**Grave Reminders : Comparing Mycenaean tomb building with labour and memory**
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## Chapter 3. Artists at work: logistics in cooperative earthmoving energetics

*So architects who without culture aim at manual skill cannot gain a prestige corresponding to their labours, while those who trust to theory and literature obviously follow a shadow and not a reality. But those who have mastered both, like men equipped in full armour, soon acquire influence and attain their purpose.*
Vitruvius 1.1.2, [Granger 1962]

Having introduced commissioner and builder motivations from collective memory, costly signalling, and altruism, I turn now to logistics in establishing a practical comparative approach to preindustrial earthmoving energetics. Logistics estimates planning, procurement, transport, manufacture, and assembly of materials through building mechanics, operational sequences, and architectural energetics, using rates of work derived from timed observations (hereafter labour rates). I hesitate to overcomplicate the process with anachronisms of a global supply chain and operations management, though eastern Mediterranean trade had advanced toward prototypical mass markets and standardisation before my period of interest (1600–1000 BC) (e.g., Berg 2004: 74; Broodbank 2013: 415). Keeping my frame of reference locked onto construction sites sharpens focus on the main logistical concerns of cooperative building. Few if any preindustrial planners would micromanage tools when coordinating construction, nor would component origins noticeably affect investment with common and multi-purpose tools. Optimised scheduling would also negate time-intensive techniques where excessive care sought precision (e.g., Blackwell 2014: 458), or when non-commoditised labour opted for inefficient methods discordant with industrialised markets (Baudrillard's (1975: 22–23) critique, see also Appadurai 1986: 31; Voutsaki 1997: 36; Voutsaki et al. 2018: 172). I propose instead to look at what has remained consistent: the average human's physical limits and the mutually intelligible sacrifice of pushing them. Whatever the case for value perception, shared technical and physiological constraints reinforce manual labour, logistically deconstructed, as a worthy comparative for past effort.

I use this chapter to explore the cross-cultural examples of earthmoving from which most labour rates derive, particularly what flies as an acceptable workload. Seldom do I mention logistics specific to Mycenaean multi-use tombs, preferring instead to contextualise these in the chapters to follow. In general terms, cooperative tomb building can be simply deduced from related tasks, though not so easily proven without written records. Local labourers likely built standard tombs with available handheld tools, at an exhausting pace surpassing daily routine but falling well short of the urgency inspired by a natural or military emergency. Available handheld tools might refer to digging sticks, chisels, and baskets sourced from nearby households and workshops, or in the case of expert stone-carving for large *tholoi*, quarrying saws wielded by specialists (Fitzsimons 2007: 104, 2011: 98). For Cyclopean fortifications Loader (1998: 46–49) split LH masonry toolkits into picks and wooden wedges for quarrying, hammers and chisels for shaping, and saws for detailed work, with reservations about copper and bronze saws being too soft to handle hard limestone and dolomite. Blackwell (2011, 2014) elaborated on LH masonry tools through tool marks, from the common kit to the pendulum saw (for this machine see Blackwell 2014: 454, 470). Examining the LH IIIB Lion Gate relief at Mycenae from a ladder, Blackwell (2014: 453) noted that the sculptors' kit contained "drills, saws, chisels, punches, hammers/mallets, scoring implements, and polishing devices", including rasps and whetstones. The technical demands of LH III stonework partly spurred this lengthy catalogue from competent yet modest beginnings. Tool scarcity at MH sites contrasted sharply with contemporary Crete and subsequent LH sites, where metal tools—particularly "bronze chisels and double axes" for stone- and woodworking—proliferated alongside Minoan and possible Hittite influences (Blackwell 2014: 452–453). From bowstring-powered tubular drills to simple hammerstones, manufacturing variety made use of sand, emery (rock type containing abrasive mineral oxides of aluminium and iron), water, oil, reed, bamboo, wood, bronze, and stone to abrade, polish, split, lever, cut, penetrate, and pound materials into shape (Blackwell 2014: 453–456). Unlike the toolkits accommodating ashlar elaborations in *tholoi* (Fitzsimons 2007: 104), most chamber tombs likely only required a fraction of these skills and materials.

With a credible workforce, economised daily-use tools could favour multi-purpose types and expedient local sources to cut waste and transport expense. Forged tools demanded a longer chain of nonlocal manufacture already embedded within regional trade, with evidence largely derived from catastrophic change (LH IIIB–C) or shipwrecks (e.g., Deger-Jalkotzy 2008: 401–402; Kristiansen and Suchowska-Ducke 2015: 363; Mee 2008: 363–365). Tracking the supply chain of tool components—distant ores in alloys for forged tools, for instance—would be superfluous in one-to-one comparisons for tomb building, as more such steps misrepresent worker readiness. Some careful analogies offset the gap where my shortcuts to tomb construction may seem unimaginative or flat, particularly where I omit speculative transport costs. The numbers that I ultimately call upon in the catalogue of tomb labour (Chapter 4) avoid becoming a spectacle themselves through simplicity. Their value is in comparing rather than retelling construction, dispensing with minutiae by cancelling out shared tasks. In other words, modelling tomb construction alongside a median standard needs no long strain of proof equations.

I arrive at the catalogue (Chapter 4) through two digital surveying methods—reflectorless total station drawing and photogrammetry—modified from Pakkanen (2009, 2018). Both were meant to undercut the cost of other three-dimensional digitisation of architectural remains while still providing accurate measurements. With that cost falling, however, most other forms of digital survey may soon be rendered obsolete. Given its explosion in popularity in recent years, photogrammetry is still comparatively inexpensive, and my trial-and-error anecdotes may prove useful for similar work. From this accounting of building materials—mostly rocky earth removed to shape the tombs—I infer the original dimensions and transient tasks that are less visible after construction. Transient tasks included temporary works such as shoring or scaffolding—otherwise termed "falsework" and deployed especially in the case of masonry vaults that were "virtually impossible" to construct without it (Fitchen 1986: 21, 85–87)—as well as supervisory and supporting roles that left no direct record while potentially doubling the associated workforce (de Haan 2009: 13). Quantification of tasks then requires estimates of the effort involved, usually measured in labour-time, energy, or wages in later monetised economies. Variability in these labour rates and their limited reporting stands out as one of the primary concerns of this chapter and the supplementary tables in Appendix 1 (see also Aaberg and Bonsignore 1975: 61; Abrams 1989: 76; Abrams and McCurdy 2019: 20; Lacquement 2009: 156; Remise 2019: 91; Turner 2018; Chapter 1, this volume).

After establishing my preferences for modelling earthmoving logistics, the final methodological step defines completed architectural forms and the taphonomic cycle that obscures them (Gifford 1981: 365; Schiffer 1972: 158). Since no preindustrial construction remains pristine, digital models must account for post-depositional modifications—most often denudation and ploughing for earth, decay for wood, and robbing, reuse, or collapse for stone. The method described at the end of this chapter shows the capabilities and limitations of digital surveying tools in measuring architecture for labour costs. Common problems here were inflated volumes caused by ceiling collapse of burial chambers and the failed rendering of models in tight, dark spaces. These spawned the supplementary short descriptions of other tombs in Appendix 2 with protocols for restoring the models from existing data (photos and georeferenced photomarkers). Like the tombs themselves, the only hindrance to a larger catalogue of labour models is time.

### 3.1. Construction planning and alignment: pragmatic signalling

Adding to those constraints from Chapter 2, here I review practical considerations in launching cooperative construction, with function (pragmatic signalling) helping to track socially cohesive (group signalling) and assertively deviant (costly signalling) architectural choices (see also Čučković 2017: 528; Gittins and Pettitt 2017: 470). As will be shown in Chapters 4 and 5 with greater nuance, Mycenaean tomb builders could opt for cohesive group signalling (Portes chamber tombs: same shape, similar scale), assertive costly signalling (Menidi *tholos*: isolated and expensive, with an innovative relieving system), or pragmatic signalling deploying both (or neither if the burden goes unnoticed) in a small space (Voudeni chamber tombs: freedom in shape and scale).

In this way, the labour indexing to follow in the remaining chapters can shed loaded signalling terminology in favour of a tripartite cohesive–pragmatic–assertive scale for investment. More generally for earthmoving, a simple ditch can functionally reflect control over the immediate environment, water or waste management, and defence or delineation of territory, inspiring proportionate responses from labourers. Few have ever gleefully dug a latrine, but erecting a sacred place abounded with material and spiritual incentives. In each instance, function influenced scale (to a degree) and, by extension, labour investment. Those projects that overshot an expected standard retained pragmatic roles but exceeded the bounds of practicality, capturing labels of *monument* or *folly* (see Chapter 2). Rather than search for the pragmatic/monumental threshold through volumetrics or energetics, this chapter deconstructs logistical constraints as a companion to the grave reminders that guide tomb shape and scale through collective memory and signalling, costly or otherwise (see Chapters 2 and 5). Cross-cultural examples illustrate logistics for earthmoving as the most widespread and analogous task in human environmental modification.

Practical functions for earthmoving included navigational and calendrical aids, additions and modifications to infrastructure, and socioeconomic manipulations, such as diverting excess labour in times of crisis. As to the latter, researchers have highlighted power behind elite-sponsored, aggressive increases in cooperative construction (Fitzsimons 2007: 112–114; Trigger 1990: 127; Squatriti 2002: 16), though others have challenged the timing of increasing monumentality and power (e.g., Aaberg and Bonsignore 1975: 62; Abrams 1989: 62; Erasmus 1965: 278–280). In one common narrative, elites mobilised labour for aggrandisement or legitimation, tracking monumentality through a top-down flow of power (DeMarrais et al. 1996; Renfrew 1983; Price 1984; Sidrys 1978; Trigger 1990). In this sense, elite sponsors of construction acted as prime movers to exploit labour for diverse but predictable reasons. One such manipulation by ruling lineages called for the calculated redirection of surplus labour to invigorate redistributive economies and divert internal tensions (e.g., Abrams 1994: 92; Broodbank 2013: 420; Polanyi et al. 1957; Saitta 1997: 21). Leaders may have perceived a threat from the accumulation of idle time during resource-rich years, whether deriving from technological advances, successful conquests, or perhaps just a string of fortunate seasons triggering expansion (e.g., Clark 1998: 67; Webster 1990: 339–340). Repurposing part of that surplus away from survival tasks reset the balance and gave leaders a shield against restlessness among followers who might rebel. It also backfired where projects distracted from more immediate issues, like the European obsession with ditch-digging in the martial eighth century AD (Squatriti 2002: 14–15).

Visually influencing potential rivals and supporters, conspicuous displays in construction boosted the emergent elite as well as craft specialists, expanding economies to incorporate new roles. This has been articulated for the Mycenaean polities through administrative records and mortuary behaviour (e.g., Cavanagh and Mee 1999; Fitzsimons 2006, 2007, 2011; Parkinson et al. 2013; Pullen 2013; Voutsaki 1997, 2001; Wright 1987). Craft specialisation in tomb architecture cycled through several modes of elaboration: surface treatments like painted or plastered surfaces (Demakopoulou 1990: 113–115; Galanakis 2011: 223; Gallou 2005: 68–69; Karkanas et al. 2012: 2731; Kontorli-Papadopoulou 1987: 153; Sgouritsa 2011: 737–739; Smith and Dabney 2014: 148), sculpted scenes on stelae (Mylonas 1951), and non-structural decorative flourishes like the marble half-columns at Atreus (Mason 2007: 38) or the experimental relieving slabs at Menidi (Laffineur 2007: 122; see below and Chapter 4). Other specialisations included engineering and management, onsite roles that are less visible in the archaeological record than separate crafting workshops leaving structural and portable material remains. For instance, attached workshops generated palatial ceramics at Mycenae and catered more specifically to *kylikes* at Pylos, filtering to secondary centres like Tsoungiza (in Mycenae's case) as recognisable assemblages (Pullen 2013: 437). Ceramics like these frequently ended their use-lives in tombs alongside other items that flaunted a flourishing production network, for which the literature is vast. Mycenaean specialised crafts that can be tied to grave offerings and funeral/post-funeral activities included elaborate textiles, perfumes, glass, and metalwork known primarily from Linear B references to production and intermediary roles (Killen 2006: 87; Nakassis 2015: 584–588; Parkinson et al. 2013: 413).

Socioeconomic systems that channelled this creative energy through elite patronage redirected semi-skilled labour as well—the kind presumed to be directly responsible for multi-use tomb construction. Such labour was stimulated by bulk payment or raw material loans in exchange for their products (see *ta-ra-si-ja* in Killen 2001; Nakassis 2015: 584–585 with references; Shelmerdine 2001: 360). DeLaine (1997: 11) framed a similar scheme in the Roman tradition as liberality and munificence in aristocratic-led building during peacetime. Mycenaean economies spawned certain crafts and construction within administrative networks built around elite nodes of wealth, partly redistributed using established systems: households, communities (*damos*), and sanctuaries (Lupack 2011: 207; Pullen 2013: 441). Although their dependence on palatial centres is debatable (e.g., Killen 2006; Lupack 2011; Palaima 2015: 638; Parkinson et al. 2013: 414; Shelmerdine 2006: 84), elites named on tablets orchestrated a substantial flow of goods and services, from chariots and perfumes to smithing and shepherding (Nakassis 2015: 584–585; Schon 2011: 221–222; Shelmerdine 2001: 360–361). No great interpretive leap barred those elites and advancing sub-elites from commissioning larger, better-built tombs to strengthen and preserve their families' position. Perhaps the sizeable middle class suggested by Broodbank (2013: 415) as supporting eastern Mediterranean trade during the second millennium BC can partly account for the scale and spread of standard chamber tombs across southern Greece. Whether these tombs measurably boosted an otherwise vibrant economy is less critical than their place in an existing system capable of efficient construction. Locals drove exchange of portable crafts and were more than capable of building and filling multi-use tombs with metalwork, jars of perfumed oils, and other materials from near and far (see tomb descriptions in Chapter 4).

That aptitude for earthmoving was likely honed outside mortuary construction, with infrastructure stimulating interconnected economies in a feedback loop. Earthmoving enhanced infrastructure and connected regional partners. Roads and dykes generally claimed priority—both in order of construction and research—but more elaborate transportation also demanded labour-intensive earthmoving. Bronze Age planners circumvented the Aegean's broken terrain with bridges and water transport by dredging harbours and canals (Fitzsimons 2007: 112–113, 2011: 109–110; Hope Simpson and Hagel 2006; Mason 2007: 39–40; Shelmerdine 2001: 339). Through networks of canals and terraces, irrigation and erosion control also bolstered agrarian economies susceptible to variations in annual rainfall (Aaberg and Bonsignore 1975: 44; Arco and Abrams 2006; Hard et al. 1999), a noteworthy problem in southern Greece (see Chapter 2). Terraces were incorporated into the extensive road network connecting major sites in the Argolid, as well as during new construction at Pylos, Tiryns, and the extensive LH IIIA2 remodelling of Mycenae's acropolis (e.g., Mason 2007: 40, 44–45; Nelson 2007: 150–151).

Perhaps the most visible pragmatic role for earthmoving lay in defence. Unmodified, earthen ramparts offered very little as a practical obstacle apart from hinting at a larger defensive force, inspiring confidence in communal wherewithal, and deterring expedient raids (Tracy 2000; Turner 2018: 207–210, with references; Tyler 2011: 157). Early medieval chroniclers Gildas and Bede openly disparaged earthen defences, which they cast as a long fall from Roman engineering (Squatriti 2002: 27; Tyler 2011: 159). Ironically, engineers in Roman Britain had built substantial turf forts like the first century AD Lunt near Coventry, partially reconstructed by prison labour in 1966 (Coles 1973: 79–82). Real or imagined, major linear earthworks served practical needs for martial posturing, and smaller earthen enclosures had merits in communal defence and food security (Turner 2012, 2018). Rather than earthen ramparts, stone rubble and earthen fill sheathed in stone masonry constituted the bulk of Mycenaean circuit walls (Boswinkel forthcoming; Loader 1998), but it is the stones that have attracted the most attention. Accumulating earthen fill for a wall required ramps, mass coordination, and brute strength, parallels only the largest known *tholoi* would share from mortuary construction. Cutting a smaller tomb into soft rock or building it from stones less than 50 kg each demanded small teams and far less planning (see below, *Transport* under Section 3.3.2 for human portage limits). For my case studies, only the Menidi *tholos* and the largest chamber tombs at Voudeni would benefit significantly from intensive planning, particularly in the organisation of wheeled transport to move materials to and from their entrances.

Scheduled earthmoving could be recurring or executed on demand depending on task-related timekeeping. Earthmoving itself marked time, tying into food security and socioeconomic incentives with calendar and repetitive acts that reinforced collective memory and group signalling (see Chapters 1 and 2). I treat scheduling here as another influence to the planning and scale of tomb construction, since most of my case studies were presumably purpose-built (unscheduled, rarely pre-emptively built or seemingly never used, e.g., Boyd 2002: 59; Papademetriou 2001: 67) and angled with the surrounding slope without apparent regard for celestial alignment (see below and Chapter 4). Elsewhere, timekeeping with earthmoving did rely on line-of-sight spatial relationships, notably with celestial bodies as reconstructed through archaeoastronomy (Baity 1973; Ruggles 2005). Most attempts at incorporating cultural astronomies—historical and contemporary social conceptions of celestial phenomena—have focused on the orientations of earthworks and megaliths, particularly entryways marking sunrises or sunsets at certain times of the year (Aveni 2003; Hively and Horn 2013; Kelley and Milone 2005; Ruggles and Barclay 2000). Connecting timekeeping and food security, star and planet alignments that signal a solstice or equinox provided a benchmark for important seasonal events, such as the migration of game or optimal planting windows (Malinowski 1927; Leach 1950; Rice 2007; Varisco 1993). Applications of archaeoastronomy in Greece have typically focused on traditions from the fifth and fourth centuries BC (Boutsikas 2007; Boutsikas and Ruggles 2011), but precedents have been found centuries earlier for alignments of tombs at Mycenae (Maravelia 2002) and palatial architecture at Knossos (Goodison 2001, 2004).

Timekeeping through construction also manifested as regular social reinforcement, building in part on collective memory. Occurring at set intervals, activities like mound-building highlighted episodes of social cohesion that strengthened group identity for scattered populations. For instance, Neolithic pastoralists in southern India erected ash mounds of burned cattle dung as a means of maintaining an annual ceremonial rhythm (Johansen 2004). Similar recurrent mound-building strategies have been inferred from geoarchaeological analyses of mound sites in the south-eastern U.S. (e.g., Sherwood and Kidder 2011), notably shell middens in coastal areas and iconic earthen complexes in the interior. Multi-period mound construction proliferated in the later prehistory of eastern North America, where conical burial mounds and low, rectangular platform mounds marked areas for recurrent gatherings and feasts (Lindauer and Blitz 1997: 186), some of which were linked to observed traditions like the "green corn dance" of the Muskogee (Knight 1986: 683 with references). Micro- and mesoscale approaches to mound stratigraphy here have identified patterns where collective labour and feasting created a seasonal cycle of intensive resource exploitation (Sherwood and Kidder 2011: 72; Sherwood et al. 2013: 345). Similarly, feasting supported Mycenaean construction activity in the sense of redistribution and camaraderie (Brysbaert 2013: 84), as well as accompanying funeral/post-funeral activities honouring the dead (Borgna 2004: 263–264; Cavanagh and Mee 1998: 111; Gallou 2005: 112; Gallou and Georgiadis 2006: 128; Hamilakis 1998: 119–120).

Even with ambiguous calendrical importance, all visible earthworks could serve as geographical markers, complementing natural landmarks in the mental maps of pre-literate trackers and the physical recordings of early cartographers. In this sense, navigation prolonged the influence of cooperative construction as long as the feature remained noticeable. Mycenaean case studies for navigation via earthworks have focused on routes through broken terrain. For Mycenae, the mound over the LH III Treasury of Atreus occupied a prominent position that confronted observers travelling along roads outside the citadel (Mason 2007: 47–48). The mound temporarily blocked views and forced a circuitous route to the citadel for visitors approaching from the south. The proliferation of earlier LH II *tholoi* likely stemmed from local elite, but they have also been cast as territorial signs of Mycenae's expanding influence in the Argolid and Corinthia (Fitzsimons 2011: 99–100). For Pelon (1976: 99), however, Aegean tumuli did not occupy prominent places deliberately, with the many existing examples on summits being products of erosion or survey bias (Cavanagh and Mee 1998: 25; see also Alcock 2016: 4). Homeric tumuli were variously lookout points, territorial markers, and testaments to heroism (Schnapp-Gourbeillon 2016: 207). Whether occupying a topographic highpoint or not, tumuli tended to hold commanding views along the axis of adjacent ravines and in many if not all cardinal directions (Angeletopoulos 2016: 2). Galanakis (2011: 223–224, 227) limited claims on visibility to close-quarters viewing for Messenian *tholoi*, many of which were built above ground and subsequently covered, occasionally with a protruding vault coated in plaster as a visual draw. For the case studies presented in Chapter 4, the tombs were indeed carved into hills with commanding views (absent the current tree canopy shielding much of Portes). Despite closed and hidden entrances, clustered hilltop tombs would be recognisable to contemporaries as territorial markers, orienteering aids, and memorials of social and spiritual significance. If closed and relatively inconspicuous, they achieved this from privilege or deference in collective memory, primarily from post-funeral repetitive acts (Boyd 2014a, 2015a; Galanakis 2011; Gallou 2005). This could change if evidence surfaces of aboveground markers like the grave stelae at Mycenae, set above Shaft Graves and vulnerable to collapse (Mylonas 1951; for the reset stele of Grave Gamma see Button 2007: 85; for tomb visibility see also Chapter 1, this volume).

Navigating space relative to visible structures is straightforward, but the orientation of the structures themselves poses interpretive problems. Some Messenian *tholoi* have been enriched by unambiguous connections to nearby settlements. The LH I *Tholos* IV at Ano Englianos, otherwise known as the Palace of Nestor in Pylos, opened directly in line with the north-eastern gate of the early LBA fortification wall encircling the summit (subsequently to house palatial buildings) opposite the tomb (Galanakis 2011: 224–225). Together with the Vagenas Tomb 400 m to the south on the opposite side of the ridgetop, *Tholos* IV has been cast as a territorial marker (Galanakis 2011: 225, citing Bennet 1998, 2007; Wright 1984). For the expanding Pylian polity, the construction of *Tholos* III 1 km southwest of Englianos also played into this idea of spreading monumental markers for travellers to encounter (Galanakis 2011: 226), similar to the MME *tholos* at Nichoria (Wilkie 1987: 128–129). For the hilltop tombs at Voudeni and Portes, however, most entrances simply followed contours in a radial pattern, cutting into the slope toward the summit (Chapter 4). The Menidi *tholos* similarly faced away from higher ground. This was logical for keeping more ballast above the burial chambers, thereby mitigating risk of collapse through better distribution of forces in overlying soils and perhaps economising by supporting vaults directly on bedrock (Boyd 2015a: 202; Cavanagh and Laxton 1981: 115–119; Galanakis 2011: 223; Giannakos 2015: 71). It was also easier to remove materials nearer the surface by funnelling them downslope, an advantage that evaporated with depth from the countering slope of the *dromos* itself. Since people were economically and technologically capable of building bigger, the final logistical constraint to moving many tonnes of earth and rock lay with socially appropriate timing.

### 3.2. Further projections on time constraints

The timing of increasing construction scale challenges social acceptability rather than capability, as emergent leaders risked leveraging personal gains against communal obligations (Bourdieu 1990: 153). For Late Archaic builders in the Central Andes, large-scale public building originated with corporate authorities that avoided displays of personal interest (Sara-Lafosse 2007: 154–155). Early farmers in the Tehuacán Valley of Central Mexico likewise began work on the earthen Purrón Dam before differential wealth for leading factions fully materialised, allowing wealth accumulation to begin in earnest over the control of water for vital irrigation in an arid region (Spencer 1993: 49–51). The latter case especially illustrates the capabilities of communal construction to overcome environmental limitations, even without strong central leadership. Similar irrigation works directed under comparatively limited political authority have been attested in East Africa (Goldsmith and Hildyard 1984; Gray 1963; Moore and Puritt 1977), the American Southwest (Gilman 1987: 545; Trafzer 2015), Polynesia (Kirch 1990, 1994), and Bronze Age Turkmenistan (Arciero forthcoming). Scaled up under complex labour organisation, water manipulation with earthworks was writ large, for instance, by Mycenaean engineers who emptied the Kopias basin (Giannakos 2015: 73) and Roman engineers who redirected flows in water-rich Britain (Rogers 2013: 130) or along the Tiber itself (Purcell 1996).

A long view of behavioural parallels in building starts with a simple diachronic look at nomadic versus sedentary habits. Nomadic constructions generally paired lower initial efforts with anticipation of shorter use-life as populations continually relocated (Abrams 1989: 54; McGuire and Schiffer 1983: 284). Seasonal cycles of semi-sedentary groups encouraged cooperation with multiple local groups, allowing larger communal efforts to coalesce around important nodes of recurrent activity. Social importance of locales snowballed along a compounding accretion mechanism, easily imagined for earthen mounds built in stages of construction over generations as well as the repeated use of mortuary spaces. For domestic architecture and other environmental modifications, initial investment increased to offset greater long-term costs in upkeep for recurring settlements (Abrams 1989: 55; McGuire and Schiffer 1983: 286). Although no longer couched in these terms, White (1943) and Cottrell (1955) simplified similar construction evolutions by pairing increasing energy reserves from technological advancement with the expansion of labour potential and pursuits beyond subsistence. Labour studies advanced along these lines to track the culprit behind increased scale and elaboration in construction. Focus shifted away from social hierarchies (e.g., Childe 1950; Morgan 1881; Squier and Davis 1848) toward labour indexes for relative demography (Cheek 1986), complexity (Erasmus 1965), and specialisation (Abrams 1987).

Lack of chronological resolution and contextual clarity discourages converting labour into demography and socioeconomic impact from individual construction sequences. Where no clear sequence of construction survives, labour studies approximate a reasonable series of events but rarely synchronise activity with calendar years. Abrams (1987: 488) argued from practicality for sequential rather than simultaneous construction for the Main Centre at Copan, citing calendar inscriptions and stylistic dates that packed events within a decade (AD 763–771). LBA Aegean contexts typically lack chronological resolution with short-term changes due to subsequent activity on crowded sites like Mycenae (e.g., Boyd 2015a: 201). Although my case studies stretch into centuries of use, their initial construction and episodic reuse were likely limited to a fraction of that time. In that sense, tomb labour should be detached from the sense of rolling costs that total labour typically conveys. A similar reversal toward episodic tomb construction rather than cumulative costs has been applied in Laconia, albeit with a strong critique of other energetics approaches (Voutsaki et al. 2018: 172).

One way of comparing earthmoving without conflating or compressing multi-period construction comes from the well-studied moundbuilding phenomenon in North America. When facing multi-stage mound construction spanning more than a century, Lacquement (2009: 143) rightly pointed out the benefit of applying energetics to discrete episodes of construction, rather than the abstract pursuit of total labour costs. He used roughly a month-long window for construction and capped available labour to total population at 1:5—a conventional ratio for estimating population from households (e.g., Aaberg and Bonsignore 1975: 45; Moore and Puritt 1977: 2). Lacquement (2009) also split labour along hypothetical requirements for three stages of mound construction at Moundville (ca. 1200 AD) in western Alabama. These ranged from smaller episodes capable of completion by kin-based groups (minimal lineages) to large endeavours requiring communal participation organised by the centralised elite. Such occurred at several mound complexes along major rivers east of the Great Plains during the early second millennium AD (e.g., Barrier 2011; Holley et al. 1993; Knight 2004; Peebles 1971; Reed et al. 1968; Trubitt 2000; Welch and Scarry 1995). Since isolated, lump sum labour costs for multi-stage construction can be decried as oversimplified or flat, more is needed about the progression of work from daily routine to communal effort.

### 3.3. Tracking progress from household to cooperative labour

Study of past labour typically separates the built environment and portable material remains when reconstructing daily routine. Both fall into the objects and work categories of Monica Smith's (2012: 45) tripartite division of human quotidian activity, with the third being food. Disassociating labour from elite exploitation with a broader definition of work, Smith (2012: 46) added to simple physical costs with "intangible activities such as storytelling, memory-work, adjudication, and other forms of communication". Examining labour in terms of earthmoving requires a breakdown of physical costs as well as these integrative mechanisms of communication that encouraged cooperative behaviour among non-related individuals. Allowing for altruistic labourers and gambling sponsors in shaping tombs (see Chapters 2 and 5), there should be a pragmatic way to track progress and consequences. In other words, what happened when logistical constraints challenged the resolve of participants in changing daily routine? If, for instance, surplus labour required the maintenance of cooperative effort over fragmentation from self-interest, what strategies did leaders deploy for cohesion and how did the strength and frequency of these strategies change closer to the fracture threshold that halted work? This has been a marked concern in the evaluation of pre-modern states and the tracking of inequality in the global market economy (e.g., Collins 1988; Levi 1988; Lichbach 1995, 1996; Rothstein 2000). More relevant for my focus, I contend that low-cost, low-skill labour requirements had an outsized, compounding effect on communal tolerance for lineage extravagance, and that this could hide behind deceptively low labour costs. Thus a comparative labour index (Section 3.4.2) can frame tolerance and extravagance as factors of signalling (cohesive/group–pragmatic–assertive/costly) or scaled investment (undersized–standard–exceptional). For instance, taking 9 days with 70 labourers to build the exceptionally large chamber tomb 75 at Voudeni sounds much less extravagant than when phrased as a tomb 9 times the standard cost and 51 times the cheapest completed chamber tomb (VT3) (see Chapter 4). The problem of how to express labour in meaningful terms can be traced back to where labour studies diverged along qualitative and quantitative inquiry.

Where comparative labour developed from earlier descriptions of architecture, one contentious divide separated qualitative and quantitative comparisons. The advantage of quantitative studies, no matter how measured, offered a comparable medium directly linked to the structures and artefacts into which people invested their time (Abrams 1989; Price 1982). This empirical shift in thought did not immediately translate to higher accuracy, as conclusions still funnelled toward problematic categorisation of social complexity (e.g., Cottrell 1955; Erasmus 1965). Early estimates for labour costs often misfired from fatuous historical accounts. Cottrell (1955: 33), for instance, inflated the severity of Egyptian construction: "The population was held constant or even diminished, since men were worked to death about as fast as they could be brought to maturity". Under this prelude, he repeated historical hearsay from Herodotus that 100,000 slaves, or 4% of the population, built the Great Pyramid at Giza in 20 years. Dunham (1956: 165) quickly revised Herodotus's "gross exaggeration" down to a more manageable 2,500, not counting those involved in supporting tasks beyond the main construction site.

Quantitative approaches to the built environment split further regarding what to measure: the final product or the invested process tracked through volumetrics and energetics. In many multi-stage constructions, energetics maintains analytical advantage over volumetrics's tendency to repeat abstract cumulative costs, whereas energetics can be split into episodes of construction more relevant to labour's impact on populations (Abrams 1989, 1994; Lacquement 2009, 2019). This has not deterred effective comparisons with volumetrics as the preferred baseline for the macro-scale view of moundbuilding (e.g., Blitz and Livingood 2004), despite limitations on available dimensions leaving these studies more exposed to revision.

Volumetrics and derivative energetics must tread carefully with their chosen measurements, particularly when relying on reported figures. Updating the volume estimates for the 32 earthen mounds at Moundville, Lacquement (2009: 25) discovered that previous volume estimations had exaggerated the size of some mounds by more than half, revising the total from 275,000 to 192,000 m$^3$. As shown elsewhere (Turner 2018), even a 30% reduction in size does not affect the corresponding energetic cost as much as a seemingly small tweak in the labour rate used. Sorant and Shenkel (1984) observed that planimetry using contour maps yielded greater accuracy than solid geometry, with Shenkel (1986: 213) later indicating differences ranging from -60 to +130% over previous measurements for monumental earthworks across the eastern U.S. Milner (1998: 145) showed much the same phenomenon for eleven mounds at Cahokia, with differences of 2–27% and a 6% average.

In correcting these volumetric issues, Lacquement (2009: 32) recognised that outdated technology and time obviated the use of planimetry over modern techniques. His gridding method also relied on contour lines, but using the SURFER (v. 8.0) and DIDGER (v. 4.0) programs to digitise contour maps and aerial photographs, he broke the three-dimensional model of the mound into thousands of rectangular prisms. These he likened to the virtual stacking of dice as opposed to the "frustum-shaped pancakes" limited to the few contour lines encompassing a mound in the previous technique (Lacquement 2009: 32–34). This accounted for many more variations in mound shape that undermined previous geometric methods of measurement, including irregular mound shape and sloping pre-mound surfaces. Digital modelling with measurements from total station survey and photogrammetry largely skirted these considerations for my purposes, but it is important to mark this step away from simple volume equations.

With a handle in place for measuring physical dimensions, comparisons should account for past perspectives with a recognisable standard, such as house construction (e.g., Devolder 2013; Harper 2016; McEnroe 2010; Walsh 1980; see also Boswinkel forthcoming). For instance, reconstructions of wattle-and-daub Neolithic houses yielded estimates of 150 person-days for total construction, with the 9 tonnes of clay used in the walls requiring 5 person-days (10-hour workday) to dig (Coles 1973: 55–57, citing Hansen 1961, 1962). This compares favourably with estimates from Abrams (1994: Table 8) for the lowest-tier of domestic architecture around Copan, requiring roughly 100 person-days for a wattle-and-daub structure set on a low earth-and-rubble platform. In contrast, observations of log cabin construction in northern Canada during the late eighteenth and nineteenth centuries showed that 4 person-days were sufficient for a 6-x-4 m rectangular structure, since this type required only a fraction of the materials used in wattle-and-daub construction and no wall-trench (Coles 1973: 55, citing Guillet 1963). In any case, reporting a larger house or tomb with a standard cost means more than the cost itself, such that one with a house worth 1,000 person-days fails to convey the message of excess that one worth 10 houses would. Social tolerances fluctuated to accommodate bolder choices in domestic and mortuary architecture since the communal benefits therein were unclear. In relative comparisons of house size, ethnographic surveys have shown size disparity for leaders in formative ranked societies, going so far as a direct index of political standing in the case of Polynesian sanctuaries (*maraes*) on Tahiti (Goldman 1970: 177). Redirection of surplus labour for personal use in stratified societies amplified residential inequalities, whereas restrictions formerly would have appeared to curb domestic extravagance where egalitarian values still predominated (Fried 1967).

Labour studies have commented previously on the ramifications of communal overreach, wherein a population surpasses its limits and readjusts. This logic has often appeared under discussions of systems collapse (e.g., Tainter 1988). Problematically, most empirical approaches to labour have used minimalistic costs that undermine the effects of communal effort, reducing it in some cases to a diminutive fraction of preindustrial potential. Reporting house construction costs at Nichoria as 1.1 million person-hours over 750 years, Walsh (1980: 80–85, 100) trimmed the annual cost to under 2,000 person-hours (40 days for a 5-person crew working 10-hour days), reducing skilled workers to part-time for having so little to do. Abrams (1987: 493–494) likewise rejected the potential for socioeconomic stress from labour demands for monumental construction in the case of Late Classic Copan. He cited estimates for labour involvement in elite projects as low as 1.5% of the annual available labour. Abrams contended that the degenerative effects, if any, of unreasonable construction demands could only form a small part of a much larger problem. This view rightly corrected qualitative overestimation, but it omits the multiple, compounding issues implicit in systems collapse and household overreach.

Demography and territoriality have played a larger role in comparative labour studies in European contexts. Case studies have ranged from the proliferation of small fortified sites with stone towers in late prehistoric Scotland (e.g., Armit 1990; Gilmour and Cook 1998; Hedges and Bell 1980; Parker Pearson et al. 1996) and Sardinia (Webster 1991) to medieval earthen constructions demarcating territory or rudimentary defence in northern Europe (Biddle and Kjølbye-Biddle 1992; Graham 1988; Hill 2000; Redknap 2004; Squatriti 2002). Problems arose when drawing these studies into the comparative frame, since labour rates that appeared here also privileged timed observations from the Americas. For example, preliminary assessments of labour deflated qualitative assumptions of significant effort in the building of *nuraghi* (stone towers incorporating corbelled vaults) on Sardinia, but these conclusions relied upon labour rates from Abrams (1984) and Erasmus (1965) using volcanic tuff half the density of the target material of basalt (Webster 1991: 852). Investing labour rates with more robust comparative value requires an intensive reassessment of preindustrial logistics.

### 3.3.1. Preindustrial construction logistics

Retracing preindustrial logistics rewinds work from architectural remains, accounting for post-depositional effects and breaking apart construction into its myriad components. Although threatened by minutiae and speculation, restructuring labour costs with logistics faithfully models the construction process *and* contemporary perception. The following sections attempt to run diagnostics on direct aspects of preindustrial construction: planning, performance, and product.

*Planning and guidance*

Before breaking ground on a project, sponsors wishing to mobilise workers called upon a management framework, either an existing one, such as a lineage, guild, or military group, or one purposefully designed. Such frameworks could change throughout a project but must have lent stability under duress. Stability derived from many sources: charismatic leaders, visible progress, and completion incentives being the first to mind (see below). Circumstances aside, an effective management network could bridge the narrow gap between success and failure. Concerning management relationships in Classical Greece (Burford 1969: 128–144), the building commissioners and prominent financial supporters of public works left most technical decisions to the architect and contract holders. Sponsors exercised duties of oversight as problems arose or completed work stages demanded the next payment instalment. However, by virtue of status and personal wealth, many in this position developed some technical expertise as a matter of interest and spectacle (Burford 1969: 128).

In addition to the individual or group commissioning projects, primary designers fulfilling the role of architect, engineer, or master builder translated ideas into reality. Whereas heads of households initiated construction for domestic needs, community councils or respected voices encouraged mid-level communal projects that called upon familiar skills already deployed by households. The novelty in higher-level demands was more an issue of scale and vision than one of technical advancement (Smith 2012: 57–58). Setting aside delegation to specialists and supervisors, few concurrent persons operated at the top of larger-scale projects. Vigorously studied, such commanding personalities in construction emerged as iconic Classical Greek architects. From inscriptional evidence and Plato's perspective, the role of the Greek *architekton* was that of a master builder (or master carpenter in the original sense) and overseer of construction, directing work on-site rather than designing from afar (Burford 1969: 138–140; Coulton 1977: 15). In practice, the role covered a far-ranging spectrum of duties from administrative clerk to engineer, inspector, and designer, all without a formal system of mechanical theory until the late fourth century BC (Coulton 1977: 16). Working primarily from inscriptions, Burford (1969: 144) highlighted the temporary, reputation-dependent status of two architects for the fourth-century temple complex of Asklepios at Epidauros, characterising Polykleitos as an experimental artist and Theodotus as more of a robotic follower of training. Abrams (1987: 492–493) also made a convincing case for a lone royal architect at Copan by stripping the role of its modern implications (e.g., compliance with governmental regulations, coordination with specialists, mediation of land disputes) and suggesting simplicity in its preindustrial manifestation.

Although heavy with modern comparisons, when placed into context the preindustrial architect did contend with extraneous issues, just under different circumstances and labels. Coulton (1983: 453) mused that the Pergamene kings Eumenes and Attalos may have conceived of projects and hired workforces led by a master architect, but it was the architect who controlled details like palm capitals. Architects in Classical Greece navigated the restrictions of tradition, pre-existing sacred spaces, and cult prescriptions in religious architecture, such that the demands of designing new constructions could not benefit from the freedom of a blank slate (Burford 1969: 41–42). Meeting demands of patrons while still erecting a viable structure involved more than aesthetic decisions, and coordinating with specialists could haunt the mediator with logistical nightmares. In place of the plumbers and electricians Abrams (1987: 492) mentioned as examples of dropped interactions, plasterers and sculptors required oversight from the master architect. Autonomous skilled positions could prove advantageous—or threatening if mishandled—to patrons and architects. Burford (1969: 206) asserted the relative independence of skilled workers from city patrons, who courted them to strengthen the labour capabilities of their respective communities. Reducing the role of architects and skilled workers gives the false impression of shells only responsible for repeating architectural designs that were already established. What appears now as flat in the *longue durée* may not have resulted in a generational copy-and-paste when these structures were in use. Such complications rang true for the Roman context, wherein DeLaine (1997: 45–68) tracked the architect's design hurdles for the Baths of Caracalla through reconstructed blueprints and lessons from Vitruvius.

Recruitment and supervision followed the project conception or design in the steps toward material realisation. Grain allotments mentioned in the Linear B tablets from Pylos have been linked with preparations for unskilled labour recruitment (Nakassis 2010). On labour recruitment at Copan, Abrams (1989: 73) suggested available sources along a three-tier system of need: family volunteers for basic domestic work, cooperative recruits from a larger corporate kin subset for upscale structures, and corvée labour for monumental public works or private investments by leaders. In a more popularly known example, there were strong indications for the importance of kin groups in organising labour for the movement of the Easter Island *moai* stone statues (Cotterell and Kamminga 1990: 225). Supervision proportional to the size of the workforce and the complexity of the task factored somewhat less than the average labour pool, with DeLaine (1997: 107) citing 3–20% as an appropriate portion and 10% as the most often employed (see also Brysbaert 2015: 101–103; Pakkanen 2013).

Although less so than other building materials, earthmoving required coordinated efforts to shift from the first load. Subsequent loads claimed less thought as they followed the first, so long as the basic tasks (e.g., digging, carrying, depositing, tamping) found their rhythm. Where and how an earthen construction took shape needed foresight on sourcing and placement to minimise interference and waste, but the real obstacle to navigate remained worker motivation. Since a single labourer saw no immediate benefits when performing repetitive tasks for a much larger purpose, management networks triggered one or more powerful cooperative emotions, such as pride or fear (see below). Fear ranked foremost in previous models of coercive labour (e.g., Cottrell 1955: 33), but societies where power remained diffuse earned alternative explanations. Symbolic importance, not coercion, was responsible for the sustainment of Chaco Canyon with maize from up to 90 km away (Benson et al. 2003; Saitta 1997; Windes and McKenna 2001). Enthusiasm and confidence in vested parties completing work contracts sustained the building of the first stone temple at the sanctuary of Asklepios at Epidauros, although threatening fines for failing contracts also encouraged compliance (Burford 1969: 59, 88–118). Communality, pride, and ritual influence have been suggested for platform mounds and pyramidal monuments in Central and North America (e.g., Aaberg and Bonsignore 1975: 49; Blitz 1993; Erasmus 1965). Late Archaic building at Poverty Point in Louisiana especially has defied previous assumptions with its nonlocal labour in the absence of coercion (Aaberg and Bonsignore 1975: 62). This ties into the discussion above on the social dimensions of earthmoving (see also Chapter 2), where reasons for building multiplied with socioeconomic complexity, despite inherent difficulties in disentangling motivational cause-and-effect.

With a management framework guiding a motivated workforce, cultural memories and personal skills from instruction and experience shaped labour into material reality. Initiated toward a communal objective, received instruction and heuristic experience informed individual tasks. Instruction sparked learned skills much as coming-of-age ideals revolved around shared myths and their recurring quest-for-value components (Greimas 1987; Propp 1968) Skills filtered through recipients (relatives, students, acolytes, apprentices), who augmented or devolved them depending on their own aptitude and interest. Subsequent generations either passed the torch or saw the flame extinguish from resource exhaustion, falling demand, or abrupt catastrophe. For the Aegean Bronze Age, pedigrees emerged from the founders to their offshoots where techniques and materials—like tomb shapes (Kontorli-Papadopoulou 1987: 145–147), pottery (Maran 2007: 174), and cylinder seals (Broodbank 2013: 415, citing Sherratt 2010), were openly imitated, improved, or ignored.

Instruction began early through familial ties. This allowed for a chain of inherited memories that relayed resource locations, optimal workflow, and tool use. The complement to this, heuristic experience, rewarded exploration and innovation rather than repetition of received instruction. Prevailing wisdom appealed to conservatives but eventually ran afoul of finite resources or waning interests, prompting chain reactions that withered support from supply or demand. If unchecked, conservatism led to errors in contemporary designs, such as that seen in Egyptian calendar ceilings and water clocks (Cotterell and Kamminga 1990: 60–61; Neugebauer 1983). It also led to bitterness over perceived changes in life's pacing. Although simplifying instructions from Vitruvius on the making of timekeepers, Faventinus hinted at the importance of the sixth and twelfth hours in functional design and accuracy, while dismissing the notion of accuracy less than an hour with the quip that men are in such a hurry that they will only ask what hour it is (Plommer 1973: 81–83).

Generational disruptions weakened instruction among households and small communities, but larger populations absorbed losses through innovation. Innovation could also backfire when mechanical theory lagged. In the case of parachutes, for instance, Cocking's inverted parachute and Reichelt's parachute jacket both resulted in the deaths of their inventors (Cotterell and Kamminga 1990: 45). Harder to trace without immediate consequences, structural failures in prehistory would have been no less dramatic. Blame may not have landed on the right culprit every time, but patterns would stand out where collapse occurred repeatedly. Adaptive changes to designs addressed structural issues without necessarily requiring understanding of the underlying mechanical theory (Coulton 1977: 16), much of which did not develop until the last half-millennium. Expected knowledge and responsibility were relative. Romans divided architecture into eight constituents, an elaboration on five inherited from Greek tradition, as "order, disposition, beauty, measurement, distribution, building, siting and mechanical engineering" (Plommer 1973: 41). Much of this had to do with managing water. Plommer (1973: 20–31) covered anecdotal instructions for cistern and well-making, baths, and hydraulics, originally in the refined prose of Vitruvius directed at public architecture and later modified for the private scene by Faventinus and Palladius. Competency could still ignore wilful mistakes, as the widely known deleterious properties of lead-piping failed to force the switch to earthenware (Plommer 1973: 53).

While not as susceptible to conservative or innovative misfires as other building methods, earthworks acquired sods or clay caps, layers of sand or shell for renewal, colour-coded sources for alternating visual contrasts, or ritual sweepings from adjacent plazas in annual festivals (e.g., Bourgeois 2013: 174; Kidder 2004: 529; Knight 1986: 683; Sassaman 2008: 14–15; Sherwood and Kidder 2011: 72). For Mycenaean cemeteries, clay was occasionally used to cap pits or underlie biers within burial chambers (see Portes Chamber Tombs 3, 9 and 18, Chapter 4, this volume). Manipulation of colour with stone types has also been noted in the context of the Upper Citadel at Tiryns (Maran 2006b: 82–83, Figure 12), but rock-cut tombs are limited to applied colour-contrasts like the aforementioned clay and painted plaster (e.g., Demakopoulou 1990: 115; Gallou 2005: 68–69; Karkanas et al. 2012: 2731; Sgouritsa 2011: 737–739; Smith and Dabney 2014: 148). Each of these elaborations relied on instruction and experience. Labourers and planners who recalled previous sources collected the same material for a desired effect without unreasonable delays in scouting sources anew. Far more difficult has been the identification of these sources, especially stone, for appropriate transportation costs (Brysbaert in progress-2020; Brysbaert et al. in progress-2019; Devolder 2013: 134–136). Compacting alternating layers as they were added likewise had mechanical advantages, limiting the risk of slumping, or in the case of dams and dykes for flood control, the risk of catastrophic failure (Bowles 1984: 277, 286; see Chapter 2, this volume).

Where instruction and experience combined, early labour exchange systems exploited developing specialists first. Abrams (1987: 494–496) addressed the issues of labour organisation and instruction among both specialists and nonspecialists at Copan. From his energetics assessment of the monumental masonry palace Structure 10L-22, the number of specialists plastering and sculpting represented a surprisingly low portion of the total labour force (40 persons from a total of 411). Given that this involved only 0.3% of the approximate total population around Copan, Abrams concluded that specialists passed knowledge along familial ties, such as parent to child, and low demand simply never sparked an expansion of this class. Abrams applied similar principles to nonspecialist labour where lineages organised household labour, and subsequent elite recruitment operated most efficiently through such an existing system. The implication here is such that a nonspecialist with aptitude demonstrated at the household level for masonry, for instance, applied these skills when called upon by the elite for communal construction. Where the cost of material procurement rose, the number of nonspecialists with access fell, and ability once considered nonspecialist became specialised. In an example from Classical Greece, the defeat of Athens at the end of the Peloponnesian war disrupted skilled labour exchange, which took roughly a generation to rebound (Burford 1969: 204–205).

As seen above under household instruction and master-apprentice relationships, knowledge transfer seems straightforward. That illusion shatters under Foucault (1972: 153–154), where the "history of ideas"—of thought at its broadest and most reflexive—rests on a crumbling mess of innumerable, vanishing "exchanges and intermediaries", like endless forgotten book passages or conversations with teachers. One outlet from there leads to indirect transfer among observers, tracking where innovation started rather than how it arrived (Granovetter 1973: 1366, 1372). Contact exposed others to sights and ideas, and these spread into the network equivalent of inkblots connecting strangers from otherwise separate pools of collaborators (Granovetter 1973: 1366; 1983: 202). Kindled interest drove others to recreate the descriptions of an eyewitness or messenger, those who may have had no further motive beyond repeating the story. Rumours undoubtedly played a significant role in fanning the competitive spirit of outdoing peers, much like the "mythology of rumor" continues to drive market speculation with "the quasi-magical search for the formula" to incomprehensible wealth (Appadurai 1986: 51). Existing earthworks goaded leaders into eclipsing predecessors—for an early medieval Mercian example, see Offa's Dyke doubling the length of Wat's (though obscurely named and without a definitive patron, see Tyler 2011: 159). As architecture grew more complex, however, mimicry faltered, and successful copies disseminated through more direct and official channels (e.g., the exchange of experts), leading back to a pedigree of instruction. For a portable instance, faience *kylikes* at Mycenae expressed in local form a technology demanding Egyptian (or Syro-Palestinian) skills-exchange (van den Berg 2018: 60).

For exceptionally large earthworks, indirect observation and rumour may have been sufficient to provoke responses among neighbours and rivals to attempt construction of larger tombs (Fitzsimons 2006: 90), longer canals (Squatriti 2002: 14–16), and more expansive ramparts and terraces (Tyler 2011: 159). Unlike stone- and woodworking, where concentration on size in wilful ignorance to practical considerations of building mechanics invited disaster, earthworks were generally not susceptible to catastrophic structural failure (cf. the discussion of earthen structural failures in Chapter 2). Cautionary measures against slumping, slides, and sinks included effective drainage, care with soil textures, and perhaps some considerable luck with the underlying geology (Bowles 1984: 213–215, 418–419; Brandt and Thornes 1987). With enough willing hands, elites bent on erecting larger earthworks needed only to heed communal tolerance by safeguarding the health of the project's supporters (see Chapter 2).

*Support*

Although procurement, movement, and placement of materials dominated the total labour cost of a project, less visible (and less considered) secondary tasks escalated the cost and reach of a project beyond the construction site, perhaps overshadowing primary tasks over a wider scale (de Haan 2009: 13; Homsher 2012: 22). Secondary or supporting tasks included anything not directly involved in construction but without which building would cease. Through nearly limitless degrees of separation, an arbitrary line cordons a manageable model (Abrams and Bolland 1999: 267). The supporting roles I refer to here may take many forms, but the most important revolve around the health of the workforce (see also Chapter 2). To remain viable, workers must hydrate, eat, and sleep with some regularity, and the same applies to any draft animals. As with building materials, proximity dictated much of the labour involved in procuring food, fodder, water, and housing.

Above all else, daily access to drinking water determined whether a project succeeded or what constituted a habitable position (e.g., Harper 2016: 216–217; McMahon 2015: 32; Maghsoudi et al. 2014: 81; Runnels and van Andel 1987: 323, 329). Under the wrong conditions, often unavoidable when performing intense labour on a dry summer day, the human body hits its limits surprisingly quickly, with the undersold threats of dehydration and heat exhaustion rearing under little more than an intense walk (Ainslie et al. 2002: 185–186). From manufacturing drinking vessels to maintaining a steady supply of potable water, the need for water demanded continuous investment throughout the construction process, necessitating transport personnel or portable containers for each worker and time enough for trips to the source.

Labour involved in food and fodder procurement varied according to primary subsistence strategies (see also Timonen forthcoming). Mixed strategies for food and fuel from cultivation and foraging prevailed over the eastern Mediterranean, at least where forests were not depleted (Klinge and Fall 2010: 2623). Halstead (1998: 212) noted montane foraging for livestock in north-western Greece, where "in the limestone area of the western Zagri, in villages up to ca. 1,000m altitude, evergreen bushes of prickly oak (*Quercus coccifera*) could be cut fresh for stall-feeding or browsed by sheep and especially goats even in quite deep snow". When combined with foraging, intensive agriculture allowed surpluses but remained susceptible to shortages from poor yields or livestock mismanagement. Only a few dry years separated much of the Bronze Age Mediterranean from catastrophe (Wilkinson 1997: 67–69). Regardless of yield, two high-intensity seasonal work episodes, planting and harvesting, amplified the burden of other concurrent activities. Caretaking between planting and harvesting depended upon the crop, but none could go entirely unattended without substantial risk to yield. Multi-purpose use in early Cycladic olive domestication, for instance, demanded continual labour-intensive pruning (Margaritis 2013: 752). Animal husbandry involved a similar annual cycle, with seasonal relocation of herds and culling of non-breeding stock to reduce the burden on winter stores, once a dire concern in northern latitudes (e.g., O'Connor 2010: 12). The influence of weather upon agriculture and its timing constrained other major activity calendars in warfare and construction, and from its unpredictability, sowed investment in divine intervention. For factors beyond mortal control, like a punishing season, personnel may have diverted more time to intercede with divinities (for the archetype of the Minoan procession leader see, e.g., Soles 2016: 250 with references), reasserting ritual or symbolic investment in construction enterprises or, at worst, basic survival.

In the absence of intensive agriculture, construction tethered to a resource-rich area or occurred at a time where gathering dispersed bands could stockpile collective stores. Seasonality still applied, and the construction window tightened or closed altogether in lean years. Despite these restrictions, durable architecture from communal efforts in nonlocal, marginal zones rose in defiance of environmental circumstances by pooling labour and resources from the periphery, such as occurred at Chaco Canyon (Benson et al. 2003; Betancourt et al. 1986) and Poverty Point (Kidder et al. 2008; Ortmann and Kidder 2013; Sassaman 2008) in North America. Messenian MH tumuli also tended to centre on productive areas that attracted cooperative behaviour against rival claims (Angeletopoulos 2015: 2).

Housing, as another concern of supporting construction, factored less into projects within reasonable daily commutes for the majority of the workforce. Reasonable is relative, as farmers surveyed on Melos routinely walked two hours to fields formed from eroded hillslopes that have exposed up to 40% of the island's rocky surface (Horden and Purcell 2000: 75). Temporary huts in fields facilitated agricultural work further away from the outlying settlements of the fourth-century BC mainland *polis* (Jameson 1990: 94–95). Around this time Athens and its Piraeus port comprised a network of roughly 30 "subordinate communities" with another hundred spread across 2,600 km$^2$ of Attica (Jameson 1990: 94). In a rough demographic estimate for Classical Greece, Jameson (1990: 94) wrote that in "the acme of the civilization there were perhaps some six hundred city-states, most with populations of two or three thousand persons (some four to five hundred houses) and territories of no more than 400 sq. km". Similar crowded landscapes have been proposed for Mycenaean territories at their height (e.g., Bintliff 2019; Cavanagh et al. (eds) 2002; Davis et al. 1997; Wells and Runnels (eds)

1996; see also Timonen forthcoming), with up to 30,000 Messenians in 2,000 sq. km under Pylos at 112–200 per ha depending on rural/urban context (Bintliff 2019). New cemetery construction would seldom find a periphery in densely settled land, particularly where uninhabited areas were also likely strenuous to traverse. In densely settled areas like the LH II/III Argolid and Messenia, new housing for construction need not apply, but their daily commutes should be considered further.

No matter how symbolically distant from daily routine (Dakouri-Hild 2016: 13, citing Turner 1979: 97 on the concept of heterotopia; see also Hamilakis 1998: 118–119), Mycenaean tombs and public spaces were rarely constructed more than a few kilometres away from settled space (Mee and Cavanagh 1990: 238–239). Chamber tomb cemeteries in the Argolid occurred within 1.5 km of the closest major associated settlements. This was true even for those cited by Cavanagh and Mee (1990: 55) to be surprisingly distant, as at Berbati, Kapakli, Prosymna, Tiryns, and Nauplion—all of which were still within 1.5 km of nearby settlements (Mee and Cavanagh 1990: 225–226). Due to weak correlations in their cluster analysis, however, Cavanagh and Mee (1990: 59–62) determined that "there are no clear choices made in siting the tombs closer or farther away from nearby settlements, so convenience alone holds little weight". There was also no clear pattern of placement for Messenian MH tumuli in relation to nearby settlements apart from a general proximity, in most cases no more than 2 km distant (Angeletopoulos 2016: 5). Together with the isolated Barnavos chamber tomb, the six chamber tombs at Ayia Sotira in the Nemea Valley lay within 1 km of the settlement at Tsoungiza, visible to one another and with reasonable access to water (Smith et al. (eds) 2017: 168). Rather than relate directly to known roads, the cemetery at Ayia Sotira seemed to correlate more with cultivated fields and an apparent desire to protect the tombs from human and natural disturbances. Comparatively rural Achaea, despite research weighted toward tombs, likewise held corresponding settlements within a kilometre of cemeteries (Papadopoulos 1979: 26–31, 49). Considering proximity with established settlements, the location of cemeteries along prominent communication routes may be over-interpreted by modern research (cf. Boyd 2015a: 208–212, 2016; Galanakis 2011; see also Chapter 1, this volume). I would argue that convenience was a principal contributor in siting new tomb construction, at least to the extent that inconvenience was avoidable. Few alternate choices would have been available. Crowded landscapes of broken terrain, crisscrossed by existing optional routes (Boyd 2015a: 214), offered no advantages to wandering far from transport lines, particularly when sensitive cargo demanded wheeled vehicles. Even if smaller stones and tools allowed for overland expeditions, one does not typically sling a prepared corpse across a pack animal or expect a litter team to hike. Tomb construction and funeral processions were not the time for trailblazing. Furthermore, closed chamber tombs, even with markers, are not billboards easily spotted and relocated. Pragmatically, accessibility must have played a role in new tomb locations.

*Gendered work*

Often overlooked, supporting roles that sustained a workforce must draw from a depleted labour pool, one presumably showing a noticeable gender gap after the departure of the male-dominated workforce (a scenario flipped in the account by Gray 1963: 36–37, see below). Intentionally passing over able-bodied women and children in favour of unfit (e.g., age, illness, disability) men would require powerful taboos preventing others from participating in building itself. Even so, men cannot fill all roles. Historical analogy and its attendant fog of male-centric thinking fostered the fallacy of men alone building monuments. Gender bias in archaeological research has been peeled back for household industries (Dobres 1995: 27–29; Dobres and Hoffman 1994: 240), but communal construction continues to be envisioned as primarily male. Circumstances are few in ruling out half the available labour in prehistory. The first use of "person-day" was linked to Abrams (1984) when the methodology was initially laid out to denote participation by both sexes "on many different scales" and by children (Abrams and McCurdy 2019: 3–4). With this in mind, gender-biased units in descriptions of preindustrial labour costs have diminished.

Preindustrial labour has shown a contested field on diversity in the labour pool. After acknowledging the likelihood of women and children as fuel collectors and light industry assistants making ropes, baskets, and bricks, DeLaine (1997: 106) resignedly stated that her sources for rates restricted her from envisioning a workforce beyond one "composed entirely of men". This assertion stemmed in part from "the post-classical sources for labour constants", or in other words, from the revisionist observations of men writing centuries later. Despite a footnote reference to Egypt's strict division of labour, Cotterell and Kamminga (1990: 217–218, citing Atkinson 1956; Skjolsvold 1961) reported diverse workforces including youths and women in experimental examples of heavy transport for Stonehenge and Easter Island. Daily water retrieval by Mesopotamian households was "probably performed by women or older children, and therefore rarely documented" (McMahon 2015: 32). The advent of a new watermill in the late first century BC led Antipater of Thessalonica to declare an end to women's labour grinding grain (Cotterell and Kamminga 1990: 43). Into the mid-twentieth century in the villages along the Pindos range of north-western Greece, women handled small-scale herding and farming while men supplemented income from travelling trades, sometimes for intervals of years (Halstead 1998: 212). Although dwindling, similar rural labour-sharing survives in isolated cases. A young woman shepherded her father's large herd of goats daily along the mountain road at Portes during our 2017 fieldwork season (see Chapter 4).

Few taboos prevented the employment of children in supporting tasks, where ethnological examples have foregrounded a sense of 'all hands on deck' to survive. Cottrell (1955: 36–37) referred to each child as "an economic asset" in the context of field clearing among the Bantu in sub-Saharan Africa, and for rural Yunnan in south-western China during the early twentieth century AD, children likewise supported impoverished adults. Similarly, women and children handled meal preparation and peripherals during ceremonial construction among the Oku of north-western Cameroon, where they also represented—not coincidentally—a measure of male power and economic reach (Argenti 1999: 26). In a case that I discuss further in the section on labour rates below, East African Sonjo women reversed the men-at-work refrain by ploughing, planting, and harvesting all while juggling housework and childcare (Gray 1963: 36–37). For exceptionally large chamber tombs and *tholoi* (see Menidi and VT75, Chapter 4), builders were likely not occupied for more than a season, during which non-builders would cover all other supporting tasks. However, strategic scheduling could alleviate that potential strain and spread communal workloads to fit annual schedules.

*Scheduling*

One counter to communal construction shifting the labour pool beyond the gender and age divide due to overlapping demands has been the concept of intentional timing during the agricultural offseason, a three-to-four month period typically stretching from late fall to early spring. This offseason has been cast as a window of opportunity for construction in agrarian societies. The window worked where the agricultural offseason coincided with the dry season in tropical climates, but the elevated rainfall in a Mediterranean winter rendered these months more problematic for wheeled transport, giving an advantage to sleds only to the extent that traction was not hindered by mire.

Agrarian scheduling certainly served as an impetus to complete essential construction within an acceptable timeframe. For Abrams (1989: 66), 60 to 100 days sufficed. This followed a reduction from the 120-day window for construction taken from ethnographic analogy (e.g., Bierbrier 1982; Redfield and Rojas 1934; Vogt 1969). Aaberg and Bonsignore (1975: 45) set the minimum as 40 communal working days per household for Mesoamerica, derived from Erasmus (1965), who reported a similar figure (45 days) from New Guinea. Expanding the workforce beyond "the adult male head", each household could expand to 200 working days per year or, for instance, match the frost-free growing season of 220 days in the south-eastern U.S. (Aaberg and Bonsignore 1975: 45, 53). Among the longest preindustrial working calendars, de Haan (2009: 2–3) estimated 328 working days per year (one day off in every ten with 8-hour working schedules) for Egyptian pyramid builders.

For the Roman construction calendar, DeLaine (1997: 105–106) preferred a 12-hour workday and onsite operations totalling 220 days over a 9-month period (March to November), allowing for a longer 290-day window over 12 months with offsite tasks such as timber and stone procurement. This scheduling optimised daylight hours and avoided the frequent rains of shorter winter months. Other tasks were also weather-dependent. The timing of Roman mudbrick manufacture avoided the intense heat of summer and its attendant uneven drying of bricks, wherein the outer layers dried too quickly, causing sufficient cracking to render the entire batch useless (Plommer 1973: 57). For slower, more even drying, spring was recommended by Vitruvius (II, 3) and echoed by Faventinus and Palladius (VI, 12). Referencing Faventinus, Palladius placed the optimal time for mudbrick manufacture in May and timber procurement in November (Plommer 1973: 3).

For Neopalatial Crete, Devolder (2013: 119, 129–131) utilised 8-hour workdays over a 90-day period. In southwest Greece, Walsh (1980: 99–100) cited a 75-day window for house construction at Nichoria. Given the variability of construction seasons used in previous studies, resolving the question of construction duration has depended upon the chronological resolution for the case example. Where this remains unsatisfactory due to limitations in the archaeological record, simulations scheduling work with modern computer-aided efficiency have substituted (e.g., Abrams and Bolland 1999; Harper 2016; Walsh 1980). I have avoided simulating work schedules for fear of outpacing the preindustrial experience of coordinating construction with limited means. As in the discussion of mechanics below, I have compromised with a technical review only to reconstruct the forces Mycenaean tomb builders would recognise by consequence rather than name.

*Mechanics*

Prior to the invention of the pulley in the early first millennium BC, construction relied upon variations of levers, inclined planes, and wedges to manipulate heavy objects (Blackwell 2014: 453–456; Coles 1973: 78; Cotterell and Kamminga 1990: 89; de Haan 2009: 2). With only muscle and gravity to initiate useful mechanical work, individual limitations are expressed in terms of Système Internationale (SI) units: 1) force, the newton (N); 2) the measure of mechanical work, the newton metre or joule (J); and 3) power, the joule per second or watt (W). Thus expressed, values are not typically transferable as an end-product comparison of preindustrial labour, for which real-time conversions are needed with observed labour rates that align closer to physiological effort. Since the difference between useful mechanical work and physiological effort has already been expressed (e.g., Cotterell and Kamminga 1990: 74–75, 195), I should reiterate that modelling preindustrial logistics measures physiological effort, something I explore further in the section on labour rates below. Before delving into those values for muscle-power, forces affecting structural stability should be discussed. The capability of materials to withstand these forces depends upon their inherent properties as well as construction design, typified in the problem of open space.

As a means of spanning open spaces, such as that required for roofs and bridges, Mycenaean builders could choose between a trabeated system (post-and-lintel) and a corbelled vault. The first confirmed truss did not appear until Andrea Palladio's (1518–1580) sixteenth-century bridge over the Cismone River in northern Italy, although earlier forms have been suggested for Classical Greek and Roman architecture (Cotterell and Kamminga 1990: 116–117; Coulton 1977: 159). The corbelled vault allowed heavier loads, but it did not approach the capabilities of arcuate (true arch) systems developed independently by Roman and Chinese architects. On the delay in inventing the true arch, Cotterell and Kamminga (1990: 121) mused that the instability of the incomplete arch seeded doubt regarding the strength of the completed form. Coulton (1977: 159–160) blamed the disinterest of mathematicians in practical experiments for the comparatively late development of structural theory, with Classical Greek architects deferring to the trusted method of proportionality in form as evident in their lack of understanding and under-utilisation of alternate roofing techniques like arches and trusses. Corbelling, on the other hand, was adopted early for a variety of civilisations, many preceding the LBA Aegean by centuries. Mediterranean examples appeared in Iberia, Sardinia, Malta, Anatolia, and the Near East before appearing in the Peloponnese around the sixteenth century BC (e.g., Blackwell 2014: 477; Cavanagh and Laxton 1981: 109; Jones 2007: 168; Maner 2012: 56; Trump 2002: 62–63; Webster 1991: 844–845). The popular load-bearing technique remained susceptible to catastrophic failure if not supported against the tensile stress that later true arches converted safely into compression stress.

Aware of the risks involved in collapse mechanisms if not the theory behind them, many early architects overcompensated with conservative techniques. This was especially true for Classical Greek and Roman structures, which when analysed by modern methods could withstand loads far greater than the daily norm, in turn allowing many to survive violent earthquakes. In limiting the maximum bending stress on lintels at the Temple of Aphaia to a fiftieth of the modulus-of-rupture for limestone, "[t]he Greeks were decidedly timid in their approach to stone lintels because they did not understand the mechanics" (Cotterell and Kamminga 1990: 114). Coulton (1977: 96) found the same conservatism benefiting wider column-spacing in smaller Classical Greek buildings, which performed well since the preferred intercolumniation of larger examples went beyond structural requirements.

Egyptian builders showed similar caution in supporting roofs over the inner chambers of pyramids. Used in place of a relieving triangle, horizontal blocks supported primitive arches by absorbing side thrust from the gabled walls that would otherwise buckle inward along their base. Builders of the Great Pyramid at Giza took extreme cautionary measures by using five of these bridging stones to support the roof above the King's Chamber (Cotterell and Kamminga 1990: 120). That technique also appeared above the entryway to the Menidi *tholos* discussed as a case study in Chapter 4. Counter to the misleading phrase of "relieving chambers" used by architectural historians, the spaces between these horizontal slabs "do nothing to relieve the load" (Cotterell and Kamminga 1990: 120). Losses in stability countering side thrust offset structural advantages from less weight. Similarly, seventh- and sixth-century BC Greek temples at Prinias, Syracuse, and Naxos attempted to lighten lintel blocks with U- and L-shaped cutaways that provided no structural advantage but at least reduced transport and lifting costs (Coulton 1977: 146). Since the viability of an arch depended on the distribution of weight, too much loading on the sides initiated collapse if the weight of the crown did not force the angle of stress into equilibrium with the angle of the arc (Cotterell and Kamminga 1990: 123). In many cases, cracking did not lead to disaster so long as load apportionment and external stress remained within the failure limits of material and design (see Figure 3.1 for trabeated and corbelled spanning at the Menidi *tholos*).

### 3.3.2. Labour rates

Before outlining a possible timetable for a preindustrial construction project, an appropriate rate of progress for each task must be suggested. Three types of sources are available: historical records, ethnographic observations/analogies, and experimental studies. Each type carries its own advantages that sustain debate as to which might harbour the closest resemblance to reality. In the end no single type can stand alone, and taken together they allow for a persuasive model of labour progress. This section explains the history of each type, outlining aspects for improvement with representative examples, which have largely been reserved for the relevant subsections on tasks below.

The first source type for labour rates is the historical record. The oldest of the three, historical record has the advantage of being closer in time to the actual construction with fewer intervening anachronisms. Some records bear a direct connection to the builders, while others maintain some indirect relationship through neighbours or successors. This closeness can include shared heritage, values, knowledge, and technology, items only accessible in the present through material remains. Certain constructions were also better preserved at the time of historical observation, giving the recorder access to dimensions and elaborations now lost or diminished (e.g., losses to ploughing, misunderstanding, or reuse, Hammerstedt 2005: 79; Holtorf 1996: 135, 1998: 33; Turner 2010: 68; Maran 2016: 161–162, see *Reuse* below). Timber is a good example, both for its abysmal preservation in certain climates and the historical record's tendency to oversell it. To fulfil Wen Amon's order

Figure 3.1. Trabeated and corbelled spanning at the Menidi *tholos*.

of timber for the ceremonial barge of Amon-Re, for instance, the prince of Byblos purportedly sent 300 men and as many cattle into the mountains to cut and transport the timber after allowing it to dry for a season (Meiggs 1982: 68). Following the Biblical account from the first book of Kings, Meiggs (1982: 70) highlighted Solomon's dubious monthly rotation of 10,000 corvée labourers from an overall 30,000 reserved to assist Hiram's timber-cutters in Lebanon in the unskilled stripping of logs.

Disadvantages for historical record revolve around glaring inaccuracies in reported numbers, missing or incomplete information, and loss of context. Limitations with measurements and timekeeping, deliberate or poetic exaggeration, and disinterest from the author or audience could all lead to imprecise figures in reported completion times. Where historical reports have undergone review by modern research, discrepancies are unclear when not egregious. For instance, Burford (1969: 251) estimated that 175–200 labourers and craftsmen could complete the Asklepios temple in two years and eight months, leaving two years of leeway with the recorded time of completion and comparing favourably with the 107 men listed for the final construction in the Erechtheion inscriptions. Burford (1969: 193–196) also recorded labour rates for stonework in monetary costs, leaving labour-time estimates for her Appendix III. Her only mention of earthmoving comes in relative costs for digging drains, which prove inconsistent when analysed by measurements (a 10 ft channel is only three times the price of a single foot in one instance, whereas a 4 ft channel is nine times the cost of a single foot in another).

In contrast to incidental inscriptional errors, deliberate misrepresentation of construction magnitude spread fame or infamy on leaders and opponents through propaganda. In the unsuccessful attempt to drain Lake Fucine under the direction of Emperor Claudius, the Elder Pliny excused technical problems as unfinished business left at his untimely death, whereas Tacitus declared the project an instant failure with a mockery of opening ceremonies (Reitz 2013: 78–88). Suetonius's *Life of Claudius* attempted to report numbers for the draining tunnel's construction, but his estimate of 30,000 men working continuously for 11 years to finish a

3,000 ft channel was repudiated by Thornton (1985: 107–112), who could not envision space enough to work for more than 3,000 (Reitz 2013: 92). Authors without a vested interest in a project may omit details in favour of other foci or simply withhold the information to fulfil a grudge, as the Elder Pliny omitted the works of Nero in his list of aqueducts (Reitz 2013: 78–80). Even if details were recorded, many do not survive intact for modern review. Relocated, re-recorded, exchanged and forgotten, historical records have passed through many hands to reach current researchers. Whether closer to fabricated narratives or faithful accounts of past events, historical records remain informative for how contemporary audiences viewed labour, if not for how we measure it.

Before the late fifteenth century AD, most historical records that include observations on preindustrial labour came from Europe, Asia, and northern Africa. Fragmentary reporting on provisions, fortifications, and monumental constructions survived from the earliest writing systems in the Near East and early China (e.g., Abrams and Bolland 1999: 265 with references; Broodbank 2013: 367; Ristvet 2007: 198–199). More complete recordings spread with the Greek city-states and major imperial powers of the last millennium BC (see Burford 1969: 251 on the Erechtheion inscriptions), culminating with Hellenistic and Roman writers of architectural treatises (Plommer 1973). Some of the more useful surviving historical sources on earthmoving include Julius Caesar's dubious observations on the ramparts surrounding the Nervii winter encampment (MacDevitt 1915), early medieval ditches and fortified bridges (Coupland 1991; Squatriti 2002, Tyler 2011), and exhaustive medieval tax records (Bachrach and Aris 1990). The most common historical sources for labour rates still in use are nineteenth-century architectural handbooks (Hurst 1865; Pegoretti 1865; Rankine 1889; see below).

The second source type, ethnography, falls to the observations made among preindustrial populations by outsiders, made popular within the toolkit of cultural anthropology. The fascination with ethnographic accounts of "pure" societies hit its high watermark during the past three centuries, prompting extensive writings attempting total coverage of life for preindustrial or marginalised populations. This has resulted in many cultural histories that often contain direct observations for traditional labour practices. Although not a primary goal for ethnography, detailed recording of labour through interview and observation can enhance comparative labour research with a closer look at construction processes and their immediate effects. Often these observations focus on the age and gender division of labour with food production and crafting sources. Gray's (1963: 36–37) account of irrigation work among the Sonjo of East Africa is an excellent example of ethnographic detail for daily labour, one showing strong gender dichotomy:

> *Hura* cultivation starts in September, the first task being carried out by the men, who flood the fields to soften the ground and then pull up or dig up the stalks and large weeds from the previous year. This is not difficult work and is usually performed by a man working alone or with the help of his sons. Thereafter, a man's share of the work is limited to flooding the fields periodically with irrigation water.
>
> The women then arrive on the scene with digging-sticks and first clear off and burn the trash which the men have left behind. Then the back-breaking work of loosening the soil begins. A seed bed is prepared by digging up the whole field to a depth of six or eight inches. The only implement is a digging-stick (*molo*, pl. *meleo*) about five feet long with a bevelled point. The digging-stick is used with a special technique which involves a rhythmic movement of the body akin to that of the prevailing dance technique. The stick is grasped by the hand about a foot from the point, the woman's body is flexed sharply [p. 37] at the hips, and she plunges the point into the ground. The loosened clod of earth is then thrown backwards between the legs with the free hand. The woman stands in loose earth and faces the unbroken soil as she works. Groups of from six to twenty women are usually seen working together for the initial cultivating of a field. They form a line which works from one end of the field to the other. When the first woman's fields are finished the whole group moves to the next woman's, and so on until all the fields are ploughed. This work is done during the heat of the day. While working in groups they always sing work songs, without which the work would be intolerably hard and tiresome. The rest of the agricultural work—planting, weeding, and harvesting—is done by each woman alone, or with the help of daughters or perhaps a daughter-in-law. This requires a period of field work almost every day. The daily routine of a housewife starts early in the morning with a trip to the stream for water, which may involve an hour's climb down the steep path and up again. The rest of the morning is spent working at home or resting or gossiping with other women. After an early noon

> meal with the family she goes to her fields, carrying a digging-stick and calabashes, and perhaps also an infant, if she has one with no older daughter to look after it. The empty calabashes are left at the main stream, as she crosses it, to await her return. When her afternoon's work is finished she stops at the stream to bathe and rest in the shade with other women, then she fills her calabashes and returns home to prepare the evening meal.

Gray's (1963: 45–46) account continues with a thorough economic review of crafting tasks: women handled leatherwork and dyeing, older men strung bows with strips of goat muscle, and other crafts apart from skilled ceramics and metalwork fell individually to those men with aptitude. Irrigation, without which their agricultural system would fail, claimed the time of men and women, flooding and aerating alluvial fields of heavy loam and upland fields of sandier soils with little more than digging sticks (Gray 1963: 36–38).

Advantages of ethnographic observation and analogy for labour rates include extensive detail of people and process, high-accuracy measurements and timekeeping, and residual connections to past construction. As late as the mid-twentieth century, isolated populations in South America, Africa, and the Pacific Islands engaged in earthmoving activities using traditional techniques if not always traditional tools (ECAFE 1957; Shaw 1970). Nineteenth- and twentieth-century examples likewise filtered through from Europe (e.g., Bachrach 1993, 2005: 270; Squatriti 2002: 41). In some cases, observers were present to record task rates, with many expressing surprise at the speed and efficiency of the preindustrial labour process (e.g., Erasmus 1965: 285). Although not always relatable to past construction, some informants indicated motivations behind the work, including inspiration from oral histories, monuments, and material remains all in complex interplay (*sensu* Dakouri-Hild 2016: 16).

Ethnographic observation and analogy falter where modern tools and techniques replaced traditional technologies, recorders incentivised informants to elicit a desired effect, or the author focused elsewhere than construction (see below). Pre- and post-contact elements often became intermixed before records began in earnest. For instance, to symbolically dissolve kin ties and protect family reputations, a Tobelo marriage ceremony in eastern Indonesia was safeguarded through the sacrifice of a Taiwanese tin plate, which had added value from its origins abroad (Platenkamp 1990: 89). In his work on the Yanomamo, Chagnon (1996: 670; Chagnon et al. 2013) repeatedly addressed rumours of his supplying the Amazonian tribes with machetes and other Western supplies, which had arrived more than a century prior alongside the bananas and plantains that overtook native cassava cultivation. In most post-contact encounters, the rapid spread of metal tools eventually resulted in the replacement of traditional digging implements (e.g., shell and stone hoes, antler picks, digging sticks) with the metal spade, shovel, and hoe. Similar technological replacements affected transportation, introducing wheeled containers and pack animals in place of basket loads and tumplines. The difference in efficiency made these clear choices for labourers. Even where traditional technologies survived, the very presence of an outside observer may have altered construction approaches, prompting labourers to dissemble or impress depending on their own feelings toward being watched or questioned about their work. From the above example, Gray (1963: xii) spent the first month in the field under constant supervision before suspicion relented. Even under optimal conditions of traditional technologies and uninterrupted processes, an ethnographer may simply have diverted focus away from quantitative observations in favour of parsing out the qualitative social effects of labour.

The third and final source type for labour rates originates with experimental study. Deliberate and dedicated, these sources offer the highest accuracy with regard to quantitative observations but are the furthest removed from the original construction in time and motivation. Owing to their flexibility in designing the experiment, quality experimental studies focus on recreating the right conditions for the construction process under question, from replicating technology and techniques as closely as possible to matching material properties such as soil compaction and texture (e.g., Ashbee and Jewell 1998: 491; Coles 1973: 74; Erasmus 1965: 285; Hammerstedt 2005: 46; Milner et al. 2010: 106–109). Where they fail to grasp the reality of preindustrial construction, however, is their very attention to detail and its attendant hyperbaric efficiency. Short-duration experiments of an hour or less further raise questions over stamina and rate stability over a full day's work. In order to truly recreate a real-world scenario, experimental studies must remain self-aware and avoid overcomplicating the exercise.

Regardless of source, units to measure labour costs take many forms: labour-time (e.g., Abrams 1987: 489–491; Ashbee and Jewell 1998: 491; DeLaine 1997: 116–121; Devolder 2013: 42–47; Erasmus 1965: 284–287), wages (e.g., Burford 1969: 55–59, supplemented with labour-time estimates 246–251; Pakkanen 2013: 72–74), physiologic conversions (e.g., Consolazio et al. 1963; Durnin and Passmore 1967; Edholm 1967; Edholm et al. 1970: 1099–1101; James and Schofield 1990: 133–135; Lacquement 2009, 2019; Vaz et al. 2005: 1158–1183), and indirect equivalencies obtained through respiration (e.g., Shimada 1978) or a volumetric standard (e.g., Thornton and Thornton 1989: 20–21). Abrams (1989: 64) placed timed observations at the top of the hierarchy of labour rates, above interviews and speculation through biased historical accounts. Labour-time estimates account for the natural work progression that includes unproductive time (e.g., breaks, repeated tasks, interacting personnel), whereas measurements of mechanical work and physiological effort do not. Although Abrams (1989: 65) hesitated to place these quantifications as "*a priori* closer to the truth", it is clear that comparative energetics raises important questions that would otherwise be missed. In a tempered call for more cross-cultural analyses, both Abrams (1989: 75) and Lacquement (2009: 153–156) asserted that future energetics studies would benefit from an expansion of the corpus of labour rates, organised according to variability in cultural choices and environmental circumstances. Several researchers in recent years have begun to address that deficiency, notably in two recent volumes (Brysbaert et al. (eds) 2018; McCurdy and Abrams (eds) 2019).

Reproduction of task rates in the literature has varied from passing mentions of a single rate to comprehensive tables detailing multiple processes. Common practice resulted in uncritical usage with caveats deployed as an afterthought. This led many to treat task rates with suspicion or forbearance, overpowering them with contextual detail en route to answering other research questions. The most often cited task rates come from the timed observations of Erasmus (1965: 283–285), who organised several experiments comparing the efficiency of wooden tools with their modern steel counterparts at Las Bocas, Sonora, and Uxmal, Yucatan, with male Mayo and Maya villagers, respectively. One bold cross-cultural use of these appeared in the aforementioned study by Webster (1991) on the *nuraghi* of Sardinia. Others opted for borrowing from nineteenth-century handbooks on architecture (e.g., Cotterell and Kamminga 1990; DeLaine 1997). DeLaine (1997: 104) cited her main source as the Italian manual by Pegoretti (1865) with occasional cross-referencing to its English counterpart by Hurst (1865). On the accuracy of rates, DeLaine (1997: 109) limited her final calculations to a maximum of three significant figures to avoid the illusion of overly precise estimates, further deferring to the reliable first significant figure. Defending her choice of labour rates, DeLaine (1997: 105) opted for maximum output to express the lowest possible cost, referring to the opposite as "ludicrous" and dismissing equally any notion of averaging.

Among the latest to review problems with task rates for earthmoving, Lacquement (2009, 2019) converted volumetric recalculations at the multi-mound centre of Moundville into units capable of seamless incorporation to studies from natural and medical sciences (e.g., physics, geology, physiology, ergonomics). His use of mass (volume multiplied by density) and energy in kilojoules (kJ) allowed for a comparative medium appropriate for interdisciplinary research, but he acknowledged these units' limitations for reincorporation into the archaeological narrative (Lacquement 2009: 8–10). Despite the impressive figure of 3.8 billion kJ for Moundville's total energy expenditure, Lacquement's (2009: 125–126; 2019: 170) model ran with a least-cost perspective, always taking the low estimation for labour rate at each of the three stages (excavation, transportation, and compaction). He concluded by decrying the use of solid geometry equations in volume estimations and the borrowing of energetic rates, which yields unrealistic results where variables differ, such as the density of soils (Lacquement 2009: 156). In comparing the rates of Erasmus (1965: 285) and Hammerstedt (2005: 46), the differences originated with the lighter, sandy soils of Las Bocas (0.59 $m^3$/ph or 1.7 ph/$m^3$) being easier to move than the heavier, silty clays found in many areas of the U.S. Southeast (0.29 $m^3$/ph or 3.45 ph/$m^3$).

As Lacquement (2009: 153–156) also suggested, more original experiments and more extensive use of studies outside archaeology could settle what constitutes an acceptable workload per task—in other words, comparative labour rates applicable in more contexts.

*Procurement*

Tools, worker stamina, and soil type significantly influence excavation rate, and the compilation of rates in Appendix 1 reflects this in comparable terms. Already acknowledged as a fault in volumetrics, false equivalencies comparing material volume with various densities have plagued the reproduction of soil excavation rates. Working in sandy soils, participants in Erasmus's (1965: 285) experiments had no trouble posting surprisingly high numbers for soil excavation, including 2.6 $m^3$ (with a digging stick) and 7.2 $m^3$ (with a metal shovel) per 5-hour workday, roughly 0.52 and 1.44 $m^3$/ph (0.7–1.52 ph/$m^3$), respectively. Working in chalk with antler picks, ox scapulae, and woven baskets, Ashbee and Jewell (1998: 491) recorded a more modest excavation rate (5 $ft^3$/mh, 0.142 $m^3$/ph, or 7 ph/$m^3$) in their Overton Down Experimental Earthwork Project. They derived this figure from weighing basket loads in the hundredweight (cwt) unit, which equates to 112 lbs in the U.K. or 100 lbs in the U.S. With the approximate equivalency that 1 $ft^3$ of chalk weighs roughly 1 cwt, the original rate states 5 cwt/mh (254 kg/ph or 560 lbs/ph). Seeing the rate adopted uncritically, however, Ashbee and Jewell (1998: 491) reiterated that pace would change radically under different circumstances, slowing as the distance increased from excavation to deposition. Burford (1969: 247) likewise cautioned limitations over labour-time analogies to modern masonry rates with 8-hour workdays.

Timed observations for the range of soil types between sand and chalk have appeared but not in a widely distributed fashion (Turner 2018: 198–199). Manual labour estimations from a report by the UN Economic Commission for Asia and the Far East (ECAFE 1957) give 0.1 to 0.334 person-days as the required effort for "common" and "dry hard clay" soils, respectively. Converted to $m^3$/ph, this ranges from 0.6 to 2.0 (0.5–1.67 ph/$m^3$), the fastest manual excavation rate noted outside of historical exaggeration. By comparison, the rate achieved by Penn State University graduate students using a short-handled chert hoe in compact silty loam could only achieve 2.0 $m^3$ per 7-hour person-day, or 0.29 $m^3$/ph (3.45 ph/$m^3$) (Hammerstedt 2005: 45–46). From unspecified ethnographic sources for canal construction and an experimental source from the Bolivian Amazon, Erickson (2009: 303) listed a rate of 1 $m^3$/ph sustainable through a 5-hour workday.

Other cases make implicit use of data and limit the conversion of rates with missing information. In one early example on labour costs for excavating tombs at Mycenae, Wright (1987: 174) estimated one cubic metre per person-day as an appropriate soil excavation rate. Although the length of the workday was not mentioned, he referred to calculations in man-hours by Atkinson (1961: 292–297). Modifying rates from the Overton Down experimental earthwork, Atkinson (1961: 295) derived the empirical formula $H = V(120 + 8L + 2F) / 1000$, where H is man-hours, V is volume of chalk in cubic feet, and L and F represent the vertical and horizontal distance between the centres of gravity for an adjacent ditch-and-bank system. It is unclear what hourly rate was intended here. Wright (1987: 174) likely meant an hourly rate between 0.1 (10-hour workday) and 0.125 (8-hour workday) cubic metres, rather than 0.2 $m^3$ when tied to the common 5-hour workday cited as productive time by Erasmus (1965: 285).

Through Pegoretti's (1865) architectural handbook and experimental archaeology on brickmaking, DeLaine (1997: 118) reported clay extraction rates as 14 man-days for 93 $m^3$ and 7 man-days for 49 $m^3$, or 0.5536 to 0.583 $m^3$/ph (1.72–1.81 ph/$m^3$) when accounting for her 12-hour workday. Loading and carrying the clay to preparation areas for moulding into bricks demanded a further 59 man-days for 93 $m^3$ and 31 man-days for 49 $m^3$, or 0.131 to 0.132 $m^3$/ph (7.58–7.63 ph/$m^3$). Although reproducing clay extraction rates for the brick-making process, DeLaine (1997: 133) briefly treated the excavation of clay for the terraces and foundation trenches in the early stages of building the Baths of Caracalla. Rates and quantified details are unclear amid the dismissal of how straightforward this stage of the process was.

To summarise, reported rates for the excavation of soils in just those studies referenced above range from 0.1 to 2.0 $m^3$/ph (0.5–10 ph/$m^3$). When viewed critically, neither rate would be appropriate for contexts beyond the original parameters of their parent studies. However, such single-rate adoption has hitherto prevailed. In a hypothetical scenario, an energetics approach to a ditch system requiring the removal of 1,000 $m^3$ of soil would arrive at 7,042 ph using one rate and just 500 ph using the other. In comprehensible terms, completing the same ditch in two weeks could require 10 or 100 people, enough to sway interpretations to either a light burden for a kin group or a substantial communal effort suggesting more complex labour mobilisation. One counterargument to this problem relies on multiple comparisons using the same rate, but this adds little beyond a simple volumetrics comparison if the rate fails to highlight the differences in each construction process. When comparing multiple earthworks applying rates appropriate to soil type and tools used, however, energetics surpasses the analytical utility of volumetrics without generating false equivalencies or erroneous interpretations. For the simplest energetics comparisons, case studies relying upon multiple timed observations can form a baseline for analysis without adding further variables and calculations. Indeed, so long as the goal is not to model total costs, basic diachronic assessments of ditch systems or rock-cut tombs, for instance, can proceed with multiple rate sources. More robust comparisons, however, require rate sources for more material types and techniques, as well as those that explore beyond procurement.

Alongside the comparatively simple task of earthmoving, wood procurement adds further complications of technique—such as girdling (stripping bark in a ring around the trunk or branch) versus chopping or sawing—to the variability of material and tool type. Citing several Eurasian studies in land clearance with stone axe experimentation, Coles (1973: 20–21) gave rates for tree-felling by tool type and target diameter, with scattered references to wood type. Reported numbers included Iversen's (1956) clearance with flint axes of 2,000 $m^2$ of oak forest in Denmark—trees greater than 35 cm were girdled, and trees smaller than that were chopped down in roughly 30 minutes, with 3 men able to clear 500 $m^2$ in 4 hours. Stelci and Malina (1970) showed that a polished stone axe could fell small trees (14–15 cm in diameter) in 7 minutes in a mixed hardwood and pine forest in former Czechoslovakia, with 21 minutes needed for a 40 cm diameter pine and only 3 minutes for a 13 cm diameter spruce (Coles 1973: pl. 3). Semenov (1964: 30) used a polished nephrite axe from a Neolithic site near Leningrad (St. Petersburg) to chop down a 25 cm diameter pine in 20 minutes, matching work by Smith (1893) with hafted flint axes (Coles 1973: 20). Semenov's observation reflects a rate plateau when linked to Stelci and Malina (1970), in that pines 25–40 cm in diameter took roughly the same amount of time to cut with a stone axe.

Stonecutting likewise varies according to tool and material type, with additional costs from manufacturing finished blocks through shaping and polishing. Burford (1969: 246–251) reported labour-time estimates for stonework involved in the Asklepios temple at Epidauros, with rates sourced from modern restorations on other temple works. For example, one man polishing Pentelic marble for eight hours a day could polish 21 $m^2$ in 40 days. From quarrying to polishing porous limestone, three months were required for one man to produce 0.792 $m^3$, and it took five times as long to work Pentelic marble (Geddes 1960). Using a range of experimental and historical building manual sources, including those from Abrams (1994: 46–47), DeLaine (1997: 111, 121), and Lehner (1997: 206–207) among others, Boswinkel (forthcoming, Tables 7.2 and 7.3) has compiled stoneworking rates for quarrying, transporting, and dressing stone. Citing a reasonable average as 0.5 $m^3$/ph (2 ph/$m^3$) for most stone rubble procurement, Boswinkel (personal communication, 2019) noted many quarrying rates that have an astonishingly burdensome ceiling under channelling (granite, 0.00052 $m^3$/ph or 1923.1 ph/$m^3$ from de Haan (2009: 3)) and sawing (*pierres dures*, 0.001 $m^3$/ph or 1,000 ph/$m^3$ from Devolder (2013: 43)), beneficial only in reducing later dressing costs to finalise block size.

*Transport*

Far less variable than procurement are transport rates for human portage. Manual labour reduced or repurposed after industrialisation has shifted perception for what constitutes an acceptable load for a pedestrian bearer, from the 90-kg loads of coal porters in eighteenth-century London to the 30-kg packs of British infantry in World War I (Cotterell and Kamminga 1990: 193; Desaguliers 1745). Excessive loads still appear in developing regions, such as the 90-kg loads of Nepali hill porters (Malville 1999, 2001: 234) and Bhutan examples of 100-kg potato sacks (Cotterell and Kamminga 1990: 193; Scofield 1976: 680). However, occupational regulators (and experimental archaeologists) are reluctant to assign loads greater than half the bodyweight of the bearers, lest they invite personal injury and its attendant losses.

Excavations of platform mounds in the eastern U.S. have supplemented experimental sources for the weight of basket loads from their apparent outlines in the soil. Lacquement (2009: 129) cited a wide range from previous studies at Poverty Point in Louisiana and the Mitchell site in Illinois, from 7.3 to 52.2 kg and averages at 11 and 22.7 kg. For timed observations of earthmoving, basket loads tended to be on the lighter side of the spectrum. Erasmus (1965: 284–285) found the average carry load to be 20 kg (0.02 $m^3$) for distances of 50 and 100 m, figures that Hammerstedt (2005: 224–225) later adapted for the Annis site in Kentucky. Woven baskets carrying chalk rubble in the Overton Down experiment averaged only 13.5 kg (Coles 1973: 73). Citing studies in North America and South Asia, Aaberg and Bonsignore (1975: 47, 50–57) found a preference for 22 kg (0.011 $m^3$) basket loads, setting weight limits at 15 (0.008 $m^3$)and 40 kg (0.020 $m^3$) and distance-to-source limits at 1 km for clay, 3 km for rock, and an arbitrary 5 km for lime. For earthmoving with nearby soils, the upper transport limit was a 10-minute walk of 600 yards, ca. 545 m (Aaberg and Bonsignore 1975: 53, 57).

Several studies in physiology and ergonomics have reviewed the metabolic cost of unloaded and loaded walking (Abe et al. 2004, 2008a, 2008b; Bastien, Schepens, et al. 2005; Bastien, Willems, et al. 2005; Cavagna et al. 2002; Heglund et al. 1995; Maloiy et al. 1986). Archaeological studies that have adapted these figures in pursuit of kilojoule measurements for transport have avoided the trap of conflating mechanical work and physiological effort (e.g., Lacquement 2009), but it is important to reiterate. Nowhere is the difference between these measurements more prevalent than in the mechanics of walking. Due to limitations on storing potential energy within our joints and metabolic requirements for negative mechanical work (i.e., work done on us as our centre of gravity falls in step), "to provide 1 J of positive and 1 J of negative work we expend 5 J of metabolic energy" (Cotterell and Kamminga 1990: 195). The issue of metabolic cost also arose in experimental woodcutting—coincidentally with costs quintupled from tool inefficiency. Citing Saraydar and Shimada (1971) and their oxygen consumption efficiency tests comparing stone and steel axes, the lighter granite axe apparently consumed 5 times the kilocalories and took 6 times as long as the steel axe, conclusions that Coles (1973: 21) asserted could be reworked with more details on the widths and weights of the tools.

Avoiding wasted energy in moving loads is partly intuitive. Strategies for bearing a load efficiently keep the weight close to the bearer's centre of gravity and distribute the force away from the arms to larger core and leg muscles (Knapik et al. 1996). The modern backpack does so with shoulder straps, and more rugged hiking packs add chest and hip straps to stabilise the load and alleviate shoulder fatigue. Tumplines with head or chest straps appear to be the preferred method of bearing heavy loads in historical Native American contexts (Mason 1896), as well as more recent ethnographic and experimental examples for the Classical Maya (Sidrys 1979), later prehistoric Europe (Webster 1991), and the modern Himalayas (Malville 1999, 2001). Other methods include head-borne baskets among Kikuyu women in East Africa (Maloiy et al. 1986). Evidence for the wheelbarrow does not surface until the second century AD in China, making it unknown in Europe until the Late Medieval Period (Cotterell and Kamminga 1990: 214–215). By the third century AD, wheelbarrows enabled Zhuge Liang's soldiers to each transport a year's ration of rice (180 kg) 10 km per day (Needham et al. 1965: 260).

Since Old World heavy transport has relied upon animal traction for millennia, researchers must compare the benefits of precision in human portage with the raw power available from beasts of burden. The earliest example of wheeled transport comes from pictographic evidence at Uruk near the end of the fourth millennium BC, showing an important figure drawn on a covered sledge held on captive rollers and propelled by a pair of bovids tethered by their horns (Littauer and Crouwel 1979: 14). Mules and bovids are shown pulling baggage carts and commissary wagons in the 1274 BC Battle of Qadesh (Littauer and Crouwel 1979: 84). Referring to the relevant passage in Homer's *Iliad*, Meiggs (1982: 108) recalled that pack mules were purportedly used for transporting oak from Mount Ida in preparations for the cremation of Patroclus, a task for which oak is well-suited as fuel given its high-temperature output. As reported by the Kanesh texts in the early second millennium BC, Mesopotamian merchants (Akkadian *tamkarum*) led donkey caravans carrying metals and cloths, with up to 250 donkeys hauling 60 kg each for 40 days (Broodbank 2013: 367). Burford (1969: 184–187) placed the maximum load of a single-yoke oxcart at 500 kg, limiting wood transport, for instance, to one squared beam of silver fir (366 kg, or 15.9 kg/ft$^3$).

Land transport capacities compiled by DeLaine (1997: 107–108) mostly through literary sources included maximum values for humans and animals: 50 kg for men carrying baskets with similar volume capacities of 0.026 (Roman 2-modius basket) and 0.03 m$^3$ (nineteenth-century builder's basket), 55 kg for a small donkey, 120–135 kg for a large mule, 400–640 kg for a single yoke oxcart, and 340–380 kg per yoke for 8 to 9 yoke teams with a guide per yoke. From Xenophon and the Theodosian Code, Burford (1960: 4) reported similar losses in multi-yoke traction largely due to harnessing issues, with 1,100 lbs (ca. 500 kg) or 25 talents as an acceptable maximum load for a single yoke, only a fifth of the limits for their modern counterparts. As she indicates with Plutarch's tripled limit, the lower quota may reflect more on military and state caution regarding roads and valuable transport stock, and may not necessarily be heeded by private interests (Burford 1960: 9–10).

Each animal carried its own advantages and disadvantages. Cuneiform tablets referred to horses nearly exclusively in their role of pulling chariots. Riding was yet unsophisticated according to pictographic representations, and the animals were too valuable for hauling (Burford 1960: 9; Littauer and Crouwel 1979: 83). Speed was the purview of early horses drawing light chariots, being "too precious, too lightly built, and too nervous for heavy work" (Burford 1960: 9). Such was the value of horses that cavalry lagged behind chariotry due to the stronger herd instinct of early domesticates, as well as the need for effective horseshoes to limit the increased wear-and-tear from bearing the full weight of the rider (Littauer and Crouwel 1979: 11–12). Compared to the sensitive horse, the robust ox could handle rougher terrain, heavier loads, and coarser fodder with less risk to capital investment on the hoof (Burford 1960: 7–9; Cotterell and Kamminga 1990: 207). Regarding the importance of that investment, elites rightly worried over the health of their herds, enacting protective measures and showing formulaic courtesy in well-wishing rival stock (Brysbaert 2013: 64–65; Littauer and Crouwel 1979: 83).

Carrying techniques for animal transport depended on terrain, load weight, and harnessing technology. Carts and wagons in the later second millennium BC showed six-spoked wheels and propulsion by bovid pairs or mules in Hittite and Assyrian representations (Littauer and Crouwel 1979: 73–74). Egyptian baggage carts reflected a similar two-wheeled design resembling modified chariots, while the purported reliefs of "Sea Peoples" ca. 1180 BC had central disk wheels and a rare bovid draught setup of four abreast (Littauer and Crouwel 1979: 74). Most evidence from the period focused on the higher-profile, more glamorous form of wheeled transport in chariots. Road quality determined the efficiency of wheeled transport over pack transport, since quadrupedal beasts of burden did not require a smooth surface to keep pace (Cotterell and Kamminga 1990: 196–197). Oxcarts transporting Pentelic marble to Eleusis performed the 22-mile (35.4 km) journey in 2.5 to 3 days (Burford 1969: 189). Payment for transport was not standardised, perhaps for the multiplicity of variables involved for each load. DeLaine (1997: 98) referenced 5 km/h for donkeys, mules, and a man carrying a burden but only 1.67 km/h for a loaded oxcart, thus the only gains expected from cart transport resolved to weight per load. Even so, too much weight threatened to bury wheels or snap axles, making the sledge a safer option for heavier loads despite the amplified friction. Wheeled carts (two-wheel) and wagons (four-wheel) originally developed from the use of rollers with sledges, which remained in use for the heaviest loads to avoid repeated broken axles (Littauer and Crouwel 1979: 8–9). Problems and repairs associated with heavy transport were listed for Eleusis with the reporting, among other figures, of 17 broken axles (Burford 1969: 252). Wheels and timber rollers on tracks, more durable than the martyred axle yet difficult to manoeuvre, behaved in a similar fashion to modern roller bearings in the exchange of elastic strain energy and alleviation of friction (Cotterell and Kamminga 1990: 199).

Empirical comparisons for lubrication in heavy transport rely on physics and mechanical engineering, but the effects are noticeable without this understanding. Scenes depicted Egyptian VIPs standing alongside water-bearers ahead of massive loads being pulled on wooden sledges, such as the 26-person crew dragging the capstone of Sahure's pyramid (Lehner 2015: 465–466). Lubrication could reduce friction coefficients to 0.15–0.20 and drop the required number of haulers to a third of those needed for an unlubricated sliding load, such that 6,000 men exerting 300 newtons (N) each could haul 1,000 tonnes rather than the far less manageable team of 18,000 men (Cotterell and Kamminga 1990: 222). Rollers on a rough track can drop the friction coefficient further to 0.11 to enable six men to drag a tonne, while well-made rollers can take this value as low as 0.002–0.008, giving one the ability to drag 4 tonnes (Cotterell and Kamminga 1990: 223–224). Evidence for the use of rollers in moving monumental items increases with Classical Greece, but "roller stones" have been found in association with megalithic monuments on Malta dating to 5000–3000 BC (Hannah Stöger, personal communication 2017). Use of rollers for smaller loads are known in early examples from Sudan (Cotterell and Kamminga 1990: 224).

Scheduling and coordinating transport demanded further considerations from organisers of preindustrial transport. DeLaine (1997: 100) discussed the logistics of timber transport from mountainous sources to the crowded streets of Rome. Teams of 6–8 men shouldered logs 20–50 ft or more in length and weighing over 250 kg, depositing them where river currents could take over in floating timbers downstream. Seasonal scheduling factored heavily here, requiring delays for sufficient rains and manipulation of stream flow. Coordinating movement of massive loads also involved conveying orders. In work organised by Domenico Fontana in the sixteenth century AD, the threat of execution quieted spectators for the coordinated movement of the 350-tonne Vatican obelisk that required 900 men, 74 horses, and trumpets to call orders (Dibner 1970: 33).

Labour-saving with water transport has been attested as early as the Egyptian 4th Dynasty, where barges borne on Nile floodwaters brought granite blocks to the Giza staging area of Heit el-Ghurab (Lehner 2015: 430–431). For Roman water transport, DeLaine (1997: 108) presented tonnage classes for ships and river boats: 70–80 tonnes (smallest still suitable for long-distance), 300–400 tonnes (common), 1,000–1,200 tonnes ("supercargoes"), 150–200 tonnes (large river boats), and 70 tonnes (maximum for Tiber River up to Rome) (see also Purcell 1996). For other constants, DeLaine cited crews of 4–10 men, speed under favourable conditions at 3–4 knots, and range at 75–95 miles per day. For river transport, 3-man crews sufficed, with towing capacities for oxen given by teams (38 tonnes for 4 pairs, 95 for 5, and 140 for 6, giving the fair estimate of 20 tonnes per pair) (DeLaine 1997: 108–109). The mechanical advantage of water transport survived into later preindustrial times where speed was not a factor, since the advantage was sufficient to allow one horse to pull a loaded coal barge along a canal (Atkinson 1961: 293).

Apart from the large lintel blocks set above the *stomion* of the Menidi *tholos*, no such considerations of heavy transport have been factored into the labour analysis of tombs (Chapter 4). Wheeled transport likely aided work at the *tholos* by bringing bulk loads of stone, such as the small schist slabs that clad its walls, as well as removing material for its construction and that of the largest chamber tombs at Voudeni (VT4 and VT75). The *dromoi* for these three tombs are wide and gently sloping enough to allow wheeled transport without manoeuvring, which would certainly require unhitching the team to rearrange an unloaded cart. For Portes, the largest chamber tomb (PT3) is too deeply set and narrow to allow for wheeled transport within, but that does not preclude removal of materials from its entrance or a system of ropes and rollers to remove loaded sleds as far as the threshold, alleviating a burdensome, basket-chain system continually making the steep climb.

*Placement*

Placement of culturally modified soils has shown substantial variation depending on the desired effect, from bulk removal of ditch fill into spoil heaps to ritually significant layering of multi-stage mounds. Raising earthworks generally involved some element of soil compaction to stabilise the matrix and retain a desired shape, as well as strategically sourcing less compact fill materials for wholesale volume. Coles (1973: 76) questioned compaction with experimental earthworks reconstructed using heavy machinery and monitored for changes by erosion. Patience with reproduced preindustrial efforts invested soil compaction's effect on earthwork site formation, which has taken generations to observe for British experimental earthworks and world war trenches (Ashbee and Jewell 1998: 485–489, 493–496; Curwen 1930: 98–99). Compaction also affected labour investment but has rarely been measured. Lacquement (2009: 21) tracked compaction energy for earthen mound construction at Moundville, noting substantial differences in density for alternating soil layers used in multi-stage construction: heavy clay for "sheathing" and living surfaces and less dense bulk layers for increasing size. As he pointed out, volumetrics and energetics reliant on construction volume alone have not accounted for differences in expenditure on heavier materials.

For Mycenaean tomb construction, I primarily reverse compaction scenarios to account for the reduced cost of removing bulk fill from reused *dromoi*. Reopening *dromoi* proceeded faster than digging them for the first time, when the undisturbed rocky matrix was at its most compact. Fill compacted over years of rainwash (Smith and Dabney 2014: 150), increasing the required effort for late reuse but not to a level measured here. What might have taken 12 hours to carve initially could likely be reopened with a third of the effort (4 hours with the same team or, more likely, a reduced workforce), and such is reflected in the comparative labour columns on reuse (see Chapter 4 and Appendix 1). Cost of reuse can then be scaled upwards following the number of times a tomb was likely reopened—albeit over an extended period not meant to absorb the burden all at once. Closing the tomb would be among the least costly acts in construction, doubling progress over the standard rate of excavating disturbed fill, from 4 ph/m$^3$ removing it to 2 ph/m$^3$ dumping it back and tamping it down (see below). Smith and Dabney (2014: 146–147) addressed the limited evidence for chamber tomb use and reuse by excavating the Ayia Sotira (Nemea) tombs stratigraphically, leaving baulks and examining layers of fill with macro- and microstratigraphic means. Microstratigraphy of these tombs was the subject of another paper (Karkanas et al. 2012). Evidence showed the tombs were filled from above and partially reopened to allow for cost-effective construction of side chambers (Smith and Dabney 2014: 149–153). As a deferred, final stage, closing need not factor into comparative labour modelling.

Measuring soil compaction requires methods from geotechnical engineering and the application of principles from soil mechanics. Doing just that, Lacquement (2009: 102–103) deployed the sand cone density test and the Proctor compaction test to convert his volumetric recalculations for Moundville into mass, accounting for 375 million kg as the total mass of culturally modified soils (mounds plus the artificially levelled plaza) there. The relative weight of soil types hinges partly on compaction with few—like 2,000 kg per cubic metre of 'heavy clay' (Aaberg and Bonsignore 1975: 53)—stated explicitly. Hoping to spark further study on earthwork compaction, Lacquement (2009: 106; 2019: 170) noted the gap waiting to be bridged between his assessment of mechanical energy in reaching mound fill density through the Proctor compaction test and actual human energy expended. The latter remains unknown in the absence of timed observations on compaction technique and details from each soil layer. Where compaction studies have not been published, standard soil densities serve as placeholders (Lacquement 2009: 116; 2019: 169–170).

In calculating compaction energy, Lacquement (2009: 120) found a staggering 31.5 billion ft-lb/ft$^3$ (43.3 million kN-m/m$^3$) involved in setting the density of mound fill, taken from his constant of 5,000 ft-lb/ft$^3$ (240 kN-m/m$^3$) found on Mound R. The latter value is taken as a reasonable average for mechanical energy invested in compacting soil layers for multi-stage earthworks (Lacquement 2009: 124). This does not reflect the actual physiological cost of compacting the soil, a figure one should expect to push much higher given the disparity between the mechanical effort required and the limitations of human efficiency in achieving this, particularly with burdensome tamping and stamping methods. In a recent paper, Lacquement (2019: 170) updated the energy expenditure for compacting mound layers using the baseline for level-ground marching (1440 kJ/hour per James and Schofield 1990: 134), acknowledging variability in compacting uneven upturned earth but reasonably assuming volumetric progress twice as efficient as excavating.

*Reuse*

Beyond procurement, transport, and placement, another consideration affected labour input in the preparation of the construction site itself, which included clearing, recycling, or reusing building materials from previous structures. Later construction destroyed elements of the prehistoric cemetery at Mycenae, for instance where the Tomb of Clytemnestra intersected part of the Grave Circle B wall (Button 2007: 89; Gallou 2005: 17). Nelson (2007: 150–151) wrote of Pylian palatial construction that "builders at Pylos let nothing stand in the way of their palace; they built massive retaining walls to expand the hilltop and when it came time for the new megaron, leveled and graded the hill in preparation for it". For Mycenae and Tiryns, builders likewise terraced in preparation for new construction (Nelson 2007: 151). Curiously at Tiryns, mudbrick walls from the EH III *Rundbau* survived to a substantial height (diminishing partly after excavations in 1912 and 1984) rather than getting stripped to their stone foundations for reuse by buildings on the LH III Upper Citadel (Maran 2016: 161–162). Reuse of local soils would disappear in secondary construction, but other building materials, particularly worked stone, stand out when reused in earth and rubble fill. Abrams (1987: 487–488) equated reuse of faced stones and broken sculptures in wall fill with a much reduced labour input, citing cuts to two time-consuming stages in primary construction with less transport and manufacture required for onsite reuse. He rightly expanded this reuse to include archaeologically invisible recycling of soil and stone rubble, indistinguishable from newly procured materials in fill contexts (Abrams 1987: 488). This reduction of labour input encouraged secondary use for building materials, no matter the difficulty tracking it.

The simplest cost-analysis compromise for tracking reuse would estimate a likely percentage of recycled materials in the final construction, then reduce the corresponding transport costs omitted by having more material nearby. Such could apply for the reuse of fill in blocking *dromoi* in Mycenaean chamber tombs, but only when space allowed for nearby storage while the passage lay open. Raised areas for Roman Ostia in the first century AD incorporated up to a metre of debris from earlier construction to develop solid foundations for large apartment blocks (Hanna Stöger, personal communication 2017). On reuse and repurposing of ruins, Palladius advocated the use of column fragments in preparing threshing floors and, in a departure from earlier writers, included marble within the list of stones to assist lime production for concrete. Plommer (1973: 37) took the latter case to mean the robbing of marble from abandoned buildings, a practice known from the Later Roman and Medieval periods. Procurement of new materials, apart from disturbed soils being easier to excavate, would not influence the total cost of earthen construction as heavily as with stone, since reused stones also shed manufacturing costs in shaping blocks.

Compiling rates into a comparative labour format (Appendix 1) addresses problems in shortcutting scale comparisons for monumental construction, a common refrain in modelling socio-political complexity. Regional specialisation has limited the versatility of comparative study in forcing a shift to secondary and tertiary sources without the balance of primary data, weakening chances for critical review and reinterpretation (Drennan and Peterson 2012). This has become a pervasive problem for energetics studies that adopt labour rates uncritically, such that some rates pass into conventional wisdom. In one example of a self-styled "cocktail napkin" (i.e., simple and expedient calculation) approach to labour estimates, Peterson and Drennan (2012: 88–89) attempted a sweeping comparative view of community growth for eleven "large-scale social formations" dispersed around the globe. They concluded that most had communal labour requirements of less than one five-hour workday per worker per year (Peterson and Drennan 2012: 123), an artificially low estimate for communal effort. Although the full calculations are not explicit, the basic formula compares demographic estimates against the period of use for multi-stage monumental constructions. This suffices for long-term trends and broad comparisons, but revisions using similar data could produce quite different results on regional scales. Their earthmoving rate derives from Erasmus (1965), claiming 5.25 person-days per $m^3$ of fill for all earthen mound construction. What the original rate measured was the total for rock and earth excavation and transport, the total for earth alone being 1.25 person-days per $m^3$ (Erasmus 1965: 289). The latter rate would also be problematic in a single-use comparative scenario, since loose sandy soils demand less than a compact silty-loam, which Hammerstedt (2005: 45) measured as requiring 3.45 person-days per $m^3$. Most energetics approaches can be strengthened with explicit use of labour rates and careful application when taking a wider geographic and temporal set of case studies.

### 3.4. Measuring success

As illustrated above, comparative labour often surprises with cost estimates that are far lower than expected. Minimal costs, particularly through single rates and diachronic averaging, are largely to blame. Single rates often lose their primary source context and ignore warnings of limited parameters set by their original authors. Dual rates, cited as minimum-maximum, offer radically different scenarios, rightly pointing out the potential for mischief in preferring one over the other. Single rates simplify quantitative comparisons but require rich contextual details to strengthen minimum costs (Abrams 1987: 488; DeLaine 1997: 105). Alternative usage of labour rates, such as trimmed ranges and various indexes of centre, rarely receive consideration within labour analyses. Moreover, the resulting frameworks have remained weakly prepared to counter arguments or prevent tentative interpretations from reinforcing conventional wisdom on complexity. Following the accessible explanations of Drennan (2009: 27–29), the application of appropriate statistical approaches to labour rates strengthens the final model by curbing inadvertent bias, such as the tendency to select numbers that superficially appear more acceptable in calculations. Presented in Appendix 1, the interquartile range of timed observations for earthmoving removes outliers and enables more precise measurements for both expedient and intensive calculations.

With defensible labour rates set in an operational sequence, measurements of built features complete models for preindustrial construction. Many approaches assist with this task: past survey and excavation records, modern and historical maps and photographs, and digital modelling using total station survey, photogrammetry, and 3D scanning (Pakkanen 2009, 2018). Since photogrammetry was the preferred field method for the current study, a separate section below explains this process in detail. Where circumstances limit these field methods, alternate approaches must rely on existing records and other sources accessible remotely through written records or satellite imagery. The section on alternate data collection outlines these tactics.

#### 3.4.1. Modelling tombs with photogrammetry

When site accessibility is not an issue, measurements from total station survey and photogrammetry combine to create efficient, detailed models with high accuracy. Through a simple coding program developed by the Finnish Institute at Athens, the reflectorless setting on two Leica total stations (T500 and T1000) enabled drawing of architectural features, as well as a Digital Elevation Model (DEM) of the local topography. The method has been described in detail by Pakkanen (2009, 2018) from whom it was adopted through training in a field school on Salamis. Combined with a differential GPS, the total station data produced digital models, georeferenced and operational in AutoCAD and ArcGIS, for tombs in their current state of preservation. A daily average of 3,000 measurements with millimetre accuracy goes beyond the needs of logistical labour models but assists local authorities with the preservation of sites.

For earthworks at least, photogrammetry more than suffices for digital reconstruction. The trade-off in much-reduced fieldwork requirements for photogrammetry versus total station survey is a substantial increase in post-fieldwork processing times. Depending on the size of the model and computing power, photo sets of

500 or more for large tombs took weeks to process, with no guarantees that the model would successfully render before the computer ran out of memory. RAM bottlenecks tripled the processing time of several detailed models and occasionally prevented complete rendering, most often during the texturing phase. Lower resolution settings helped where more detail held no useful information for earthen fill and roughly shaped stones. Sparse point clouds captured shapes far beyond those conceivable in hand-drawing under the same time restrictions. They also reproduced volumes within 0.1% of the textured models built under the highest settings. The only alarming discrepancies that occurred were large error margins associated with some photomarkers, presumably from those that shifted slightly or were mistakenly recorded with a different station point.

Despite the accuracy of modern survey technology, the measurements taken are still restricted to the present form of the construction, which in many cases does not represent the original dimensions. If understood, site formation processes can help rewind the denudation of earthworks due to erosion or maltreatment from later activity. Mentioned previously, the Overton Down Experimental Earthwork Project maintains this goal of tracking the denudation of earthworks over the course of multiple generations, with the next cross-section scheduled for 2024 (Ashbee and Jewell 1998: 503). Results thus far have shown that the most dramatic changes to earthworks can occur within the first 25 years, so long as maintenance activities have ceased (Ashbee and Jewell 1998: 496). Under the right conditions (e.g., exposure to inclement weather), denudation of earthworks causes rapid initial loss in shape and total volume before plateauing. This phenomenon allows an earthwork, after its initial decay, to remain relatively unchanged for millennia, barring any extraordinary circumstances. Chamber tombs and *tholoi* are susceptible to ceiling collapse under certain conditions (Cavanagh and Laxton 1981: 114–115; Cavanagh and Mee 1978: 42), potentially inflating estimates for their original construction volume if not taken into account. Known instances—mostly obvious from shallow tombs but with others hidden by reconstruction—were flagged in the labour analysis (Chapter 4).

*Alternate data collection*

Whether restricted by vegetation, preservation, or permission, limited site access requires alternate means of data collection. Site reports detailing survey and excavation records generally record architectural dimensions, but these can be fraught with inaccuracies and missing data. Some older reports relied on estimations and pacing, especially where local informants recounted features since lost. This has often been the case for smaller earthen mounds destroyed by ploughing in the eastern U.S., as well as the decay berm left behind by the former kilometre-long palisade at Moundville (Turner 2010: 68). Loss from subsequent construction was especially rampant at large and dense settlements like Mycenae (Boyd 2015a: 201), and several tombs surveyed in Chapter 4 appear modified from their original form when lying too near the surface or in an overcrowded cluster. Where systematic recording methods compatible with modern standards finally took hold, accuracy of measurements remained at the mercy of crew consistency and supervisor competency. Despite frequent fallibility, historical records still hold clues to major dimensions and visible architectural techniques.

Augmenting site records from previous investigations, existing maps and photographs open another avenue for remote study. Topographic surveys conducted over the last century revealed the extent of large earthen monuments, and areas undergoing Light Detection and Ranging (LiDAR) survey show smaller anomalies in 0.6 m contour lines, even in near-impenetrable tropical regions (e.g., Chase et al. 2011: 387; Evans et al. 2013). Combining topographic data with aerial images and satellite data, even the remotest sites yield to basic labour analyses. Some clues as to chronology, materials, and techniques would be required for a worthwhile model, but at their core, each labour assessment needs only rates and dimensions.

Reviewing methods of volume measurement in the absence of digital 3D analyses, Lacquement (2009: 27) explained older methods invoking solid geometry, contour lines (planimetry with topographic maps), and his own computer-aided gridding technique by highlighting gradients of measurement points used in each calculation, from least (solid geometry) to most (gridding). Rightly indicating the exaggeration of size from formulas for a rectangular prism (lwh) and much less recognisable formulas deployed in frustums of truncated pyramids, Lacquement (2009: 27–29) acknowledged the sacrifice in accuracy for a reasonable comparison between readily available data sets. With regard to rectangular prism formulas used for several mounds at Moundville, relative comparisons between mound sizes were still possible such that the size rankings matched that obtained from modern volumetric estimations, despite overestimations averaging 35 percent preventing the former's use in energetics (Lacquement 2009: 46). What is not touched upon is the loss of material through erosion, such that the original form of the mound may have been closer to the volume estimations idealised from geometrical forms (Ashbee and Jewell 1998: 493, 496; Curwen 1930: 99). Mercifully, volumetrics have been greatly aided by digital 3D analyses, and in place of a losing battle with formulas for a jigsaw of tetrahedrons and circular paraboloids, a suite of software packages paves the field with far greater accuracy. In this regard, I have relied mostly on Agisoft Photoscan to measure the volume of tombs with cropped photogrammetric models, cross-checking on occasion with solid geometry approximations that frequently varied with their digitally obtained counterparts from -20 to +25% depending on the irregularity of the shape.

### 3.4.2. Finding sameness with Euclidean distance

In the chapter to follow, I have generally opted for a baseline cost of excavating the tombs, focusing on variation in procurement rates from the initial expense of cutting into the soft rock to the far less burdensome fill removal in reuse. This sheds the confusing list of transport, placement, and elaboration tasks that would throttle the comparative function of a labour index (Turner 2018: 197). The reported cost of construction is meant only as an analogy to the unknowable real cost, as proponents of energetics have explicitly maintained (e.g., Abrams 1989: 65–68, 1994: 40; Abrams and Bolland 1999: 266–267; Webster and Kirker 1995: 379). Critiques of such incomplete empirical approaches have quieted upon reflection, given its pervasive multi-disciplinary anxieties across epistemology (Foucault 1989: 266). Although originally issued as a challenge to opponents of energetics, Webster and Kirker's (1995: 379) phrasing "*on a scale that matters*" is a useful guideline for the method itself to heed, lest it self-destruct with minutiae.

Too many measurements muddy the reconstructed tomb models, encouraging dimension reduction from computer-aided correspondence analysis. In other words, I sought which variables (e.g., *dromos* length, *stomion* width) were most interrelated and which were nearly irrelevant in terms of cost and mimetic design. Casting off extraneous details trimmed data tables from an illegible switchboard of decimals to color-coded patterns intelligible at a glance. To achieve this I used IBM SPSS Statistics 25 to collate data from Microsoft Excel into a dissimilarity matrix with Euclidean distance (imagining each data point as spatially related to another), first a table comparing the tombs and a second derivative one comparing measurements against a new standard tomb, AA01 (Figures 3.2–3.4, see below). The exercise was inspired by Bourgeois and Kroon (2017: 10), who in turn derived the method from similar practices in genetics research. Before launching the program, variables were interrelated and levelled, such that volumes, linear measurements, and present/absent data could be intermixed. Further, spread from the largest outliers was trimmed by a relative index (e.g., Drennan 2009: 275)—in my case, median measurements derived from the most complete tombs. The Tomb Relative Index, styled conservatively as RexT before leaning into the obvious choice (Ann Brysbaert, personal communication 2019), was a late addition to organise my data into a more manageable framework. I settled on the concept after scrawling a schematic tomb into a notepad and finding the dimensions oddly functional.

#### *AA01 standard and the Tomb Relative Index (TRex)*

By way of a benchmark for comparing all tombs, I have created a fictional idealised chamber tomb (AA01) based upon the median measurements obtained from the better-preserved case studies presented in Chapter 4 (Figures 3.2–3.4). AA01 has a total volume of 27.75 $m^3$ and would cost 250–333 ph to excavate using the rates discussed above and simplified here to 9–12 ph/$m^3$ (4 ph/$m^3$ for re-opening, 2 ph/$m^3$ for closing) of compact earth or soft rock (see also Appendix 1). With an arbitrary team of ten labourers—three digging, six carrying, and one supervising—initial construction for a standard tomb would likely be commissioned prior to the death of the first user and require seven working days of five *effective* hours each, allowing for longer, less-efficient working days in practice without tampering with the calendar time to completion. Re-opening the same closed tomb would take less than two days for a five-person team and could shadow closely the deaths of subsequent users. Whether reuse waited for the last breath is an open-ended question. Sudden death, violent or otherwise, gives only reactionary options without prophetic fortuity. Rapid decay of an untreated body lying in state might provoke the macabre scene of reopening a tomb in anticipation of death, something exceptionally large tombs could hardly avoid in warm climates without embalming or charnel storage. Such tombs frequently bore evidence for anticipatory construction with elaborate preparations for display, such as painted surfaces and re-touched clay coatings, as in the case of the LH IIIA2 Prosilio tomb 2 for a lone 40- to 50-year-old male elite of Orchomenos (Bennet 2017; Yannis Galanakis, personal communication 2019; see Chapter 5, this volume). Secondary treatment of remains was common enough for Mycenaeans to imply contact with putrefaction beyond the modern Western intolerance for it. I offer only windows of possibility for construction and reuse, as the question of timing is better addressed by bioarchaeological and micromorphological analyses on a case-by-case basis. Comparing all tombs to one architectural standard at least, based upon a scale recognisable to Mycenaean tomb builders as neither too big nor too small, emphasizes extreme outliers and the extraordinary risk of investment that the largest tombs represent (see Chapter 5). It also highlights where risks of design changes were generally not taken, as is clear with the fairly consistent widths of *dromoi* and *stomia*. AA01 functions best when compared with other chamber tombs, but it is schematically similar enough to the Menidi *tholos* to link its dimensions to the same scale bar.

| AA01 Fictional | Dromos | Stomion | Vault | Total | Labour (ph) | Workforce | Days |
|---|---|---|---|---|---|---|---|
| TRex | 1 | | 1 | 1 | Low rate | 9 ph/$m^3$ | |
| Volume ($m^3$) | 13.5 | 0.75[a] | 13.5 | 27.75 | 250 | 10 | 5 |
| Length (m) | 6 | 1[b] | 3 | 10 | High rate | 12 ph/$m^3$ | |
| Width (m) | 1.5 | 0.75 | 3 | | 333 | 10 | 7 |
| Height (m) | 3 | 1 | 2.5 | | Reuse rate | 4 ph/$m^3$ | |
| | | | | | 54[c] | 5 | 3 |

[a] The *stomion* volume for all tombs has been included within the total for the vault for ease and consistency with measurements (thus TRex values for vaults are compared against 14.25 $m^3$). [b] TRex values of *stomion* dimensions for length and width are always equal to their recorded measurements, since the AA01 value for these is 1 m. [c] Reuse cost was calculated from *dromos* volume multiplied by 4 ph/$m^3$, representing a single reuse that can be scaled up by the number of proposed opening/closing events.

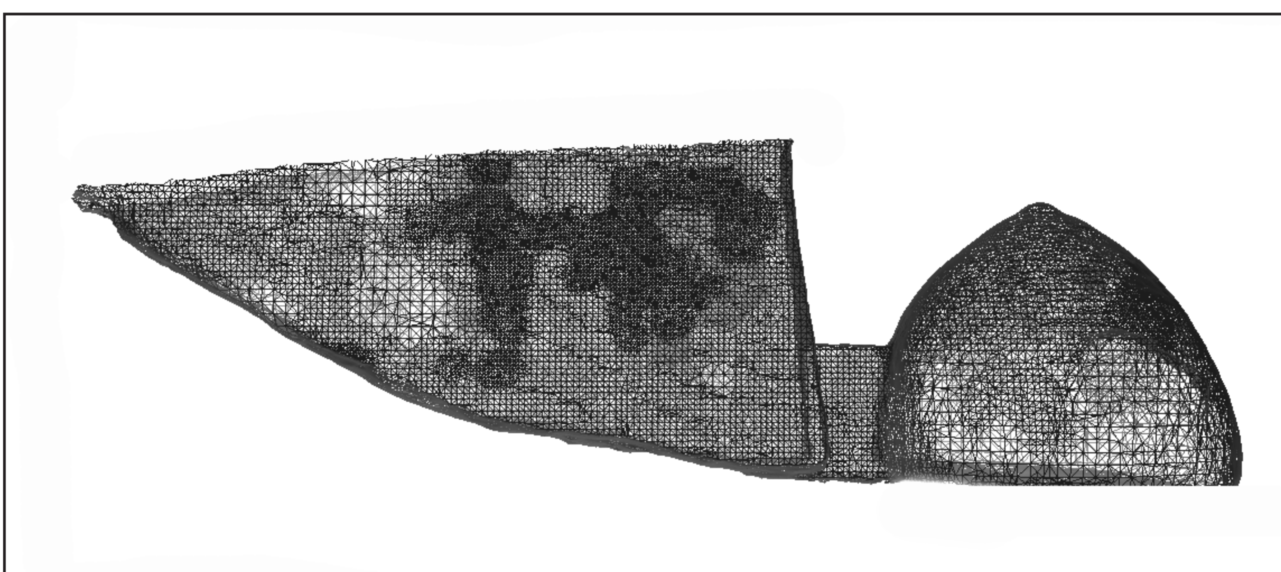

Figure 3.2. Wireframe model (based on the well-preserved VT28) for the fictional AA01 idealised chamber tomb forming the basis of the TRex values (relative index built on median measurements from intact tombs).

In order to correlate the surveyed tombs with the AA01 benchmark, I have created relative index variables that highlight variation among certain tomb features (e.g., total volume, *dromos* length). Such variables allow for useful classifications within the catalogue of tomb construction (Chapter 4) and facilitate rapid scanning of otherwise dense tables. They also place the dataset on equal footing, optimised for correspondence analysis and other statistical tools. The classification thresholds are subjective but not entirely arbitrary. For instance, whereas TRex stands for Tomb Relative Index or relative index total (volume and cost):

Undersized (cohesive or group signal) = TRex < 0.75
Standard (pragmatic signal, can be cohesive or assertive in context) = 0.75 < TRex < 1.5
Exceptional (assertive or costly signal) = TRex > 1.5

Roughly this translates to investment for a working party of 10 tomb builders as either undersized/cohesive (under 5 days), standard/pragmatic (between 5 and 10 days), or exceptional/assertive (greater than 10 days). Mycenaean tomb builders and commissioners may not have seen such strict cost divisions, but they certainly would have recognised the difference in labour input and its attendant message. Other relative index variables break the tombs down into successively smaller (and, as it turns out, less relevant to comparative labour) components, such that RexD is the relative index for *dromos* volume and Rex_sw is the relative index for *stomion* width. As an aside to the label, why not RiT, RID, etc.? Partly the choice is aesthetic, but mostly the inclusion of certain characters (India in the NATO phonetic alphabet and the numeral 1, for instance) in many fonts causes unnecessary coding transcription issues.

A separate list of relative variables appear for tombs that benefit from comparisons with a site-based list of median expected values (e.g., $MedT_p$ for the median expected value of tomb volume at Portes). These function similar to the AA01 relative index variables and cover the same range of component features, the only difference being restriction to surveyed tombs on site. The Portes chamber tombs especially, with their close adherence to a formal chamber shape (hive type with rounded floors and vaulted or incline-vaulted ceilings, see Chapter 4 Section 4.2), lent themselves to site-based median comparisons.

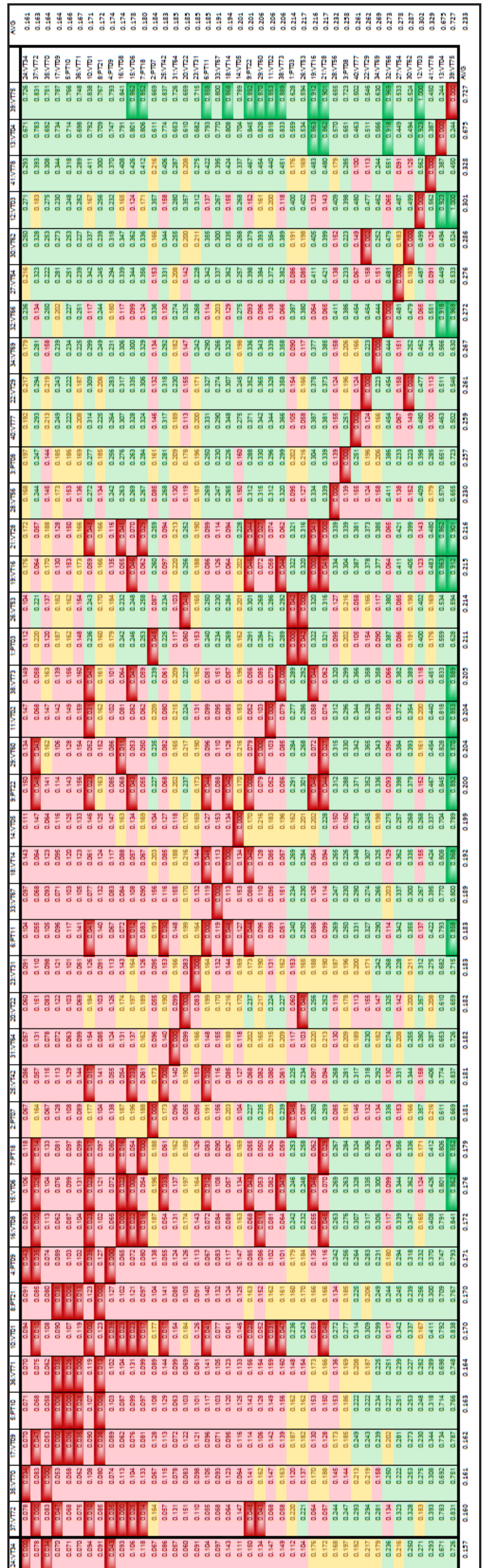

Figure 3.3. Square symmetrical matrix comparing tomb dimensions using correspondence analysis with Euclidean distance.

Proximity Matrix

| | Rescaled Euclidean Distance | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Labor | Dromos | Vault | Total | D_length | D_width | D_height | V_length | V_width | V_height | S_length | S_width | S_height |
| Labor | 0.000 | 0.129 | 0.134 | 0.000 | 0.315 | 0.946 | 0.660 | 0.851 | 0.589 | 0.762 | 0.584 | 0.924 | 0.768 |
| Dromos | 0.129 | 0.000 | 0.207 | 0.129 | 0.382 | 1.000 | 0.727 | 0.919 | 0.662 | 0.832 | 0.637 | 0.988 | 0.837 |
| Vault | 0.134 | 0.207 | 0.000 | 0.134 | 0.343 | 0.970 | 0.683 | 0.868 | 0.596 | 0.772 | 0.615 | 0.941 | 0.784 |
| Total | 0.000 | 0.129 | 0.134 | 0.000 | 0.315 | 0.947 | 0.660 | 0.852 | 0.590 | 0.762 | 0.585 | 0.924 | 0.768 |
| D_length | 0.315 | 0.382 | 0.343 | 0.315 | 0.000 | 0.662 | 0.386 | 0.568 | 0.326 | 0.480 | 0.342 | 0.646 | 0.509 |
| D_width | 0.946 | 1.000 | 0.970 | 0.947 | 0.662 | 0.000 | 0.376 | 0.244 | 0.431 | 0.296 | 0.462 | 0.203 | 0.309 |
| D_height | 0.660 | 0.727 | 0.683 | 0.660 | 0.386 | 0.376 | 0.000 | 0.287 | 0.204 | 0.206 | 0.290 | 0.363 | 0.277 |
| V_length | 0.851 | 0.919 | 0.868 | 0.852 | 0.568 | 0.244 | 0.287 | 0.000 | 0.306 | 0.150 | 0.391 | 0.209 | 0.268 |
| V_width | 0.589 | 0.662 | 0.596 | 0.590 | 0.326 | 0.431 | 0.204 | 0.306 | 0.000 | 0.229 | 0.283 | 0.395 | 0.269 |
| V_height | 0.762 | 0.832 | 0.772 | 0.762 | 0.480 | 0.296 | 0.206 | 0.150 | 0.229 | 0.000 | 0.325 | 0.247 | 0.235 |
| S_length | 0.584 | 0.637 | 0.615 | 0.585 | 0.342 | 0.462 | 0.290 | 0.391 | 0.283 | 0.325 | 0.000 | 0.447 | 0.384 |
| S_width | 0.924 | 0.988 | 0.941 | 0.924 | 0.646 | 0.203 | 0.363 | 0.209 | 0.395 | 0.247 | 0.447 | 0.000 | 0.268 |
| S_height | 0.768 | 0.837 | 0.784 | 0.768 | 0.509 | 0.309 | 0.277 | 0.268 | 0.269 | 0.235 | 0.384 | 0.268 | 0.000 |

This is a dissimilarity matrix


| | Labor | Dromos | Vault | Total | D_length | D_width | D_height | V_length | V_width | V_height | S_length | S_width | S_height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Labor | 0.000 | 0.129 | 0.134 | 0.000 | 0.315 | 0.946 | 0.660 | 0.851 | 0.589 | 0.762 | 0.584 | 0.924 | 0.768 |
| Dromos | 0.129 | 0.000 | 0.207 | 0.129 | 0.382 | 1.000 | 0.727 | 0.919 | 0.662 | 0.832 | 0.637 | 0.988 | 0.837 |
| Vault | 0.134 | 0.207 | 0.000 | 0.134 | 0.343 | 0.970 | 0.683 | 0.868 | 0.596 | 0.772 | 0.615 | 0.941 | 0.784 |
| Total | 0.000 | 0.129 | 0.134 | 0.000 | 0.315 | 0.947 | 0.660 | 0.852 | 0.590 | 0.762 | 0.585 | 0.924 | 0.768 |
| D_length | 0.315 | 0.382 | 0.343 | 0.315 | 0.000 | 0.662 | 0.386 | 0.568 | 0.326 | 0.480 | 0.342 | 0.646 | 0.509 |
| D_width | 0.946 | 1.000 | 0.970 | 0.947 | 0.662 | 0.000 | 0.376 | 0.244 | 0.431 | 0.296 | 0.462 | 0.203 | 0.309 |
| D_height | 0.660 | 0.727 | 0.683 | 0.660 | 0.386 | 0.376 | 0.000 | 0.287 | 0.204 | 0.206 | 0.290 | 0.363 | 0.277 |
| V_length | 0.851 | 0.919 | 0.868 | 0.852 | 0.568 | 0.244 | 0.287 | 0.000 | 0.306 | 0.150 | 0.391 | 0.209 | 0.268 |
| V_width | 0.589 | 0.662 | 0.596 | 0.590 | 0.326 | 0.431 | 0.204 | 0.306 | 0.000 | 0.229 | 0.283 | 0.395 | 0.269 |
| V_height | 0.762 | 0.832 | 0.772 | 0.762 | 0.480 | 0.296 | 0.206 | 0.150 | 0.229 | 0.000 | 0.325 | 0.247 | 0.235 |
| S_length | 0.584 | 0.637 | 0.615 | 0.585 | 0.342 | 0.462 | 0.290 | 0.391 | 0.283 | 0.325 | 0.000 | 0.447 | 0.384 |
| S_width | 0.924 | 0.988 | 0.941 | 0.924 | 0.646 | 0.203 | 0.363 | 0.209 | 0.395 | 0.247 | 0.447 | 0.000 | 0.268 |
| S_height | 0.768 | 0.837 | 0.784 | 0.768 | 0.509 | 0.309 | 0.277 | 0.268 | 0.269 | 0.235 | 0.384 | 0.268 | 0.000 |


Figure 3.4. Square symmetrical matrix, original and colourised, comparing variables using correspondence analysis with Euclidean distance.

## 3.5. Summary

Adopted long before the signalling and mnemonic framework presented in preceding chapters, comparative earthmoving laid the groundwork for the methods deployed here and in the following chapter. Timeless and adaptable, earthmoving imposes few technological or economic constraints on monumental expressions, unlike its more demanding wood, stone, and metallic counterparts. Comparatively low cost and intuitive execution led to its pervasive use in defence, infrastructure, and commemorative construction. As such, it forms a manageable baseline for energetics studies comparing large data sets without volumetric false equivalencies or contextual minutiae. Combining sufficient understanding of building material and mechanics with a relative index recognisable to others as a standard example, more time can be devoted to gathering and interpreting data with greater confidence.

For Mycenaean tomb construction, focus naturally falls on dense clusters of comparatively simple rock-cut chamber tombs rather than their more complex stacked-stone counterparts in *tholoi* and built chamber tombs. The shared tripartite character of *tholoi* and chamber tombs affords baseline comparisons for the excavation costs of their footprints, but the vagaries of stonecutting and transport derail all but the most contextually rich total-cost examples where quarry source and masonry techniques are firmly established. In developing the Tomb Relative Index (TRex), I opted for a chamber tomb closely tied to the median values of as many reliable photogrammetric measurements as I could gather in two seasons of fieldwork. The results of that work are presented in the following chapter.