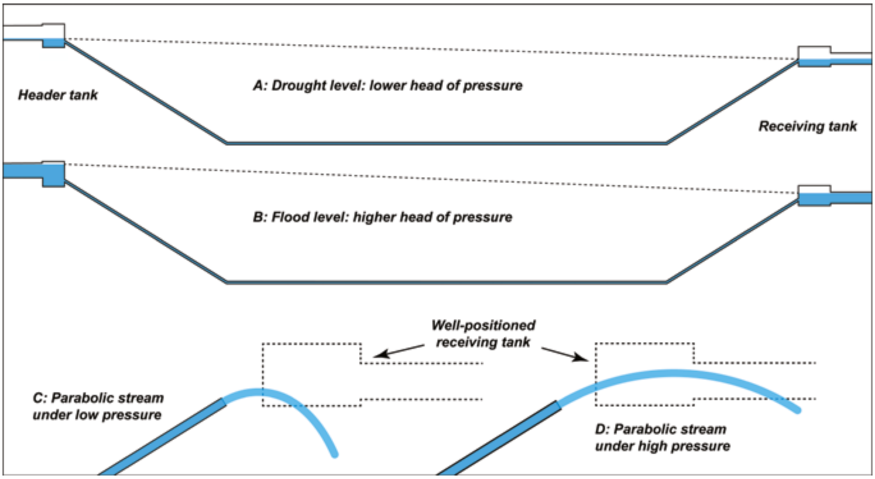


FIGURE 13.5 Hypothetical sector of a Roman aqueduct with a siphon operating under drought and flood conditions
IMAGE: RABUN TAYLOR

used.[46] We can thus conclude that whenever the system's volume exceeded those parameters, the third option went into effect: all additional water simply overflowed from the header tank into the valley below.[47]

What needed testing during construction, then, was the capacity of the siphon and its receiving tank to handle as much water as possible under heavy, overflow conditions as well as light, drought conditions—two situations that could be modeled temporarily in normal weather. To simulate flood conditions, engineers could direct water into the channel from both the source and an upstream reservoir (filled in advance, probably also from the source). To simulate drought conditions, most of that water could be diverted or shut off, allowing just a few inches to flow in the channel. Both conditions could then be used to model the precise height to which the pipe(s) should ascend at the far end of the valley (fig. 13.5c and d)—i.e., what length to make the final pipe segment(s), and just how high and deep to make the receiving tank. The minimum and maximum flows would determine at what elevation, exactly, the floor of the downstream open-flow channel (and possibly its vault, too) should

46 I am grateful to Paul Kessener for this observation.
47 Smith 2007, 39–40.

take as it emerged from the receiving tank.[48] Such modeling helped to ensure the system could work under either extreme, and anywhere in between.

5 Four Motives Driving Ancient Innovation

If we suppose that modeling often (but not always—as we just saw) accompanied innovation, then we can derive from this brief analysis some understanding of the incentives driving it. I count four principal motives propelling Greco-Roman innovation, and thus by implication modeling:

1) *economic, political, or military urgency*;
2) *project-specific problem solving*, which may or may not have outlasted the project itself;
3) *prospective gain*, which assumes risk in anticipation of a sustained future reward;
4) *reactive gain*, where the prior process succeeds so decisively that everyone jumps on the bandwagon, then tinkers with the new technology—as clearly happened with the diffusion of the right-angled gear and then the crankshaft.[49]

All these tendencies were limited or unevenly distributed across time and geography, and for many reasons—moral hazard, custom, environmental constraints, weak links in operational or distribution chains, etc. Examples of the first and second motives (war machines, building or engineering projects) have been discussed above. Mining for metals to pay armies provides another example of the first, and potentially the second.[50] I want to add just a word about the third motive, and by implication, the fourth.

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48 Intermediate hydraulic towers or peaks punctuating long siphons offer no discernible barrier to my hypothesis. Their introduction simply means that the process I have described might have happened in serial, being repeated after the completion of each intermediate pipe section between towers. Kessener (forthcoming), however, presents a compelling new hypothesis on the Yzeron siphon at Lyon suggesting that tower tank height, slope of the offtake pipes, and number of intake and offtake pipes were all essential factors in calibrating compound siphons on account of the complex behavior or air bubbles in downhill sectors. Precisely how a) the elevation of the hydraulic tower tank, b) the number of uniform pipes (10) leading into the tank and leading out from it (6 or 7), and c) the angles of the intake and offtake ramps were established *in medias res* to achieve the necessary equilibrium at tolerable cost are open questions.

49 Other incentives can be envisioned such as *shared need*, i.e., access to a limited resource across a substantial region or population; but case studies exemplifying them are hard to identify.

50 Wilson 2002.

In general, modeling and the profit motive are not closely aligned in antiquity. Relatively few occupations, it seems, innovated on the *promise* of economic gain. Milling evidently did, but not in any uniform way.[51] The grain trade at least (and perhaps by extension, milling) had the advantage of being powerful organized professions with senatorial and equestrian sponsorship that could, to some degree, govern policies and behaviors via private companies and trade guilds.[52] Their remits, however, rarely extended beyond the local or regional scale. Oil and wine presses innovated—or not—according to regional economic or status priorities.[53] Arguably, wholesale or consumer goods manufactories did too. But these latter industries were limited by the same circumstances that expanded their potential, and their advances owed more to scaling existing technologies than to modeling new ones.[54]

Often operating under imperial incentives, shippers and shipping companies innovated too—mostly by scaling quantitatively, multiplying conventional vessels rather than sea-testing new designs.[55] A few transport vessels, however, were supersized, a development that can be attributed to high-level investment or incentivization. Hieron II of Syracuse reportedly commissioned a freighter estimated at 1,700 to 1,900 tons, but the source describing it is troublesome.[56] More reliable is the estimate that some imperial grain freighters carried about 1,300 tons.[57] Somebody designed, built, and tested these ships, probably motivated by something akin to venture capital. Indeed the annual grain flotillas to Rome provided excellent opportunities to test prototypes, which could accompany the conventional ships while carrying mostly ballast.

51 Wikander 2000; Wilson 2002, 2020; Brun 2006, 2016.

52 Meiggs 1973, 311–336; Temin 2013, 97–113.

53 Mattingly 1996.

54 The large *sigillata* kilns at La Graufesenque come immediately to mind, or the marble sculpture production facility at Chemtou, or the steel and bronze works on the Magdalensberg. None exhibits great technological breakthroughs. See Wilson 2008; Straube (ed.) 1996.

55 Garnsey 1988, 233–235; Temin 2013, 102–113.

56 Ath. 5.208f–209e.

57 Casson 1995, 172–173, 183–189. Hieron's freighter is not the famous *Syrakosia* but a vessel that 'accompanied it.' The problems in interpreting the tonnage as described are considerable, as Casson explains. The preceding passage (5.206d–208e) describing the construction of the *Syrakosia* under the direction of Archias of Corinth and Archimedes himself recounts challenges encountered along the way, and ingenious solutions—but no mention of prototypes or models. However, the detail describing how Archimedes devised a method to drag the empty, lead-sheathed hull down to the sea, where the ship's decks and masts were to be added, suggests that the move was devised to test the hull's seaworthiness.

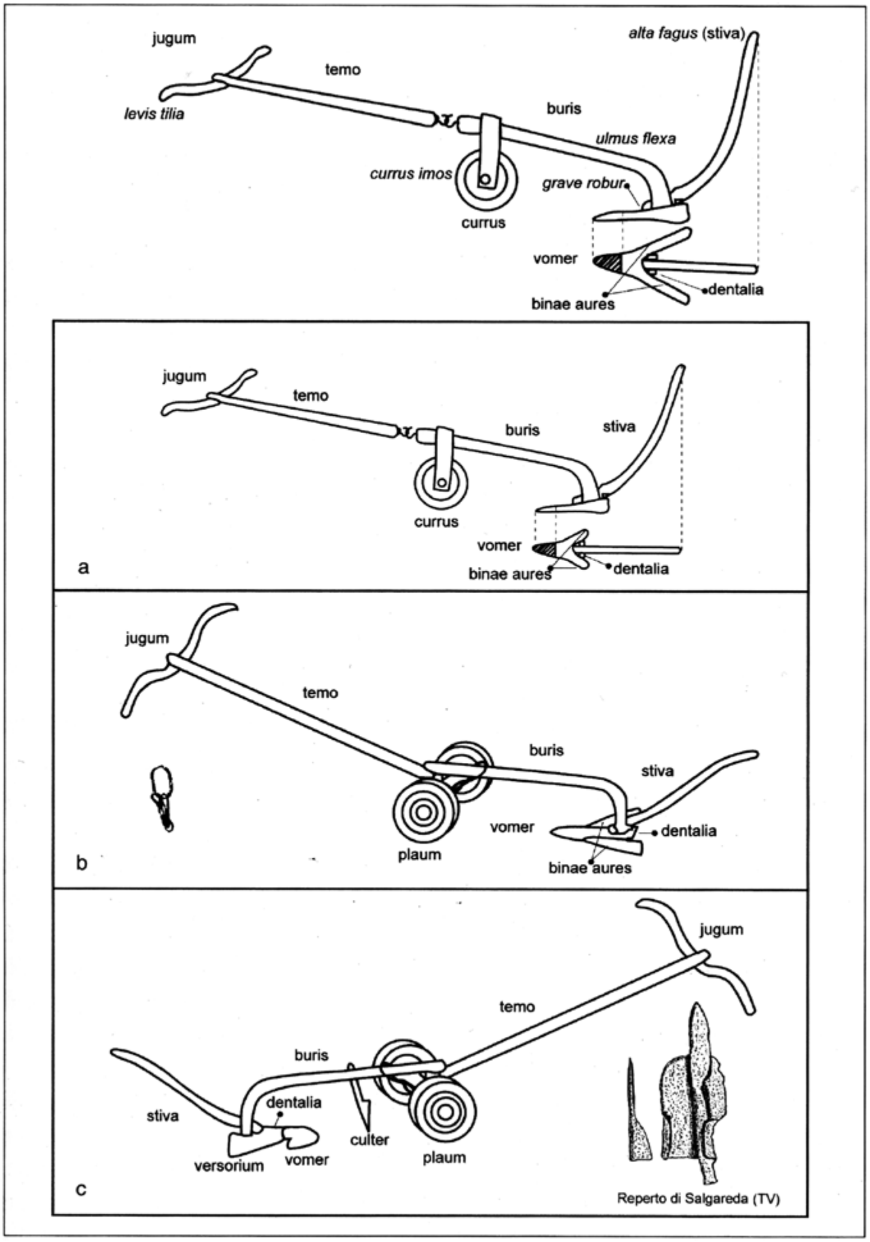

FIGURE 13.6 Progressive plow technologies of the Roman imperial period in northeastern Italy. Forni 2006
COURTESY OF CASA EDITRICE EDIPUGLIA

Investment for profit was far from ubiquitous in the Roman world but it was a common strategy in large-scale agriculture—especially on a regional scale, as discussed above.[58] It is no wonder, then, that a quasi-evolutionary development may be observed in the plows used in the lower Po valley and the Veneto in northeast Italy. The *currus* plow described by Vergil, supported on a single wheel, yielded to the *plovum* or two-wheeled trolley plow, which was superseded in turn by the *versorium* type, a variant of the former with a moldboard and coulter.[59] Prototypes probably emerged according to the 'tinkering' paradigm, especially if a wealthy landowner in a partnership with other investors or clients with relevant skills turned his in-house artisans to the task.[60] Successful new plows yielding better harvests on these seigneurial farms would not, however, have guaranteed broad diffusion of the technology beyond them. It is the fourth process, *reactive gain*, that would explain the widespread uptake and trickle-down of the technology, which—when all is said and done—posed only a modest investment risk. Such plows were doubtless expensive for a small freeholder, but perhaps no more so than a tractor for a family farm in the 1930s. Before anyone could adopt the new technology, it had to be made available—dare we say *marketed?*—and that too was a matter of investment. The wealthy sponsors could then turn to expanding the productivity of their woodshops and smithies to meet the demand—and this, in turn, may have encouraged further innovation (fig. 13.6).

6 How Models Could Anchor Innovation with a Community of Craftsmen

Strictly speaking, the previous section focused on motives driving innovation rather than modeling per se. But when modeling was tied to innovation it carried its own more pragmatic motive: to give an operational advantage to a new idea by making the idea seem intelligible and achievable to those with the training and expertise to realize it. Any innovation needed to anchor itself in the cumulative knowledge and successes of the past. But it might just as likely be 'thrown an anchor'—that is, impeded or thwarted altogether—by reactionary resistance within the artisan class before ever reaching clients or public.[61] The success or failure of innovation, then, turned not just on variables

58 Erdkamp, Verhoeven, and Zuiderhoek 2020, 13–14; Lewit 2020; Wilson 2020.
59 Verg. *G.* 1.160–75. Forni 2006.
60 On such partnerships see Brokaert and Zuiderhoek 2015, 148–149.
61 Sluiter 2017, 32–33.

such as private investment or public reception but on an innovator's capacity to generate a successful prototype that was simultaneously familiar to his community of peers or workmen and adaptable to the unfamiliar. In effect, it needed its own rhetoric, exhorting craftsmen to venture beyond their professional mythos into the extraordinary. If slick concept drawings of a yet unrealized building could seduce fickle *patrons*, models needed to seduce the *makers*.

Let us then briefly consider professional limitations on modeling. For such sponsored activities as high-end building, aqueduct construction, bulk transport, or regional agriculture, it is easy to envision modeling strategies even if the reality did not always rise to the occasion. But was simulation desired or encouraged among other trades and professions? Some Roman occupations probably placed limits on modeling, innovation, or both. The medical profession was hardly renowned for conservatism—its most successful practitioners were often freewheeling individualists who disagreed rancorously among themselves—but its capacity to make empirical progress was limited by taboos or restrictions on human dissection.[62] These restrictions were far from universal, but tellingly even the great Galen seems never to have dissected a human body himself. Instead, following a practice extending back at least to Aristotle, he dissected animals as proxies for the human body. In his writings he explicitly vaunts the epistemic value of this practice, recommending the regular and intensive dissection of apes, monkeys, and other animals because of their anatomical similarity to humans was instructive both in understanding the human body and in perfecting surgical procedures.[63]

This exemplum of analogical modeling may seem unusual from a technological perspective as it seems to invite neither invention nor adaptation into the cognitive feedback loop, only substitution. Yet practice by proxy then, as now, allowed physicians and medical students to develop not just understanding but new surgical and analytical techniques. That in turn could lead to improvements in the tools. In a recently discovered text Galen notes that he had devised new instruments by fashioning wax models that metalsmiths could then reproduce.[64] We might infer that some were surgical instruments he had developed from working with animal cadavers.

62 Dean-Jones 2018.

63 *On Anatomical Procedures* 1.2, 2.3, 3.5, 3.9, 5.6; *On the Usefulness of the Parts* 2.3.

64 *Avoiding Distress* 3.4–5 BJP. Translated by Nutton (2013), 79. She suggests they could have been reproduced directly through the lost-wax casting process. Bliquez (forthcoming) identifies similarly creative practices among less exalted physicians; cf. *POxy* 59.4001.

But what of other trades? Except for those with high-level patronage and direct connections to Rome, craft guilds must have been conservative and regulatory. Though they financed and facilitated investment ventures among their members they also embodied a culture of conformity that encouraged adherence to expected norms.[65] Any departure from those norms, including perceived attempts to gain an unfair market advantage, would have rankled. How, then, would a man like Ammianos have acquired permission and capital to develop his water-powered dual stone saw (see fig. 13.1)? We may suppose that the underlying motive for his potentially disruptive innovation was profit, prestige, or both, as the veneers of 'Hierapolitan marble' from the Thiounta quarries later catered to an elite market extending as far as Constantinople. His venture was complicated by the fact that it touched on numerous professions known to have been represented by guilds in the region—water-milling, wood-sawing, quarrying, stoneworking, building.[66] How did sawyers react to the prospect of their own potential obsolescence? Or the city council to a new demand on the city's water supply?[67] Did he then establish a consortium of like-minded investors among leading citizens who were patrons of other guilds? Did he have to go rogue, sacrificing his professional credentials for glory and profit? Nothing in his funerary inscription hints at his membership in any guild, let alone the one to which he would have most naturally belonged, the *hydraletai* or water millers at Hierapolis.[68] So was he a savvy consensus-builder, or a lone wolf? Where he succeeded (if he succeeded at all—his standard-issue sarcophagus suggests he didn't die rich), were others deterred by the pressures of institutional conformity and comity—or of cross-guild feuds, or jealously guarded privileges? We simply don't know.

Such matters, though barely visible from a distance, merit careful consideration if we are to understand institutional forces of incentivization and deterrence in the complex and contested history of Roman technological innovation. Professional feuds must have been common, especially in cities full of freewheeling commercial activity and strong competition for patronage. Evidence for cross-guild conflict appears occasionally in the Roman record; and at Ostia, loose federations of discrete, ultra-specialized guilds where one would expect consolidation might even betray strong disagreements about

65 Brokaert and Zuiderhoek 2015, 152–155.

66 Ritti, Grewe, and Kessener 2007, 142–146.

67 On just how ferocious the opposition of trade associations—and presumably their wealthy patrons—could be to disruptive new initiatives, see Dio, *Or.* 40.7–9; 45.15–16; 47.16–17, 19–20. On this occasion the city's blacksmiths successfully opposed their famous fellow citizen's attempt to displace their workshops with a colonnade.

68 Members of professional associations at Hierapolis projected strong civic identity and cohesion through their corporate status; see Arnaoutoglou 2016.

boundaries of professional conduct.[69] But even fractious groups probably held one another in check, as they ultimately had to work cooperatively within the system.

Veto power over disruptive innovation, then, probably played a significant role in maintaining social comity within professional communities. To assert, however, that internal resistance to 'upstart start-ups' was somehow myopic or reactionary would amount to devaluing any peer-review process. Poorly designed models, even those supporting ingenious ideas, probably betrayed defects fatal to the project—defects that might become evident only in mid-project when the gulf between professional competence and expectations proved unbridgeable. Even a successful model could yield a product that functioned as desired yet failed the larger test of personal or social benefit. Peer judgment was just as crucial for this higher order of evaluation. This is not to pretend that petty prejudice or blind obstructionism were somehow absent; but all necessary caveats aside, an artisan class anchored at both levels—those of the workshop (models) and the boardroom (adoption, promotion, diffusion)—was more an asset to innovation than a liability.

Because Roman sources are notoriously reticent about the inner workings of artisan communities, let alone the minds of their members, we can't hope to observe the processes I have just described up close. But almost every ancient technology can be studied using material and textual evidence combined with ethnological studies of recent and living artisan communities alongside other fragments of culture and knowledge—assemblages we can again call bricolage, the stuff of the creative tinkering.[70] Missing models can never be reconstructed with complete confidence, however, and while the effort may be worthwhile, the ultimate value of such exercises is more anthropological than technocentric. Considering the complex webs of agency entangling innovation, or the ways conservative communities negotiated its costs and values through processes of judgment and testing, the most interesting implications may well be the social, cognitive, and economic ones that are central to the idea of anchoring innovation.

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CHAPTER 14

Of Myths and Machines: Anchoring Technology in Mythology in Imperial Rome

Michiel Meeusen

1 Myths and Technology

The relationship between science and myth, and between *logos* and *mythos* more generally, in the Graeco-Roman period, is a notoriously complicated one.[1] Mythology served as a narrative frame of reference and explanation that counted as common cultural good throughout Antiquity. This helps to explain the relative prominence of mythological materials even in ancient technical-scientific writing, where the use of myths and the roles of gods and heroes are not completely rejected, even as rational philosophical accounts of nature are offered.[2]

Of at least equal complexity is the interaction between ancient myths and technology, understood as a materially applied form of science. Since the nineteenth century, the development of technology in Antiquity has often been inscribed into the paradigm 'from *mythos* to *logos*', where it was seen as being emancipated from religion to constitute a new and independent, rational discipline.[3] Nowadays, however, critical voices can be heard about the idea proposing that, for most of Antiquity, technology was a procedure about which rational discourse was the rule.[4] Ancient mythology is rich in tales about technological wonders made by divine and legendary craftsmen (e.g.,

* Images drawn from Woodcroft 1851; all translations mine.

1 Buxton 2001², Hawes 2014, 18, with n. 33 for further literature.

2 Taub 2008, 31–78. Also, e.g., Meeusen 2016, 264–274.

3 E.g., Vernant 1983, 299, who speaks of a process of 'secularisation' of technical skills.

4 Studies on the intersection between myths and technology, in terms of how specific technological themes and topics were formulated and imagined in ancient myths, include: Graf 2001², on the development of metallurgy; Lively 2006, on classical cyber myths; Devecka 2013, on mythic automata as a culture's expressions of utopian desire; Mayor 2018, on robots and artificially intelligent lifeforms; Chesi and Sclavi 2020, on Pandora as a cyborg; Gerolemou 2023, 31–66 on dramatic automation. The present paper will approach the interaction between myth and technology from a different, yet complementary perspective by looking, vice versa, at how ancient inventors incorporated mythological elements in their technological designs, and why.

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Hephaestus, Daedalus, *etc.*), but what is perhaps even more striking is that, the other way around, *historical* inventors, too, crafted devices and mechanisms to illustrate or evoke the ancient myths (e.g., amazing *automata*—self-moving machines—enacting mythic scenes during religious processions).[5]

Taking this as our starting point, in what follows I propose to examine the ways in which such mythical elements were artificially programmed and conveyed by such technological inventions and designs, what influence this process had on the technology itself, and how the old stories were revivified and transformed by it. What are the intentions of the inventor/teller in this interaction, the expectations of the audience, the habits of tradition, the demands of context? The argument comes in the form of a case study of the High Roman Empire (ca. first–second century CE), a pivotal period in political and scientific history.[6] Most of my attention will go to the first century CE inventor Hero of Alexandria and his use of mythological motifs as anchorage points for his mechanical inventions as described in the *Pneumatics* and *On Making Automata* (most notably his 'automatic theatre' but several other devices will be passed in review too).[7] Although engineers like him may well have seen themselves as the historical heirs to the inventors of the ancient myths, they seem to have been more inclined to position themselves in the tradition of historical predecessors, on whose works they explicitly—and quite literally—build, but even so they are still eager to connect with the world of mythology and ancient story-telling as well.

2 Story-Telling Technologies

That stories and myths, and the recounting of them, formed an important facet of ancient technological practice defined broadly (without restriction to mechanical engineering) is suggested, most notably, by the very first

5 Cf., e.g., Ath. *Deipn.* 5.196a–203b, on the festival held by Ptolemy Philadelphus in Alexandria, featuring multiple automata. On the religious backdrop of ancient Greek automata, Bur 2016.

6 The scientific achievements of this time are contemporary with revolutionary changes in politics witnessing the ascent of Roman Imperial rule and concomitant shifts in social and cultural frameworks. Both economically and intellectually, this time stands out as the pinnacle of Greek culture in a Roman-led world: e.g., Swain 1996, Schmitz 1997, Whitmarsh 2001. On the cultural function of technology at the Ptolemaic court in Hellenistic Alexandria, see Berrey 2017, 163–190; his point that 'court science' more generally displays an 'aesthetic similarity to poetry or other culture performed for entertainment of the court' (5) does not seem to have radically changed in the Imperial era, as we will see.

7 On 'anchoring innovation' in ancient technology more generally, Sluiter 2016, 27–28.

Chapter of the first Book of Vitruvius' *On Architecture*, where we read that the well-educated architect 'ought to know many stories', as he should be able to 'give an account to inquirers' about the ornaments that he uses in his constructions, for example the use of Caryatids in lieu of columns (i.e. marble statues of long-robed women).[8] These ornaments are meant to commemorate an historic episode, so Vitruvius writes (see further), which is indeed different from incorporating features drawn from fictional mythical stories. But as we will see, these historical elements have virtually the same aesthetic value and their narrative function and embedding is at least equally straightforward, making Vitruvius' Caryatids a usefully comparative case.

The conflating of an architectural element with the human body is indeed perplexing and as such provokes an account (*ratio*) from the side of the accomplished architect, who should be able to explain its origins so as to demonstrate his well-rounded education, beyond his professional architectural expertise. Vitruvius goes at considerable length to provide such an account himself, drawn from history, thus showing to his readers what such a *ratio* should look like. He explains that these statues represent the enslaved women of Caryae, a Peloponnesian city that had conspired with the Persian enemy against Greece. They originally functioned as some kind of an architectural apotropaic embodying a clear historical lesson: 'the architects of that day', so Vitruvius writes, 'designed for public buildings figures of those women, placed to carry a burden, in order that the punishment of the sin of the Caryatid people might also be known to posterity and committed to memory'.[9]

The broader cultural implications of Vitruvius' historical digression are straightforward: as a skilled expert, the well-educated architect ought to be able to publicly demonstrate—presumably indeed in the presence of his cultured patrons and, thus, his potential clientele—that his architectural training is not restricted to technical know-how exclusively but involves a much wider, all-round education, which allows him to speak, with knowledge and authority, on any given architectural-historical topic when prompted to.[10] The architectural use of Caryatids, thus, not only allows the cultured architect to

8 Vitr. *Arch.* 1.1.5: *Historias autem plures novisse oportet, quod multa ornamenta saepe in operibus architecti designant, de quibus argumentis rationem, cur fecerint, quaerentibus reddere debent.*

9 Vitr. *Arch.* 1.1.5: *Ideo qui tunc architecti fuerunt aedificiis publicis designaverunt earum imagines oneri ferundo conlocatas, ut etiam posteris nota poena peccati Cariatium memoriae traderetur.* The Spartans, so Vitruvius continues, built their Persian Porch/Colonnade in the same way by use of 'statues of their prisoners in barbaric dress' (*Arch.* 1.1.6).

10 On Vitruvius' concept of the architect's ideal education as part of his construction of scientific authority in *On Architecture*, Harris-McCoy 2017, 110–112.

demonstrate his technical skill in contriving aesthetically pleasing ornaments but also his wider learning in architectural history and his ability to 'give an account' (c.q. a historical aetiology) of their design when asked to. In other words, architecture was as much about 'art' as it was about 'science'—our 'soft' and 'hard' skills?—, and the well-trained architect had to be able to adopt his ornamental designs not just aesthetically but also cognitively to the cultural norms and traditions against which they operated. To go no further afield, one is reminded of the insistence of that other famous technician, Galen of Pergamum, that the best doctor is also a philosopher, or Lucian's defence of pantomimic dancing.

Although Vitruvius is talking about 'history' rather than about 'mythology' proper, the narrative element is straightforward. As architectural ornaments, the Caryatids have a story to tell, and it is the architect's task to bring these stories back to live, and to keep them alive for posterity. How much of this story-telling design applies to the field of ancient mechanical engineering too, where, as we saw, mythology is relatively prominent, will be explored in what follows.

3 Mythological Mechanics

To take a fresh start from Vitruvius' *On Architecture* it is notable that the tenth and final Book deals with different types of machines, both civil and military. Among the civil machines, Vitruvius gives lengthy accounts in Chapters seven and eight of Ctesibius' water driven pump and organ (also his water clock in Book nine, Chapter eight). He thus deliberately confines his selective use of Ctesibius' Greek devices to those which he—in line with contemporary Roman attitudes[11]—considers 'useful' rather than 'entertaining':

> The rest, which are not suited to necessity but to the pleasure of entertainments, may be found, by those fond of such refinement, in the commentaries of Ctesibius himself.[12]

Among the devices which Vitruvius attributes to Ctesibius, one wonders how 'useful' an organ really is or can be (the *hydraulis* was indeed generally considered Ctesibius' invention: see n. 32). The fact that this device counted as one of

11 Cf. Plin. *NH* 36.64–76 and 101–8.

12 Vitr. *Arch.* 10.7.5: *reliqua, quae non sunt ad necessitatem sed ad deliciarum voluptatem, qui cupidiores erunt eius subtilitatis, ex ipsius Ctesibii commentariis poterunt invenire.*

the foremost showpieces of their inventor's Greek ingenuity apparently overshadowed Vitruvius' Roman insistence on the practical utility of such devices. His ambition has now shifted, it seems, to providing fellow experts an accurate technical account, in Latin, of its complex construction, in an attempt to match—if not appropriate—Ctesibius' ingenious Greek design by means of his own native language.[13]

Indeed, the perceived Greekness of such inventions, as witnessed most obviously in the automata-making tradition, cannot be overemphasized, and it is not surprising therefore that many, if not most, proponents of this longstanding tradition were Greek by origin. As for the literary genre of automata-making manuals, Tatiana Bur may well be right in positing a Hellenistic origin for them: 'Given that both Philo and Hero dedicated entire treatises to automata, it seems highly probabl[e] that Ctesibius' now lost writings on technologies that had as their purposes the "pleasures of entertainment" would have included something on automata. If this hypothesis is correct, technical manuals on self-animated machines would have existed at least from the third century BC which sits comfortably with our early attested processional automata such as the snail of Demetrius of Phalerum at the Great Dionysia of 309/8 BC [...], or the automata used in the Grand Procession of Ptolemy Philadelphus soon after [...].'[14]

In what follows, I will turn to the Imperial stage of this Greek tradition, as personified, approximately one generation after Vitruvius, by Hero of Alexandria, the 'Machine Man' (ὁ μηχανικός). Although relatively late, Hero self-consciously builds on much of the mechanical achievements of his Greek predecessors (especially Philo of Byzantium, ca. 280–220 BCE) thus promising a fresh perspective on the ancient mechanical tradition at large and on the technological and intellectual culture of the High Roman Empire in specific.

Several of the mechanical devices described by Hero embed mythological elements in their designs, ranging from discrete mythological motifs or *topoi* involving automatic objects (for instance, self-opening temple doors, *Pneum.* 1.38–39 Schmidt = 37–38 Woodcroft; the 'eternal', i.e. self-trimming and self-refilling, lamp, *Pneum.* 1.34 Schmidt = 33 Woodcroft) over small scenes involving mythological agents and creatures (for instance, Heracles shooting a dragon, 1.41 Schmidt = 40 Woodcroft; an animal drinking on the revolution of a carved figure of Pan, 1.30–31 Schmidt = 29–30 Woodcroft) to entire mythological narratives (most notably, Hero's automatic theatre telling the myth of Nauplius in five scenic settings, *Aut.* 20–30; see further).

13 Vitr. *Arch.* 10.8.6.
14 Bur 2016, 105.

Within this fascinating, and still under-explored field, my interest specifically lies in how this procedure of mechanical programming of mythological materials served as a powerful tool to anchor technological inventions and developments in the target audience's own cultural frame of reference, rather than merely offering an amusing and aesthetically pleasing way of masking the mechanics at work behind the scenes. The one does not of course exclude the other, but my point is that this additional mythological layer was added not only for 'the pleasure of entertainment' (to use Vitruvius' words) but has wider cultural implications. Arguably, the engineer's creative use of myth is instrumental in producing some sense of cultural familiarity—in cognitive terms, rather than in terms of Bourdieu's cultural capitalism—, in that it facilitates acceptance of the intrinsic alienness and perplexity typically engendered by many such devices. Without this additional layer, presumably, acceptance of these devices as being the product of their ingenious and cultured inventor would be hampered, at least to some extent.

The famous device that became widely known as 'Hero's engine' (i.e. the 'aeolipile', 2.11 Schmidt = 50 Woodcroft), and which is often hailed as the world's first steam engine, serves as a suitable example.[15] Its basic motive principles were not, of course, put to any productive use in the way of the steam engines that powered much of the Industrial Revolution. Even still, it is interesting to see how one specific device in Hero's *Pneumatics* relies on virtually the same mechanical principle of motion as the one found in the aeolipile, and to which Hero expressly—and thus significantly—cross-refers at the end of his description,[16] that is the device that makes small figurines dance by fire on an altar (2.3 Schmidt = 70 Woodcroft). Referred to generally as ζῴδια ('figures', 'statues', 'images'),[17] these figurines are not specifically characterised as figures from myth or religion but one is reminded of the dancing Maenads in the dynamic automaton of Hero's *On Making Automata* (which includes an automated shrine of Dionysus, showcasing a set of stock features relating to

15 Keyser 1992, 117: 'an unwarranted retrojection of post-Renaissance ideas'. The term itself ('aeolipile') is etymologically rooted in ancient mythology, deriving from the name of the Greek god of air and wind (Αἴολος) and the Latin word for ball (*pila*), hence 'the ball of Aeolus'.

16 *Pneum.* 2.11 Schmidt = 50 Woodcroft: 'as with the dancing figures' (καθάπερ ἐπὶ τῶν χορευόντων ζῳδίων, phrase omitted in BCPL). The dancing figurines mechanism substitutes steam with heated air.

17 Cf. also *Pneum.* 1.12 Schmidt = 11 Woodcroft, and 2.21 Schmidt = 60 Woodcroft, with Bur 2016, 141–142.

the traditional Dionysus myth and cult, including dancing Maenads).[18] Their mechanically produced 'dancing around' may well evoke the ancient audience's familiarity with the circular dances of cultic experience.[19] The device consists of a small altar in which a rotating drum is connected to the hearth by means of a pipe, which is itself connected at the bottom to small tubes that lie at right angles to each other and are bent at their extremities. By their curvature, the pipes produce a circular motion when the air, heated by the fire, escapes through them (as is also the case in the aeolipile device, where air is substituted by steam as motive force).

The fire being kindled upon the altar, setting the contraption in motion, is an essentially ritual action, so there is reason to assume that a feature of divine agency is implied in Hero's description of the mechanism's design. It is particularly intriguing in this regard that nothing is 'hidden' in the device, since elsewhere it is usually stressed that it is precisely by hiding the mechanism that wonder or amazement (θαῦμα) is engendered.[20] In fact, Hero specifically emphasises—I assume this is not a gloss—that 'the altars shall be transparent, either of glass or horn' (οἱ γὰρ βωμοὶ διαφανεῖς, ἤτοι ὑάλινοι ἢ κεράτινοι, ἔσονται). On the one hand, the dancing figurines might not be visible if this were not the case, but, perhaps, the emphasis on the altar's transparency can also be taken to imply that the wonder engendered by the device ensues precisely from the complete visual absence of a driving mechanism or motor and the use of pulleys and counterweights (note that these are cleverly hidden in other devices, for instance, in the self-opening temple doors mechanism, a *topos* traceable to Homeric epic, which is likewise set in motion after a small altar is being lit).[21] The physical substance driving the device is of course air, heated by the fire on top of the burning altar, but this is invisible to the naked eye (hence presumably air instead of vapory steam). As a result, it seems as if the divine agency of the fire itself is what causes the figurines to dance, which in turn hints at divine, preternatural interaction.

18 The Dionysus shrine, placed on top of the construction, includes a moving statue of the deity, with wine pouring from his wine cup onto a panther lying beneath him, and milk or water shooting up from his thyrsus, and Maenads dancing around, accompanied by the sound of drums and cymbals (*Aut.* 4.1–4).

19 Bur 2016, 144. Schmidt 1899, 215 glosses the passage as "Der Opfertanz".

20 Hero repeatedly highlights the ingenious hiding of mechanical parts (e.g., the case of the mobile automaton hides the wheels: *Aut.* 2.7); the same idea is expressed in the Pseudo-Aristotelian *Mechanical Problems* 848a37: 'Craftsmen construct a device hiding the principle so that only the marvel of the machine is visible but its cause unclear.' (οἱ δημιουργοὶ κατασκευάζουσιν ὄργανον κρύπτοντες τὴν ἀρχήν, ὅπως ᾖ τοῦ μηχανήματος φανερὸν μόνον τὸ θαυμαστόν, τὸ δ' αἴτιον ἄδηλον).

21 Meeusen, forthcoming.

By contrast, in comparison to the dancing figurines mechanism, the aeolipile device, marked by its bare abstraction from any such mythical-cultic shrouding of its mechanistic design, offers a decontextualized and somewhat outlandish model appropriate, presumably, for instruction and/or theoretical debate of physical/mechanical principles among expert engineers and natural philosophers (e.g., regarding the principle of pneumatic pressure exerted by steam, comparable to the expansion of elemental air when heated—notably, Vitruvius discusses the aeolipile mechanism in a meteorological context),[22] rather than for public display before the eyes of stupefied non-initiates. More careful cultural embedding and engagement with the 'visual literacy' of the spectators was probably required in order to facilitate the wider uptake of these mechanical inventions as cultural products and the sense of astonishment that they 'magically' produced (which is different from claiming that the lack of such cultural embedding would render this uptake altogether impossible).[23]

4 Cultural Webs

Transhistorically speaking, scholars agree that automata have the ability to invoke 'the uncanny' (in reference to Freud's famous 1919 essay).[24] This is no less true of the type of artificial animation under review, albeit firmly

22 Viz. in light of the idea that wind is a wave of air, produced by heating of moisture. This is in the context of Vitruvius' account of city-planning where the architect should take winds into account (*Arch.* 1.6.2). The lofty cosmological overtones are noticeable at points and stand in sharp contrast with the smallness of the artificial invention that is the aeolipile device, which serves as their miniature analogue: 'That this is true we may learn from bronze aeolipiles, and thus by means of an artificial invention discover a divine truth hidden in the laws of the heavens. [...] Thus we may know and judge, from a small and very brief spectacle, about the great and immense causes of the nature of the sky and of the winds' (*id autem verum esse ex aeolis* [corr. *aeolipilis*?] *aereis licet aspicere et de latentibus caeli rationibus artificiosis rerum inventionibus divinitatis exprimere veritatem.* [...] *ita scire et iudicare licet e parvo brevissimoque spectaculo de magnis et inmanibus caeli ventorumque naturae rationibus*). By contrast, Keyser 1992 presumes anti-Aristotelian critique in Hero's aeolipile, more precisely of Aristotle's theory of motion (viz. the core idea that motion requires friction or resistance) as expressed in *De Motu*.

23 Moreover, there are potential links with contemporary natural philosophical concepts of dualist causation by which physical/mechanical and divine causes were believed to go hand in hand in producing the world's 'wonderful' ordering, as could be symbolised by these automatic designs. Cf. the (also transparent) device representing the cosmos in *Pneum.* 2.7 Schmidt = 46 Woodcroft (possibly reflecting Stoic cosmology: Keyser 1992, 115 with further literature). Meeusen 2016, 258–264 on dualistic causality in the Platonic thinker Plutarch of Chaeronea, who in *Per.* 6 mentions sundials as examples of how divine signalisation works. More generally, Berryman 2009, especially chs. 5–6.

24 See Bur 2016, 5.

reconfigured within the cultural webs of ancient Graeco-Roman society. In many cases, the astonishing effect that such devices were often explicitly (cf. notions of ἔκπληξις, 'astonishment' passim) supposed to engender in their audiences ties in directly with the conceptual framework of divine presence and interaction. This is most obvious in the case of self-moving temple devices, or the moving statuettes of divine beings, as they entail a very visceral sensation (mostly, but not exclusively, visual) of preternatural agency. Yet, to confine the cultural setting in which such devices operated to religious temple or procession contexts exclusively would be too reductionist, as we have sufficient evidence that they also had their proper function in other, more domestic contexts.[25] Most notably, the festive events of ancient symposia and dinner parties formed an exquisite avenue for the performance of such mechanical devices.[26]

Petronius, for instance, in his *Satyricon* describes a number of mechanical tricks featured as part of Trimalchio's *triclinium* entertainments, including automata.[27] His guest Encolpius, conditioned by the ludic nature of the event, even came to expect such things: 'so I started looking around the entire dining room in case any automaton should come out of the wall'.[28] Several of the devices in Hero's *Pneumatics* operate against the same convivial backdrop: for instance, several types of 'wonderful' drinking vessels are mentioned as being used to distribute or mix wine (Hero meaningfully speaks of κρατῆρες more than once).[29] The link with sympotic *spoud*(*ai*)*ogeloion*, that is the mix of 'seriousness' and 'play' which figures as a well-known sympotic topic and protocol in ancient literary sources, is evident in Hero's description of the 'magical' vessel that discharges wine and water in varying proportions, which he concludes by saying:

25 Acknowledged by Bur 2016, 7. Moreover, their ecplectic ambitions are very much in tune with the overall poetics of contemporary wonder-writing and paradoxography.

26 On '*triclinium* theatricality', see Beacham and Denard 2023, 426–483; also 85, 219 and passim for the link between Hero's automatic theatre and domestic theatre-related practices in the Roman house more generally.

27 Petr. *Sat.* 34.8–10; 36.3–4; 54.4; 60.1–3. The most impressive example of such convivial machines is undoubtedly the revolving dining room in Nero's *Domus Aurea* (Suet. *Ner.* 31.2). Beacham 2013, 15 links Hero's miniature theatre with Nero's infamous itch for theatricalism.

28 Petr. *Sat.* 54.4: *itaque totum circumspicere triclinium coepi, ne per parietem automatum aliquod exiret.*

29 *Pneum.* 1.14 Schmidt = 13 Woodcroft; 1.19 Schmidt = 19 Woodcroft; 2.12 Schmidt = 51 Woodcroft; also κρατήριον and κρατηρίδιον: 2.34 Schmidt = 74 Woodcroft. Cf. Bur 2016, 130: 'It is perhaps worth noting that these are described as *kraters*, further indicating a sympotic context, as opposed to the *spondeia* and *phialai* that make up the category of the "wondrous".'

> It is also possible to pour in water first, and then, stopping the vent-hole, pour wine upon it, so that pure wine is poured for some, mixed wine for others, and for those whom we wish to joke with (ἐμπαίζειν), water.[30]

The final line of the description reminds us of the light-hearted nature of the festive situation, in addition to the fact that in a convivial context intellectual debate—viz. of mechanical and, more generally, natural scientific/philosophical principles—formed an intrinsic part of the entertainment.[31] This is indicated by contemporary sympotic literature, as seen, for instance, in the intellectual symposia described in Plutarch's *Table Talk*, Aulus Gellius' *Attic Nights*, and Athenaus' *Learned Banqueters* (the latter has a discussion of the working of the ὕδραυλις where it is attributed to Ctesibius).[32] By consequence, devices such as these can be surmised to have served as technological tools to enliven the debate at symposia and to establish the intellectual prowess of the host. Especially the Preface to Hero's *Pneumatics*, with its lengthy discussion of the existence and nature of the void, makes it clear that these devices have a philosophical purpose and are no mere 'party pieces' as they served as a means to demonstrate core principles of theoretical physics, not without a taste for epideictic amusement and marvel (compare Galen's anatomical demonstrations for the elite in Rome).[33]

Presumably, these drinking devices do not, generally, employ mythological motifs as anchorage points since they tap directly into well-established convivial protocols, in that they, in and of themselves, succeed in their effort to facilitate a direct liaison between convivial revelry and entertainment, and concomitant social and intellectual norms relating to upper-class drinking

30 *Pneum.* 1.9 Schmidt = 8 Woodcroft: ἔξεστι δὲ καὶ προεγχέαντα ὕδωρ καὶ προκαταλαβόντα τὸ διαύγιον οἶνον ἐπιχέειν, ὥστε τοῖς μὲν καθαρὸν προέσθαι οἶνον, οἷς δὲ κρᾶμα, οἷς δὲ καὶ βουλόμεθα ἐμπαίζειν, ὕδωρ.

31 On the ideal symposiarch, cf. Plut. *Quaest. conv.* 1.4.620D: 'the person who governs drinkers must be akin to seriousness and no stranger to jest' (δεῖ δὲ καὶ σπουδῆς τὸν ἄρχοντα πινόντων οἰκεῖον εἶναι καὶ παιδιᾶς μὴ ἀλλότριον).

32 Ath. *Deipn.* 4.174a–f: i.e. the hydraulic organ, described by Hero in *Pneum.* 1.42 Schmidt = 76 Woodcroft. Gellius records Favorinus' account of Archytas' mechanical wooden dove (*NA* 10.12.9–10).

33 *Pace* Bur 2016: 130: 'The trick vessels would likely have been considered objects of the newest technology which wealthy hosts could pull out to impress their guests possibly in sympotic contexts, or which could have been used by minor entertainers such as the elusive *thaumatopoioi*. In many instances, the vessels rely on optical illusions and there is a focus on the flow of liquid being "contrary to nature" (*para physin*), particularly by harnessing the ability of the siphon to make liquid travel upwards. These were essentially performative vessels where the audience's expectations of liquid flow were inverted.'

and feasting. Mythology is not, indeed, the only 'additional layer' thinkable for this type of inventions, as is clear, for instance, from the 'idyllic' scene setting of many other devices or the conflation of both (e.g., the mechanically produced chirping of birds embellishing a fountain, which effectively sublimates the nature/*techne* divide).[34] But, as a particular type of anchorage, the traditional 'mythosphere' does have the benefit of adding an inherently narrative feature to such mechanical devices, as it opens up pathways into the imaginative world of ancient stories and legends. By revivifying, and perhaps indeed recounting,[35] these mythological tales, the mechanical engineer can position himself in a wider literary tradition cherished in learned, elite milieus at the time (as already seen in the case of Vitruvius' Caryatids).

By far the best example to illustrate this is Hero's static automaton or 'automatic theatre' described in detail in the second Book of his *On Making Automata*, which tells the myth of Nauplius in five scenic settings using all kinds of special effects (*Aut.* 20–30).[36] As I have argued elsewhere (and will not repeat at length here),[37] this is of course a very peculiar, if not unique, case: as a technical show-piece in its own right, the device is firmly anchored, not just in the epic cycle, but also in the wider mechanical tradition, as it self-consciously builds on previous mechanical constructions, most notably Philo of Byzantium's.[38] But as it connects with the epic tradition, the mechanism's design is also densely anchored in the poetics of ancient visual culture and theatre culture more generally: including such typical features as the *deus ex machina*, and also by evoking a sense of artificial vividness (*enargeia*), as well as by being relatable even to the ekphrastic tradition (i.e. the 'verbal description of a visual object/artwork' as known best from Philostratus' *Imagines*, which itself presents a large number of images depicting myths that

34 Gerolemou 2023, 4 (with further literature): 'instead of singing under the blue sky, they [sc. pneumatic mechanical birds] are placed inside a hall and sing during a banquet. This is associated with the fact that the mechanical procedure, in general, is not merely mimetic but it depends on the potential of the machine to produce things that can go beyond physical reality.' Arguably, the presence of mythological elements could reinforce the preternatural aesthetic of such devices (e.g., an animal drinking on the revolution of a carved figure of Pan, 1.30–31 Schmidt = 29–30 Woodcroft).

35 Cf. Beacham 2013, 33.

36 For digital renderings of Hero's 'toy theatre', see Beacham 2013.

37 Meeusen, forthcoming, tentatively arguing that the automatic theatre may well have been deployed as part of a sympotic performance.

38 Hero is proud to have innovated Philo's old design of the miniature theatre at some points (viz. by improving the apparition and disappearance of Athena and by including the lightning bolt falling on Ajax with the accompanying sound of thunder: *Aut.* 20.2–3). Allusion is made throughout the text to the fact that Hero is writing in dialogue with his predecessors both on matters of mechanics and styling (*Aut.* 1.1; 1.7; 5.1; 20.1–5; 22.1–2).

were the subject of theatrical performance).[39] Although Hero is embedding his mechanical device in the traditional framework of the Nauplius myth (as previously attempted also by Philo), rather than looking for ways of revivifying the old story as such, the old story did become revivified in the process (as did Philo's device).[40] The same is true, *mutatis mutandis*, for his other mythological devices (mentioned previously) as they produce a 'live' rendering of old stories and mythical elements in front of the spectators.

This all yields a very concrete idea of the performative function of myth as embodied, live, enacted events conveyed through such technology—in addition to the inherent technical qualities of the devices themselves—, and how they relate to the conceptual framework of ancient visual and theatrical culture more generally. Devices such as these give unique expression to ancient, mythically inspired, concepts of automation, the preternatural, divine agency, and as such allow us a window into peculiar aspects of ancient technological and literary culture in the High Imperial era.

5 Conclusion

All in all, the mechanical engineers' choice to embed their technological innovations in mythological fashion is probably more than just a superficial nicety to make them more digestible for the intended audience. By crafting

39 E.g., 1.18: the *Bacchae*, 2.10: *Cassandra*, 2.23: the *Madness of Hercules*, 2.4: *Hippolytus*, 2.29: *Antigone*. As Richard Beacham aptly observes in this regard (2013, 33): 'it is striking how in Hero's scenario each of the scenes depicts an episode of precisely the type which in actual tragic performance as it customarily took place would not have been *acted*, but rather *recounted* by the chorus. In other words, events which in conventional theatre practice were evoked and painted in the mind's eye of the spectators through *language*, were in Hero's theatre depicted by actual *images*.' On ancient *ekphrasis*: Webb 2009, Roby 2016, Squire 2018.

40 The appeal towards novelty and creativity is emphatic in *Aut.* 2.12: 'One should also avoid antiquated arrangements, so that the device looks newer; for it is possible, as stated previously, to create ever different arrangements by means of the same methods. Whoever is contriving a more pleasant arrangement will fare better in these affairs' (δεῖ δὲ καὶ τὰς τῶν ἀρχαίων ἐκφυγεῖν διαθέσεις, ὅπως καινότερον τὸ κατασκεύασμα φαίνηται· δυνατὸν γάρ, ὡς προείρηται, ταῖς αὐταῖς μεθόδοις χρώμενον ἑτέρας καὶ ἑτέρας διαθέσεις ποιεῖσθαι. βέλτιον δ᾽ ἐν τούτοις ἀναστρέψεται ὁ χαριεστέραν ἐπινοῶν διάθεσιν). The allusion to what was 'stated previously' is to *Aut.* 1.8: 'So in this Book we write on mobile automata setting forth an intricate arrangement of our own, which will adapt to every arrangement, so that whoever prefers to arrange differently will be able to do so, not lacking anything for the arrangement's performance.' (ἐν μὲν οὖν τούτῳ τῷ βιβλίῳ περὶ τῶν ὑπαγόντων γράφομεν ἐκθέμενοι διάθεσιν ποικίλην κατά γε ἡμᾶς, ἥτις ἁρμόσει πάσῃ διαθέσει πρὸς τὸ δύνασθαι τὸν προαιρούμενον ἑτέρως διατίθεσθαι μηδὲν ἐπιζητοῦντα πρὸς τὴν τῆς διαθέσεως ἐνέργειαν).

their devices in this way, they were looking for ways of anchoring their innovations as cultural products within a broader cultural paradigm. At the same time, by the use of such mythological embellishments, engineers seem to have had a specific aim of positioning themselves as stakeholders in a wider cultural marketplace: without a doubt, their priorities were primarily technological, but the consequences are not, therefore, without relevance for cultural history. Without denying their entertainment value, these mythological devices self-consciously hint at a shared cultural paradigm between inventor and audience. As such, they operate against the backdrop of very much the same cultural norms, values and standards according to which other *technitai* (like architects and doctors) were evaluated and vetted in Imperial Rome.

In their validation of ancient technologies, and more specifically in response to the vexed question of a *blocage* of ancient technological progress (i.e. the idea that something 'blocked' the ancient mind and prevented it from making connections between technology and economy, or technology and wider applications, which remains fiercely debated among historians of technology),[41] scholars generally take a relativizing stance, rightly arguing that any technology is culturally determined and that, by consequence, any conception of the history of ancient technology in terms of our own contemporary (read: neoliberal) notions of technological progress is methodologically flawed. Yet transhistorically speaking, I believe there is something to say for the idea that any cultural framework—and related to it, any anchoring of innovations and inventions in it, intentionally or unintentionally—can very well have adverse effects on the nature and scope of the science it produces (applied or not), *even* according to the scientific standards of its contemporary (i.e. historical) practitioners.

To stay in the context of Imperial Rome, the ban on human dissection and the ensuing flaws it effected in Galenic anatomy are well-known. Likewise, the concrete (and explicit) application of Hero's 'steam engine' in the dancing figurines mechanism, with its possible cultic and religious overtones, serves as a suitable example of the same dynamic. It can be read as a fine case of how firmly anchored such technologies had to be in the wider cultural paradigm of the time in order to facilitate their wider uptake and approval as cultural products (or to put things less optimistically: how they were, or could become, so helplessly fixated in it). Arguably, by being so firmly anchored in the webs of Graeco-Roman culture, this branch of mechanical engineering was never truly meant to survive Antiquity, and this probably explains much of its technological incommensurability, but also much of its ancient charm, for us today.

41 E.g., Greene 1994, 2000, Cuomo 2007, 3–4, Oleson 2008, 5–6, Devecka 2013, Bur 2016, 10–23.

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PART 4

Science

CHAPTER 15

Authorizing Prognosis in *Prometheus Bound*

Marianne Govers Hopman

1 Introduction

> I hold that it is an excellent thing for a physician to practice forecasting. For if he discover and declare unaided by the side of his patients the present, the past and the future, and fill in the gaps in the account given by the sick, he will be the more believed to understand the cases, so that men will confidently entrust themselves to him for treatment.[1]

These are the opening sentences of the treatise *Prognostic* transmitted under the name of Hippocrates and usually dated to the second half of the fifth century BCE.[2] After further considering the usefulness of forecasting in affirming doctors' authority and carrying out treatments, the author offers detailed instructions on how to identify and interpret symptoms (σημεῖα) to predict the course—fatal or not—of (primarily acute) diseases.

The practice of prognosis played an important and perhaps distinctive role in Hippocratic medicine. While *Prognostic* offers the most systematic and comprehensive description of the practice, other early Hippocratic treatises allude to one or more aspects of it, suggesting a widespread interest from the fifth century BCE onward. *Koan Prognoses, Prorrhetic* 1, and *Aphorisms* offer lists of 'good' and 'bad' signs depending on whether they signify recovery or death. *Prorrhetic* 2 insists on differentiating between doctors who make 'marvelous,' mantic-like predictions about the future, and the author's interest in more modest prognoses that carefully analyze bodily signs in order to predict recovery or death (*Prorrh.* 2.1–2). Helen King has even suggested that the ability of Hippocratic medicine to offer patients a narrative linking their past, present, and future—thus giving meaning to their sufferings—sets it apart from

1 Here and throughout the chapter, I quote Hippocratic texts using the chapter divisions and translations from the Loeb edition by W.H.S. Jones, E.T. Withington, P. Potter, and W. Smith (1923–2022). *Prometheus Bound* (hereafter abbreviated *PV* after the standard Latin title *Prometheus Vinctus*) is quoted using the Loeb edition and translation by A. Sommerstein.

2 On the date, see Jouanna 1992, 555–556; Craik 2015, 234–237. To this date the most systematic treatment of Hippocratic prognosis remains Edelstein 1967. See also Langholf 1990, 232–254; Nutton 2013, 87–103.

the narrative-free healing practices of temple medicine.[3] Yet, the protreptic structure of *Prorrhetic* 2 also suggests that the practice of prognosis could be a risky and contested enterprise. The treatise warns of the double-edged impact of prognosis upon a doctor's reputation, highlighting how accurate prognosis would result in the patient's admiration while erroneous prediction might cause 'hatred' and accusations of insanity (*Prorr.* 2.2). In addition, the introduction to *Prognostic* shows how prognosis was inextricably enmeshed with a recognition of the limits of the healing power of medicine.[4] It is precisely because 'to restore every patient to health is impossible' that 'it is necessary to learn the nature of such diseases, how much they exceed the strength of men's bodies' (*Prog.* 1). That knowledge will allow the doctor both to be more effective in saving those who can be cured, and to remain 'blameless' (ἀναίτιος ἂν εἴη, *Prog.* 1) if the patient dies. Thus prognosis is constructed as a response to the challenge of establishing doctors' authority in the face of the ineluctability of death; it involves a re-evaluation of the goals of medicine and a new emphasis on knowledge beyond clinical success.

For reasons that I will discuss below, scholars have suggested that the long speech in which Prometheus describes the future itinerary of the cow-maiden Io in *Prometheus Bound* may be fruitfully compared with Hippocratic prognosis.[5] The goal of this chapter is to examine that hypothesis and to investigate the ways in which the tragic reference to a recently theorized, and probably contested medical practice may have worked to naturalize and strengthen its authority among Athenian audiences. I first analyze the context of Prometheus' speeches and the extent to which the play's interest in medicine supports the comparison to Hippocratic prognosis. I then show how the multivalence of Prometheus' speeches tightly connects prognosis to his prophetic skills, thus 'anchoring' the medical innovation onto a traditional type of speech act, before exploring in the final section how the resulting blend carries special authority and plays a pivotal role in the tragic plot.

2 Prometheus' Speech to Io

Transmitted under the name of Aeschylus but most likely authored or finished by another poet, *Prometheus Bound* was performed in Athens sometime

3 King 1998, 111–112.

4 On Hippocratic doctors' acknowledgment of the limits of their art, see also *Prorrh.* 2.9; *Art* 3, 2; 8, 1–7, with Nutton 2013, 92–93.

5 Saïd 1985, 193; Guardasole 2000, 43–48.

between 479 and 414 BCE, with a date in the 440s being the most likely candidate.[6] The tragedy famously stages the conflict between the supreme god Zeus and Prometheus, fire-giver and inventor of all civilizing arts. Among other themes, it asks whether and how human arts—which were rapidly developing in fifth-century Athens—may be integrated into the traditional Olympian order. The performance opens on a brutal scene whereby Prometheus is tortured and nailed to a rock by Zeus' agents, followed by Prometheus' interaction with a series of visitors—the chorus of Ocean's daughters, Ocean himself, the cow-maiden Io, and Hermes. Their songs and dialogues highlight the contentious status of fire and the arts, framed by Prometheus as acts of resistance against Zeus' decision to exterminate humankind (231–233), but viewed instead by his interlocutors as transgressions against the essential divide between men and gods (30; 253; 507). As Prometheus becomes progressively more stubborn and defiant, the play ends with an environmental disaster. The Titan gets swallowed into the earth in a cataclysm that highlights both the importance and the difficulty of reconciling Zeus and the master inventor.

After Ocean, the second individual visitor to Prometheus' rock is the cow-maiden Io, whose long exchange with Prometheus occupies almost a third of the total performance time. Io, impersonated by an actor wearing a cow mask, enters in a state of delirious hallucinations. After puzzling about Prometheus' circumstances, she presses him to 'give [her] a clear indication (τέκμηρον) of what still lies in store for [her] to suffer' as well as 'a means of escape, a cure for [her] affliction (φάρμακον νόσου)' (604–606). In response, Prometheus delivers a three-part speech that forecasts her immediate and long-term future: how she will journey eastward to the eponymous Bosporus ('ox-bridge') between Europe and Asia (700–741); how she will travel all the way to Egypt, where she is to settle (782–818); how she will be cured by Zeus

6 While Aeschylus' authorship was never challenged in antiquity, it has been debated in modern times ever since R. Westphal questioned it in 1869. The main arguments are laid out in Herington 1970 and Pattoni 1987 (supporting the attribution to Aeschylus) vs. Griffith 1977, Taplin 1977, and West 1979. Regarding the production date, a *terminus post quem* is provided by a reference to the 479 or 475 BCE eruption of Aetna, while a *terminus ante quem* comes from the likely parody of *PV* in the 414 BCE production of *Birds*. On external evidence for the date, see Griffith 1977, 9–13, with bibliography. West 1979 convincingly demonstrates that *PV* fits well in the intellectual climate of the 440s, thus making it contemporary with the earliest treatises in the Hippocratic collection. Additionally, Hippocratic ideas would have circulated orally before being consigned in writing, and the Hippocratic treatises were most likely not the earliest medical literature (Jouanna 2012), suggesting that the practice of prognosis was known by the time *PV* was performed.

and give birth to a son; and how her descendants will include the murderous Danaids as well as Prometheus' future liberator, Heracles (823–876).

3 Prometheus as a Hippocratic Doctor

The comparison of Prometheus' prediction to Io with Hippocratic prognosis may at first seem out of place. The term prognosis is not used in the play and the action takes place in the primordial times of human history. Yet we know that the genre of Athenian tragedy, while set in the vagueness of heroic times, often reflects the concerns and values of the poet's time. As Bernard Knox put it, 'the contemporary reference in all Attic tragedy is so obvious and insistent that the term "anachronism", often applied to details of the tragic presentation of the mythical material, is completely misleading; in Attic tragedy of the fifth century anachronism is not the exception but the rule'.[7]

The character of Prometheus in *Prometheus Bound* offers a prime example of that temporal multi-valence. On one level, Prometheus is a Titan—an old, pre-Olympian divinity—who actively participated in the divine wars that led to the establishment of Zeus' order (199–223) and whose conflict with Zeus belongs with Mircea Eliade's *illo tempore*—the distant, primordial times of mythical origins. On another level, Prometheus' narrative of his culture-defining gifts to humans—the so-called 'speech of the arts'—closely intersects with achievements elsewhere attributed to the Trojan War hero Palamedes, described in Aeschylus' eponymous play as the inventor of astronomy (sch. on *PV* 457) and numbers (Aesch. fr. 181a). At a third level, and even closer to Athenian contemporary life, Prometheus repeatedly speaks or is addressed as an everyday physician. The chorus implicitly compares him to a doctor when they metaphorically construct his gift of Hope as 'a drug for the disease (φάρμακον νόσου)' of foreseeing one's death (249). Later in a brief interruption of the speech of the arts, they ironically compare him to a bad doctor who has fallen sick and is unable to cure himself (473–475).[8]

7 Knox 1966, 61, quoted in Easterling 1985, 1. A famous and oft-quoted example involves Aeschylus' *Suppliants*: when Danaus reports to his daughters the process whereby the Argives decided to give them asylum, he describes a vote by show of hand (*Suppl.* 604, 607, 621) that closely parallels democratic practices in the Athenian Assembly. Sourvinou-Inwood 1989 proposes the phrases 'distancing devices' and 'zooming devices' to describe the contrasting techniques whereby Athenian drama alternatively emphasizes or reduces the distance between the fiction enacted on stage and the contemporary world of the spectators.

8 On the metaphor of Prometheus as sick doctor as a leitmotiv in *PV*, see Petrounias 1976, 97–127.

More specifically still, Prometheus occasionally engages with ideas and vocabulary attested in Hippocratic texts.[9] As Ocean seeks permission to plead Prometheus' case to Zeus and reminds him that words are 'healers of a sick temper' (*PV* 377–378), Prometheus replies that this is true 'if one tries to soften the heart at the right moment' and 'does not try to reduce the swollen spirit against its will when it is still firm' (ἐάν τις ἐν καιρῷ γε μαλθάσσῃ κέαρ/καὶ μὴ σφριγῶντα θυμὸν ἰσχναίνῃ βίᾳ, 379–380). Such emphasis on temporizing and finding the right moment to treat a disease is a recurring concern in the Hippocratic corpus.[10] 'Life is short, the Art long, opportunity fleeting (ὁ δὲ καιρὸς ὀξύς), experiment treacherous, judgment difficult', warns the first sentence of *Aphorisms* (*Aph.* 1.1; cf *VM* 19.5; *Morb.* 1.1). The resemblance between Prometheus' advice and Hippocratic practices was not lost on the ancient scholiast, who compared lines 379–380 with the Hippocratic maxim, 'Treat them when they are ripe, not raw' (sch. A on *PV* 379a; cf. Hipp. *Aph.* 1.8; *Hum.* 6).[11]

The possibility that Prometheus' instruction to temporize evokes contemporary medical debates is further supported by dictional features that are rare in extant Athenian drama but parallel Hippocratic usage.[12] Anger, previously identified as a disease by Ocean, is depicted by Prometheus as a 'swelling of the heart' (σφριγῶντα θυμόν, 380). That use of the verb σφριγάω 'to be full, swell' to denote pathological inflation differs from its occurrences in Attic drama, most of which refer to youth and vigor (Eur. *And.* 196; Ar. *Nu.* 799; Ar. *Lys.* 80, etc.), but parallels its use to describe pathological swelling in Hippocratic texts (Hipp. *Mul.* 1.71). Prometheus' allusion to a treatment consisting of 'softening' (μαλθάσσῃ, 379) and 'reducing' (ἰσχναίνῃ, 380) the swelling is reminiscent of Hippocratic practices as well. The only parallel for the collocation of those verbs within a ten-word interval in Greek texts comes from the Hippocratic

9 On the interaction of Hippocratic ideas with other areas of intellectual life in Athens, see Thomas 2000 (on Herodotus and medical writings); van der Eijk 2005; Craik 2015, xviii–xix. On the complex issue of the presence of medical thinking in Athenian tragedy, see Dumortier 1935; Collinge 1962; Jouanna 1987 (Engl. transl. in Jouanna 2012); Guardasole 2000; Kosak 2004; Mitchell-Boyask 2008; Holmes 2010; Allan 2014. One methodological challenge in recovering possible allusions results from the absence in the fifth-century BCE of a medical language distinct from everyday speech, which makes it difficult to rigorously identify and interpret so-called 'medical terms' (that is, words also attested in the Hippocratic corpus) in the tragic scripts. See Collinge 1962, 53 n. 1; Guardasole 2000, 30–32.

10 On *kairos* in Hippocratic medicine, see Eskin 2002; Trédé-Boulmer 2015, 155–193.

11 On possible Hippocratic echoes in Prometheus' reference to temporizing, see Thomson 1932, 143; Dumortier 1935, 30–31; Petrounias 1976, 103 and n. 398.

12 On the lexical parallels, see Thomson 1932, 154; Fowler 1957, 179; Saïd 1985, 183; Guardasole 2000, 53–55.

treatise *On the Use of Liquids* in the context of a discussion of the benefits of heat (*Liqu.* 6.14 and 6.34). Thirdly, Prometheus' mention of an organ (κέαρ, 'heart', 379) as the object of the verb μαλθάσσω ('soften') has few if any parallels in drama, where the object of the verb is usually a person (Aesch. *Eum.* 134; *PV* 1008; Eur. *HF* 298; Soph. *Ant.* 1194); however, it frequently occurs in Hippocratic texts to describe treatments designed to release the tension in an organ (Hipp. *Artic.* 40.13 and 50.27; *Acut.* 5.18, 7.29; *Aff.* 20.13; *Nat. Mul.* 109.75; *Liqu.* 6.31, etc.). Altogether, Prometheus' injunction to 'soften the heart at the right moment' links him to ideas and language circulating in Hippocratic circles.

4 The Io Scene as Medical Consultation

Such characterizations of Prometheus as a doctor in the first third of the play are fully deployed when a delirious and exhausted Io enters the stage, begging for help. Her story—in which Zeus' love triggers the jealousy of Hera, who turns Io into a cow and sends a gadfly to torment her until she reaches Egypt—was already familiar to Athenian spectators from Aeschylus' *Suppliants* and perhaps Sophocles' *Inachus*, but the version in *Prometheus Bound* is remarkable for its interest in exploring Io's perspective on her physical and mental torments.[13] Her opening song highlights how the terror caused by the gadfly has deeply affected both her body and mind. Her desperate wanderings are caused not just by the sting of the insect, but also by the terrifying 'vision of the earth-born Argos (εἴδωλον Ἄργου γηγενοῦς)' who, despite being dead, is still on the move in her mind's eye (567). By the end of the episode, Io exits on a 'spasm' (σφάκελος, 878) that is simultaneously understood as the result of the 'prick' of the gadfly (879) and as a bout of madness (μανίαι, 879; λύσσα, 883). Her symptoms, described with quasi-clinical precision, resemble those mentioned in the Hippocratic treatise *On the Sacred Disease*, usually dated to the second half of the fifth century BCE.[14] Like the victims of a 'sacred disease' seizure, Io experiences aphonia (*PV* 877, 884; cp. ἄφωνον καθιστᾶσι καὶ ἄφρονα τὸν ἄνθρωπον, 'the patient is rendered speechless and senseless', *Morb. Sacr.* 10); rolling eyes (*PV* 882; cp. τὰ ὄμματα διαστρέφονται, 'the eyes roll', *Morb. Sacr.* 10); the pressure of internal organs upon one another (*PV* 881; cp. πνίγεται δὲ τοῦ ἥπατος καὶ τῆς ἄνω κοιλίης πρὸς τὰς φρένας προσπεπτωκότων, 'the liver and the upper

13 On the Io myth in *PV* and other Athenian plays, and their relative dates, see Murray 1958; Griffith 1983, 189–190; West 1984.

14 On parallels between *PV* and *On the Sacred Disease*, see Dumortier 1935, 69–79; Saïd 1985, 172; Guardasole 2000, 167.

bowel are forced against the diaphragm and the mouth of the stomach is intercepted', *Morb. Sacr.* 10); and confused thoughts (*PV* 885; cp. οὐδὲν φρονέουσιν, 'intelligence fails', *Morb. Sacr.* 10). Here as in Io's opening song, the gadfly seamlessly blends with a condition that has radically affected Io's body and mind. Her hybrid identity opens the possibility of exploring the *oistros* as both an insect and an underlying, chronic condition warranting a medical approach.[15]

Io's understanding of her condition as a sickness leads her to beg Prometheus for a cure and thus—unbeknownst to her—to reinforce his characterization as a doctor earlier in the play. In her first address to him, she refers to her condition as a 'disease' (νόσος, 597 and 606), urges him to 'give [her] a clear indication (τορῶς τέκμηρον, 605) of what still lies in store for [her] to suffer (παθεῖν, 606)', and asks for a 'means of escape, a cure for her affliction (φάρμακον νόσου)' (606).[16] Her use of the term 'drug' (φάρμακον) echoes Prometheus' own description of what he labels his 'greatest gift' to mortals: the fact that he remedied the 'lack of drugs' (φαρμάκων χρείᾳ) that previously caused their doom and taught them how to 'mix gentle curative drugs' (κράσεις ἠπίων ἀκεσμάτων) with which 'they can now defend themselves against all kinds of diseases (τὰς ἁπάσας ἐξαμύνονται νόσους)' (478–483). In addition, the verb τεκμαίρω, 'show', through which Io urges Prometheus to forecast her future sufferings (605), and that denotes a conjecture based on the critical examination of signs, occurs in medical texts (among other sources) where it refers to the practice of forecasting patients' futures from their symptoms (τοῖσιν ἄλλοισι σημείοισι συντεκμαίρεσθαι, Hp. *Prog.* 2; τεκμαίρεσθαι τοῖς ξύμπασι σημείοισι, Hp. *Prog.* 24). Those medical overtones in Io's request to Prometheus are further emphasized by the chorus when they sententiously highlight how 'it is sweet for the sick (τοῖς νοσοῦσι) to know accurately the rest of their disease' (*PV* 698–699). Like Io, the

15 On the polysemy of oistro- compounds and their reference to both physical and mental torments in *PV*, see Daniel 2007. The deployment of the term *oistros* in *PV* anticipates its semantic evolution in the second half of the fifth century, when the word occurs in contexts devoid of any insect referent to describe both phenomena that cause erratic or violent behaviors, or those behaviors themselves. Cf. Davies and Kathirithamby 1986, 162–163.

16 Here I disagree with scholars and translators who understand *nosos* at line 596 to mean simply 'trouble'. That translation assumes, first, that Io is not genuinely sick and that the term *nosos* only metaphorically applies to her situation and second, that by the time when *PV* was performed, *nosos* has become a 'dead' metaphor and that the tension between tenor and vehicle has disappeared. Both assumptions are questionable. Io's reference to her pains and mental strain suggests that she understands her condition as a disease. In addition, even if we were to understand *nosos* metaphorically here, translating the term as 'sickness' is crucial for embedding it in the rich nexus of medical vocabulary that pervades the entire play (Fowler 1957).

Oceanids frame Prometheus' predictions as a form of medical forecasting that previous references to Hippocratic ideas in the play would have primed audiences to compare to Hippocratic prognosis.

The prediction itself hardly says anything about Io's symptoms. Rather, it focuses on identifying the landscape markers, rivers, mountains, and peoples that define Io's path all the way to Egypt. Thus, while the prediction culminates in Io's cure by Zeus' gentle touch, it differs from Hippocratic prognosis in its emphasis on geographical rather than bodily signs as indicators pointing to the positive outcome of Io's condition. And yet, on several occasions, Prometheus' predictions intersect with Hippocratic concerns and interests in a way that further supports the general stylization of Io's and Prometheus' interaction as a medical consultation. One shared feature involves the question whether it is advisable to disclose patients' futures. As Io eagerly asks Prometheus to describe the end of her travails, he expresses concern that such knowledge may be a source of distress, highlighting the fact that 'it is better for [her] not to learn than to learn' about the end of her wanderings (624) and emphasizing his reluctance to disturb [her] mind (628). Although the idea that knowledge of the future may be painful and inadvisable occurs elsewhere in Athenian tragedy, it also intersects with the concern evidenced in Hippocratic texts that not all patients may be ready to hear their future, and that a doctor who delivers a negative prognostic should be sensitive to its possible impacts on the patient.[17] *Prorrhetic* 2 instructs the physician to tell a third party that the victim of a copious hemorrhage is likely to die (*Prorrh.* 2.6.23). *On Decorum* (a treatise usually dated to the Imperial period) forbids telling a patient what lies in store for them because of potential evil consequences (*Decent.* 16). The recurrence of this idea across the Hippocratic corpus suggests its importance in the Hippocratic tradition.

Another resemblance to prognosis appears at the beginning of the third section of Prometheus' prediction. Following a brief choral response to his foretelling of Io's reaching Egypt, he offers an account of her experiences before her arrival at his rock, notably her visit to Zeus' oracular shrine in Dodona, where she received a prophecy that she would become 'Zeus' glorious consort', and her wandering along the coast of the eponymous Ionian sea (829–841). Prometheus' interest in supporting the authority of his forecasting through a demonstration of his knowledge of Io's past aligns with the practice of seers such as Aeschylus' Cassandra, who impresses the chorus with her knowledge of the past horrors of the House of Atreus before going on to predict her and

17 Edelstein 1967, 76.

Agamemnon's double murder (Aesch. *Ag*. 1087–1129).[18] However, Prometheus' self-consciousness in retracing past events most closely parallels Hippocratic recommendations that doctors combine the identification and interpretation of premonitory symptoms with the presentation of information familiar to the patient. The author of *Prognostic*, alluding to the temporal omniscience of the Homeric seer Calchas who knows 'past, present, future' (*Il*. 1.70), encourages doctors to tell 'the present, the past, and the future' and to 'fill in the gaps in the account given by the sick' in order to gain the trust (πιστεύοιτο) of their patients (*Prog*. 1).[19] Similarly, Prometheus reflexively identifies his account of Io's past as a means of supporting his authority, and he does so using language used by Hippocratic doctors to describe their scientific method. He introduces his analepsis as a way to show 'that [Io] can know that what she has heard from [him] is not an empty story' (824) and to offer 'evidence (τεκμήριον) verifying [his] words' (826), and he concludes the flashback by characterizing it meta-linguistically as a 'sign (σημεῖα) that [his] mind can see more than what is manifest' (842–843). Prometheus' motive for evoking Io's past parallels that of prognosing doctors. In addition, the reflexive characterization of the analepsis as 'evidence' (τεκμήριον, 826) and 'sign' (σημεῖα, 842) parallels the language used by Hippocratic doctors to refer to the symptoms upon which their prognosis is based (*Prog*. 17.34; 25.10). While Prometheus' response to Io's request primarily reads as a geographical and genealogical catalogue, the speech is specifically framed as a doctor's response to a patient and repeatedly evokes prognosis—one of the many ways in which *Prometheus Bound* deploys medical metaphors and highlights medicine as Prometheus' most decisive gift to humans.

5 Prometheus as Seer

So far I have argued that Prometheus' predictions about Io's future may be understood within a specialized framework of forecasting theorized by Hippocratic doctors. Yet in the context of the play, Prometheus' speech also—and primarily—emerges as a prophecy delivered by a seer whose access to foreknowledge derives from divine sources. This characterization progressively becomes more obvious. From the beginning, Prometheus' speech intertextually echoes the paradigmatic prophecy of the magician Circe to the

18 On tragic prophets' concern to give proof of their forecasting abilities, see Kamerbeek 1965, 30.

19 Langholf 1990.

wandering Odysseus in *Odyssey* 12. Both texts feature a divinity with special knowledge describing the traveler's future itinerary through a combination of imperative and future indicative verbal forms. Circe promises that she will 'indicate everything' to Odysseus (ἕκαστα σημανέω, *Od.* 12.25–26), just as Io requests that Prometheus 'indicate' the rest of her sufferings (σήμαινε, 684). Both helpers start their speech with an intimation to listen ('listen to what I shall tell you', *Od.* 12.37–38; 'take my words to heart', *PV* 705–706) and then break down the itinerary into a series of three encounters—the Sirens, Scylla and Charybdis, and Thrinakia for Odysseus, and the Scythians, the Chalybes, and the Amazons for Io—the first of each being introduced with similar phraseology. Circe tells Odysseus that he will first reach the Sirens (Σειρῆνας μὲν πρῶτον *ἀφίξεαι*, *Od.* 12.38) while Prometheus mentions to Io that 'first … she will come to the nomad Scythians' (Σκύθας δ' *ἀφίξῃ* νομάδας, *PV* 709). In addition, both speeches recommend minimizing interactions with potentially dangerous inhabitants. Odysseus is told to row past the Sirens (*Od.* 12.47), quickly drive [his] ship past Scylla (*Od.* 12.108–109), and not harm the cattle of the Sun (*Od.* 12.137–138), while Io is advised to avoid the Scythians (*PV* 712–713) and beware of the Chalybes (*PV* 714–716).

Both Io and Prometheus himself use language that aligns his predictions with those of oracles. Io occasionally addresses him as if he were an oracular god. The verb σημαίνω, meaning both 'give a sign' and 'interpret pre-existing signs', through which she repeatedly voices her requests to him (σήμηνον, 564; σήμαινε, 684; σήμηνον 763), is used by Heraclitus with reference to Apollo speaking through the Delphic oracle.[20] Later, Io refers to Prometheus' prediction of his liberation by one of her descendants as an 'oracular answer' (χρησμῳδία, 775). Those indications culminate in Prometheus' claim that his forecasting to Io stems from an oracle (χρησμός) that he received from his mother, Themis (873–874). The word χρησμός had previously been used by Io to refer to oracles solicited by Inachus from Delphi (661–662), and Themis' authority as an oracular divinity had also previously been highlighted in Prometheus' account of her prophecy that guile would be the decisive factor in securing victory in the Titanomachy (209–213). Prometheus' identification of Themis as the source for his prediction to Io further links it to the oracle that led to the installation of Zeus' rule.

Thus Prometheus' predictions to Io are simultaneously stylized—through situational context, intertextual references, specialized vocabulary, and

20 Heraclitus fr. 93 D-K: ὁ ἄναξ, οὗ τὸ μαντεῖόν ἐστι τὸ ἐν Δελφοῖς, οὔτε λέγει οὔτε κρύπτει ἀλλὰ σημαίνει. On the verb σημαίνω as a marked verb in Herodotus that may indicate both encoding by a divinity and re-transmission by an intermediary, see Hollmann 2011, 20–27.

metapoetic characterization—as two genres of future-oriented speeches, belonging within two distinct regimes of truth. They are framed as and occasionally resemble Hippocratic prognosis that forecasts a patient's future on the basis of symptom observation, but they are also received by Io and eventually described by Prometheus as a prophecy grounded in the authority of the oracular divinity, Themis. If indeed divination and prognosis were historically related, and prognosis emerged as a specialized form of divination, then Prometheus' prediction to Io displays that genetic relation on the stage.[21] The multi-valence of his speech-act anchors the newer genre of medical prognosis onto a traditional form of future-oriented speech based on the assumption that gods exist and pay attention to humans.

6 Anchoring and Authority

The resulting blend of tradition and innovation carries special authority and plays an important role in the plot of *Prometheus Bound*.[22] The tragedy unfolds between two violent and spectacular events, Prometheus' binding to a Scythian rock in the parodos, and his engulfment into the earth in the final scene. In between, his status undergoes a tremendous change, from the victimized and seemingly helpless opponent of Zeus mocked by Kratos in the

21 In presenting Prometheus' forecasting speeches as simultaneously partaking of divination and prognosis, the *PV* poet touches upon a contentious question among Hippocratic authors. Some recognize the overlap between both practices. As mentioned above, the author of *Prognostic* echoes the description of Calchas at *Iliad* 1.70 when he says that the doctor should 'tell in advance, in the presence of his patients, the present, the past and what is to come to be' (*Prog*. 1.1). The author of *Epidemics* 1 references the Muses of Hesiod's *Theogony* (32) in recommending that doctors 'declare the past, determine the present, foretell the future' (λέγειν τὰ προγενόμενα, γινώσκειν τὰ παρεόντα, προλέγειν τὰ ἐσόμενα, *Epid*. 1.5). Others, however, are concerned that resemblance to divination may undermine the authority of the art. The author of *Prorrhetic* 2 opens with an attack on the idea that 'marvellous' and exact predictions are possible in medicine and says that he will not engage in such 'divination' (οὐ μαντεύσομαι, *Prorrh*. 2.1). The writer of *On Regimen in Acute Diseases* is concerned that disagreement among doctors may lead laymen to compare the art to divination, since the observation of birds and entrails feature similar variety of opinions among practitioners (*Acut*. 3). On the relation between divination and prognosis as discussed by Hippocratic writers, see Lloyd 1987, 41–46; Langholf 1990, 232–254. Van der Eijk 2004, 193 highlights how Hippocratic writers were keen to present divination and prognosis as fundamentally different areas without always being able to spell out what the difference was.

22 On the presence of a 'plot' in what has often been seen as a static play, see Yu 1971; Conacher 1980, 25–26; Bollack 2006.

prologue (85–87), to the confident adversary who so boldly taunts Zeus in the final scene, leading the latter to dispatch Hermes to find out Prometheus' secret and eventually to swallow him into the earth. The psychological change is not caused by physical action. In fact, as has often been pointed out, very little happens onstage except for the (spectacular) entrances and exits of Prometheus' interlocutors. Instead, the performance features a mental journey that involves both Prometheus' gradual realizing *and* convincing his internal audience that he and only he holds information crucial to the stability of Zeus' rule, which he will use to negotiate his release.

The prediction to Io stands at a turning point on both counts. Previously, Prometheus' allusions to the possibility of regaining his freedom had been unclear at best.[23] In the parodos, he mentions that he will be able to negotiate his release by leveraging his knowledge of a 'new plan' by which Zeus could be stripped of power (168–177), but the idea remains vague, and does not convince the chorus, who warns Prometheus of the danger of speaking 'too freely' (180) and stresses that Zeus is 'immovable' and 'inexorable' (184–185). Similarly, Prometheus' brief allusion in the first episode that the 'end of his trials' will only take place at Zeus' will (257–258) meets with the chorus's skepticism that such an event could ever happen (259–261). Contradictory premonitions, including a vision of endless bondage (98–100) and a statement that Prometheus has no device by which to escape from his present sufferings (469–471), further undermine audience trust in his early predictions about his future release.

By contrast, the Io scene opens up a space of heightened expertise and authority that coincides with a fuller account of the threat to Zeus' rule and the possibility of Prometheus' freedom. Once Prometheus completes the description of Io's travels up to the Bosporus, the scene morphs into a quick-paced dialog (stichomythia) when Io's questions about the nature and future of Zeus' rule prompt Prometheus to offer a fuller version of his previous predictions, to announce that Zeus' rule could be overthrown by the offspring of a fatal marriage (γάμος, 764), and to explain that one of Io's descendant will release him from his bonds (772). Thus the stichomythia is the locus of a hermeneutic reversal.[24] Prometheus initially states that 'now there is no end set for [his] agonies until Zeus is thrown from his tyranny' (755–756), suggesting that his freedom is incompatible with Zeus' rule, but he eventually reaches the opposite conclusion that only a freed Prometheus could prevent Zeus from being overthrown by a stronger son (770). The additional discovery that his release

23 On inconsistencies in Prometheus' foreknowledge, see Gantz 1976.

24 Conacher 1980, 63.

will be performed by one of Io's descendants (772–774) is repeated at the end of the third section of his prediction to Io, where it caps the list of her descendants (871–873). In other words, Io's and Prometheus' futures are found to intersect. His expert knowledge of her future—anchored in his double identity as doctor and seer—translates into a newly-found lucidity regarding his conflict with Zeus.

Prometheus' discovery and announcement of crucial information in his predictions to Io further coincide with a heightened confidence in his forecasting skills compared to the beginning of the play. Even though Hephaistos highlights Prometheus' descent from the oracular divinity Themis early in the prologue (18), Prometheus' initial utterances offer uncertain and at times contradictory perspectives on his prophetic abilities. Much as the chorus describes Prometheus as a bad doctor unable to heal himself (472–475), so too does the beginning of the play cast doubt upon Prometheus' ability to foresee and understand his own fate. In his opening song, his insistence that he has 'precise foreknowledge of all that will happen' (101–102) is initially framed and undercut by his own anxious doubts about the limit (τέρματα) of his sorrows (99–100), and a few seconds later by a string of agitated questions about the nature of the sounds and smells harbingering the chorus' entrance (114–116). Prometheus, it seems, did not have a full understanding of the intensity of the pain that would result from his resistance to Zeus' rule, nor did he anticipate the Oceanids' arrival. His unpreparedness paves the way for intense emotions of pain (πάσχω, 92) and terror at the approach of the harmless chorus (127). His distress and uncertainty about the length of his future sufferings is not unlike Io's, who uses similar language to request information about her future pains (755, 823, 828). Prometheus continues to oscillate between displays of extreme confidence and almost naive concessions of ignorance in the first episode, when his promise to give the Oceanids a full account of his future fortunes (272) is ironically preceded—and partly undermined—by the acknowledgement that he had not anticipated the extent of his own punishment (268–269).

In contrast, Prometheus' predictions to Io exude self-confidence, as measured by the length, tone, and theatralization of his speech. Early in his interaction with Io, Prometheus leads the audience to expect a thorough narrative about Io's future through the promise that '[he] shall tell [her] clearly all [she] wishes to learn' (609–610). Those expectations are fulfilled when he takes the stage and holds it for 120 lines (about one tenth of the total performance time), interrupted only by brief exchanges with the chorus and Io. That sheer length—and the associated stamina demanded from the actor—reflect his confidence in his knowledge and in his ability to command audience attention.

The speech further stands out for its imperious tone. The prediction opens with a *captatio benevolentiae* in which Prometheus urges the chorus to 'listen to Io's future sufferings at Hera's hands' (703–704) and orders Io to 'take [his] words to heart' (705–706). The double imperative sets the tone for the rest of the speech. Prometheus' predictions are organized as lists of injunctions telling Io which route to follow, whom to befriend (728), and whom to avoid (804, 807). His favorite verbal modes are imperatives (708, 810), infinitives used as imperatives (713, 804), and other modes of command (721, 730).[25] Even though his speeches are cast as prophecies, and thus technically reflective of an external principle of authority, what we hear are *de facto* orders pronounced by Prometheus as if he were the initiator of Io's future toils.

Moreover, Prometheus is highly aware of, and highlights to his audience, the performative power of his own utterances. Io will follow his orders, and as a result will endure tremendous toils, but ultimately be cured. Prometheus' awareness of the impact of his words appears in the concern mentioned above that his predictions may cause his addressee immediate pain and fear (696–697; 743–744). The performative power of Prometheus' predictions is further highlighted by metaphors that emphasize their impact upon Io's body. Prometheus opens his prediction by urging Io to 'take [his] words to heart (θυμός)' (705–706), thus putting his speech in direct contact with the main organ of thought and emotions. The second section of the prophecy opens on the striking injunction that she 'write this [his word] on the mindful tablets of [her] mind' (789). The phrase resembles Danaos's admonition to his panicked daughters at *Suppliants* 179, yet in a context where Prometheus had described himself as the inventor of writing, it also projects his invention upon Io's mind and body.[26]

Prometheus' self-confidence in his knowledge and in the power of his words rubs off on his listeners. His predictions to Io coincide with an increase in the authority and status granted to him by his internal audiences. Io accepts Prometheus' authority from the beginning of their interaction. Their conversation, primarily structured as a series of questions and answers, assumes a hierarchy of knowledge between the omniscient Titan and the wandering cow-maiden. She enters the stage on a stream of questions about her whereabouts and Prometheus' identity (561–565), and he calmly and accurately states

25 On the grammatical manifestations of Prometheus' authority, see Saïd 1985, 200. On the imperiousness of Prometheus' prophecies, see Rosenmeyer 1963, 69–70 and Podlecki 2005, 206.

26 On the equivocal power of writing, simultaneously liberating and coercive, see Steiner 1994, 8 and 248.

her father's name and summarizes her story so far (589–592). She asks further questions about her future (593–609) and he promises to tell her all she wishes to learn (609–612).

Io's acceptance of Prometheus' authority also affects the chorus's response. Perhaps because of the emotional connection and the deep sympathy that the chorus feels for Io—whose fate they fear might happen to them (887–907)—the Oceanids' relation to Prometheus gets reshaped over the Io scene, resulting in a new recognition of his authority. In previous interactions, the chorus had sympathized with Prometheus' pains but also criticized his actions, castigating his bold language and misplaced gifts to humans (180–182; 259–260; 507–508), deploring the loss of his wits (472–473), and comparing him to a bad doctor unable to cure himself (473–475). In contrast, the Io scene shows the Oceanids reverently addressing Prometheus as a 'teacher' (διδαχθήτω, 634; ἐκδίδασκε, 698). The move is especially significant given the importance of teacher imagery in the play. A sardonic and triumphant Kratos had enjoined Prometheus to 'be taught' (διδαχθῇ, 10) acceptance of Zeus' rule in the prologue; later the Ocean scene had pivoted around the shifting of the teacher role from an initially confident Ocean (ἔμοιγε χρώμενος διδασκάλῳ, 322) to an increasingly assertive Prometheus (ἐμοῦ διδασκάλου, 373; δίδασκέ με, 382).[27] From the viewpoint of Prometheus' interaction with his internal audiences, the Io scene marks a decisive step in an arc of progressive empowerment leading from the terror of his initial speech to his flippant defiance of Zeus in the final scene.[28]

After Io's exit and a short choral song, the progress of Prometheus' increased lucidity and authority culminates in his vivid description of how, without his help, Zeus will be overthrown by a more powerful son, complete with striking details about the special fire—more powerful than the lightning-bolt—that the latter will use to 'plague the sea and shake the earth' and eventually enslave Zeus (927). While the chorus initially suspects Prometheus of wishful thinking (928), the prophecy—which ironically will not come to fruition—carries enough authority for Zeus to dispatch Hermes to order Prometheus to disclose the name of Zeus' fatal bride, and to engineer a cataclysm in response to Prometheus' refusal. Despite his immobility, Prometheus works toward his release through the sheer power of his forecasting skills—or perhaps more precisely, since we will never know whether his prediction is accurate, through his ability to convince his audience of the authority of his forecasting. The blending of Hippocratic prognosis and prophetic speech in his predictions

27 On the Ocean episode and the reversal suggested by the development of the teacher imagery, see Konstan 1977.

28 On Prometheus' growing belligerence, see Griffith 1983, 10.

to Io simultaneously anchors the newer practice and renews the authority of the older one, making the speech a turning point in the 'mental plot' of *Prometheus Bound*.

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CHAPTER 16

Anchoring in *tekhnê*. Weaving and Plato's Distinction of Pure and Applied Knowledge

Giovanni Fanfani, Ellen Harlizius-Klück, and Annapurna Mamidipudi

> Of course, no man of sense would wish to hunt for the definition (*logos*) of the art of weaving (τῆς ὑφαντικῆς) for its own sake (αὐτῆς ταύτης ἕνεκα). (Plato, *Statesman* 285d9–10)

> Much of the conversation [sc. in Plato's *Statesman*] is devoted to a minute and seemingly tedious analysis of the art of weaving [...]. (S. Rosen, *Plato's* Statesman: *the Web of Politics*, 1995, 1–2)

1 Introduction: Arithmetic, *diairesis* and Weaving in Plato's *Statesman*[1]

Early into Plato's *Statesman*, the main interlocutors—the Eleatic Stranger, who guides the discussion, and Young Socrates, a pupil of the mathematician Theodorus—agree on conducting their enquiry into the nature of statesmanship by first detecting the form of science (*epistêmê*) possessed by the

1 The research presented in this contribution has been conducted in the frame of the ERC project 'PENELOPE. A Study of Weaving as Technical Mode of Existence', funded by the European Commission under the HORIZON 2020 Research and Innovation Programme (No. 682711). We would like to thank the organizers of the 'Anchoring Technology in Greco-Roman Antiquity' conference and the editors of this volume. While this contribution and its argument have been conceived and shaped by the three authors in close collaboration, Giovanni Fanfani is the primary author of sections 1, 3, 4, 5, 6; Ellen Harlizius-Klück of section 2; Annapurna Mamidipudi of section 7. Greek and Latin texts follow the most recent Oxford Classical Texts editions, with a few exceptions: Euclid's *Elements* and Pindar's epinician odes are cited after the respective Teubner editions, the Presocratic thinkers after Diels and Kranz's edition (D-K), lyric poets after Page's *PMG*. English translations follow the most recent Loeb editions.

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statesman (258b2–7). The dialectical method framing the investigation is that of *diairesis* ('division'), consisting in the repeated binary division—whose mode is defined by Plato as 'according to forms and dichotomous/dyadic', κατ' εἴδη καὶ δίχα 262e3–4—of a genus/kind/form into two subordinate classes (each in turn being both 'genus/form and part', γένος ἅμα καὶ μέρος, 262e8), one of which is abandoned while the other further halved/divided until the classification reaches its terminus and provides the *logos* ('reasoned definition', 'explication') of the object under scrutiny.[2] The first and fundamental step in the *diairesis* of the statesman's science is the split between 'the two forms of the unitary *epistêmê*' (258e6–7): one, disengaged from the practice, only supplies knowledge and is thus called 'gnostic/theoretical' (*gnôstikê*, 258e5); the other has *epistêmê* embodied in the practice and is thus labelled 'practical' (*praktikê*, 258e5). This passage, the details of which will be discussed below in section 5, has been seen as articulating 'the distinction between theory and practice [...] perhaps for the first time in Western thought'.[3] Indeed, a first look at the *technai* presented by the Eleatic Stranger as instances of the two modalities of science—*arithmêtikê* 'arithmetic, number theory' exemplifying abstract knowledge; *tektonikê* 'carpentry' and *kheirourgia* 'handicraft' epitomizing embodied, practical knowledge—may seem to warrant, in conjunction with other epistemic pronouncements by Plato (especially *Phlb*. 55d–57a and *Resp*. 525a–526b), a rendering of *gnôstikê* and *praktikê* as 'pure' and 'applied science' respectively.[4]

However, a second look at the specific strand of ancient mathematics at which the term *arithmêtikê* apparently points here does complicate the picture. The reference is, we argue, to the doctrine of odd and even, a theory grounded on binary features of number, their relations and compositional configurations: multiplication/division, addition/subtraction, factorization into prime numbers, and the pattern of continuous halving or doubling—whereby the

2 Interestingly, the Platonic phrase δίχα διαιρεῖσθαι 'to divide in two equal parts/dichotomously/dyadically' (*Plt*. 262e4), resurfaces identical in the Euclidean definition of even number (*Elements* 7 def. 6): Ἄρτιος ἀριθμός ὁ δίχα διαιρούμενος, 'An even number is that which is divisible into two equal parts'. At *Plt*. 262b6–c1 the Eleatic Stranger remarks the correctness of sectioning 'through the middle' (διὰ μέσων) in the method of *diairesis*.

3 Márquez 2007, 31.

4 This is the translation adopted by Skemp 1987[2] (1st ed. 1952). In *Phlb*. 55d–e *arithmêtikê* is the 'purest' (καθαρώτατα) and 'closer to *epistêmê*' component of handicrafts (χειροτεχνικαῖς, 55d4). In both *Phlb*. 56d and *Resp*. 525a–526b the mathematics of the philosophers, grounded on abstract numbers and undifferentiated units, is explicitly contrasted with embodied numbers as applied to various practices, crafts and technologies.

label 'dyadic arithmetic'.[5] To be sure, several Platonic occurrences of the term *arithmêtikê* seem coextensive with the notion of 'study of odd and even' (e.g., *Resp*. 510c4; *Grg*. 451b3, 454a1); in the *Statesman*, odd and even figure as the primary forms/kinds (*eidê*) that a correct *diairesis* of the notion of *arithmos* obtains (262e3–5).[6] Leaving to the final appendix (section 8) a few historical considerations on the Pythagorean connotations of the theory of odd and even and on its formalization and inclusion in Euclid's *Elements*, it is worth remarking at this stage that the doctrine is prevalently seen by historians and philosophers of Greek mathematics as the result of internal reasoning, with no material origin or application of it—except for the practice of manipulating and arranging stone calculi/pebbles (*psêphoi*), which an early source (Epicharmus 23 B2 D-K) associates with the distinction between odd and even numbers.[7]

In fact, a central claim of this chapter is that there *is* a technology, namely weaving, that generates order and create patterns by manipulating threads and numbers—threads being material instantiations of numbers—via a binary logic that corresponds to the operations described in the theory of odd and even as we find it in Euclid. In other words, number is embedded in weaving as an ordering function: the fundamental division of the warp threads into even and odd determines constraints and possibilities of patterning on the loom. This is remarkably different from the way in which numbers work in other technologies and crafts, as for instance carpentry. Which brings us back to Plato's *Statesman* and to the separation between abstract and practical modes of knowledge—or pure and applied science. We see the 'abstract' and 'pure'—in the case at stake, *arithmêtikê* as theory of odd and even—as an operator or ordering function that, embedded in material practice, is extracted and recast as universal arithmetical knowledge, and propose to frame the split operated by Plato between abstract and practical science (i.e. between *arithmêtikê* and craft) as a case of innovation.

Arguing that fundamental operators of weaving technology travelled, in the form of number features, to dyadic arithmetic does not bear the implication

5 Becker 1992, 96–100: the 'dyadic' procedure of halving and doubling is the doctrine's 'chief instrument for carrying out its proofs' (p. 100), together with 'the specific properties of the number 2' (p. 96).

6 Cf. Klein 1968, 17–25.

7 Becker 1936 and Szabó 1978, 257 see the theory of odd and even, in the form preserved in the propositions closing book 9 of Euclid's *Elements* (props. 21–34, but also 35–36), as the earliest corpus of Greek (specifically Pythagorean) deductive mathematics. An authoritative confutation of Becker's argument is Burkert 1972, 434–438. Becker 1936 takes *psêphoi* arrangement as a proofing tool; Asper 2009, 108–109 as a heuristic device.

that Greek arithmetic as a whole is derived from weaving. Rather, we see this as an instance of a broader pattern that this contribution sets out to investigate: weaving generates concepts of order that travel to, and at times ground innovation in, different domains of archaic Greek thought—arithmetic (section 2), cosmology (section 3), musical terminology and metrical theory (section 4).

This pattern may be explored within the heuristics of anchoring innovation, with the *Statesman* complicating the model in two significant ways. On the one hand, Plato's distinction between pure and applied science splits a knowledge (the knowledge of weaving) that in archaic time was perceived as unitary and establishes an epistemic hierarchy that posits the abstract—the theory of odd and even, originally an ordering function of weaving—before and above the material (section 5). On the other hand, the philosopher makes this innovation, and the implied hierarchy, bear on his treatment of the art of statesmanship as *epistêmê*, and he does that by way of anchoring in weaving, via *diairesis* (section 6). Indeed, weaving features prominently in the dialogue: it is the model/example (*paradeigma*) selected by the Eleatic Stranger for analogically illustrating the nature of statesmanship (279a7–b2: the two *technai* share the same 'activity', πραγμάτεια) through an extended *diairesis* (279c8–283b5). Coherently, the *logos* of weaving, defined as 'the *technê* of intertwining weft and warp' (283b1–2), deeply informs the imagery of the final section of the *Statesman*, where statesmanship is described as the intertwining (*sumplokê*) of 'courage' (*andreia*) and 'temperance' (*sôphrosunê*) (305e8–306a3; 311b7–c1). And yet, at the end of the *diairesis* of the art of weaving, the Eleatic Stranger discards any significance of weaving as such, its function merely illustrative of statecraft (285d9–10).[8] Less noticed, but relevant for our argument, is how Plato's text seems to suggest (282b4–c3) that weaving, which uniquely embeds the two technological postures of combination (ἡ συγκριτική) and distinction/separation (ἡ διακριτική), stands as a *paradeigma* for the dialectic method itself.

The brief conclusive remarks (section 7) pay attention to some of the long-standing consequences of Plato's epistemic innovation, especially in the way the relation between abstract science and technology has been shaped by the split between pure and applied knowledge; the split, in turn, is framed in terms of a reconfigured relation between the notions of *tekhnê* and *epistêmê*.

8 'Of course, no man of sense would wish to hunt for the definition (λόγον) of the art of weaving (τῆς ὑφαντικῆς) for its own sake (αὐτῆς ταύτης ἕνεκα).' A few lines later, the 'long *logos*' of weaving is said to have been carried out 'for the sake of annoying' (ἕνεκα τῆς δυσχερείας, 286b7).

2 Weaving as Knowledge: Ordering through Number and the Theory of Odd and Even

An attempt at reconstructing the knowledge of ancient weaving cannot be grounded on textual descriptions, which are absent, nor on textile finds, fragmentary and scarce. However, due to the binary character of weaving and the logic of fabric construction, it is possible to reconstruct the considerations necessary to create the woven motifs we see depicted on sculptures, vases, or frescoes.

Pattern generation works through the manipulation of a set of elements (the threads) in which the distinction between odd and even numbers is a primary technological condition: in the vertical warp-weighted loom in use in ancient Greece, warp threads (the vertical ones) are divided into two halves by placing every other warp thread in front of a horizontal bar roughly in the lower half of the loom (*kairos*), and every remaining thread behind. And while weaving may have the appearance of employing geometry because of the patterns it generates, its logic is in fact arithmetic. Every geometric or figurative shape appearing on the fabric is the result of considerations of ratios (*logoi* in Greek) between numbers and properties of integers: evenness, oddness, primality, and the respective combination; determining the odd- and evenness of sets of threads for generating patterns implies mastering number composition and factorization.[9] Patterns are not just repeated on a limitless space. Due to the technology of the warp-weighted loom where the warp is set up with a starting border, the amount of warp-threads is there in advance and the pattern needs to fit in. Sill today, some weavers use a specific algorithm to determine possibilities of factorization: in case of a pattern repeat of six threads, and if the width of the warp is small enough to be grasped from both ends, they take groups of six threads away alternating (for example by thumb and index finger opposition) and check which amount of threads is left in the middle.[10] Determining with both hands if a factor works for the given number of warp

9 The logic of generating a woven pattern on the warp-weighted loom, and its relationship with early Greek mathematics are discussed in greater detail in Fanfani and Harlizius-Klück (forthcoming a) (dyadic arithmetic as formulated in Euclid's *Elements*), Fanfani and Harlizius-Klück (forthcoming b) (relationship between geometry and arithmetic, incommensurability). Cf. also Harlizius-Klück 2004, *passim*.

10 Interestingly, the operation of grasping numbers/units from both ends of the warp with both hands resonates with the definition of even number in the Neo-Pythagorean Nicomachus (*Introduction to arithmetic* I 7 Hoche 13.7–14.12, 'The even is that which can be divided into two parts, without a unit inserting itself in the middle'); if the halving is done that way, there are only two possibilities for the algorithm to end: either, no thread

threads does not request to know that number, just the factor one wants to test. What weavers do is not actually count but calculate possible arrangements of given thread counts. The most important knowledge for the weaver is to distinguish between numbers that can be composed from other numbers, and numbers for which no such composition is possible. Crucially, we find such a distinction formalized in definitions 6–15 opening book 7 of Euclid's *Elements*, which, together with propositions 21–34 closing book 9, constitute the theory of odd and even—or the doctrine of dyadic arithmetic.[11] The arithmetical notion of *diairesis* as division into two equal parts—which in Euclid determines the evenness or oddness of a number in terms of it being or not δίχα διαιρούμενος 'divisible into two (equal parts)'—emerges as a relevant component of the weaver's knowledge, both in the initial halving of warp threads into odd and even, and as a method for determining pattern properties. As an exemplification of how certain operations of pattern repeats calculation in weaving appear to find an apposite—yet abstract—description in the Euclidean theorems that form the core of the theory of odd and even, we propose to set a sample of the two in dialogue.

a) Rules for calculating warp counts to be achieved, consisting in number composition through addition and multiplication of even and odd numbers (the pattern repeat can be either odd or even):

(Eucl. *El.* 9, prop. 23) Ἐὰν περισσοὶ ἀριθμοὶ ὁποσοιοῦν συνθετῶσιν, τὸ δὲ πλέθος αὐτῶν περισσὸν ᾖ, καὶ ὁ ὅλος περισσὸς ἔσται 'If as many odd numbers as we please be added together, and their multitude be odd, the whole will also be odd'.

(Eucl. *El.* 9, prop. 28) Ἐὰν περισσὸς ἀριθμὸς ἄρτιον πολλαπλασιάσας ποιῇ τινα, ὁ γενόμενος ἄρτιος ἔσται 'If an odd number by multiplying an even number makes some number, the product will be even'.

b) Rules for ordering the warp, or for finding out possible pattern repeats, consisting in number composition through subtraction, division, and the 'dyadic' operations of halving and doubling:

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remains in the middle and the whole is even; or one thread remains in the middle and the whole is odd.

11 For the notion of composite number(s), see book 7, definitions 13 ('A composite [σύνθετος] number is that which is measured [μετρούμενος] by some number') and 14 ('Numbers composite to one another are those which are measured by some number as a common measure'); examples of composition of odd and even numbers are definitions 8-9-10 on even-times even number, even-times odd number and odd-times odd number.

(Eucl. *El.* 9, prop. 27) Ἐὰν ἀπὸ περισσοῦ ἀριθμοῦ ἄρτιος ἀφαιρεθῇ, ὁ λοιπὸς περισσὸς ἔσται 'If an even number is subtracted from an odd number, then the remainder will be odd'.

(Eucl. *El.* 9, prop. 30) Ἐὰν περισσὸς ἀριθμὸς ἄρτιον ἀριθμὸν μετρῇ, καὶ ἥμισυν αὐτοῦ μετρήσει 'In an odd number measures an even number, it will also measure (one) half of it'.

(Eucl. *El.* 9, prop. 31) Ἐὰν περισσὸς ἀριθμὸς πρός τινα ἀριθμὸν πρῶτος ᾖ, καὶ πρὸς τὸν διπλασίονα αὐτοῦ πρῶτος ἔσται 'If an odd number is prime to some number, it will also be prime to its double'.

When pointing to the logic of pattern weaving for tracing back the doctrine of odd and even to a material origin in embodied *tekhnê*, we aim to make a case for an ordering and calculating practice that provided a transitional ground from which dyadic arithmetic was able to emerge.[12] As a technology of order generating patterns out of numerical relations that yet result in a multifarious and variegated appearance, weaving provided a capacious ground as well for the emerging reflection on the nature and arrangement of the cosmos, as the next section argues.

3 Weaving as Cosmology: Ordering *kosmos* in Pherecydes of Syrus

Recent scholarship on early Greek philosophy in sixth century BCE Ionia has foregrounded ways in which a combination of technological progress, familiarity with craft knowledge and an interest in mathematics may have triggered the development of the cosmologies of the first Presocratic philosophers.[13] As aptly put by a scholar, Ionian philosophy takes shape in the context of 'an emergent awareness of order, whose genesis, whose coming-to-be, was rooted in

12 See Høyrup 1994, 67 on the transition to mathematics as 'the point where *preexistent and previously independent* mathematical practices are coordinated through a minimum of at least intuitively grasped understanding of formal relations'.

13 Cf. Hahn 2001, who situates Anaximander's column-drum model of the cosmos (12 B5 D-K) as a projection of monumental temple building, in turn supported by the architects' geometry and rules of proportion. The impact of technological advancements, especially in temple architecture, for the development of geometry is clearly attested by terminological borrowings in the direction architecture → geometry: cf. Burkert 1972, 419.

the early Greek perception of craft as the revelation of *kosmos*'.[14] Cosmic order is thus somewhat embodied in the pattern of the craftsman, and the pattern is cast as a template for the structure of the universe—a trajectory inscribed into the broadening of the semantic range of the term κόσμος in archaic Greek texts, from the domain of crafts to the vocabulary of the Ionian *physiologoi*.[15] Our interest here is on how the ordering of weaving, embedded in and as patterned fabric, travels into and shapes the cosmology of Pherecydes of Syros, a contemporary of Anaximander and the author of the first Greek prose book.[16] The longest extant fragment of his theo-cosmogony describes the marriage of Zas and Chtoniê—two of the eternal, pre-existing deities who, together with Chronos, form Pherecydes' divine pantheon.[17] At the third day of the wedding 'Zas makes a robe, great and beautiful, and in it he patterns (*poikillei*) Earth, Ogênos, and the dwellings of Ogênos'.[18] Terminology is the vehicle through which the modality of generating patterns in weaving, and the way in which the woven pattern is perceived and apprehended by the senses, are projected and translated onto the structure of the cosmos. The adjective-verb series *poikilos-poikillein* conveys notions of variegation (in both colour and texture), radiance, and patterning in both nature and the crafts, and is prominently

14 McEwen 1993, 79, with the corollary that 'the craftsman lets *kosmos* appear through the artifact' (p. 73). The notion of *kosmos* as the orderly arrangement of elements constituting the physical world can be traced back to Ionian thinkers: cf. Heraclitus 22 B30 D-K, the un-generated κόσμος as eternal fire; Aëtius 2.1.1. reports that Pythagoras 'was the first to call what surrounds all things *kosmos* because of the order [τάξις] in it'.

15 The double occurrence of κόσμος at Hom. *Od.* 8.489, 492 is an interesting case for exploring the semantics of the term: the bard Demodocos is praised by Odysseus because 'in exceedingly good order' (λίην γὰρ κατὰ κόσμον, 489) he has sung the fate of the Achaeans and is then asked (vv. 492–3) to sing the 'fashioning (*kosmos*) of the wooden horse' (ἵππου κόσμου ἄεισον δουρατέου).

16 In terms of respective chronology Pherecydes-Anaximander, the priority of the former's prose book is generally accepted by modern scholarship: see e.g. Schibli 1990:4 n.9; the doxographical testimonia on this aspect of Pherecydes' book are collected by Schibli: frr. 1 (Diogenes Laertius I 116), 2 (*Suda* s.v. Φερεκύδης Φ713 Adler), 9 (Plinius *Historia Naturalis* VII 205), 10 (*Suda* s.v. Ἑκαταῖος Ἡγησάνδρο, E360 Adler), 11 (Apuleius *Florida* 15), 12 (Isidorus *Etymologiae* I 38.2), 13 (Strabo I 2.6).

17 See Diog. Laert. 1.119 = Pher. fr. 14 Schibli. By establishing three divine principles as eternal and un-generated, in analogy with the *arkhai* of the Ionian *physiologoi*, Pherecydes takes a novel posture in opposition to traditional theo-cosmogonies featuring a progression from chaos to order. This is probably what gains Pherecydes a special mention by Aristotle among the 'mixed' theologians (*Metaph.* 1091b8–10); cf. Laks 2009.

18 fr. 68 Col. 1 5–6 Schibli = 7 B2 D-K τότε Ζὰς ποιεῖ φᾶρος μέγα τε καὶ καλόν, καὶ ἐν αὐτῶ[ι] ποι̣κ̣[ίλλει Γῆν] καὶ Ὠγη[νὸν καὶ τὰ Ὠ]γενοῦ δώματα. The uncertain readings of the Grenfell-Hunt papyrus (MS Gr. clas. f. 48 [P]) have been confirmed, and the lacunose sections integrated, by Clem. Alex. *Strom.* 6.2.9.4 who quotes Pherecydes.

associated with weaving and textiles in archaic Greek literature.[19] In association with cosmic imagery (the starry sky, the dappled surface of the earth blossoming in springtime), the quality of being *poikilos* displays a number of features: symmetry, repetition, multicoloured texture.[20] Especially interesting are instances of *poikillein* that, as in the Pherecydes fragment, point to cosmic generation as the result of craft: in Empedocles 31 B23 D-K the verb is predicated of painters harmoniously mixing (ἁρμονίῃ μείξαντε, v. 4) the pigments of many colours to depict forms resembling all things: the ordered structure of the physical world obtains by patterns of discrete elements (coloured threads in weaving, pigments in painting) mixed and juxtaposed—though not blended—to create the multifarious appearance of *kosmos*.

The earliest instance of cosmic weaving in Greek thought, Pherecydes' fragment presents a significant case of textile terminology travelling to a different domain while also projecting the logic of the woven fabric as an ordering device on the macro-architecture of the world. As increasingly acknowledged in recent scholarly discussions on the origin and emergence of Presocratic thought, Pherecydes' novel cosmological enterprise was part of a broader intellectual reaction to the Hesiodic tradition of mythical theogonies.[21] While the introduction of a divine craftsman who generates the cosmos through the use of *tekhnê*—a model that will resurface only in the *dêmiourgos* of Plato's *Timaeus* some two centuries later—is an element of originality which has not escaped the attention of scholars,[22] we see the significance of Pherecydes' cosmological enterprise as providing a particularly bold example of a complex structure (the cosmos) conceptualized in terms of weaving, and a further

19 Grand-Clément 2015 is a fine discussion of the notion of *poikilia*. Fanfani 2018, 9–13 investigates the associations of *poikil*-terminology, through weaving, with archaic Greek choral lyric song and performance; Fanfani and Harlizius-Klück (forthcoming a) discusses in detail the connections between weaving technology and the semantic spectrum of the series *poikilos*/*poikillein*.

20 The *poikilia* of the firmament: Plato *Resp.* 529c–d (the patterns of the night sky as reliable model for the study of geometry), *Tim.* 40a, Euripides *Hel.* 1096, Kritias *Sisyphos* 33–34 = 88 B25 DK; see Schibli 1990:53n.6. The *poikilos* appearance of the blossoming earth: *fr. adesp.* 964 *PMG* = Sappho fr. 168C Voigt ποικίλλεται μὲν / γαῖα πολυστέφανος, Pind. *Isthm.* 3/4.36–36b ποικίλα (Hartung; mss. ποικίλων) … / χθών …

21 Cf. Granger 2007; Kahn 2003, 143–145; Laks 2001; Santamaría 2019, 92–96, Santamaría 2021.

22 This novel aspect of Pherecydes' thought is highlighted by Granger 2007, 152–153 ('Pherecydes makes his creator-god a craftsman who weaves and embroiders … Even if Pherecydes is influenced by foreign ideas, he is no less daring or original for introducing the idea of a craftsman-god among the Greeks'); West 1971, 1–60 traces the potential connections between Pherecydes' cosmogony and Near Eastern parallels.

instance of the mechanism by which the order of weaving travels to, and is available for, other domains.

4 Weaving as Technical Lexicon: *plekein* ('Plait, Weave'), Musical Innovation, and the Ordering of Rhythms

A longstanding and revered tenet of classical scholarship holds—on the ground of comparative linguistics and literary analysis—that the repertoire of craftsmanship metaphors for poetry- and song-making that informs the imagery of archaic and classical Greek choral lyric is to be considered a generic feature inherited from Proto-Indo-European poetics.[23] However, recent work on the contexts of execution and on the ritual and pragmatic frames—both real and conjured up by poetic imagery—of choral performances in early Greek culture has significantly altered that picture. What has emerged is the range of intersections, material rather than metaphorical, between the chorus (as social institution and ensemble of singers-dancers) and the technologies and practices that, on the one hand, provide vehicles for conceptualizing choral singing and dancing in terms of (among other crafts) weaving, carpentry, architecture and archery, but that, on the other hand, could also provide locations and occasions for choral performances.[24] In this regard, textile technology is a case in point: weaving and related techniques (plaiting, stringing, interlacing) attract much choral imagery and appear capable of mapping key structural aspects of the song's composition—including its rhythmical design—and of the orchestic patterns executed by the dancers.[25] Our concern here is with occurrences of the verb *plekein* 'weave, plait, braid'—often found in compound forms with different pre-verbs (συν-, δια-, ἀμφι-) attached to its root—as technical terms in two distinct contexts: in one case, weaving

23 Cf. West 2007, 31–45; Durante 1976, 167–179, Nünlist 1998, 39–227, with the solid objections expressed by Maslov 2015, 294–307 to the notion of a supposed continuity in the social function of the poet as 'verbal specialist, who claims unique expertise in ritual/poetic language' (p. 294). Examples of craftsmanship metaphors: 'song is a plaited crown', 'to weave a hymn', 'building a paean'; once this type of images is reduced to crystallized tradition and formulaic language, the function of crafts in them becomes merely ornamental.

24 Steiner 2021 discusses the exchanges and interactions between choral performances and weaving, alphabetic writing, architecture and cataloguing in textual, visual, and epigraphic evidence.

25 See Fanfani and Harlizius-Klück 2016 for a study of how features of weaving technology can be mapped on the structure of archaic Greek poetic compositions. Fanfani 2018, with further bibliography, explores the associations between the domain of weaving/plaiting and the phenomenology of choral performance.

terms used within choral lyric compositions advertise innovation and experimentation in the realm of instrumental music;[26] the second example sees the semantics of *plekein* convey the notion of the interweaving of rhythms as a mechanism to form metrical patterns. We see these as instances of weaving knowledge in which it is terminology, as vehicle of order, that travels to other domains and registers; in the cases examined here, textile terms are appropriated by and—we would argue—anchor the emergent lexicon of music and rhythmical theory.[27]

Pindar's *Pythian* 12, a victory ode (or epinician, from Greek *epinikion*) composed in 490 BCE to celebrate the success in the *aulos* competition (*aulêtikê*) by Midas of Acragas at the Pythian Games in Delphi, is the only Pindaric epinician devoted to a victorious musician: the occasion elicits the poet's engagement with musicological concerns of his time around innovations in *aulos*-music, both in terms of melodic range of the tunes (called *nomoi*) and instrumental practice.[28] Pindar's strategy is one of reframing novelty and experimentation as tradition—or, as a scholar puts it, of giving 'the new the patina of antiquity'[29]—by offering a divine aetiology for, and thus casting into the realm of myth, the invention of the *aulos* and of the very *aulêtikê tekhnê* (or 'auletics') in which Midas triumphed at the Pythian Games.[30] Pindar situates

26 As pointed out by D'Angour 2011, 184: '*Mousikê* provides the most explicit and enduring examples of innovationist discourse in any sphere of Greek cultural activity'. D'Angour's detailed survey of the rhetoric of novelty in archaic and classical Greek poetry (pp. 184–206) keeps its focus on the so-called 'New Music' revolution at the end of the fifth-century BCE; for innovation vs. tradition in New Music poetics cf. LeVen 2014.

27 See Rocconi 2003 on the mechanisms, both cognitive and semantic, by which the vocabulary of auditory pragmatics (especially terms denoting modalities of plucking strings instruments) contributes to the emergence and formation of a lexicon of musical theory. Fanfani 2017 explores cases of semantic switches in the direction weaving technology→musical terminology, with a focus on κρέκειν (etym. 'to beat the weft with a κερκίς').

28 The view of Pindar as an active member of the early fifth-century musical avant-garde in the sphere of *aulos*-music, heir and continuator of a generation of sixth-century innovators in the instrument's technical possibilities, is a recent scholarly acquisition; ancient and ideologically biased musicological sources, interested in foregrounding the contraposition between traditional, old-style *mousikê* and its perversion at the hand of late fifth-century New Music, position the poet as embodying austerity in musical style; cf. Steiner 2013, 173 n. 1.

29 Steiner 2013, 175. The mythical *aition* presented by Pindar for the invention of *aulos*-music, with Athena devising the instrument and its music by imitating the wailing of the Gorgons, was not the only one known in fifth-century and can also have been introduced by Pindar. The mainstream version seems to have been the story of Athena and Marsyas: see Melanippides *PMG* 758 and Telestes *PMG* 805.

30 The poem begins with an invocation to Acragas (the Sicilian city), requested to receive Pindar's choral song as a crown of victory (στεφάνωμα) from Pytho, and to welcome

the origin of *aulos*-music within the remit of technological innovation and sonic reconfiguration, and it is here that weaving comes into the picture.[31] Athena, the goddess of invention, craft and weaving (cf. Ov. *Met.* 6.1–145), discovered (ἐφεῦρε v. 7) the *aulêtikê tekhnê* (τέχνᾳ v. 6) by 'weaving together' (the verb is διαπλέκειν) into music the deathly dirge (οὔλιον θρῆνον v. 8) of the Gorgons, thus effecting via the operation of *diaplekein* an aural reframing: from the realm of bestial noise (the Gorgons' wailing) to the sonorous setting of *aulos*-music—and even of a specific tune, executed by Midas in his performance and possibly also reproduced by the *aulos*-player accompanying the choral singers of *Pythian* 12.[32] In tracing the origin of *aulêtikê tekhnê* back to the invention by Athena of the 'many-headed tune' (v. 23), this described a few verses earlier as 'a melody (μέλος) with every sound of the *auloi*' (v. 19), Pindar appears to hint at contemporary experimentations with the sonic and mimetic possibilities of the instrument in the direction of musical variegation and manifoldness, a notion captured by the concept of *poikilia* (so often referred in literary text to the multifarious appearance of woven patterns).[33] We encounter a similar archaizing rhetorical strategy of self-legitimation in a New Musical composition by the dithyrambist Telestes (*PMG* 806), effected by adopting the technical term *amphiplektein* 'to weave/plait around' to illustrate—in a language strongly characterized by its materiality in the description of the mechanics and sonic quality of the *aulos*—the variegated and composite nature of the 'Lydian tune (*nomos*)'.[34] The use of compound forms of *plekein*

Midas, who 'defeated the Greeks in the art (τέχνᾳ) which Pallas Athena once invented (ἐφεῦρε) by weaving into music the fierce Gorgons' deathly dirge (θρασεῖαν ⟨Γοργόνων⟩ / οὔλιον θρῆνον διαπλέξαισ' Ἀθάνα)' (vv. 5–6).

31 A prominent aspect of Athena's act of invention in *Pythian* 12 is the way in which it is framed as a form of heuristic mimesis: the goddess 'found' the melody of the *aulos* (ἐφεῦρε v. 7, εὗρεν and εὑροῖσ' v. 22) by imitating (μιμήσαιτ' v. 21) the echoing wail (ἐρικλάγκταν γόον v. 21) of the Gorgons.

32 The lament of the Gorgons is described by Pindar as 'pouring forth from the unapproachable (ἀπλάτοις) snaky heads of the maidens' (vv. 9–10) and thus, as noted by Phillips 2016, 257, as 'something which requires Athena's technological intervention to become assimilable to human experience'. The melody for the *aulos* that Athena fashions, and names 'the many-headed tune' (κεφαλᾶν πολλᾶν νόμον, v. 23), might have been used by Midas.

33 Steiner 2013, 184–194 discusses musicological developments in auletics both earlier than and contemporary to Pindar as reported in the Ps.-Plutarchean *De Musica*. For musical *poikilia*, both in Pindar and in New Music, see LeVen 2014, 101–112.

34 The passage, quoted by Athenaeus (14.617b = *PMG* 806), depicts the 'Phrygian king of the fair-breathing holy *auloi*', probably Olympus, as the first 'who fit together the Lydian tune (Λυδὸν ἅρμοσε … νόμον), rival of the Dorian Muse, weaving around (ἀμφιπλέκων) his reeds of quick-moving forms (αἰολομόρφοις καλάμοις) the fair-winged breeze of his breath (πνεύματος εὔπτερον αὔραν)' (transl. LeVen 2014, 104).

in the context of programmatic statements of poetics suggests that the craft of weaving represented a favourite source of technical terminology for illustrating innovations in instrumental music.

Transitioning to the field of ancient metrical theory, or more precisely to its emergence, the image of the rhythmical structure of sung poetry as an 'interlacement' (the relevant term is still *plekein*) of metrical units out of a number of primary rhythmical kinds/forms (*eidê*) is Platonic. At *Republic* 398c–400c, within a discussion of musical modes (*harmoniai*) and rhythms informed by the teaching of the sophist Damon, Glaucon, encouraged by Socrates to reveal what are the 'rhythms of an ordered and courageous life' (399e9–400a1) are, admits that he is only able to observe that 'there are just three kinds of *rhythmoi* from which (all) the steps [= metrical feet] are interlaced' (τρί' ἄττα ἐστὶν εἴδη ἐξ ὧν αἱ βάσεις πλέκονται, 400a4–5). The use of the verb *plekein* in a technical discussion of rhythmical theory at the time of Plato is quite remarkable; the peak of its currency is to be found later, in Hellenistic metrical treatises. That said, the notion of the interlacement of rhythms might be traced back as early as the sixth-century BCE thinker and musician Lasus of Hermione, known for his experimental approach to matters of musical harmony.[35] In fact, the rhythmical *eidê* referred to in the *Republic* passage—most likely 2:2 (*ison*), 2:1 (*diplasion*), 3:2 (*hemiolion*)—are analogous (and correspond in part) to the four fundamental ratios (*logoi*) that ground Pythagorean harmonics and its arithmetical approach to musical intervals (epitomized in Philolaus 44 B6 D-K): the association between textile technology and the notion of musical rhythm as consisting of numerical ratios (i.e. of relations between integers) resonates, we suggest, with the hypothesis of seeing the order of weaving as connected to the emergence of early Greek mathematics.[36]

35 See Lomiento 2004, who refers to Martianus Capella's mention (*De nupt.* 9.936) of the notion of πλοκή as 'rhythmical science' in Lasus. As Lomiento also observes (pp. 116–117), Plato's application of *plekein* to rhythmical architecture seems to be picked up by Dionysius of Halicarnassus (*De comp. verb.* 18, where the verb used is συμπλέκειν) and then elaborated into the notion and doctrine of *epiplokê*, a mechanism of metre generation and modulation within specific rhythmical kinds/genera (*genê*).

36 See Sauvanet 1999, 68 on the Platonic image of the 'fabric of rhythmical types' and its link to Pythagorean harmonics as ratios of musical intervals. Fanfani and Harlizius-Klück (forthcoming a) discuss the relevance of the arithmetical notion of ratio between numbers for the logic of pattern construction in weaving. Szabó 1978, 99–184 sees in Pythagorean harmonics and its arithmetical foundation a pre-Euclidean theory of proportions.

5 The Split between Pure and Applied Knowledge: Plato's Epistemic Innovation

Sections 3 and 4 have attempted to make a case for weaving as knowledge-through-order that travels to different media and realms, on occasion providing ground for the anchoring of innovations; when this happens, and even when the order of weaving is embedded in terminology, knowledge never gets rid of its material dimension: it is a *tekhnê*, and in archaic Greek thought there is no epistemic separation between *tekhnê* and *epistêmê*.[37]

Back to where we took off, at the beginning of the *Statesman*, Plato takes a decisive step towards theorizing a distinction—or, as we propose, operating a split—between abstract, universal knowledge (represented by *arithmêtikê* as dyadic arithmetic) and embodied, productive knowledge (exemplified by different material practices and technologies).[38] This is particularly clear at 258d4–e5, where the Eleatic Stranger presents *arithmêtikê* and 'certain other arts akin to it' (ταύτῃ συγγενεῖς) as being 'bare of practices/actions' (ψιλαὶ τῶν πράξεων) and 'offering only knowledge/insight' (τὸ δὲ γνῶναι παρέσχοντο μόνον, 258d5–6), while technologies of construction (αἱ περὶ τεκτονικὴν [*sc.* τέχναι], 258d8) and practices of handicraft (χειρουργία, 258d9), which possess *epistêmê* embodied in, and congenital to, practical activities (ἐν ταῖς πράξεσιν ἐνοῦσαν καὶ σύμφυτον τὴν ἐπιστήμην, 258d9), produce instead (or, more precisely, 'assist in the completion of', συναποτελοῦσι, 258e1) 'corporeal realities which did not exist previously' (σώματα πρότερον οὐκ ὄντα, 258e2).[39] A couple of contextual observations help situating this statement within the frame of Platonic philosophy and, more narrowly, of the *Statesman*'s concerns. On the one hand,

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37 Cf. the surveys of the two concepts in Schaerer 1930; Löbl 2002 and Johansen 2021 discuss *tekhnê*; focus on the Platonic usage of *tekhnê* and *epistêmê* in Lyons 1963, Hulme Kozey 2019, and Parry 2021. Interestingly, as early in archaic Greek thought as Homer's *Iliad* (18.599), a cognate of the term *epistêmê* (the verb ἐπίσταμαι) is employed for the 'knowing feet' (thus an instance of embodied cognition) of dancing youths.

38 Plato's enquiry into the nature of knowledge (cf. e.g., *Tht.* 146c3 τί σοι δοκεῖ εἶναι ἐπιστήμη;) makes for an epistemology different in its concerns from Parmenides' foundational distinction between what may and may not be an object of knowledge (though cf. *Ti.* 27d6–28a3 with Carpenter 2015, 184). However, the stability and unchangeability of Plato's *epistêmê* (when this coincides with abstract mathematics) may bear implications that come close to Parm. 28 B8.1–7 DK. Cf. Hussey 1990, 29–34.

39 The reference to arts closely akin to *arithmêtikê* seems to point to the complementary discipline of *logistikê* (see the appendix below, section 8), which is mentioned by the Eleatic Stranger in the next cut of the *diairesis* at 259e5–6 as one of the two ramifications in which theoretical science is divided, and is defined as that art which 'knows the difference between numbers'.

underlying the particular form of the Eleatic Stranger's pronouncement—the emphasis on what each form of *epistêmê* 'provides' or 'produces'—is the recurring motif of determining the 'function' or 'goal' (*ergon*) of a given *tekhnê*, 'often identified with a result separate from the activity of the craft'; abstract science, like *arithmêtikê*, has no separate product.[40] On the other hand, the distinction between theoretical and practical knowledge, standing as it does as the first bifurcation in the *diairesis* of the statesman's science ('thus, divide [διαίρει] the totality of sciences', 258e4), is, to a certain extent, functional to Plato's project of including statesmanship in the first category of science (theoretical *epistêmê*): as a scholar has noted, the difference is between 'activities where knowledge is embodied in bodily performance (πρᾶξις) [...] and activities where knowledge is distinct from any bodily performance necessary to make it effective'.[41] There is, however, a further implication, no less ontological than epistemic, in the split between *arithmêtikê* and material practices: the objects of abstract arithmetic—odd and even as forms/kinds of number, and the notion of *arithmos* as multitude of pure units—are cast as aeternal and universal entities, existing before and above the objects of embodied knowledge. Here, we submit, lies Plato's innovation: the theory of odd and even, which we propose to see as an operating and ordering function of weaving technology that grounds the emergence of dyadic arithmetic, is dis-embedded from the practice and reframed as an instance of pure *epistêmê*, entirely disengaged from the material—while embodied knowledge is recast as bearing a lower epistemic status. A broader context for this reading of the *Statesman* passage is provided by a section of the coeval *Philebus* (55c–57a) that tackles the issue of (varying degrees of) knowledge pureness in association with *arithmêtikê* and *tekhnai*. While pursuing a search for what is 'by nature the purest' (καθαρώτατον φύσει, 55c7) element of 'mind and knowledge/*epistêmê*' (νοῦ δὲ καὶ ἐπιστήμης, 55c5), Socrates proposes to

> consider whether in handicrafts one part is more allied to knowledge [lit. 'have more of a hold on knowledge'], and the other less, and the one should be regarded as purest, while the other as less pure (55d5–8).

40 Parry 2014, who points to *Resp.* 346a1–3, *Euthyd.* 301c, *Ion* 537c. The most relevant occurrence of this topic for the present argument is *Charm.* 165d–e: Critias and Socrates seem to agree on the principle that, for something to be a science (*epistêmê*), it must be a science of something, and at the same time it must produce a result (ἔργον ἀπεργάζεσθαι, 165d1, 165d5).

41 Márquez 2007, 34, who discusses the nature of this distinction ('which rests on a difference in the relation of knowledge to *body*', p. 37) in comparison to the one drawn in the *Sophist* (219d1–4) between acquisitive and productive knowledge.

> ἐν δὴ ταῖς χειροτεχνικαῖς διανοηθῶμεν πρῶτα εἰ τὸ μὲν ἐπιστήμης αὐτῶν μᾶλλον ἐχόμενον, τὸ δ᾽ ἧττον ἔνι, καὶ δεῖ τὰ μὲν ὡς καθαρώτατα νομίζειν, τὰ δ᾽ ὡς ἀκαθαρτότερα.

In order to effect such a distinction, Socrates argues, the ruling elements of each art should be separated from the rest, as if *arithmêtikê* and the science of measurement (*metrêtikê*) and weighing (*statikê*) were taken away from all *tekhnai* leaving just guessing and conjecture based on practice and experience (55e5–7).[42] In turn, arithmetic itself shall be divided in two kinds, that 'of the people' and that 'of the philosophers' (56d4–5), the latter dealing with undifferentiated and countless units (56e1–3).[43] While the way in which this epistemic statement addresses the distinction between pure and applied science—with the latter consisting in the application of the rules of arithmetic that exist outside of any materiality—may seem largely complementary to, if not almost a refinement of our *Statesman* passage, the differences are significant and have a bearing for the present argument.

The *arithmêtikê* referred to in the *Philebus* is a quantitative mathematical discipline grounded on the notion of accuracy (*akribeia*, 56c5) of counting and reckoning, and relying on instruments of measurement; this makes carpentry (*tektonikê*, 56b4) 'more scientific than most forms of knowledge (τεχνικωτέραν τῶν πολλῶν ἐπιστημῶν, 56b5). On the other side, as suggested above in sections 1 and 2, the *arithmêtikê* of the *Statesman* corresponds to dyadic arithmetic: its modality of manipulating number, grounded—we have argued—in weaving technology, obeys to a logic of order different from the counting and measuring that apply in carpentry.

But while we see the order of weaving lurking beneath the mention of *arithmêtikê* as instance of pure knowledge at *Plt.* 258d4, it is mainly as a *tekhnê*—ἡ ὑφαντική (τέχνη), 'the art/technology of weaving', as it is introduced at 279b–that weaving performs the function of anchoring in the *Statesman*: its epistemic import in the dialogue is crucially connected to the way in which statesmanship is presented as belonging to the realm of theoretical *epistêmê* and in need of an anchor in *tekhnê*. Plato's act of splitting knowledge into pure and applied seems to serve the aim, as the next section suggests, of including statesmanship among forms of theoretical knowledge; weaving as *tekhnê* provides, via *diairesis*, the anchor for the philosopher's innovation.

42 τὰς τοίνυν ἡγεμονικὰς διαληπτέον … χωρίς, 55d10–11. On this passage and its implications in terms of Platonic epistemology see Carpenter 2015, Moss 2019, Hulme Kozey 2019, 92–95.

43 Interestingly, we find here the earliest occurrence of the term μονάς in the mathematical sense of 'unit'.

6 Anchoring Innovation in Plato's *Statesman*: Statesmanship, Weaving and *diairesis*

The inquiry into statesmanship that constitutes the subject of the *Statesman* moves from the initial assumption, agreed upon by the Eleatic Stranger and Young Socrates, that the *politikos* is among those 'who have an *epistêmê*' (258b2–5); statecraft, thus, is a science (ἐπιστήμη), and its form (ἰδέαν, 258c5) must be investigated through *diairesis* (258c4–9). As rehearsed above in section 5, the first step of the division effects the fundamental split between *gnôstikê* and *praktikê*—a split that, with the necessary caveats and within a precise range of applications (*arithmêtikê* as grounded in weaving knowledge), may be configured as introducing the distinction between pure and applied science, which we have framed as a case of innovation on the part of Plato. The innovation consists in splitting a knowledge (the knowledge-through-order of weaving) that was perceived as unitary, and in creating an epistemic hierarchy by extracting an ordering function from weaving (the theory of odd and even) and recasting it as an incarnation of theoretical *epistêmê*. Part and parcel of this hierarchy is the implied lower status of embodied, practical (or applied) knowledge—of *tekhnê*, one might say, although the pattern of usage of the terms τέχνη and ἐπιστήμη in the *Statesman* cannot be consistently mapped onto an epistemic distinction.[44] In choosing to elevate statesmanship to the realm of theoretical *epistêmê*, Plato engages with a form of knowledge that generates order—the order of the city, as the final *diairesis* of statesmanship reveals. No surprise, then, when the Eleatic Stranger affirms that the king (a figure here coextensive with the *politikos*) 'has more familiarity with gnostic science than with handicrafts and, in general, with practical knowledge' (259c10–d1). Indeed, the second step of the first *diairesis* (259d6–260b5), which divides *gnôstikê* in two halves, provides decisive ground for the inclusion of statesmanship within theoretical sciences. The bifurcation distinguishes between a kind of knowledge called *kritikê* ('judging'), exemplified by *logistikê* ('art of calculation', whose affinity with *arithmêtikê* is discussed in section 8 below), i.e. the ability to recognize 'the difference between numbers' (259e5) and whose task is to 'judge/distinguish the things it knows' (259e6), and another kind labelled *epitaktikê* ('the art of command/supervising'), epitomized by the architect/master carpenter (*arkhitektôn*) who 'is a ruler of workmen and not a workman himself' (259e8–9). As it has been noted, Plato seems to introduce here 'a middle ground between the purely theoretical and the

44 See the detailed discussion in Márquez 2005, 78–85.

practical', reflecting the fact that, while the ruler 'needs to be able to engage in purely theoretical investigation', he also needs 'to bring order into the city'.[45] Interestingly, this has implications for the analogy between statesmanship and weaving that informs the final portion of the dialogue: the *epistêmê* of the *politikos* 'weaves together' (συνυφαίνουσαν, 305e4) the other more specific *epistêmai* (for instance generalship and judging, 304e5–305c10) that—via *diairesis*, i.e. via distinction among *eidê*—have emerged as those sharing in the responsibility of governing the city; in turn, as the *paradeigma* for statesmanship in the realm of *tekhnê*, the art of weaving has to know and order, via *diairesis*, the materials that it will weave together. Let us, then, verify this through a brief look at how the diairetic method shapes the way in which weaving incorporates and anchors Plato's distinction between theoretical and practical knowledge, at the same time providing the model for the art of statesmanship.

Notoriously, the function of *paradeigmata*, defined at *Plt.* 278c2–6 as the cognitive ability to recognize the identical in a different and apparently unconnected thing/context, is illustrated by the Eleatic Stranger through the example of learning to read by progressively recognizing combinations (*sumplokai*, 'interlacements') of letters in syllables (*Plt.* 277d9–278c).[46] The illustrative function of using models—especially aimed at grasping and explicating 'the greater matters/ideas', 277d1–2, by studying them 'in small matters', 286b1–2—is complementary and beneficial to dialectical inquiry: 'becoming better dialecticians' (285d6) is the higher purpose of any philosophical research, and this explicitly applies to the long and detailed *diairesis* of the art of weaving, whose *logos*, the Eleatic Stranger remarks, should not be 'hunted for' for the sake of weaving itself as *teckhnê* (285d9–10). In fact, coherently with its investiture as *paradeigma*, weaving is said to share the same 'activity' (*pragmateia*, 279a7–b2) as statesmanship. On the one hand, the proper interlacement of warp and weft (εὐθυπλοκίᾳ κρόκης καὶ στήμονος … πλέγμα, 283a5–6), defined as the *logos* of the art of weaving, shapes the image of the *sumplokê* of 'courage' (*andreia*) and 'temperance' (*sôphrosynê*) that characterizes statesmanship as *epistêmê* (305e8–306a3). On the other hand, the diairetic inquiry performed

45 Parry 2014, who adds that 'the Visitor turns to the latter activity [= giving order to the city] when he compares the kingly or political knowledge to weaving'. Scodel 1987, 32 sees a deficiency in the division of *gnôstikê* in that 'ἐπιτακτική ought rather to have been a division of the "purely critical arts", for exercise of judgement must precede the giving of orders'.

46 On relation between this first model and the *paradeigma* of weaving cf. Scheid & Svenbro 1996, 23–25. See Pender 2003, 63–72 on the cognitive import of *paradeigmata* in Plato, with a focus on the *Statesman*, in the context of a discussion of the relationship between *eikôn* and *paradeigma*.

by the two interlocutors foregrounds and reveals the nature of weaving as a collaborative undertaking: by keeping together and coordinating a variety of *tekhnai*—tool-making, fulling, carding, spinning—whose function is that of 'co-workers' (συνεργῶν, 280b2) and 'collaborators' (συναιτίας, 281c4), weaving may provide a fitting model for Plato's notion of political art as encompassing 'a community constituted by the active cooperation of its members'.[47] At one fundamental level, Plato in the *Statesman* grounds the analogy between the art of weaving and statesmanship in their nature of arts of combination—of warp and weft, of courage and temperance; or, put differently, he anchors statesmanship as *epistêmê* in weaving as a *tekhnê* of combination.[48] The bifurcation that divides the art of wool-working into the art of separation (ἡ διακριτική) and the art of combination (ἡ συγκριτική) (282c6–8) represents, we suggest, the entry point for accessing Plato's strategy of anchoring his innovation in weaving. That combination and division, in fact, lie at the core of the logic of weaving, at the same time characterizing the practice of bifurcational *diairesis*, is explicitly observed by the Eleatic Stranger at *Plt*. 282b5–7, where the two *tekhnai* are said to find application 'in every domain' (κατὰ πάντα).[49] Indeed, these two technological principles are so deeply embedded in weaving that 'the art of manoeuvring the *kerkis*' (ἡ κερκιστική, 282b3) is integral to both combination and separation.[50] While the division of wool-working into art of separation and art of combination results in the latter being selected for proceeding towards the *logos* of the art of weaving, we would propose to shift the focus towards the option that is here rejected by the Eleatic Stranger—the art of separation or division—but that, as we have seen in section 2 above, defines weaving in terms of knowledge-through-order and anchors the possibility for the order of weaving to ground the emergence of dyadic arithmetic. Separating and distributing the odd and even warp threads on the loom's bar is

47 Miller 2017, 128, who acutely remarks how the paradigm of weaver introduces a non-bifurcational form of *diairesis* that accounts for just this collaborative mode of knowledge and production embedded in weaving.

48 More specifically, weaving is defined as 'the portion of the art of combination applied to the art of wool-working' through 'the proper interlacement of warp and weft (εὐθυπλοκίᾳ κρόκης καὶ στήμονος 283a5–6).

49 To be sure, the label *diairesis* obfuscates the fact that the Platonic method of dialectical classification encompasses, in addition to division, the complementary process of collection or *synagôgê*: cf. *Phdr*. 265d3, *Soph*. 253b9–e2, *Plt*. 285b4–6.

50 See *Plt*. 282b4, where 'the half of the art of κερκίζειν' is grouped together with 'all the arts that separate the things that are united'; cf. *Crat*. 388a–b, where the *kerkis* is consistently associated with the division of threads. This may be due as well to the multifunctional nature of the κερκίς, which might have acted as weft-beater, spool, and 'shuttle': cf. Fanfani 2017 with further bibliography.

a diairetic practice, as it is the division of number into the *eidê* of odd and even (*Plt*. 262e3–5). Plato's innovation, the split between pure and applied knowledge, can be seen as anchored into weaving and its *diairesis*; in order to cast statesmanship as *epistêmê*, weaving has to be reduced to practical knowledge, and its *logos* made to result from the technological posture of combination.

7 Conclusion

When Plato introduces the distinction of pure and applied science in a dialogue that features arithmetic and (prominently) weaving, this distinction may appear to us at first sight as a description of the nature of things, based on the assumption that craft people apply in their practice the universal rules of mathematics. In fact, our aim in this paper has been to demonstrate that the split between pure and applied knowledge—in the case at stake, between dyadic arithmetic and the domain of crafts and technologies—operated by Plato in the *Statesman* is an innovation grounded in a *tekhnê*, weaving, that already included a system of order since millennia. The order of weaving, we have argued, was available in archaic and early classical Greek thought as ground for new concepts of numbers, of cosmic generation, of musical terminology and rhythmical theory, and of political order. The knowledge of weaving as *teckhnê* is unitary: on the one hand, it generates concepts of order that travel to other domains; on the other hand, as technical knowledge and embodied practice, weaving always functioned as an order allowing for change and in need of constant change.[51] This is the epistemic landscape against which we situate Plato's innovation, the split between pure and applied knowledge; we see this distinction as mappable, to a certain extent, onto the separation between the notions of *tekhnê* and *epistêmê*, whereby the latter came to indicate pure knowledge or the intellectual component of *teckhnê*. Aimed at supporting a claim for statesmanship as *epistêmê*, the distinction introduced by Plato between theoretical and practical knowledge produces a new epistemic hierarchy: pure, everlasting knowledge stands before and above knowledge

51 Cuomo 2007 points out that *tekhnai* are both essential to social stability but also potentially disruptors of the social order. *Tekhnê*, in the eyes of aristocratic-oriented thinkers like Plato and Aristotle, was 'marked by a dangerous propensity to upset the prescribed social order' (p. 38) and thus needed to be tamed and controlled through taxonomy and definition.

inherent in practices, which produces things that ‘had not been there before’ (*Plt.* 258e1) and is rejected as epistemologically and ontologically inferior.[52]

In sum: by positing dyadic arithmetic as pure science (*epistêmê*) and weaving (qua *tekhnê*) as paradigm for statecraft, Plato establishes a tradition, that of casting abstract science and technology into opposite modes (of pure and applied knowledge), which still defines what is familiar for us today. This is the philosopher’s sleight of hand: he anchors his innovation—the split or distinction between pure and applied knowledge—in weaving in order to make it comprehensible to common understanding of his time. Once the philosopher establishes dyadic arithmetic (*arithmêtikê*) and statesmanship as forms of pure knowledge, and weaving as applied knowledge, he has innovated the hierarchy within the distinction—which allows him to raise the status of pure knowledge over the domain of material practices. In present time, Plato’s innovations are familiar to us; it is the details of textile technology, in which the philosopher anchored those innovations for making them acceptable, that mostly escape our understanding.

8 Appendix. The Theory of Odd and Even: Ancient Sources and Scholarly Hypotheses

First, the (few) facts. The theory of odd and even survives as a self-contained corpus of definitions and propositions in Euclid’s *Elements* (books 7 and 9, as we have seen) and resurfaces, in what seems a parallel tradition, in (much later) Neo-Pythagorean sources (Nicomachus of Gerasa, Theon, Iamblicus); both traditions, apparently, go back to early Pythagoreanism.[53] A further fact is Plato’s sustained interest in odd and even as the fundamental kinds/forms (*eidê*) of number understood as assemblage of pure units, and as the object of study of the two integrated disciplines of *arithmêtikê* and *logistikê* (both mentioned as instances of pure science in the *Statesman*: 258d4–6, 259e1–6). However, the

52 This paradox of early Greek thought is aptly noted by D’Angour 2011, 120, who remarks how ‘the notion that some kind of elemental stability underlies the appearance of change has ambiguous implications for the notion of novelty’; this applies especially to Parmenides, who, ‘in arguing for the impossibility of change … rules out the possibility of the new’: cf. the principle of *tertium non datur*, where change is deception (28 B8.1–7 D–K).

53 Aristoxenus’ testimonium on Pythagorean arithmetic (fr. 23 Wehrli) offers definitions of even and odd numbers different from the ones in Euclid’s *Elements* (book 7 def. 6–7) and in line with the Neo-Pythagorean tradition (preserved in Nicomachus, Theon, and Iamblichus): according to Zhmud 2012, 261–263, this may bear evidence of an older Pythagorean stratum, parallel to the one we find in Euclid. Cf. Burkert 1972, 437–8.

trajectory that leads from the Pythagoreans' engagement with the nature and epistemic function of number to the formalization of dyadic arithmetic in the *Elements* is uncertain at best and remains terrain of scholarly reconstructions.

That the doctrine of odd and even may indeed preserve an archaic sample of Pythagorean number theory, included for 'archaeological' and historical reasons in Euclid's *Elements*, is suggested by its scarce mathematical relevance for the rest of the arithmetical books (7, 8, and 9) of the *Elements*.[54] The theory's historical significance, as influentially argued by Oskar Becker, would lie in how it may embed a primordial and genuinely Pythagorean mechanism of proofs—indeed, the earliest instance of Greek deductive mathematics. According to Becker's reconstruction, the shape of proofs that lurks beneath the propositions of dyadic arithmetic in their formalized, Euclidean form (*Elements* 9 propp. 21–34) is one carried out via the arrangement of *psêphoi* ('pebbles'), a practice that, with varying degrees of mathematical connotation, sources associate with the Pythagoreans.[55] The earliest mention of odd and even as a mathematical notion in Greek literature, and interestingly in combination with the manipulation of *psêphoi*, comes from the comic stage: a Pythagorean-flavoured fragment of Epicharmus (23 B2 D-K), probably from beginning of fifth century BCE, seems to suggest that arranging pebbles on a surface may be a heuristic tool for discovering general arithmetical principles, or even generating proofs.[56] To be sure, representing numbers in geometric forms (thus called 'figured numbers': square, triangular, oblong, polygonal) through patterns of dots or *psêphoi* was a practice of Pythagorean mathematics that, in some cases, built on the features of odd and even.[57] Indeed, a

54 The theory of odd and even is dismissed by Burkert 1972, 434 as 'a trivial appendage to the sophisticated number theory of books 7 and 9'; in a similar fashion, Becker 1992, 87 remarks that the doctrine 'offers nothing new at all' to the content of books 7, 8 and 9. The relevance of dyadic arithmetic for Euclid's *Elements* lies in how it grounds the proof of the incommensurability of side and diagonal of the square (book 10, appendix 27).

55 Becker's 1936 (= 1992) attempt at restoring an original, Pythagorean facies for the proofs of the Euclidean propositions of dyadic arithmetic by *psêphoi* arrangement succeeds in demonstrating that also propositions 35 and 36 (on perfect numbers) can be applications of the theory of odd and even. Cf. Szabó 1978, 257 and, *contra*, Burkert 1972, 435, for whom 'a proof with ψῆφοι is essentially inductive and pictorial'.

56 The fragment refers to how by adding or subtracting a pebble (ψῆφος) to/from an odd number, the number becomes even: see Becker 1992, 91 and Becker 1972, 438 n. 64.

57 On figured numbers see the overview by Thomas 1939, 86–99: the sources for this practice are mainly Neo-Pythagorean; however, generating the sequence of square numbers by pebbles arrangement through placing successive odd numbers round the unit must have been a well-known arithmetical practice of early Pythagoreanism, as Aristotle reports in *Phys*. 203a10–15 (where he uses the term *gnômôn* for 'odd number').

concept of *arithmos* as pattern emerges in fifth century BCE Pythagoreanism, also in association with the definition of odd and even as the proper forms/kinds (*eidê*) of number (Philolaus 44 B5 D-K).[58] And when Aristotle (*Met.* 1092b9–10) compares the practice of the Pythagorean Eurytus—who somewhat used *psêphoi* to reproduce the numerical structure of things—to 'those who put numbers into figures (*skhêmata*), the triangle and the square', his description might in principle also apply to what weavers do when generating geometrical patterns: in a similar way to the doctrine of 'figured numbers' and its dot (or pebble) notation, where sets of discrete units could represent continuous figures, so the woven pattern emerges as an arrangement of discrete units (the threads).[59]

Whatever the heuristic significance of manipulating *psêphoi* for the emergence of dyadic arithmetic, when we get to Plato there is no doubt that *arithmêtikê* (and the companion discipline of *logistikê*) is a science of odd and even—a science that is eminently abstract, as it is in Euclid, and entirely removed from practical application and materiality.[60] A growing interest in theoretical arithmetic seems to invest later Platonic dialogues around the complementary notions of *arithmêtikê* ('the art of numbers/counting', 'number theory') and *logistikê* ('the art of calculation'): together, these shape the abstract domain of classifying kinds (*eidê*) of numbers and their internal structure, determining their mutual relations and relative quantity as multitudes of 'pure' units.[61] In this regard, particularly intriguing are Socrates' definitions of the two concepts in the *Gorgias* (451a–c), which interestingly do not feature the term *arithmos*: first describing *arithmêtikê* as dealing 'with the even and the odd, however great each of the two happens to be' (ὅσα ἂν ἑκάτερα τυγχάνῃ ὄντα,

58 Philolaus of Croton (active in the second half of fifth-century BCE) develops an epistemology of number (44 B4 D-K: 'everything that is known possesses number') and affirms that (B5) *arithmos* 'possesses two proper forms (ἔχει δύο μὲν ἴδια εἴδη), odd and even', each manifesting itself in 'many forms/shapes' (πολλαὶ μορφαί); see Huffman 1993, 184–186 on the possible interpretation of εἴδη as numbers laid down as pebbles.

59 Asper 2009, 107–109 discusses 'pebble arithmetic' as a modality of applied mathematics whereby practitioners performed calculations by placing pebbles on a kind of abacus: Asper argues that the practice could trigger the discovery of abstract arithmetical rules and it shows how 'practical knowledge could become abstract'.

60 The relevant passages are *Chrm.* 166a5–10, *Prot.* 357a3, *Resp.* 510c4, *Tht.* 198a6, *Pol.* 262e3–5, *Phlb.* 56d.

61 Cf. Klein 1968, 10–60. In *Statesman* 259e1–6 λογιστική, a purely abstract science (γνωστική τέχνη) 'that knows the difference between numbers', picks up ἀριθμητική at 258d, the implication being that the two disciplines are to some extent coextensive. Two types of ἀριθμητική are distinguished in *Philebus* 56d, 'that of the crowd and that of the philosophers', the latter concerned with undifferentiated units.

451b4), Socrates positions *logistikê* in the identical domain of the even and odd (περὶ τὸ ἀυτὸ γὰρ ἐστιν, τό τε ἄρτιον καὶ τὸ περιττόν, 451c1–2), its distinctive concern being 'the multitude that they (the even and the odd) form both in relation to themselves and to each other'.[62] To summarize: the theory of odd and even retains a peculiar status in the early history of Greek mathematics; apparently too elementary and irrelevant for the complex number theory that is the object of the arithmetical books of Euclid's *Elements*, and yet inserted there as a self-contained 'fossil' of deductive and axiomatic mathematics of Pythagorean origin, it does not seem to accommodate practical applications either—in the eyes of historians of Greek mathematics, at least.

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62 As Klein 1968, 56 observes (italics in the original), 'Precisely because the arithmos as such is not one but many, its delimitation in particular cases can be understood only by finding the eidos which delimits its multiplicity, in other words, by means of *arithmetike* as a theoretical discipline'.

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CHAPTER 17

Cultural and Cognitive Anchoring in Hero of Alexandria's *Metrica*

Courtney Roby

1 Introduction

Hero of Alexandria, who likely lived in the first century CE, composed texts on a wide range of technical topics, from pneumatic wonders to catapults, as well as a geometrical approach to land surveying and a lost commentary to Euclid.[1] His *Metrica*, the most mathematically focused text from his surviving corpus, offers a varied apparatus of problem-solving techniques for measuring the areas, volumes, and proportional relationships of geometrical figures.[2] The techniques and proofs in the work blend attributes of Greek geometry with elements of a tradition of practical mathematics that owes much to Mesopotamian and Egyptian mathematical traditions. For example, Hero often combines in the same passage the distinctive linguistic forms of Greek geometry (such as the use of third-person passive imperatives and letter-labeled diagrams) with the very different features of 'practical mathematics' (like second-person active imperatives and numerical examples) that tend to keep studies of the two mathematical genres starkly separated.

This blend of attributes long kept the *Metrica*, along with the entire tradition of practical mathematics, outside the privileged territory of Greek mathematical studies. A particularly damning response was Van der Waerden's call to 'rejoice in the masterworks of Archimedes and of Apollonius and not mourn the loss of numberless little arithmetic books after the manner of Heron'.[3] The fortunes of the *Metrica* have by now turned somewhat. Tybjerg's insightful work on Hero's 'mechanical geometry' revealed the need not simply to divide Greek mathematical texts into 'geometry' and 'other', but to develop

1 While the first century CE is the most widely accepted date for Hero, his dates are controversial and scholars have suggested alternatives ranging from the third century BCE to the third century CE: see Keyser 1988; Asper 2001b; Giardina 2003, 8–30; Sidoli 2011.

2 The most recent edition of the text, with abundant commentary and supplemental information, is Acerbi and Vitrac 2014. However, references in this paper to the text of the *Metrica* follow Schöne's text (available on the Thesaurus Linguae Graecae) for ease of consultation.

3 Van der Waerden 1954, 278.

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a more nuanced picture of geometry as allowing a certain amount of authorial variation.[4] Hence she distinguishes 'Hero's geometrical practices' (numerical examples, mechanical methods, and application to physical objects) from 'Euclidean-Archimedean geometry', and notes further that the latter was never so hermetically sealed from practical mathematics as critics like Van der Waerden might suggest.

Vitrac and Acerbi's recent edition of the *Metrica*, with copious notes and appendices, unfolded more clearly the connections between Hero's work and traditional Greek geometry, for example explicitly linking Hero's appeals (explicit and otherwise) to Archimedean proofs to their sources. Cuomo observes that this approach still gives pride of place to geometry, which is presented as a set of tools brought in to validate conclusions emerging from the metrological tradition of practical mathematics.[5] She raises a comparison to C.P. Snow's *The Two Cultures*, given that emphasis here remains on the divisions between geometers and arithmeticians. More productive, she suggests, is the linguistic model of 'code-switching', where bilingual speakers shift from one language to another depending on the situation. So rather than two mathematical traditions whose participants are largely siloed from one another, the *Metrica* might model a 'bilingual' mathematical tradition that hybridizes the practical and geometrical traditions.

Cuomo's emphasis on 'code-switching' is, I think, a very productive lens through which to view the *Metrica* (and indeed other works, both by Hero and others). The question of how the text actually serves to facilitate that kind of cognitive switching will be my focus in this paper. Responses to questions like this should ideally consider the social situations in which these types of mathematics were cultivated: as Sluiter's call to the technological side of 'anchoring innovation' suggests, 'technology solves a people problem'.[6] However, we have so little knowledge of the social history of Greek mathematics, outside of the few anecdotes of celebrated mathematicians like Archimedes and vignettes of mathematical explorations like the slave in the *Meno*, that this human context is difficult to reconstruct in any detail. Again, the fortunes of these questions are changing, as Cuomo proposes an ambitious project of investigating ancient numeracy using strategies comparable to those used to study ancient literacy.[7] Textual references to the cultural values associated with both geometrical and algorithmic mathematical practices can help to

4 Tybjerg 2004.
5 Cuomo 2019, 80.
6 Sluiter 2017, 25.
7 Cuomo 2012.

sketch out the social contexts in which these practices were developed and carried out.

Still, no external evidence suggests how a 'hybrid' text like the *Metrica* might have shaped (or been shaped by) such practices; Hero, as always, fails to appear against any robust historical backdrop. However, taking a cognitive studies approach to the text, with an emphasis on pedagogy, can help avoid the pitfall of turning a study of his mathematics into a case of 'ideas without people'. In this vein, we can refocus the questions suggested above to make use of contemporary work from cognitive science, including work from Sutton and Clark on the cognitive effects of repetitive practice with linguistic structures to enable actors to respond flexibly to new situations. Hero's hybridization of geometrical and algorithmic prose leverages early strings of markedly repetitive problems to anchor the reader's journey into the novel linguistic structures of his mathematical approach.

To return to the questions raised earlier about what the *Metrica* (and related works) might have to do with 'anchoring tradition', I sketch a two-pronged anchor—let us label its prongs 'cultural' and 'cognitive' anchoring. 'Cultural' anchoring practices link Hero's hybrid *Metrica* both to the Greek geometrical tradition and to an arithmetical tradition adapting Egyptian and perhaps Babylonian practices into a Greek (or Greco-Roman) context. These practices motivate and legitimate the knowledge developed in Hero's works by connecting it back to cultural touchstones like Plato and Aristotle's musings on the justice effected by the geometrical mean, or the legendary antiquity of Egyptian traditions of land measurement. 'Cognitive' anchoring, in turn, draws conceptual connections to help the reader build up comprehension of the text's content, rooting novel mathematical approaches in more familiar ground. Those connections are then cemented more firmly through carefully shaped opportunities for rehearsal and practice with the new concepts. The distinctive linguistic markers of the text strengthen these structural features for both types of anchor; they mark and reinforce generic conventions while simultaneously serving as what Clark calls 'linguistic scaffolds'.[8]

2 Mathematical Traditions

Greek metrological texts, including Hero's hybrid *Metrica* and the later texts that derived from it like the *Geometrica* and *Stereometrica*, as well as assorted

8 Clark 2008, 44.

papyri containing related 'practical mathematics' problems, owe a great deal to the much older Egyptian and Mesopotamian traditions of arithmetical problems focused on techniques for measuring and manipulating real-world objects. Herodotus is perhaps the earliest Greek author to comment on these connections, when in recounting the achievements of the Egyptian king Sesostris he alludes to a corps of surveyors who could measure the change in the area of a parcel of land caused by the flooding of the Nile and re-assess the owner's tax liability accordingly. He proposes that the Greeks noted these practices of land measurement, and used them as a jumping-off point to develop their own form of geometry.[9] Plato and Aristotle identify less earthbound origins for the discipline, Plato associating its origin with the god Thoth (also here credited with inventing astronomy and the board game *pesseia*) and Aristotle supposing at the beginning of the *Metaphysics* that the abundant free time enjoyed by Egyptian priests allowed them to develop mathematics.[10]

For the most part this narrative is absent from the Greek mathematical texts themselves, though a few texts do offer a narrative celebrating those imagined origins. The *Metrica* begins with an abbreviated version, which includes the origins of geometry in land-surveying but omits the Egyptian origins. More in keeping with the story found in Herodotus, the pseudo-Heronian *Geometrica* begins by explaining that the Egyptians were the first to develop the technique of measurement to maintain stable property ownership despite the flooding of the Nile, along with units of measurement still in use like the 'cord' and 'reed'. Eventually, the author writes, the use of these measurement techniques 'came around to every learning-loving man (εἰς πάντα ἄνθρωπον φιλομαθῆ περιῆλθεν)'.[11] A much abbreviated version of this history, which simply attributes the invention of geometry to the Egyptians and its adoption in Greece to Thales, is likewise found in the interpolated later chapters of Hero's *Definitiones*.[12] The Heronian texts are likely drawing on Proclus' commentary to the first book of Euclid's *Elements*, where he proposes the same basic history of the discipline: the flooding of the Nile caused the Egyptians, out of necessity, to develop

9 Herodotus, *Historiae* 2.109.1–12. For an example of an Egyptian surveying text, see Fowler 1999, 231–234.

10 Plato *Phaedrus* 274c5–d2, Aristotle *Metaphysica* 981b23–25.

11 [Hero], *Geometrica* 2.1. The *Geometrica* was not written by the historical Hero of Alexandria, but rather assembled sometime in late antiquity; this passage is repeated in the *Geodaesia*, which like the *Geometrica* is difficult to date or even establish a stable text for, so many variants are found in the manuscripts. On the troubled history of the corpus of 'Heronian' metrological texts, see Acerbi and Vitrac 2014, 429–474.

12 Hero, *Definitiones* 136.1.1–2. On the authorship of these later chapters, see Giardina 2003, 82–89.

the techniques of geometry to maintain stable property boundaries. Proclus concludes with a neo-Platonic note not present in the metrological texts, that the transition from practical necessity to abstract geometry follows the natural evolution from imperfection to perfection of everything in the 'world of generation'.[13]

Interesting as this story of textual borrowing from the Neoplatonic Proclus into the chaotic Heronian metrological corpus is in its own right, I dwell on it at length here because the problem-solving context into which this history is fitted is so *different* in Proclus compared to the Heronian texts. Proclus appropriates the Egyptian land-measurement practices as a paradigmatically ancient anchor for Euclidean geometry—pure, demonstrative Euclidean geometry, whose form and practice are so different from the Egyptian problem texts. The later Heronian texts then re-appropriate the story, putting it to work in a problem-solving context which borrows some elements from Euclidean demonstration, but much more closely resembles the Egyptian tradition of problem-solving algorithms deployed on concrete real-world objects.

Compared to those later Heronian metrological texts, the *Metrica* is much more a hybrid of the abstractions of Greek geometry with the practicalities of the algorithmic traditions. The latter tradition is marked by a number of features, including the consistent use of sample numbers for model calculations, the application of calculation algorithms to real-world concerns like building brick walls and reckoning billable hours, and the concomitant use of concrete units to measure those objects. Egyptian and Greek problem collections on papyrus in particular do, of course, feature numerical tasks like challenging the reader to express a given number as a certain number of unit fractions or find the missing side of a right triangle given the lengths of the other two. However, those problems typically either treat the quantities involved as pure numbers with no units at all, or more commonly identify them with real-world objects (fields, holes in the ground, etc.) and express them in terms of concrete units—feet, cubits, bricks, *naubia*, etc.

By contrast, Hero makes consistent use of abstract 'units' (*monades*) throughout the *Metrica*, rather than some concrete unit like feet or cubits, even in the (rare) problems dealing with real-world objects, like the washtub of 2.12 that is defined as a spherical segment. Later metrological texts associated with Hero's name, by contrast, do use concrete units almost all the time: Heiberg's edition of the *Stereometrica*, for example, begins with a sphere of diameter 10 feet and the units never let up from that point. But Hero's design for the

13 Proclus, *In primum Euclidis elementorum librum commentarii* 64.16–65.3.

Metrica itself is clear: he resists using the concrete units so typical of the practical mathematical traditions because the *Metrica* is meant to transform that tradition into something new.

Hero's plan for his *monades* is signaled already in the preface to the first book, where they are introduced alongside the possibility (quickly discarded) of describing dimensions in terms of cubits and feet (or their square and cubic analogues). He announces that his project will begin with measurements of planar figures (including hollow and convex forms), which is to say measurements of area. Here he introduces the square cubit and foot, defining them as square areas where each side is a cubit or foot long, and alludes to a system where surfaces are defined relative to those areas, or the smaller units like dactyls that make them up. Likewise, solid objects may be compared to a cube with edges a cubit or a foot long.[14]

The reader might thus be expecting a book of problems in the 'practical mathematics' tradition, where algorithms for calculation are demonstrated on objects with real-world dimensions: circles whose circumference is measured in feet, walls whose height and thickness is measured in cubits, even structures composed of certain numbers of bricks of given dimensions. But Hero immediately dashes those expectations with an alternative plan: rather than using 'feet' or 'cubits' or their subunits, he will instead simply label his numbers with 'units (*monades*)', which the reader can imagine match up to any real-world dimension they like.[15] And true to the promise of the preface, in the remainder of the *Metrica* Hero will eschew the use of conventional concrete units like the foot or cubit.

Yet he does not take for granted that the reader will be comfortable with his choice. The first book of the *Metrica*, dedicated to techniques for measuring plane figures, begins with the simple case of the rectangle. Indeed, so simple is this first problem that it seems to be as much a continuation of the argument from the preface in favor of the use of abstract *monades* rather than concrete units as it is about the rectangle itself:

> Let there be an oblong region ΑΒΓΔ, having [the line] ΑΒ of 5 units, that of ΑΓ of 3 units. [The problem is] to find its area. Since every rectangle is said to be bounded by two lines containing the right angle, and that bounded by ΑΒ and ΑΓ is one such, the area of the oblong will be of 15 units. For if each leg is divided, ΑΒ into 5 units, and ΑΓ similarly into 3 units, and parallels are drawn across the cuts in the legs of the

14 Hero, *Metrica* 1.pr.37–48.

15 Hero, *Metrica* 1.pr.51–54.

> parallelogram, the area will have been divided into 15 regions, of which each will be of 1 unit. And if the region is square, the same argument will apply.

> Ἔστω χωρίον ἑτερόμηκες ⟨τὸ ΑΒΓΔ ἔχον⟩ τὴν μὲν ΑΒ μονάδων ε, τὴν δὲ ΑΓ μονάδων γ. εὑρεῖν αὐτοῦ ⟨τὸ ἐμβαδόν⟩. ἐπεὶ πᾶν παραλληλόγραμμον ὀρθογώνιον ⟨περιέχεσθαι λέ⟩γεται ὑπὸ δύο τῶν τὴν ὀρθὴν γωνίαν περι⟨εχουσῶν εὐθειῶν⟩ καὶ ἔστι τὸ ὑπὸ τῶν ΒΑ ΑΓ περιεχόμενον ⟨τοιοῦτο, τὸ⟩ ἐμβαδὸν τοῦ ἑτερομήκους ἔσται μονάδων ιε. ⟨ἐὰν γὰρ ἑκατέρα πλευρὰ⟩ διαιρεθῇ ἡ μὲν ΑΒ εἰς τὰς μονάδας ε, ἡ δὲ ΑΓ ὁμοίως ⟨εἰς τὰς γ μονάδας καὶ δι⟩ὰ τῶν τομῶν παράλληλοι ἀχθῶσιν ταῖς τοῦ παραλληλογράμμου πλευραῖς, ἔσται τὸ χωρίον διῃρημένον εἰς χωρία ιε, ὧν ἕκαστον ἔσται μονάδος α. κἂν τετράγωνον δὲ ᾖ τὸ χωρίον, ὁ αὐτὸς ἁρμόσει λόγος.[16]

Simple though the problem is mathematically, this first passage does some heavy lifting to prepare the reader for the style and strategy of all the problems to come. Hero devotes most of the text of the passage to introducing the units in a very detailed way, spelling out how the reader is meant to imagine them as 'cuts' across the planar form.

This regime of mentally picturing the units is reinforced by the diagram, where they are shown as squares cross-hatched across the rectangle by linear cuts. The incorporation of cross-hatched units into the diagram is quite unusual; the diagrams of metrological problems that give dimensions like the lengths of a polygon's sides usually just label the relevant part of the diagram with the number. Elsewhere in the metrological tradition (both the earlier Egyptian and Babylonian traditions and the later Greek tradition as found in the *Stereometrica* and other texts), some problems do deal with quantities like numbers of bricks or roof tiles to constitute a volume or cover an area, but these are not usually diagrammed. In *Stereometrica* 2.48 in Heiberg's edition, there is a problem involving measuring sail-cloth to fit a mast given the lower yard length and height: how many pieces of linen cloth are needed to make up the sail if each is 3 × 4 feet? The diagram for that problem in the manuscripts that include it does show a lot of little rectangles pieced together into the form of the sail, but of course ontologically those squares represent something quite different from the *monades*. A closer comparison might be the 'calculus' of dots representing pebbles arranged into triangular numbers, square numbers, and so on, found in arithmetical texts. Acerbi and Vitrac point out that when

16 *Metrica* 1.1.

the actual word *monades* drops out, the neuter plural article (rather than the feminine) is often used for the numbers in question, which suggests some conceptual fluidity remains in the mental schema of the *monas*.[17]

Through this elaborate introduction, Hero teaches the reader to 'see' the units that will appear in the text's later, more complex problems, where the diagrams could not support explicit cross-hatching without obscuring other components of the diagram more specifically relevant to the problem at hand. This first problem is thus not so much about the rectangle as it is about training a reader familiar with a geometrical tradition that eschews definite numbers, or one familiar with an arithmetical tradition that insists on concrete units, to read the hybrid *Metrica*.

The preface to the second book shows that Hero still finds it important at that point to guide his reader's thinking about units—now solid rather than area units, since this book deals with measurements of solid objects. He gives the example of a rectangular prism of length 20 units, width 12 units, and thickness (*pachos*, a term Hero uses to differentiate this dimension of solid bodies from the 'depth (*bathos*)' of hollow ones) 80 units. The vagaries of the manuscript tradition have recorded an incorrect answer to the trivial problem of finding the volume of this form, but no matter. The point here is to re-introduce the *monades* in the context of solid geometry, which Hero immediately moves on to do:

> And the solid is of that many units. The proof of this is clear. For if we imagine the three distances divided into lengths of unit magnitude and extend planes through the cuts parallel to the planes enclosing the solid body, the solid will be, as it were, cut up into solids of unit magnitude, the number of which will be the stated number.
>
> τοσούτων δὲ καὶ τὸ στερεὸν ἔσται μονάδων. τούτου δ' ἡ ἀπόδειξις φανερά. ἐὰν γὰρ τὰς τρεῖς διαστάσεις ἐπινοήσωμεν διῃρημένας εἰς μοναδιαῖα διαστήματα καὶ διὰ τῶν τομῶν ἐπίπεδα ἐκβάλωμεν παράλληλα τοῖς περιέχουσι τὸ στερεὸν ἐπιπέδοις, ἔσται ὥσπερ καταπεπρισμένον τὸ στερεὸν εἰς μοναδιαῖα στερεά, ὧν τὸ πλῆθος ἔσται ὁ εἰρημένος ἀριθμός.[18]

Hero asks his reader to perform a complex imaginative task, first inviting them to imagine (ἐπινοήσωμεν) the divisions through the three dimensions, then to mentally extend (ἐκβάλωμεν) slices cutting through the form along

17 Acerbi and Vitrac 2014, 153 n. 14.
18 *Metrica* 2.pr.19–27.

each plane, until the solid is chopped into cubes that can then be numbered. Unlike the first book, no ready strategy is available for representing these three-dimensional slices in a diagram. However, his detailed description of the 'slicing' process allows the reader to transfer their understanding of the cross-hatched grid from the first book's preface to the three-dimensional application here. The orderly escalation of the *Metrica* from plane to solid figures, and from simpler to more complex within the books, is a cognitive anchoring strategy in its own right, empowering the reader to carry out novel visualizations like the one we see here.

3 Linguistic Anchors

Hero's suggestion in the preface to the second book of the *Metrica* that multiplying the units from all three dimensions is thus 'proved' to yield the volume is a rhetorical maneuver designed to anchor the *Metrica* in the tradition of geometrical demonstrations. Indeed, the *Metrica* is through and through a fusion of a geometrical tradition based on rigorously generalized demonstrative proofs with an algorithmic tradition where the text's main purpose is to model the use of particular algorithms and calculation methods. These two traditions differ considerably, not merely in method but in linguistic form. The Greek geometrical tradition and the various arithmetical traditions that may have influenced Hero's work all have their own distinctive linguistic markers.

Greek geometers in general hewed remarkably closely to a canonical model of proof-writing. In this model, proofs proceed through a series of formulaic steps from enunciation (*protasis*) to conclusion (*sumperasma*), couched in equally formulaic language.[19] All progress is evidently made not by the author's own hand but a shadowy entity adumbrated by the third-person passive imperatives that are such a peculiar verbal marker of these texts. Fowler and Taisbak memorably characterize the entity responsible for the steps of the construction and proof as the 'Helping Hand', which

> is always there first to see that things are done and to keep the operations free from contamination by our mortal fingers.[20]

19 For an explicated sample of this formulaic construction and discussion of what 'formulaic' means in this context, see Netz 1999, 9–11, 127–167. Further discussion of the features of the formulaic style associated with this genre of text will be found at Asper 2001a, 75–76.

20 Fowler and Taisbak 1999, 362.

Greek geometrical texts typically eschew direct imperatives completely, and in general first-person forms appear only in the occasional formulaic use of 'I say (*legō*)' to assert that a particular result will ensue. Other genre-defining features of Greek geometrical texts include the presence of letter-labeled diagrams and the absence of numbers. The letter labels, typically deployed in alphabetical order but skipping *iota*, represent features like the endpoints of line segments, vertices of polygons, and points on a circle; they connect text and image by appearing in both the diagram showing the finished construction and in the proof itself as that construction gradually unfolds. Generality is an important feature of the geometric proof: a proof on a triangle is meant to work for *any* triangle, not merely the one shown in the diagram. Hence numbers are not used in typical Greek geometrical problems, except to indicate proportional relationships that hold for every instantiation of a given figure.

As Vitrac and Acerbi note, Hero's *Metrica* features some variations on this model.[21] Some propositions, like I.29, generally follow the conventions of geometrical prose, but mix together features of stages of the proof traditionally kept separate, like *ekthesis* ('setting out') and *kataskeuē* ('construction'), or omit stages like *protasis* ('enunciation') or *sumperasma* ('conclusion').[22] Others, like I.33, add numerical values to letter-labeled geometrical objects (for example, the square on a line segment is denoted as 49 units). Still others, like II.13, take the introduction of numerals one step further and use a calculation by way of proof. Even though it incorporates several of the features of geometrical demonstrations, including letter-labeled diagrams whose constructions are laid out in the passive-imperative language of the 'Helping Hand', the *Metrica* could really not be mistaken for a 'typical' Greek geometry text.

The elements that separate the way material is presented in the *Metrica* from those 'typical' geometrical texts are themselves largely drawn from the algorithmic 'practical mathematics' traditions. Some features of that tradition have already been identified above: 'algorithmic' texts generally provide series of examples of problem-solving and calculation procedures rather than the demonstrative proofs characteristic of Greek geometry. Sometimes they ask the reader to perform purely numerical tasks like expressing proportions as sums of unit fractions, or geometrical tasks like calculating the areas of

21 Acerbi and Vitrac 2014, 411–16.

22 In the formulaic stages of a Greek geometrical distribution, the *ekthesis* 'sets out' the letter-labeled object (e.g. a line AB) that instantiates the object of the proof enunciated in the *protasis* (in Netz's example referred to above, the line AB is to be cut into equal parts at a certain point, and into unequal parts at another). The *kataskeuē* formally constructs all the elements of the diagram necessary to prove the proposition enunciated in the *protasis*. For more detail see Netz 1999, 9–11.

polygons, but more often the problems in these texts at least nominally deal with real-world objects, generally described in concrete units.

Just as in the case of the geometrical texts, the generic identity of these texts is as much a linguistic matter as it is a question of mathematical content. It is of course much more difficult to generalize across a variety of mathematical traditions from different linguistic and cultural backgrounds than it is to characterize the extraordinarily homogeneous Greek geometrical texts. Nevertheless, there are some common features many of these texts share. The 'Helping Hand' does not do the work in these problems. Instead, a variety of active voices appear: second-person imperatives instruct the reader, while a first-person voice may represent a 'model student' working through the steps or a teacher making assertions about the problem. These voices create a sense of an ongoing pedagogical dialogue in which the reader is implicated as they solve problems for themselves, through instructions directly focused on the problem at hand as well as generalizing statements like 'this way for similar problems'.[23]

The unfolding stages of a geometrical demonstration from enunciation to conclusion, and the algorithmic journey from problem statement to reassurance that the same method works for other problems, all follow formulaic patterns. These formulas can be explained as generic markers, but still we might ask whether there is some cognitive explanation for why mathematical texts in particular developed these formulaic patterns. The cognitive psychologist John Sutton has argued that formulaic language, even in abbreviated form, is crucial in refining the abilities of practitioners like expert cricketers or musicians. He notes that expert advice can sound unhelpful to the novice (e.g. 'jazz hands'), but eventually as embodied knowledge builds up, 'what seemed like just vague words to the novice has now become very detailed practical talk, a shorthand compendium of "caretaking practices" for toning and reshaping the grooved routines'. Formulaic language, in the form of what Sutton calls 'instructional nudges', has an 'artificially frozen nature' that works to 'stabilize cognitive flow' and 'anchor certain habits'.[24]

The language of Greek geometry is frozen extraordinarily solid, and that very stability provides guidance to the reader as they become familiar with the cues from the proof. 'If … then': the enunciation gives me my task and reveals the endpoint. 'Let there be' such and such mathematical objects: I lay them out in my mind and in the diagram, making a mental inventory of the actors

23 For some examples of these problems in action, see Bagnall and Jones 2019; Jones 2013; Robbins 1923; Rudhardt Jean 1978; Shelton 1981; Taisbak and Bülow-Jacobsen 2003.

24 Sutton 2007, 773–774.

in the drama about to unfold. 'Let them be constructed, joined, etc.': my actors spring to life, revealing the relationships that the diagram suggests but cannot prove.[25] 'Since … therefore': those relationships fall into place one by one to show that the endpoint I recall from the enunciation was inevitable. 'Which was required to be proven': the conclusion cues me to go back once more to review the problem I was given.

The algorithmic problems deliver their own stable flow of prompts to the reader, even if the stages of the action are less marked by distinctive vocabulary or grammatical elements than the 'Helping Hand' of the geometrical texts. First the object (whether purely mathematical or a notional real-world structure) is *named* and *sized* in numbers (and often in dimensional units as well). Then the mathematical task is handed down in the form of an infinitive clause: 'to find' an area, a volume, a number of bricks, etc. The action is triggered by a hortatory 'we proceed as follows' or command to the reader to do the same. At this point the numbers start flowing in the pattern dictated by the algorithm, an alternation of 'steps' and 'results' until the answer dictated at the beginning is revealed. Finally, the valediction: 'this way for similar cases'. The reader gradually builds a schematic 'script' that maps out where they can expect questions or tasks, and where given or calculated answers will be found.

As the reader of Greek mathematics works their way repeatedly through the algorithmic or geometrical scripts, the paths Sutton refers to as the cricketer's 'grooved routines' are etched in their minds as well. And not merely in the mind; the process of proof dictates habits of seeking, counting, and drawing for the eye and hand as well. While we of course cannot witness ancient students of mathematics developing their expertise, an experiment by Epelboim and Suppes tracking the eye movements of both novice and expert geometrical problem-solvers shows the development of the same kind of focus.[26] Cognitive focus and ocular focus are tightly linked in this kind of activity, as the eye gradually gains the ability to quickly extract information from the verbal problem statement and start applying it to the diagram. The novice's eye roamed aimlessly back and forth between the text and diagram, wandering around the diagram haphazardly before fruitlessly seeking additional help from the problem statement rather than considering the objects in the diagram. By contrast, the expert's eye quickly made its way through the problem-statement and then traveled to the diagram to trace over its key elements before settling in a pattern that revealed the relationships that unlocked the proof. The expert's

25 On the 'schematic' nature of Greek diagrams, see Netz 2020.

26 Epelboim and Suppes 2001.

ocular discipline manifests the 'grooved routines' developed through repeated practice with the 'script' of geometrical proof.

Sutton's ideas were amplified by the cognitive scientist Andy Clark in his groundbreaking book on distributed cognition, *Supersizing the Mind*. Clark asks why human linguistic systems take on the 'special and rather rarefied forms that they do'.[27] Like Sutton, Clark finds answers in the stable codification of linguistic prompts that themselves become tools for expert cognition, 'anchoring' (as he says) fluid reasoning processes within a given context of practice. Clark refers to language systems with the kind of stable structure we have just seen exemplified in Greek mathematics as 'linguistic scaffolds', emphasizing that highly structured language is itself a tool for action. The mathematician's developing practice with those structures, proof after proof or algorithm after algorithm, are a form of what Clark calls 'linguaform rehearsal', which has a real effect on the learner, who becomes more adept at focusing their attention as their expertise grows.

Following Sutton and Clark, I suggest that the distinctive linguistic systems associated with the geometrical and algorithmic mathematical traditions are not merely ossified formulaic traditions, but rather offer 'instructional nudges' to anchor cognitive processes. A shift in the linguistic system creates a very real shift in the cognitive activities underlying it, and that is precisely what Hero creates in the *Metrica*. He combines, often in the same problem, the distinctive linguistic forms of Greek geometry (such as the use of third-person passive imperatives and letter-labeled diagrams) with the very different features (like second-person active imperatives and numerical examples) that tend to keep studies of 'practical mathematics' starkly separated from investigations of Greek geometry.

The way Hero deploys these linguistic and cognitive shifts can be seen in a series of highly standardized problems from the first book of the *Metrica*, where Hero shows how to calculate the areas of equilateral polygons from the triangle to the dodecagon. The series follows a string of problems on trilateral and quadrilateral figures, the last of which concludes with a preview of the series to come, noting that its closing dodecagon is a good approximation to the circle.[28] The new series begins, 'First of all (*proteron*), let there be an equilateral triangle, each of whose sides is 10 units. And let it be ΑΒΓ'.[29] The *proteron* that commences this section signals that the problem at hand will serve as a jumping-off point for the rest. This problem differs from the rest, and from

27 Clark 2008, 47.
28 Hero, *Metrica* 1.16.9–11.
29 Hero, *Metrica* 1.17.

most other problems in the *Metrica*, in not including a formulaic statement (usually given in the infinitive) of what the reader is meant to do. Then again, the basic assignment of each of these problems has actually already been carried out for problem 17, for it is a special case of problem 3: find the area of an isosceles triangle.

After the unusual beginning of problem 17, the series settles down into a stable form. Each of the remaining problems begins in the same way: 'let there be an equilateral, equiangular [polygon of *n* sides], [letter labels of its *n* vertices], and let each side be 10 units. [The problem is] to find its area'. Each begins its solution with a geometrical construction that closely follows the 'prototypical' Euclidean form, using third-person passive imperatives to construct elements of the figure and indicative assertions about proportional and spatial relationships between its components.

Indeed, each of those constructions proceeds through steps familiar from Euclid: locating the center of the polygon's circumscribed circle (*Elements* III.1) and using that point to launch the triangles between center and edge that will allow Hero to demonstrate the proportional relationships between them. These constructions all reprise the bisected isosceles triangle that problem 17 borrows from problem 3; this form becomes an increasingly familiar sight as it recurs in the diagrams of all but two of the problems, serving to emphasize the coherence of the series. In the case of the enneagon and hendecagon, the bisected isosceles triangle cannot be constructed in the same way. However, in these cases the polygon's circumcenter similarly anchors the diameters that define the right triangles used for that purpose. The equilateral triangle of problem 17 is once again an exception to this pattern, since Hero does not solve the problem using a circumscribed circle, but he does make use of the familiar 'Pythagorean theorem' of *Elements* I.47.

This series of problems gives a good sense of the techniques Hero uses to anchor the *Metrica*'s novel blend of geometrical and algorithmic material solidly within the Euclidean geometrical tradition. Each problem-statement is delivered in extraordinarily formulaic language that is not only familiar to those with experience with Greek geometrical texts, but is rigorously self-similar from one problem to the next. From the simple case of the equilateral triangle, to the complexities of the pentagon, all the way up to the dodecagon, Hero uses both language and procedures familiar from Euclid to anchor his geometrical constructions.

Within the familiar Euclidean structures defined by these lockstep geometrical constructions, Hero then introduces the numerical calculations necessary to discover the areas. Here he moves into territory considerably less familiar to a faithful Euclid reader, drawing on a wide range of proportional relationships and techniques for calculation and approximation. Some of these, like those used for the pentagon, are quite challenging, but Hero helps his reader by building up his material gradually, allowing the simple form of the equilateral triangle introduced at the beginning to do considerable heavy lifting. Vitrac points out two key features of the algorithmic approach at work both here and elsewhere in the *Metrica*.[30] First, as Hero rolls through the numbers he is careful to 'chain' the numerical steps and results so each 'output' becomes an 'input' for the next calculation. Second, this continuity is further supported by consistent use of articles and demonstrative pronouns to designate numerical values—a 7 is not just a 7, but 'the' 7 that continues to participate in the algorithm. In this way, the numbers in the calculation take on something of the stable identity of a letter-labeled geometrical entity.

The numerical procedure proceeds quite similarly in each of the problems in the sequence, usually squaring the side, multiplying the result by one factor determined during the analysis and dividing by another, yielding the area. All of the results are approximations, since the numerical analyses use approximations for calculating fractions and square roots. The triangle and hexagon require an additional step of squaring and taking the square root to deliver the best approximation. Vitrac points out that in the case of the hexagon the algorithm has been slightly adapted to reduce the number of steps, somewhat obscuring the parallel between the analytical and synthetic sections.[31] That decision does, however, bring the algorithmic section into greater symmetry with the other passages, enhancing the 'anchoring' effect of the repetition.

Throughout the passages on the regular polygons, verbs are often omitted in favor of terse formulations like 'these [multiplied] by these (ταῦτα ἐφ' ἑαυτά)'. On the rare occasions when verbs appear (other than the standard impersonal *gignontai* that indicates the result of a calculation) they can take second-person forms like 'take their nearest square root (τούτων λαβὲ πλευρὰν ἔγγιστα)', or occasionally first-person plural forms like 'we will find its area more precisely'. Tellingly, the personal verb forms are found exclusively in the first three problems in the sequence. In the first problem Hero steps in to remind the reader that 'we learned this earlier'; in the second he offers the advice about a way 'we will find' a more precise value for the area; in the third he directs the reader to take a square root. Those three problems offer a hint of didactic dialogue and direction, after which the reader is left on their own as the repetitive impersonal formula clicks in.

30 Acerbi and Vitrac 2014, 419.
31 Acerbi and Vitrac 2014, 197 n. 203.

The effect is strikingly different from the numerical procedures found in many other problems in the *Metrica*, where the more discursive algorithmic approach favors direct instructions to the reader throughout the procedure. In this early series of problems, the action of the synthesis unfolds more like the geometrical passages, the impersonal formula taking the place of the impersonal 'Helping Hand'. This sequence of problems thus helps to anchor the unfamiliar hybrid approach of the *Metrica* in more familiar linguistic territory, letting the reader adapt gradually to the integration of geometrical and numerical processes. By exploiting linguistic patterns familiar on a disciplinary level as well as creating more local patterns like the repetitive calculating formula, Hero provides his reader with a kind of catechism for practice. This rehearsal and repetition can then assist them to develop the effortless expertise of Sutton's cricketers or Clark's mathematicians, a state where abbreviated linguistic cues are sufficient to direct complex cognitive activities.

4 Conclusion

Mathematical texts provide a particularly rich experience of forms of 'anchoring', since they are at one and the same time literary texts in their own right, shaped by generic conventions that an author may choose to follow or flout, as well as cognitive tools designed to allow a reader to learn and practice technical skills. In the *Metrica* Hero shapes a hybrid text that experiments with the possibilities of 'anchoring' both to support his surprising mix of geometrical and algorithmic mathematical genres, and to assist the reader in the cognitive transition needed to blend the analytical skills used in each mathematical domain into a more powerful composite.

Hero's mix of genres might be seen as transgressive, but the longstanding Greek view of geometry as somehow ancestrally rooted in land measurement, however tenuous the connection, helps to smooth over that boundary crossing. Hero leverages that view in the prefaces to the first and third books of the *Metrica*, invoking the 'old story' about the origins of geometry in the first book and appealing to the philosophical trope of just and proportional land division in the third.[32] His prefatory reminders about the notional continuity between the two genres may help the reader navigate the generic blending to come. This work of blending includes the mixture of geometrical demonstration with algorithmic tasks of measuring and calculating, the introduction of numbers

32 On the Platonic, Aristotelian, and even Stoic antecedents of Hero's appeal here, see Feke 2014, 266–267; Guillaumin 1997.

into the traditionally scale-free world of geometrical objects, and occasionally the assimilation of a geometrical form to a real-world object. Hero takes great care to walk his reader into the new approach gradually, as can be seen from the way he introduces the concept of measuring objects without concrete units, even adapting the conventions of the traditional geometrical diagram to help the reader visualize geometrical objects in a new way.

The way Hero blends the linguistic conventions of the two genres suggests more clearly the cognitive power of his 'anchoring' approach. The shift in thinking from the impersonal 'Helping Hand' of Greek geometry to the lively virtual dialogue of the algorithmic texts is a matter of more than just grammar. The formulaic structures of the geometrical and algorithmic texts are not only generic markers; they are models for a cognitive practice that gets cemented over time so that a reader familiar with those moves can cope smoothly with even a very challenging or abbreviated text.

Hero works carefully in problems like the string of regular polygons to build a new 'linguistic scaffolding' on top of the reader's existing cognitive resources. By offering the reader a series of problems framed as identically as possible (rather than choosing a different plausible strategy like using that series to showcase a range of algorithms or calculating techniques), Hero builds new 'grooved paths' for the reader to follow. Through the repetitive reinforcement of the escalating series of problems, they can then adjust gradually to the novel juxtaposition of geometrical analysis and numerical synthesis. Hero's strategies of 'cognitive' and 'cultural' anchoring root new techniques and concepts firmly in more familiar features, allowing him to construct a novel 'hybrid' mathematics on the existing conceptual edifice.

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CHAPTER 18

Galen's Use of Hippocrates as an Anchor for Medical Innovation

Teun Tieleman

1 Introduction

On numerous occasions throughout his voluminous writings Galen of Pergamon (129–*c*.216 CE) is explicit about Hippocrates being his guide (ἡγεμών) in the study and practice of medicine.[1] His choice of Hippocrates as his role model led him to embark on a huge project of writing commentaries on Hippocratic treatises but is no less illustrated by such works as *On the Elements according to Hippocrates*, *The Best Doctor is also a Philosopher* (alternatively entitled *Hippocrates*)[2] as well as the lost *On the Anatomy of Hippocrates*. This was not simply a matter of Galen being his master's voice. It could not be. The Hippocratic question goes back to Antiquity itself. Galen was fully aware that he must start by making a justifiable selection from the treatises circulating under Hippocrates' name. In addition, there was the job of interpreting the treatises accepted as authentic. Galen is capable of sensitivity to the historical context in which they were composed. But at the same time he projects later developments on to them, e.g. by ascribing Aristotelian elemental theory or later advances in anatomical knowledge to Hippocrates—I will return to the latter point. Historiographical sensibilities will be hurt no less by the idea of Hippocrates as a proto-philosopher.[3] But is cannot be denied that Galen was extremely influential in creating and promoting his own particular image of

1 *On the Therapeutic Method to Glaucon* (*MMG*) XI 2 Kühn (hereafter K.). See also e.g. *MMG* XI. 11 Kühn (hereafter K.), *PHP* 7.8.13, p. 478.4 De Lacy (V 647 K.), *Cris.* IX. 583 K. *MM* X. 346 K. *HNH* XV. 61 K. *Hipp. Epid.* XVIIa. 548, 251 K. What is perhaps the most extravagant tribute is found at *Nat. Fac.* 1.13, II. 38 K. (Hippocrates as 'the first of all doctors and philosophers').

2 See *Lib. prop.* XIX. 37 K. = IX. 14, p. 162.7–11 Boudon.

3 Galen never calls Hippocrates a philosopher in a straightforward manner, not even in the work where one would most of all expect him to do so, viz. *The Best Doctor is also a Philosopher*. Here he rather implies that one should study philosophy in order to become a true-blue Hippocratic doctor *in our own time*. He considered Plato the greatest philosopher in the stricter sense, whose teaching was reconcilable with Hippocrates' medicine: see Tieleman 2020 and *infra*, p. 310–311.

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Hippocrates. Today many people still associate Hippocratic medicine with the four humours, but this goes back to Galen's reading of the first eight chapters of a single treatise, *On the Nature of Man*, which he took to offer the original Hippocratic position—an instance of what Vivian Nutton has aptly called Galen's 'fatal embrace.'[4] The uncertainties surrounding Hippocrates go some way towards explaining his attraction for Galen, viz. the possibility of pressing Hippocrates' authority into the service of his positions: Hippocrates was as shadowy as he was authoritative and so could be used for the purpose with some ease. But as scholars such as G.E.R. Lloyd have shown, this explanation would be too simple. The authority of Hippocrates in Galen's time should not be taken for granted.[5] In fact, Hippocrates' towering status is very much the result of Galen's efforts. His preference for Hippocrates should not hide from our view the fact that other options had been open to him, as is clear from the choices made by other physicians in his day.[6] Moreover, Hippocrates was not an easy choice in every respect. Hippocrates stood at the beginning of medicine. Opting for him involved a massive project of selection and reinterpretation on Galen's part: it meant bringing Hippocrates up to date in light of later advances in medical science, notably the discoveries of the early Hellenistic anatomists Herophilus and Erasistratus, on whose work Galen also built. Thus, Galen makes the striking claim that Hippocrates practiced dissection and was knowledgeable about human anatomy. In addition, it is worth studying his Hippocratism in relation to his disapproval of the in his time still prevalent phenomenon of medical sects, or schools. Here the question arises how Galen reconciled this disapproval with his reverence for Hippocrates.

Galen's engagement with Hippocrates has been the subject of a great many studies.[7] In what follows I will argue that Galen's attitude towards Hippocrates can be explained by seeing Galen as an *innovator* on two counts: (1) his bid to establish anatomy as an integral part of medicine; (2) his ideal of medicine as a unitary science as opposed to the division of the medical landscape into

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4 Nutton 2005.

5 This observation is the starting point of Lloyd 1991, to whose discussion I am much indebted.

6 Cf. Galen, *Opt. Med. Cogn.* 2,1, pp. 46–47 Iskandar: 'I begin my discourse with a statement by Hippocrates: in the past, this man was considered eminent, among the divine men, although in our time he no longer holds this rank (transl. from the Arabic by Iskandar).' Further, Galen's constant polemic against the Methodists may be taken to attest to the prominence of this non-Hippocratic school in his time: see *infra*, pp. 312, 322.

7 Mewaldt 1909, Diller 1933, Premuda 1954, García Ballester 1968, Diller 1974, Harig & Kollesch 1975, Smith 1979, 61–176, Manuli 1984, Lloyd 1991, Manetti and Roselli 1994, Sluiter 1995, Jouanna 1997, Jouanna-Boudon 1997, Jouanna 2000a, 2000b, Nutton 2005, Manetti 2009, Hankinson 2015, Boudon-Millot 2015, Roselli 2015, Boudon-Millot 2018, Coughlin 2023.

schools. Did Galen use Hippocrates as an anchor to find support for these innovations and, if so, why and how? In regard to the first point: Galen was not the very first to promote the study of human anatomy after the long period of neglect that set in after the work done by Herophilus and Erasistratus in the early Hellenistic period. This movement, it appears, was instigated by the generation of his teachers (see below nn.11, 41 and text thereto). At the same time it is clear that they had not succeeded in reinstating anatomy on the medical program; it fell to Galen to continue the battle. Seen in this light, he is still in the vanguard of this innovative movement. In fact, he may have been more effective than others in promoting anatomical research.

2 The Martialios Episode: Anatomy and Sectarianism

Galen's Hippocratism includes his, to our eyes at least, questionable claim that Hippocrates' work presupposes the study of human anatomy including the systematic practice of dissection. It is part of Galen's campaign to reintroduce anatomy in medicine after a long period of disuse it had fallen into since the work of medical scientists Herophilus of Chalcedon and Erasistratus of Keos (first half of 3rd century BCE). In Galen's time their work still represented the pinnacle of anatomical research, not least because these doctors had been able to dissect human corpses Given the long-standing taboo in the Greek world on human dissection this was a new and unique opportunity offered by early Hellenistic Alexandria, where they had set up residence (the dissection of animals for scientific purposes is already attested for Aristotle). Indeed, as some sources tell us, they vivisected criminals on death row furnished by the Ptolemaic kings from their prisons.[8] This innovation led to numerous and important discoveries such as the discovery of the nerves and the function of the brain. However, the therapeutic relevance of anatomical research may not always have been clear. At any rate, and from a modern viewpoint astonishingly, these advances in knowledge failed to establish anatomy as an integral part of the study of medicine and the subject was not brought further.[9] Dissection fell into disuse. In consequence, doctors interested in anatomy had

8 Celsus, *De medicina* I, *Praefatio* 23–6 = Herophilus T. 63a Von Staden, Tertullianus, *De Anima* 10.4 = Herophilus T. 66 Von Staden. Some doubt about the reliability of these reports persists and it is not easy to distinguish between results from vivisection on humans and dissection on humans supplemented with result from experiments performed on animals; cf. Nutton (2018) 326.

9 For a full discussion see Tieleman (2018a) esp. 334–335.

to turn to the relevant treatises left by the great Alexandrians, at least if they felt this was of any use or interest to them. In seeking to reinstate anatomy as an indispensable part of medicine based not on books but on the systematic practice of dissection, if only on animal material,[10] Galen follows the leads of the generation of his teachers.[11] In the following passage we find a confrontation between Galen and a member of this previous generation, Martialios, who was a follower of Erasistratos and a reputed anatomist:[12]

> [Martialios] was malicious and quite contentious (φιλόνεικος), although he was more than seventy years old. Having learned that my public lectures and teachings on an anatomical issue had been highly praised by those who had followed them, he inquired of one of my friends to which school (αἱρέσεως) I belonged. He was told [scil. by this friend] that I call slaves those who present themselves as Hippocratics or Erasistrateans or Praxagoreans or in general name themselves after a particular person (τινος ἀνδρός), and that I select (ἐκλέγοιμι) what is sound (τὰ καλά) from each of them. He then asked a second question: whom of the ancients (τῶν παλαῖων) did I praise most? Having learned that I praised Hippocrates, he said that for him Hippocrates did not constitute a subject for anatomical study at all, whereas Erasistratus was marvellous in anatomy as well as in other parts of his science. Because of him, then, rather out of love of honour (φιλοτιμότερον), I wrote *On the Anatomy of Hippocrates*, in six books, and *On the Anatomy of Erasistratus*, in three books (*Lib. prop.* 1.7–10, p. 138.6–21 Boudon = XIX. 13–14 Kühn; my translation).

10 On the profits derived from the study of anatomy see esp. Galen, *AA* II. 286 K. On the importance of systematic dissection, constant practice and the limited value of learning from anatomical books see *CMG* XIII. 604–605 K.; cf. *AA* II. 220 K. (on bones, where also note that Alexandrian doctors were privileged in being able to teach on bones using a real human skeleton). On Galen being dependent on working on animals as opposed to Herophilus see *Anat. Ut.* 5.42–44 Nickel (= Herophilus T 114 vStaden). Galen dissected various kinds of animal, e.g. pigs, goats, cows and monkeys and apes, which he recommended for their likeness to humans: On dissection in Galen see further Bubb 2022, chs. 8 and 9; cf. also Tieleman 2018a. On Galen's anatomical experiments and their intellectual and cultural context see Salas 2020.

11 Marinus, Pelops, Numisianus and still others; see Grmek and Gourevitch 1994. On Marinus see also *infra*, p. 316.

12 On the Martialios episode in the context of Galen's practice of performing anatomical demonstrations, see Boudon 2012, 143–146 and Salas 2020, 192; cf. 53, 82. Cf. also Tieleman 2023b, 47–48.

The beginning of this passage shows us that there were Hippocrateans around alongside other schools but that Galen avoids association with any of them.[13] Instead, he takes a self-consciously eclectic position, selecting and combining what he deems best in each school. It is a nice touch that, at least in Galen's presentation, Martialios' question presupposes that everyone must belong to a school. It is something unexpected that Galen does not. At the same time, however, there was his admiration of Hippocrates above all others. The fine but important distinction drawn here is that between sectarian behaviour and independent research: Hippocrates should be praised because he can be proven correct or at least on the right track more than others, not because he is Hippocrates. This is also implied by Galen's point about the medical schools being named after a particular person. In joining a school, one surrenders one's intellectual freedom to such an authority and becomes so to speak his slave. This includes those who call themselves after Hippocrates. Galen criticizes the lamentable phenomenon of sects in strongly moral terms. Here its moral flaws are embodied by Martialios the Erasistratean, whom he calls contentious (φιλόνεικος), Galen's word for the wrong sort of competitiveness typical of the sectarian mindset.[14] That advances in medicine are seriously hampered by its division into different schools is one of Galen's hobby horses.[15] The following passage highlights the psychological consequences of school membership:

> [The adherents of the various schools] cling to their own assumptions and pretend to put firm trust in what they unwarrantably say in support of some dogma of those of their own school (αἱρέσεως), just as others have no qualms about lying to refute some doctrine of those who hold a different view (ἑτεροδόξων). Those who proclaim themselves adherents of some school feel duty-bound to mount a fight over all the doctrines of their school, even in those cases where there is no logical necessity in view of the core of their teaching, as with the debate on the soul (*PHP* IX, 7.5–6, p. 586, 27–34 De Lacy; my translation).

Martialios questions Galen's preference for Hippocrates for reasons with which one might well sympathize: there is no anatomy worth mentioning to

13 Of course, he had studied with doctors who saw themselves as followers of Hippocrates and recommends reading their commentaries on Hippocratic works: see *Lib. Prop.* 3.6–7, p. 98 Boudon-Millot = IX. 57 K. Cf. Coughlin 2023, 16–22. But what is at issue here is the problem of sectarianism. Galen takes an analogous attitude to Plato as distinguished from Platonism, see *infra*, p. 308.

14 See the evidence collected by Lloyd 1991, 400; cf. Tieleman 2022.

15 See also Tieleman 2022. On medical sects and identity issues see Von Staden 1982.

be found in the works preserved under Hippocrates' name. Yet Galen responds to Martialios' challenge by writing a treatise on Hippocrates' anatomy in no less than six books and another on that of Erasistratus in three, in which he exposed errors in Erasistratus' anatomical work and so, by proxy, in that of Martialios. Another nice touch here is that Galen looks back on this episode as one in which he himself showed an attitude that he ascribes to adherents of schools in other contexts: a surplus of ambition, or desire for honour (φιλοτιμότερον), which expressed itself in a strong desire to refute Martialios as a person. At the time of this confrontation Galen was still in his thirties (and this passage comes from a work of his own old age). The difference of age between the then elderly and well-established authority Martialios and young and upcoming Galen underlies this account. Galen, then, seems to imply that he has grown up whereas sectarians never do. Accordingly, Martialios is said to take an attitude that ill befits his advanced age.

Galen affiliates himself to Hippocrates without being a Hippocratean, i.e. a sectarian in the pejorative sense. One may compare his attitude to Plato and the Platonists, which is analogous to his position regarding Hippocrates and the Hippocrateans: Galen considers Plato the greatest among philosophers, but keeps his distance from the Platonists, who, he believes, often misunderstand the master after whom they name themselves. To be sure, Galen's readings of Plato were conditioned by the intervening exegetical tradition. He had studied with a Platonist, about whom he speaks in the warmest of terms.[16]

Galen was also familiar and no doubt built upon the exegetical tradition connected with the Hippocratic writings too.[17] But it is his formal, advertised position which concerns us now. Why did Galen present himself as an admirer of Hippocrates in the first place? It is not as if professing allegiance to Hippocrates was de rigueur among doctors, as the story about Martialios shows (see also p. 313 below about Thessalus the Methodist). In fact, Galen goes out of his way to show, in six books, that Hippocrates should be taken seriously as an anatomist: quite a venture. Yet this does not make Galen a sectarian of the kind from which he so emphatically distances himself. Galen explains his position in terms of a particular view of intellectual history. According to Galen's account, Hippocrates lived in an age before medical schools or sects, with their quarrels, partisanships etc. arose—a situation of presectarian bliss.[18] Compare the following passage from Galen's *On Antecedent Causes*, a tract preserved in a 14th century Latin translation only:

16 *Aff. Dign.* VIII 3–4, p. 28.9–15 De Boer; cf. Tieleman 2020, 26–27.

17 See Smith 1979, 61–176; Manuli 1983, Manetti and Roselli 1994.

18 As I have dubbed it at Tieleman 2023b, 52.

> The early philosophers, in their desire to be of benefit to mankind, not only originated and produced theories about things which are clearly known, but also attempted to find out about many things which are not clear; and hence in those times, on the basis of their findings, the growth of knowledge made its greatest progress. However, some of the doctors and philosophers who succeeded them wanted to make their reputation and despairing of ever achieving it in a just manner, they resorted to charlatanry (*astuti fieri*). And those who were unable to refute the sophisms they posed reacted in one of two ways: either they believed them to be true, or else they thought that the best course was to remain in doubt about everything (*De causis procatarcticis* [*CP*] 1,1–3, p. 1.3–22, *CMG* Suppl. II, ed. K. Bardong; p. 70.1–13 Hankinson; translation Hankinson).

It is again worth noting the strongly moral terms with which Galen describes the history of medicine and philosophy. The earliest doctors and philosophers were driven by the desire to benefit mankind[19] and conducted their research in the right spirit, with real progress resulting. Galen's point about clear and unclear things probably means (as may have been clearer from the original Greek) that their theories about imperceptible things, i.e. the causes behind the phenomena, were grounded in obvious phenomena, a recurrent methodological point in his work.[20] Things that are already clearly *known* need no proof or theory. When people deny what he considers obvious facts Galen typically sees this as a moral problem rather than an epistemological or scientific one. Here too vices such as love of honour, charlatanry and sophistry led the successors of this golden generation to found schools of their own. In present-day terms one could say that the problem is their lack of intellectual integrity.[21] It is worth noting that Galen also explains the emergence of Scepticism by reference to their new-fangled theories: they either win over people to join their camp or they create doubt about *everything*, including sound medicine and philosophy. Scepticism is indeed one of the possible responses to disagreement among experts or their schools. It is itself not a school in the same sense that

19 See *Opt. Med.* 2.8, p. 288.3–6 Boudon (I. 57 K.) (εὐεργεσίας ἀνθρώπων), *PHP*, 9.5.4, 9.5.6, p. 564.23, 26 De Lacy: φιλανθρωπία.

20 Going from the phenomena to the causes is a procedure that goes back to Aristotle, as does Galen's notion of the starting points of inquiry (clear observations as well as things clear to the mind such as axioms), but his stress on obviousness is a Hellenistic legacy. Cf. also Hankinson *ad loc.*

21 On these recurrent features of Galen's polemic cf. *MM* X. 1–9 K. *Opt. med.* 2.8, p. 288, 3–17 Boudon-Millot (I 37 K.), *HVA* 1.16, p. 32.6–15 Pietrobelli (XV. 450 K.), *Loc. Aff.* VIII. 362 K. See also Hankinson's comments *ad loc.* (p. 153).

the others are and in fact an anti-sectarian position too. For Galen Scepticism, particularly that of the Pyrrhonian variety,[22] is not the correct response and indeed one of the bad consequences of the confusion caused by the charlatans and sophists (where note the Platonic language). Apparently, then, decline set in in what we today call the Hellenistic age, when the phenomenon of schools took shape and which saw the emergence of Scepticism. We should therefore hark back to the period before that. We need not doubt that Galen alludes to Hippocrates and his circle and, on the philosophical side, past masters such as Pythagoras, Socrates and Plato, i.e. those whom he elsewhere collectively refers to as the 'ancients' (as in the Martialios passage above).[23] Galen's great work *On the Doctrines of Hippocrates and Plato* is devoted to tracing the tradition of good philosophy-cum-medicine back to the past masters mentioned in its title.

Plato refers to Hippocrates in two passages. Of these, *Phaedrus* 269c–270e (esp. 270c1–d7), where Plato recommends Hippocrates' method, was particularly useful to Galen in showing Plato's admiration of Hippocrates and his dependence on the great physician for a subject of prime importance.[24] But, surprisingly, Galen does not refer to the *Phaedrus* passage in *PHP* itself, unless he did so in one of its lost parts.[25] But Galen clearly refers to *Phaedrus* 269c–270d in connection with his project in *PHP* in the following passage from his *Method of Healing*:

22 Cf. Gal. *Diff. puls.* VIII. 711, *Art. Sang.* IV. 427 K., *Praen.* 5.9–21, pp. 96.5–100.6 Nutton (XIV. 625–630 K.).

23 On Galen's assessment of Pythagoras, Socrates and other early Greek philosophers, see Tieleman 2022. His favourable verdict on the moral thought of Pythagoras and Socrates differs from his response to natural philosophers such as Melissus and Empedocles, which is more mixed. On Galen on 'ancients' (as opposed to 'younger' or 'more recent' authors) and his view of history see now also Singer 2022, 74–89.

24 See also *On Hippocrates'* Nature of Man (*HNH*), *Proem.* pp. 4.18–5.9 Mewaldt (XV. 4–5 K.) with Tieleman 2020, 28–31. The only other occasion on which Plato refers to Hippocrates of Kos, 'the famous physician,' is *Prot.* 311c: Hippocrates appears here as the sort of expert, to whom one might expect to pay fees in return for his teaching. Doctors and money constitute a sensitive issue in Galen, who does not refer to this passage at all. At *Charmides* 156c–157c it is said that 'certain eminent doctors' hold that to cure the eye one must cure the whole body, which may have appealed to Galen because of its holistic approach. These doctors may have included Hippocrates but we do not know whether Galen read the passage this way. Cf. also Plato's reference to Hippocrates starting from the nature of 'the whole' at *Phaedr.* 269c–270d.

25 The first two thirds of book I (in De Lacy's estimation) and, if we may rely on the Arabic tradition, its tenth book are lost: see De Lacy 1978 and *Lib. Prop.* 16.3, p. 171.5 Boudon-Millot. But if so, it is odd that it left no traces whatsoever in the surviving books II–IX and the extant last third of book I.

> You hear, my noble friend [scil. the Methodist physician Thessalus, on whom see further below, p. 312], that Plato thinks it proper to use in the investigation of the soul the same method as that employed by Hippocrates in the case of the body. Or would you prefer me to quote many passages from many different parts of his works in which he particularly exalts Hippocrates of all those who came before him? However, I have already done this in another work in which I comment on the doctrines of Hippocrates and Plato, to which I refer anyone interested. The complete agreement between the two men in many of their views, particularly the most important of them, has in my view been absolutely and plainly demonstrated (*MM* 1.2.8, x. 14 K. translation Hankinson, slightly modified).

From our point of view, Galen grossly exaggerates when he speaks about the many passages showing Plato's agreement with Hippocrates.[26] But this only goes to underline the importance he attaches to the connection. Plato did not only belong to the golden generation, but he can also be presented as a follower of Hippocrates in certain ways. At the same time this is also a way of upgrading Hippocrates and associating him with Galen's own ideal of a philosophical medicine, or medical philosophy. But he also includes the one or two generations after Hippocrates and Plato among the 'ancients' who still belonged to the uncorrupted phase of history: doctors like Praxagoras and Diocles and, on the philosophical side, Aristotle and Theophrastus.[27]

Galen's narrative about what went wrong in intellectual history after an initial period of progress and high moral standards makes it clear why he sees the choice for Hippocrates not as the choice for one school of thought alongside others but as a more fundamental project which aims at the ideal of a unitary medicine marked by consensus among its participants about its aims and methods. Galen takes essentially the same view of philosophy, its history, and its progress, linking doctors and philosophers. In fact, he does not think of a parallel development but rather of an overlap if not coalescence of the two disciplines, as in *The Best Doctor is also a Philosopher* where he presents Hippocrates as anticipating the ideal stated in its title. Included in Galen's argument is his idea that Hippocrates lived in an age when men such as he could flourish in marked contrast with the morally corrupt environment provided by

26 See *supra*, n. 24.
27 Cf. *MM* 1, 2.2, x. 9 K.

society in Galen's own day—a corruption that rubs off on the medical profession too.[28]

Another passage from Galen's *On Method of Healing* further implements Galen's idealizing picture of the days of old, with particular reference to medicine:

> I hesitated to write about the therapeutic method which was inaugurated by the ancients (ἄνδρες παλαιοί), and which those who came after them have striven to complete. Even in the old days there was no shortage of dispute, as those in Cos and Cnidus strove with each other to make the greater number of discoveries; for there were still two schools of Asclepiads in Asia [...] these people were continually contending among themselves [...] practising, perpetually increasing, and attempting to complete the art of Apollo and Asclepius. But now this beneficial strife has been destroyed, or else survives only in small or weak measure among mankind (*MM* 1.1.6–7, X. 5–7 K. Translation Hankinson).

As is clear from the preceding context of this passage, Galen had hesitated to present his account of the therapeutic method because of the decline in professional standards, both moral and technical, that bedevilled contemporary medicine. One of his favourite butts is Thessalus of Tralles, a flamboyant doctor who had been active in the age of Nero and whom Galen presents as the founder of the Methodist school of medicine as it existed, and flourished, in his own day.[29] Thessalus had seen fit to present medicine as easy to learn, offering a six-month-course in it. His followers, a motley bunch of cobblers, carpenters, dyers and bronzeworkers, jumped on the medical bandwagon and now contend as to who is the best. This leads Galen to reflect on the contrasting picture offered by the competition among doctors in, roughly, the fifth century BCE in our chronology. There were different schools even then, he notes, but the competition between them was of a different, productive sort, invoking Hesiod's

28 See further Tieleman 2023a, 2023b.

29 Ancient tradition traces the beginning of the Methodist school back to Themison of Laodicea (first century BCE), a tradition accepted by Galen: see ps. Gal. *Introd.* 4, XIV. 684 K. (= 9.24–10.1 Petit; fr. 284 Tecusan), Gal. *MM* X. 35 K. (fr. 161 Tecusan). At the same time, Thessalus made doctrinal changes of a far-reaching kind so that he effectively founded Methodism *de novo*. Galen straightforwardly calls Thessalus its ἀρχηγός, founder or originator; see Gal. *MM* X. 51–52 (= fr. 162 Tecusan). Thessalus' pivotal role is also mentioned by ps. Galen, *Introd.* 4, XI. 684 K. (= p. 10.3–4 Petit = fr. 284 Tecusan). See further Nutton 2013, 193–194, Diller 1936b.

description of the two forms of strife, one bad, one sound (*Op.* 1–122).[30] In addition, we find again his idea that we owe what is good in medicine and in particular the therapeutic method to the advent of Hippocratic medicine: the label 'Asclepiads' refers to Hippocrates and his circle. It is up to later generations to complete (τελειῶσαι) what they begun. Here (as elsewhere) it becomes clear that innovation for Galen is a matter of developing what the ancients had already anticipated in one way or another. We may contrast Thessalus, to whom Galen next turns. Galen sees him as the ultimate sectarian, who in founding a new sect rejected Hippocrates and what he stood for:

> Maddened by this [scil. bad] type of strife, Thessalus denounces Hippocrates and the other Asclepiads, and setting the entire world as the tribunal of his works, he has himself judged victorious by it, crowned in competition with all the ancients, by self-acclamation. He does this in his *Communalities* and in his *Syncritica*, and his assaults do not cease in any of his other works. Take for instance the letter he sent to Nero, at the beginning of which he wrote in these very words, 'I have founded a new sect, which is the only true one, as none of the earlier doctors propounded anything advantageous either for the preservation of health or for the curing of disease.' And further on in the letter he not only says that Hippocrates recommended procedures that were harmful; he even dared to criticize the *Aphorisms* (which was the greatest indecency of all), which showed that he had imbibed nothing of Hippocratic theory from anyone, and that he hadn't even read his writings with a teacher. Yet even so he does not scruple to award himself the crown (*MM* 1.2.1, x. 7–8 Kühn; translation Hankinson).

Galen portrays Thessalus as the exact counterpart of his ideal physician. But his portrayal receives some support from Pliny the Elder, who refers to Thessalus' taste for medical stardom and his success in achieving it.[31]

Thessalus embodied everything Galen disliked about the state of medicine in his time. But his denunciation of Thessalus makes clear quite a few things about his own position also. This is based on an idealized, in part

30 On this passage cf. also Singer 2022, 77–78.

31 'The same generation during Nero's reign flocked to Thessalus, who destroyed all received opinions in a sort of frenzy (*rabie quadam*) ranting against physicians of all ages … No actor or charioteer was attended by a greater crowd of fans when he went out in public' (Plin. *NH* 29.5.9; translation mine). Pliny (*ibid.*) also notes that Thessalus' memorial among the select graves on the Appian Way bore the epiteth ἰατρονίκης: 'champion doctor.'

anachronistic picture of Hippocrates and his times. Whereas Thessalus resolutely breaks with the past (not just Hippocrates) and claims to offer something completely new, good innovation consists of building on the insights of the founders of medicine. To be more specific, Galen sees this as (1) further articulating their thought, as in the case of the physical elements.[32] Moreover, there is (2) the job of providing demonstrations to corroborate the truths discovered by the founders: these were clear in themselves but they were subverted by later generations for morally bad reasons, which the ancients, living as they did in a morally superior age, could not have foreseen. Also, there is (3) room for real additions to and occasionally improvements upon what Hippocrates achieved.[33]

3 Galen's On the Anatomy of Hippocrates

Galen's silence on *Phaedrus* 269c–270d in *On the Doctrines of Hippocrates and Plato* is not the only surprising feature of this work. Given its program, as stated in the passage from the *Method of Healing* quoted above and elsewhere, the work is lopsided in that there is much more about and from Plato to be found in its pages than there is regarding Hippocrates. This is especially true of its first six books, which contain an extensive vindication of the Platonic tripartition-cum-trilocation of the soul known from the *Timaeus*, *Republic* and *Phaedrus*. Here Galen effectively uses his anatomical expertise to prove Plato and, as he claims, Hippocrates correct.[34] One might say that Galen thus presents a scientifically updated version of Plato's celebrated theory. But he presents almost no proof-texts from Hippocrates showing that he had anticipated

32 *HNH* I.3, pp. 17–18 Mewaldt (XV. 30 K.), *Elem. Hipp.* 3.30, p. 76.16–18 De Lacy (I. 434 K.).

33 See e.g. *Praen.* 12.11–12, p. 134.1–8 Nutton: Galen and others added pulse theory). *MM* VI 4, X. 420–421 K. (= vol. 1, p. 70 Helmreich): Hippocrates followed the right therapeutical method, but one finds in his works things that are vague, unclear or incomplete; Galen therefore devotes his own *Method of Healing* to clarifying the points concerned. Cf. *ibid.* VI 5, X. 425 K. (Galen adds the proofs) and IX 5, X. 632–633 K. where Galen's compares his role vis-à-vis the Hippocratic legacy with the Emperor Trajan's policy of improving the road network of Italy. This articulation of the sound starting points provided by Hippocrates and other ancients is very much how Galen conceives of scientific progress. See Hankinson 1994; Asper 2013, 423–424; Tieleman 2023a, 130–134; Tieleman 2023b, 51–53. Cf. Lloyd (1991) 398.

34 Reports of dissections and vivisections are given in book I (brain and heart) and VI (the liver) in particular. Large parts of the books in question are devoted to refuting the cardiocentric theories of philosophers such as Aristotle and the Stoic Chrysippus and the doctor Praxagoras of Cos.

Plato with respect to the number and identity of the soul-parts and their location in the body. One might suppose that this is because of the simple reason that there is no evidence in support of Galen's at first blush extravagant claim. The Hippocratic tract *Sacred Disease* comes to mind, but it was of no use to Galen because it presents a fully encephalocentric position according to which not only reason but also the emotions reside in the brain (chapter 17; cf. 22).[35] But it is not as if Galen asks us simply to take his word on Hippocrates having anticipated Plato on the soul. He himself explains the absence of passages from Hippocratic works at the end of *PHP* book VII. Speaking about the role of the brain and the heart in producing movement he says that he has concentrated on Plato's work because he had already discussed the relevant passages from Hippocrates in his *On the Anatomy of Hippocrates* (where, conversely, the relevant Platonic passages had not received any attention).[36] There may be something to this. Both *PHP* I–VI and the *Anatomy of Hippocrates* were both written during Galen's first stay in Rome (164–168 CE). On the other hand, one would in that case expect Galen to refer to it on one or more occasions in *PHP* I–VI too. It cannot be excluded that he did so in the lost part of book I.[37] However this may be, this reference to the work on Hippocrates' anatomy is striking. It seems to imply that Hippocrates not only anticipated the Platonic tripartition-cum-trilocation but that he did so on the basis of anatomical knowledge, which can only have come from the systematic practice of dissection.[38]

As we have seen above (p. 306), the old anatomist Martialios was not inclined to ascribe the study of anatomy to Hippocrates, thereby triggering the composition of Galen's work. Unfortunately, the *Anatomy of Hippocrates*, a substantial work of six books, is lost. But we may still form a picture of at least some of its contents from further references throughout Galen's work. In addition, we get some information about Galen's justification of his remarkable

35 An isolated reference to this Hippocratic treatise is found in *Hipp. Epid.* VI XVIIb. 341 K. but this concerns another matter, viz. that the *Sacred Disease* correctly explains why the name 'sacred' disease rests on a false assumption. The meagre remains of Galen's *On the Authentic and Spurious Works of Hippocrates* contain nothing on *Sacred Disease*; cf. Das 2018.

36 See *PHP* VII 8.13–14, p. 478.3–8 De Lacy (v. 647 K.).

37 See *supra*, n. 25.

38 Galen's attribution of the Platonic tripartite psychology or at least Plato's view that the ruling part (identified by Galen with the Platonic rational part) resides in the brain to Hippocrates can be paralleled from what is left of the doxographic tradition, see Aëtius 4.5.2 Mansfeld-Runia. On Galen's use of doxographic or, more precisely, *Placita* tradition see Tieleman 2018b.

project from the preface to the second book of his *Anatomical Procedures* (*AA* II. 280–283 K.). Speaking about his predecessors in the field of anatomy, Galen tells us that those of the Asclepiad family (including Hippocrates) practised dissection from childhood under parental instruction, as they did when learning to read and write. For them, in other words, dissection was a skill learned at an early age and firmly held. In consequence, there was no need to commit to writing the knowledge thus passed on from generation to generation. At a later stage, however, the art (τέχνη)[39] of anatomy was shared with favoured adults outside the family, discontinuing the habit of early instruction. This caused a deterioration of the art of dissection and its instruction, or so Galen claims with reference to the importance to learning from childhood (ibid. 281). Decline set in and it became necessary to preserve knowledge and remedy its loss through written instruction. Galen sees Diocles of Carystus (fourth century BCE) as marking the transition from the oral to the literate stage of anatomical teaching (*ibid.* 282, Diocles fr. 17 van der Eijk).[40] Galen, then, presents written anatomical expositions as necessary, given that it is impossible to guarantee an uninterrupted oral tradition. He praises the great anatomist Marinus (active in Alexandria around 100 CE), for having written so much on anatomical procedures (*ibid.* 281).[41] But oral teaching, starting from the earliest possible age, is best and still the norm, as is clear from what Galen says about his teaching to his own pupils. Among them he notes an increasing disinclination to share their knowledge with others. In consequence Galen's teaching may be lost if he does not commit it to writing (*ibid.* 283).[42]

But where does this leave us with regard to Hippocrates' anatomy? Galen does not say or imply that we have to reconstruct it on the basis of the written works of medical authors such as Diocles, in so far as this is possible at all. But, Galen argues, we can directly turn to Hippocrates' works as *presupposing* his anatomy even if they do not formally deal with it. Anatomical works are by their nature unattractive and offer a lot of material the use of which is not immediately apparent. So good medical authors include anatomical theories (θεωρήματα) in works on therapy, prognosis and diagnosis that are more attractive and accessible. Galen tells us that Hippocrates does just that in his works (*ibid.* 282). This startling claim implies that the art of anatomy was not strictly

39 This concept involves both the skills and the resulting knowledge.

40 On this passage cf. also Smith 1979, 104–105, Vegetti 1999, 351, van der Eijk *ad loc.* (Diocles fr. 17), Boudon 2018, 305–306, Singer 2022, 78–79.

41 Cf. *Lib. Prop.* 4.8–33, pp. 147.13–152.4 Boudon (XIX. 25–30 K.). On Marinus see also Bubb 2022, 231–237.

42 See also *supra*, n. 10.

kept within the family after all, but Galen seems to think here more of the anatomical knowledge resulting from the practice of dissection. Nonetheless, Hippocrates' anatomy is presupposed by his writings and so can be studied.

We may smile at Galen's speculations about a sort of medical Golden Age, with little Asclepiads practising dissection as one of the first steps in their medical training. But ever since the Hellenistic period ideas about primitive wisdom had become widespread among philosophical authors.[43] On this model Galen produces a medical version. His observations on oral teaching and its consequences are in themselves apposite, apart from the question how far they apply to the earliest Hippocratic physicians.

On several occasions throughout his extant writings Galen refers his readers to *On Hippocrates' Anatomy* for a fuller treatment of a particular point or as one of a group of treatises written in a particular period or on the subject of anatomy. Thus, we know, e.g. from Galen's report on his confrontation with Martialios (see above, pp. 305–310), that it was one of the treatises he wrote during his first Roman period (164–168 CE), which he later described in his *On Prognosis*.[44] It was a period when he worked hard to establish his reputation as a practicing physician as well as medical scientist. In the latter role he performed anatomical demonstrations (including vivisections) on animals to impress audiences with his skills and knowledge. Apart from *On Prognosis* we find some of these experiments described in the first six books of *On the Doctrines of Hippocrates and Plato*. From the Martialios passage we also know that *On Hippocrates' Anatomy* had six books, which made it one of Galen's medium sized works and gave him sufficient room to demonstrate (1) that Hippocrates possessed a fair degree of knowledge, often detailed, of internal body parts;[45] (2) that Hippocrates' knowledge was accurate or more accurate than that of other authorities, most notably Erasistratus. Hippocrates therefore was Galen's guide (ἡγεμών) in assessing the doctrines of Erasistratus and others.[46] These points overlap with the purpose of *On the Doctrines of Hippocrates and Plato*, as is clear from its sixth book in particular. But, as we have seen, in this treatise, in spite of its title, Galen decided to concentrate on Plato in view of the project he undertook around the same time in writing *On Hippocrates' Anatomy*.[47] Both works also serve to make it clear where Galen stands with

43 On primitive wisdom, esp. in Stoicism and in post-Hellenistic philosophy, see Boys-Stones (2001).

44 *Lib. prop.* 1.7–10, p. 138.6–21 Boudon (XIX. 13–14 K.), *AA* II. 216 K.

45 *Lib. Prop.* 1.7–10, p. 138.6–21 Boudon (XIX. 13–14 K.)

46 *PHP* 7.8.12–14, pp. 476.36–478.8 De Lacy.

47 *PHP* 7.8.13–14, p. 478.1–8 De Lacy.

regard to the doctrines from the various authorities and schools that are on offer and why he opts for Hippocrates and Plato, though not with the aim of joining an existing school or founding one of his own. This is the balance Galen aims to strike and which needs explaining. At the same time, he operates in an intensely competitive environment, as is clear from the Martialios episode and other reports, and his treatises from the first Roman period also serve his campaign of self-advertisement as a learned philosopher-doctor directed, we may assume, at the upper echelons of Roman society in particular. Thus, he dedicated the *On Hippocrates' Anatomy* to Flavius Boethus, a consular and a Peripatetic, whose wife Galen had cured and who took an interest in Galen's work during his first years in Rome.[48]

From references in some later works we learn that Galen linked this treatise on Hippocrates to other great works dealing with functional anatomy such as *On the Functionality of Parts* (*De usu partium*) and, unsurprisingly, *On the Doctrines of Hippocrates and Plato*, as well as *On Semen* (*De semine*) in view of the embryological sections in the work, and cross-references in these works confirm these groupings made by Galen himself.[49] In the six books of *On Hippocrates' Anatomy* Galen could cover a lot of ground, as is illustrated by the wide array of subjects implied by his references to this work. Even so, most of them are too short to attempt anything like a reconstruction of their original contents. The only thing we know about book I is that at its beginning Galen rejected the claim made by Empiricists that Hippocrates was an Empiricist, which would exclude the systematic practice of dissection as an integral part of medicine. Their school, unlike the schools named after a person, was named after their method but it is worth noting that they claimed Hippocrates as one of their own, or at least an ancestor.[50] About Book II we get some more information, albeit related to one particular subject, the anatomy of the veins and in particular the issue of its source. Here Galen argued that Hippocratic passages on four pairs of veins descending from the brain are spurious, e.g. *Nature of Man* 11 (I 1.3, pp. 192–196 Jouanna),[51] i.e. it does not offer the authentic view of

48 *Lib. Prop.* 1.6–7, p. 137.26–138.2 Boudon = XIX. 13 K. On Boethus see esp. *On Prognosis*, e.g. *Praen.* 2.24–25, p. 80.17–27, 5.19, p. 98.28 Nutton; for the story of how Galen cured his wife see *ibid.* 8.1–21, pp. 110.13–116.23 Nutton.

49 *Ars med.* 37.10, p. 390, 1–12 Boudon (I. 409 K.).

50 *In Hipp. Art.* XVIII. 524 K.

51 This passage has also found its way into the Hippocratic *On the Nature of Bones* (*Oss.*) chs. 8–9: IX. 174–178 L. Galen does not refer to this treatise, in which, one supposes, he might have taken an interest given his project of reconstructing a Hippocratic anatomy. But we do not know whether he knew it and, if so, in what shape. In the pseudo-(?)Galenic *Explanation of Difficult Terms in Hippocrates* or *Glossarium* (*Gloss.*) some twelve terms

Hippocrates or his son-in-law Polybus.[52] In fact, Galen regarded chapters 9–15 of *Nat. hom.* as a Hellenistic forgery. Not everyone agreed: Aristotle for instance had attributed the view in question to Polybus (*HA* III.3: 512b12–513a7). He argued that the correct and authentically Hippocratic position is found in *On Nutriment* on the liver as the organ in which the veins are rooted (using the noun ῥίζωσις), using an analogy with plants (scil. *De alim.* 31: CMG I 1, p. 82.13 = p. 144.15 Joly, quoted by Galen, *PHP* 6.3.39, p. 383.18–20 De Lacy) and in the second book of the *Epidemics* (II 4.1, V pp. 120–124 L., quoted at *PHP* 6.8.59–66, followed by another reference to *On Hippocrates' Anatomy*, *ibid.* 6.8.67). Hippocrates had seen that the part from which tissues grow must be their source and starting point (ἀρχή); an indication is provided by the fact that outgrowths are always thicker at their base of origin, in this case the part of the veins close to the liver (and, Galen argues, this also applies to the arteries and the heart and the nerves and the brain). His assumption that *On Nutriment* is genuine was shared by ancient scholars and commentators, even if modern scholarship sees it as one of the latest tracts in the Hippocratic corpus, probably to be dated to the Hellenistic period or even as late as the first century CE.[53]

About Book III we are informed by a passage from *On Anatomical Procedures* (*AA* II. 337): nerves, arteries and veins reach the root of the nails but not in the way entailed by Erasistratus' concept of τριπλοκία, i.e. as a nexus of these three vessels, which he took as a basic constituent of each organ. Here Galen must have referred to the eighth chapter of the Hippocratic *Nature of the Child* (*Nat. pueri* VII. 506 L.), where νεῦρα, however, must mean sinews rather than nerves. We do not know whether this was acknowledged by Galen, who elsewhere is sensitive to its meaning in texts predating the discovery of the nerves by Herophilus and Erasistratus (first half third century BCE).[54]

Book V included discussions on the anatomy of the womb and embryological issues, most notably the different places taken in the womb by male

from the work we know of as *On the Nature of Bones* are glossed. The source in question is referred to once as 'the texts attached to the *Mochlikon*' (or *Leverage*, another treatise in the Hippocratic corpus) and once as 'On Vessels (περὶ φλεβῶν) attached to the *Mochlikon*': CMG V 13,1, pp. 222, 244 Perilli (= XIX. 114, 128 K.). See Craik 2015, 225. The authenticity of *Gloss.* is disputed, however. Its most recent editor, Perilli, sees no compelling grounds for rejecting Galen as its author (pp. 131–132).

52 *PHP* 6.3.27–31, pp. 378.36–380.24 De Lacy. Polybus was standardly taken as his father-in-law's mouthpiece.

53 See Jouanna 1999, 401; cf. Diller 1936a.

54 For a similar but briefer reference see *In Plat. Tim.* p. 9.13–10.3 Schröder: composition of the nails. On the meaning of νεῦρα in Hippocrates and Aristotle see *PHP* I chapters 9–10.

and female embryos. Here Galen referred to relevant statements from the Hippocratic *Aphorisms*.[55]

About book VI we have no information. From references without book number we know that Galen wrote about the anatomy of the brain, with reference to Erasistratus as having understood in old age that it is the source of the nerves.[56]

Further, Galen discussed the anatomy of liver and gall bladder according to a passage in *On the Natural Faculties* 1.6 (*Nat. fac.* II. 15 K.) but this may have been part of the discussion on liver and veins in book II (see above, p. 319). An intriguing passage of a somewhat different sort is found in Galen's tract on difficulty of respiration (*Diff. resp.* VII. 851 K.). Here Galen argues that difficulty of respiration is not explicitly described in the Hippocratic *Epidemics* because it is obvious. Hippocrates, he adds, is selective in his descriptions of symptoms. After all, he writes for experts, as opposed, for instance, to the historian Thucydides in his famous description of the plague that struck Athens in the Peloponnesian War (2.47–54). For a fuller discussion of Hippocrates' selectivity of information Galen refers us to his work on Hippocrates' anatomy. There, then, he will hardly have discussed the selection of symptoms but rather descriptions of anatomical relevance. One wonders whether he used this argument to give himself more license in supplementing and, in the process, tweaking Hippocratic descriptions.

4 Conclusion

This study took its starting point from *Lib. prop.* 1.7–10, p. 138.6–21 Boudon, a crucial but neglected passage when it comes to understanding Galen's interest in Hippocrates. As we have seen, it throws light on the rationale behind his choice for Hippocrates as his beacon, viz. his deeply felt conviction that the division of the field of medicine into schools creates serious, indeed fatal, problems, both scientific and moral, which stand in the way of medical progress.

55 *UP* 14.4, vol. II, p. 293.13–26 Helmreich (IV. 154 K.): male embryos on the right side, female on the left side of the uterus, which is connected with the breasts. See Hipp. *Aph.* V.38, 48 (IV. 544–545, 550–551 L.). Cf. Gal. *Sem.* 2.5.38, p., 186, 19–20 De Lacy (IV. 633 K.). *Sem* I. 12–13, p. 88.11–16 De Lacy (IV. 537 K.): vascular connections of the womb involving the technical meaning of the term κοτυληδών; cf. Hp. *Aph* 5.45 (IV. 548 L.), *De mul. nat.* 17: VII 336,14–17 L. On κοτυληδών cf. also Galen (?), *Gloss. CMG* V 13,1, p. 222 Perilli (= XIX. 114 K.).

56 *PHP* 7.3.34, p. 446.29–33 De Lacy; AA 9.1–5 (II 707–731 K. I, pp. L–LXXX Simon) functionality of of its parts: *UP* (8.2–14, 9.1–7; III 614–712 K.). This is further borne out by *PHP* 7.8.12–14, pp. 476.36–478.8 De Lacy.

Galen therefore sought to establish a new medicine marked by a broad consensus among its participants about its aims and methods. He successfully developed a methodology designed to overcome the scholastic divisions of his day.[57] This study has focused another ploy of his, viz. the anchoring of his innovation in Hippocrates, who had lived and worked before the emergence of medical (and philosophical) sects in the Hellenistic period. The older schools of Kos and Cnidus were a far cry from the sectarian divisions and disputes of later times and represented a form of competition that was conducive to progress and free from the love of honour (φιλοτιμία). Therefore we should hark back to Hippocrates and his time.

Another innovation promoted by Galen was the study of human anatomy as an integrated part of medicine involving dissection of corpses, viz. of animals given the ban on using human bodies. Here too he pointed to Hippocrates as having practiced dissection as an Asclepiad family tradition. Here Galen could draw on current ideas of primitive wisdom but he also set out to show in his *On Hippocrates' Anatomy* that Hippocratic medicine presupposes knowledge of anatomy that could only have been obtained through dissection. The references to this lost treatise in the extant works show the scope and depth of this project. Galen succeeded in reinstating anatomy as an integral part of a complete medical education, albeit one primarily based on animal material. He did not campaign to reintroduce human dissection, which he knew full well was the most desirable practice from a scientific viewpoint and for which he envied the Hellenistic doctors Herophilus and Erasistratus. He probably realized that in his social and cultural context it was inopportune and indeed hazardous to launch any such action. In subsequent centuries Galen's own anatomical treatises stood in the way of new researches and human dissection: paradoxically, since he had made it clear that his work was not definitive and could form the basis of future progress. When eventually human dissection became possible again in Christian Europe (viz. Italy in the 14th century), Galen's *On the Functionality of Parts*, with its view of anatomical inquiry as a hymn to God's creation and a form of true piety were a source of inspiration.

Galen's bid to anchor his innovations in Hippocrates involves a massive effort of reinterpreting the latter's work. In doing so Galen created a particular image of Hippocrates, which, because of his own later influence, was to become dominant in cultural memory until the present day. It made sense to hark back to Hippocrates as the founder of medicine but at the same time Hippocrates was a malleable anchor which Galen could shape to suit his purposes for his

57 See the pioneering study by Frede 1981.

own time and day. These two sides of Hippocrates explain the strategic advantage that using him as an anchor gave to Galen. This is not to say that the choice of Hippocrates, or for that matter any anchor, was an obvious one. A century earlier Thessalus of Tralles had presented his innovative (anatomy-less) school of medicine, Methodism, as something entirely novel and without ancestry. Thessalus, as we have noticed, also attacked Hippocrates. This is not so much a lack of interest in anchoring his innovation as a form of negative anchoring: to establish a new identity by emphasizing what one is *not*. Galenic medicine was in the end triumphant, but that does not mean that Thessalus was unsuccessful, as is only too obvious from Galen's own vehement polemics a century or so later, and from the continued presence of Methodism afterwards (as witnessed by the 5th century medical author Caelius Aurelianus). Thessalus' strategy, however, was not an option open to Galen, whose long and comprehensive education as both a doctor and philosopher predisposed him to position himself firmly within Greek cultural tradition. In doing so he reflected—and no doubt gained traction from—a wider tendency among his contemporaries to idealize the classical past and cultivate ideas about primordial and pristine wisdom.

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This collection of essays explores processes of innovation in Greco-Roman technology and science. It uses the concept of 'anchoring' to investigate the microhistories of technological and scientific practices and ideas. The volume combines broad, theoretical essays with more targeted case studies of individual inventions and innovations. In doing so, it moves beyond the emphasis on achievement that has traditionally characterized modern scholarship on ancient technology and science. Instead, the chapters of this volume analyse the manifold ways in which new technologies and ideas were anchored in what was already known and familiar, and highlight how, once familiar, technologies and ideas could themselves become anchoring points for inventions and innovations.

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