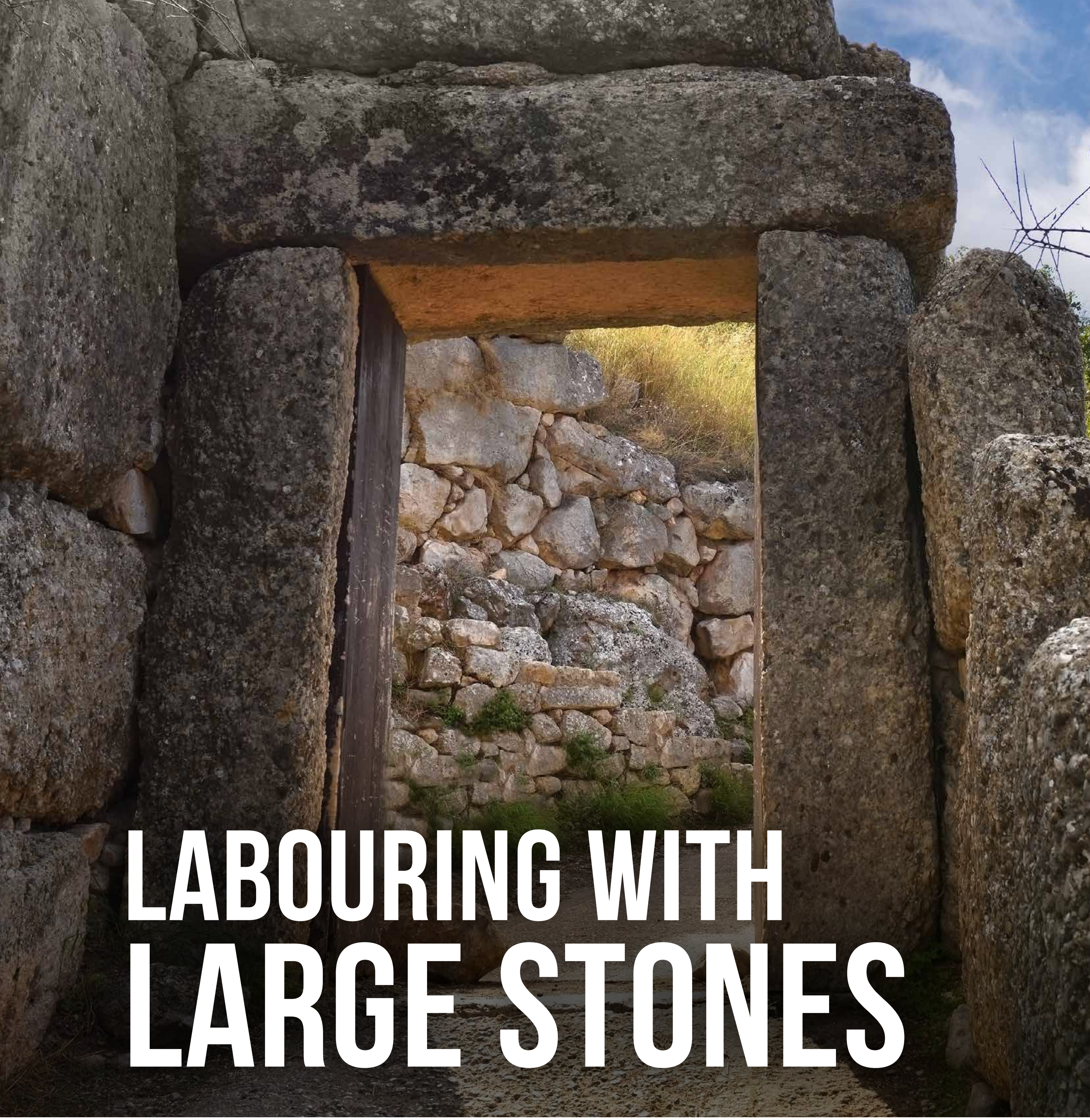

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A STUDY INTO THE INVESTMENT AND IMPACT OF CONSTRUCTION PROJECTS ON MYCENAEAN COMMUNITIES IN LATE BRONZE AGE GREECE

YANNICK BOSWINKEL

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Contents

English Summary

Mycenaean Greece (1600 – 1050 BCE) is characterised by various traits, amongst which, large-scale fortifications, built in cyclopean style. The end of the Mycenaean period is marked by widespread destruction of large settlements and various other changes that indicate a dramatic change. Scholars have been trying to understand these changes for a long time and come up with a variety of explanations. One such explanation comprises the idea that the large-scale constructions of the Mycenaean period, such as the fortifications, were so elaborate that they may have overstretched the economic capabilities of the communities, which caused their 'decline'.

In order to study this hypothesis, which is questioned in the SETinSTONE project, the study presented here aims to estimate the building costs of the fortifications at two sites in the Peloponnese, Greece. Such a labour cost study entails the deconstruction of the building process into various sub-processes for which the required effort is calculated. The data required for these calculations come from fieldwork and literature study. Through detailed documentation of the fortifications in the field, 3D models are created which provide the volumes required for the labour cost calculations. While a labour cost study could never provide an absolute answer of the building costs, since there are too many unknown or uncertain parameters involved, the relative costs can inform on the scale of the investment. This feature is further strengthened when various structures are researched and opportunities are created for thorough comparisons. Hence, besides the primary focus on the fortifications, additional structures (domestic buildings) are also studied, to provide this crucial comparative element.

The fortifications themselves provide excellent case studies to test the earlier described hypothesis, because they are amongst the largest structures from that time and the used building style comprises the use of large stone material. These characteristics are taken as indicators, by some researchers that these structures were very costly to build. Hence, if any construction project would potentially have an impact on a community, these fortifications certainly qualify. Moreover, by studying multiple fortifications a more comprehensive understanding could be reached. While both case studies are located in the Peloponnese, one is at the 'heart' of Mycenaean Greece (Mycenae), whereas the other is located in a region often seen as a more peripheral region (Teichos Dymaion in Achaea). The differences between the sites provide interesting contrasts.

The analyses performed in this research show some interesting results. First, the building style used for the fortifications is not an extremely costly style. Secondly, in comparison to domestic buildings the fortifications as a whole are indeed large investments. Thirdly, compared to each other, the costs of two fortifications show that for a smaller site, the relative costs of fortifying are substantially larger. Finally, it seems that a local community (Mycenae) or a regional community (Teichos Dymaion) would be able to carry the burden associated with constructing such fortifications. At least as long as no other factors were having negative impacts on the communities or their livelihood. It is important to point out that all analyses and subsequent interpretations are the result of the used parameters and assumptions as described in the various chapters. Hence, alterations of these considerations could significantly alter the interpretations.

Nederlandse samenvatting

Myceens Griekenland (1600 – 1050 v.o.j.) wordt gekenmerkt door verschillende karakteristieken, waarvan grootschalige fortificaties in cyclopische stijl, er één is. Het einde van deze periode wordt getekend door wijdverspreide vernieling van gemeenschappen en verschillende andere gebeurtenissen die een dramatische verandering indiceren. Onderzoekers proberen al geruime tijd deze veranderingen te begrijpen en hebben verschillende verklaringen uiteengezet. Eén van deze verklaringen beschrijft het idee dat de grootschalige constructies uit de Myceense periode, zoals de fortificaties, zo groots waren dat deze de economische middelen van de gemeenschappen uitputte, wat leidde tot een ineenstorting.

Om deze hypothese te testen, welke ter discussie wordt gesteld in het SETinSTONE project, is het doel van het hier gepresenteerde onderzoek om de kosten van het bouwen van zulke fortificaties in de Peloponnesos, in Griekenland, te bepalen. Zo een labour cost study, omvat de deconstructie van het bouwproces in verschillende sub-processen waarbij voor elk van deze processen de benodigde inspanning wordt berekend. De benodigde data voor deze berekeningen komt voort uit veldwerk en literatuurstudie. Door middel van het gedetailleerd documenteren van de fortificaties tijdens het veldwerk, kunnen 3D modellen worden gemaakt waarmee de volumes worden bepaald die nodig zijn voor de kosten berekeningen. Hoewel zo een kosten berekening nooit een absoluut antwoord kan geven over de daadwerkelijke inspanningen, aangezien er teveel onbekende of onzekere factoren zijn, kunnen de relatieve kosten wel degelijk wat zeggen over de schaal van de investeringen. Deze eigenschap wordt verder versterkt wanneer verschillende type gebouwen worden onderzocht en er de mogelijkheid ontstaat om vergelijkingen te maken. Vandaar dat naast de primaire studie van de fortificaties, er ook andere gebouwen (huizen) worden bestudeerd, die het cruciale element van vergelijken mogelijk maken.

De fortificaties zelf zijn uitstekende casussen om de hierboven beschreven hypothese te testen, omdat ze één van de grootste bouwwerken uit de periode zijn en de gebruikte bouwstijl gebruik maakt van enorme stenen. Deze karakteristieken worden vaak aangehaald door onderzoekers als indicatoren dat de fortificaties kostbaar zijn om te bouwen. Bovendien kan het bestuderen van meerdere fortificaties leiden tot een beter begrip van de structuren. Hoewel beide casussen in de Peloponnesos liggen, is één casus in het hart van Myceens Griekenland (Mycene in de Argolis), terwijl de andere in een regio ligt die vaak wordt gezien als een periferie (Teichos Dymaion in Achaea). De verschillen tussen beide sites leiden tot interessante contrasten.

De analyses in dit onderzoek leiden tot een aantal interessante resultaten. Ten eerste is de gebruikte bouwstijl niet extreem kostbaar. Ten tweede zijn de fortificaties in vergelijking met de huizen een grote investering. Ten derde laat de vergelijking tussen de twee casussen zien dat de investeringen in een fortificatie voor een kleine site relatief hoger is dan voor een grote site. Tenslotte is te zien dat een lokale gemeenschap (Mycene) of een meer regionale gemeenschap (Teichos Dymaion) de investeringen die nodig waren voor de fortificaties konden dragen. Althans, zo lang er geen andere factoren waren die een negatieve impact hadden op de gemeenschappen en hun levensonderhoud. Het is belangrijk om te onderstrepen dat alle analyse en daaruit voortvloeiende interpretaties het resultaat zijn van de gebruikte parameters en aannames, zoals beschreven in de verschillende hoofdstukken. Mochten deze overwegingen worden aangepast dan kan dit tot significante veranderingen leiden in de interpretaties.

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This book is the result of four years of research that I conducted as a PhD candidate at the Faculty of Archaeology, Leiden University. The completion of this work would not have been possible without the support, encouragement and feedback from a number of people that I would like to thank.

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Glossary

Terms – Meaning

Linear B terms/titles

wanax – king
lawagetas – leader of the host
damos – community
telestai – landholding supervisor
wrokion – individual, likely member of the elite
heketai – follower

Architectural terms

dressing – shaping blocks to a certain style
ashlar – building style with cut rectangular blocks
rubble – building style with uncut blocks
polygonal – building style with cut polygonal blocks
façade – a wall for which there is no structural need
cyclopean – building style with uncut blocks both large and small
corbelled – blocks stacked on top of each other in a way so subsequent layers overhang the layer below and as such the highest layers close of the space

Symbols and units

N – Newton, unit of force
F – force (N)
F_g – Gravitational force
F_n – Normal force, force pressing down on a surface at a 90 degree angle
F_f – frictional force
tonne – 1,000 kg
ph – person-hour
pd – person-day
sin – sinus
cos – cosinus
tan – tangent
r – radius
d – diameter

Chapter 1

Introduction

> "And the mighty Cyclopes came, and toiled to build a most beautiful wall for the glorious city, where the godlike far-famed heroes lived when they had left behind horse-pasturing Argos."
> Bacchylides Ep. 11[1]

> "The wall, which is the only part of the ruins still remaining, is a work of the Cyclopes made of unwrought stones, each stone being so big that a pair of mules could not move the smallest from its place to the slightest degree."
> Pausanias 2.25.8

This study aims to investigate the investment required to build large fortifications during the Mycenaean era in Greece (1600 – 1050 BCE). This is done by calculating the necessary person-hours. The calculated labour costs are subsequently used to interpret the potential impact that these large-scale building programs may have had on the communities in which they were constructed. As such, the following research questions will be answered:

1. How high are the costs (in labour) of the various stages of construction of monumental buildings in Mycenaean Greece?
2. What characterizes the Mycenaean fortifications and how do these features influence the labour costs?
3. What do the costs of these monumental structures tell us about the structure of Mycenaean society and the distribution of its wealth and power?
4. Is the construction of monumental architecture in Mycenaean Greece a local, regional or inter-regional affair, when we consider the origin of the material, required expertise and workforce and construction techniques?

The reason to study the fortifications is their impressive nature, even after a thousand years, they were still referred to with grand descriptions (see quotes above). Even nowadays, these constructions are often portrayed with lofty terms (Brysbaert, 2013, 2015b, 2017; *e.g.* Fitzsimons, 2006). Clearly, these structures were and still are quite imposing and as such have proven to be objects of interest to many researchers (*e.g.* Brysbaert, 2013, 2015b; Cavanagh & Laxton, 1981; Cavanagh & Mee, 1999; Fitzsimons, 2006, 2011; Grossmann, 1967, 1980; Küpper, 1996; Loader, 1995; Maran, 2006; Mee & Cavanagh, 1984; J. C. Wright, 2006, 1978, 2005).

The fortifications are built in the so-called cyclopean-style (*e.g.* Brysbaert, 2013). The style takes its name from the one-eyed giants of Greek mythology, due to the use of very large blocks of stone that, according to the quotes at the start if this chapter, could surely not have been moved by mere mortals. The fortifications are thus not only

1 All English translations of ancients texts are consulted on the website of the *Perseus Project* of the Tufts University (www.perseus.tufts.edu) and are not my own. Any misinterpretations remain my own.

impressive due their sheer size, but also as a result of their building style.

Considering their imposing nature, this study thus aims to find out how the communities coped with the investments associated with manufacturing the buildings. Analysing the cost of large-scale construction for a society has been researched before (*e.g.* Abrams and Bolland 1999, who focused on Central America), but few have made Mycenaean Greece the primary focus of such a study (but see *e.g.* Fitzsimons 2006; Harper 2016). Yet, insight in the cost of such prolonged building programmes can provide a better understanding of the build-up of a society and the impact such building activities had on that society. The SETinSTONE project, of which this research is a part, thus aims to assess "if and how monumental building activities in Late Bronze Age Greece affected the political and socio-economic structures of Mycenaean polities, and how people may have responded to these changes" (Brysbaert 2017: 1). Since these aims go beyond what is possible to study in a single PhD dissertation, the study in this book is one step towards the SETinSTONE goals. Additional studies are executed on the building activities regarding tomb-building by Daniel Turner (2020) and on the subsistence strategies and agricultural economics of the Argive Plain by Riia Timonen (forthcoming). Hence, together these studies provide the core to answer the research questions dealt with within the overarching SETinSTONE project.

The presented research explores the materials and costs of the cyclopean architecture found at two case-studies in the Peloponnese (Greece): Mycenae (Argolid) and Teichos Dymaion (Achaea). The various challenges that the builders faced are discussed. Subsequently, the influence of these structures and their costs on communities are reviewed. In contrast to earlier studies by Fitzsimons (2011) and Harper (2016), who have carried out labour cost studies (see below) based on published data, the data will come from fieldwork. This will allow several types of in-depth analyses of building materials and techniques. Therefore, in this study, the data will be more critically evaluated and subsequently more nuances can be used to come to a better founded estimation of the labour costs.

Labour cost studies are based on the principle of calculating the number of people needed, for what amount of time to perform a certain task. By calculating the required investments of structures, the opportunity is created to compare these structures. Thus interpreting these labour costs is most useful when they can be set against other calculated labour costs. Hence, not only are the fortifications of two sites studied, also a number of domestic structures are considered. This way, the costs involved with building the fortifications can be set against the construction of more mundane buildings and interpretations regarding their potential impact can be properly evaluated.

The fortifications studied in this research are documented using photographs and Total Station point recordings. The subsequent 3D models of the structures, which are created through photogrammetry, are used to calculate the volumes of the structures and where possible of the individual stones. The volumes of the domestic structures are based on data from literature, covering previous studies of these buildings. Using the earlier mentioned labour-rates, an estimate can then be provided on how many persons and other resources are needed to move the materials and achieve the subsequent construction. This method can thus provide an assessment of the costs in labour of the selected architecture.

In order to come to an accurate estimation of the costs of these structures, the construction of the building is broken down into three main stages concerning the material: (1) Acquisition of the material, (2) the transportation of the material to the construction site and (3) the assembly of the building. Additionally, the levelling of the terrain, the dressing of the individual blocks (only where applicable) and the creation of ramps for the assembly are also taken into account. Some of these stages have several sub-phases, which are individually assessed.

This book consists of nine chapters. Chapter 2 is aimed at providing information about the Mycenaean context, in which the studied structures were built. The first section is a basic chronology of the periods under investigation. Secondly, a general background is provided on Mycenaean society, focusing on how this society is seen by scholars, in particular in terms of social differentiation. This is closely intertwined with the third factor: Mycenaean economy. The reason for specifically discussing the economic organisation of Mycenaean society is its link to the aim of the larger SETinSTONE research. The impact of monumental structures on a society is not only a social matter, which may consist of intimidation, display of power and prestige, and the difference between elite and non-elites. It is certainly also an economic issue as this study investigates the required investment for the buildings. In order to explore the economic organisation, a variety of economic models is discussed to examine their applicability to the Mycenaean context.

Subsequently, in chapter 3 the fortifications are reviewed. This review encompasses the function of the fortifications, how they are perceived by modern researchers and in the past, and the used building style is discussed as well. Moreover, the construction process of the fortifications is explored. The first three studied aspects of the fortifications are not just background information, but important factors to take into account to properly interpreting the structures and the subsequently calculated labour costs. As described above, these constructions are seen as very impressive and the building style as very laborious. Hence, properly reviewing these notions and subsequently testing these against the comparisons made possible by the calculations of the labour costs can gain more nuanced insights. Moreover, the construction process of the fortification is discussed in this chapter. The steps of the building process are later used to quantify the costs of the construction of the fortifications.

In chapter 4 the selected sites are presented in more detail. This entails a chronological overview of the sites and an overview of the architecture, in particular the fortifications themselves. Furthermore, labour costs relate to how many people may be involved. To be able to conclude anything about impact, the number of people present at the sites is thus of importance. Therefore, population estimates for both sites are also discussed in this chapter.

Chapter 5 gives an overview of the various (econometric) methods that are employed in the study. It provides pros and cons of labour cost studies as an approach and an explanation of how it is applied within this study. Moreover, the chapter contains the presentation of how the various required data are gathered, through fieldwork (fortifications), literature studies (domestic structures) and reconstructions (volume of individual blocks). This also includes a brief overview of the landscape and geology, as both characteristics influence the labour costs.

The data that forms the foundation of this research is presented in chapter 6. The data revolve around the calculated volume of the various structures being studied. The volume is at the core of the labour cost calculations due to two reasons: first, because most labour rates used to calculate the costs are presented as a number of person hours per given volume. Secondly, because the volume is used to calculate the weight of the material for those steps in the building process for which this is relevant. Finally, the overall cost per volume can then be calculated, which can inform about the price of a building style, rather than informing about a building itself, as the total costs do.

In chapter 7 the labour cost calculations are presented. In this chapter, the required investment in person hours is calculated for the individual steps in the building process. A variety of labour rates is used to calculate the costs for the different steps in order to present a realistic range of the possible required investment. As there are many assumptions made throughout the process, using a range thus allows for a more realistic outcome. A total cost estimate is then provided based on the costs of the individual steps.

In chapter 8 the estimated costs of the structures will be used to make various comparisons. These comparisons will focus on comparing sections of fortifications, the fortifications of the two sites as well as the comparisons to the domestic structures. Moreover, it will be discussed how the costs provide insights into the required workforce and how these were organised. Additionally, the required workforce is compared with the estimates of the population sizes at both settlements. This will aid in evaluating whether the construction of the fortifications could be handled by the local population. All these comparisons together will ultimately provide insights into the potential impact the construction of the fortifications may have had on the communities in which they were built. This all comes together when the costs are placed in their proper context, based on the study on Mycenaean society and economy in chapter 2. A final assessment of the potential impact of the large construction projects will be presented as well as a critical evaluation of the study.

The conclusions in chapter 9 will provide an overview of the work done and the outcomes of the study, answering the research questions. Finally, the study will be critically evaluated and a look onto future research in the field of labour cost studies is provided.

Chapter 2

Late Bronze Age Greece

This chapter is intended to place the architectural study into its Mycenaean context. A number of key characteristics of this context will be discussed. First, in section 2.1, the chronology of the Mycenaean era is presented. Second, in section 2.2, the Mycenaean society is discussed. In this discussion, various interpretations of Mycenaean society are presented and the social hierarchy of this society is debated. This debate will focus on the social hierarchy and the various social institutions that were associated with that stratification. The Mycenaean economy is subsequently discussed in section 2.3, considering the role of the social institutions in the economy. In particular the various economic mechanisms that these institutions may have used is discussed. In section 2.4 the ending of the Mycenaean era, the so-called collapse, is considered. Both the social (section 2.2) and economic (section 2.3) organisation of the Mycenaean world will help to understand how the construction was arranged and how the labour costs might affect local communities. These answers are subsequently crucial to conclude anything about whether the construction processes can be in any way tied as a cause to the collapse (section 2.4). Hence, the presented deliberations in this chapter will be taken into account when the labour costs are interpreted (chapter 8).

2.1 Chronological overview

There are a variety of terms and dates associated with the chronology of the studied area. This short section is merely meant to present these terms and provide a basic overview of the timeline. The Bronze Age in the Aegean (see figure 2.1) covers the third and second millennium BCE (see table 2.1). This period is subdivided into an Early, Middle and Late Bronze Age. The focus here is mostly on the Late Bronze Age, which for mainland Greece, is further subdivided into shorter periods, known as the Early Mycenaean, Mycenaean and Late Mycenaean (*e.g.* Shelmerdine 2008: 5), as can been seen in table 2.2. Although, due to their imprecise dating these terms are used less nowadays. However, they are still encountered in much of the older literature as well as in those instances when the precise dating is less relevant. The Late Bronze Age can also be divided into periods of time referred to as Late Helladic (LH) I, II and III which can be further segmented by the designation of letters (A, B and C).[2] While even more detailed (relative) dating is in some cases possible (*e.g.* Mountjoy, 1999), it is not required for this research. The absolute dating of the construction of the fortifications being studied is difficult at best, therefore this less accurate relative dating is sufficient.

Another thing that can be noted in table 2.2 is the variance in absolute dates. This has to do with the difference in dating method. The "high chronology" is based on more recent methods like radiocarbon dating while the "low chronology" is based on traditional ceramic synchronisms with Egypt and Mesopotamia (Shelmerdine 2008: 5; Manning 2012: 12-8; Shelton 2012: 139). The discrepancy between the two chronologies is limited to a specific period, mainly the start of the LH period up to LH IIIA1 and

2 Helladic derives from the Greek word *Hellas*, meaning Greece. The Helladic period corresponds with the dates of the Bronze Age.

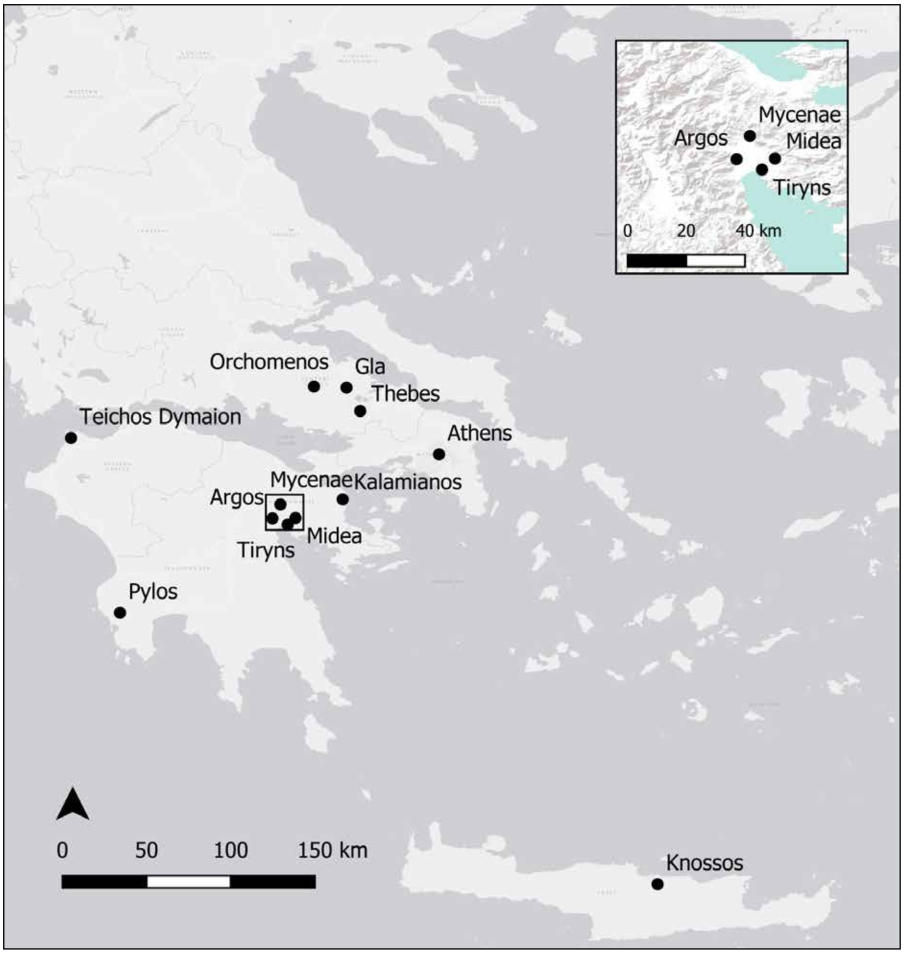


Figure 2.1 Map of the region and the mentioned sites. The inset map shows a section of the region known as the Argolid. The plain in the centre of this section is known as the Argive Plain (created by author, background map by ESRI (light grey and terrain)).

Relative Chronology	Associated dates
Neolithic	7000 BCE – 3100 BCE
Early Bronze Age (Early Helladic)	3100 BCE – 2000 BCE
Middle Bronze Age (Middle Helladic)	2000 BCE – 1700 / 1600 BCE
Late Bronze Age (Late Helladic)	1700 / 1600 BCE – 1050 BCE
Iron Age	1050 BCE – 800 BCE
Archaic	800 BCE – 480 BCE
Classical	480 BCE – 323 BCE
Hellenistic	323 BCE – 146 BCE
Roman	146 BCE – 330 CE
Late Roman	330 CE – 700 CE
Byzantine	700 CE – 1500 CE

Table 2.1 The relative and absolute dates of the various periods on the Greek mainland (after, Manning 2012; Shelmerdine 2008; Bintliff 2012).

never exceeds a divergence of 100 years. It is beyond the scope of this dissertation to go into the (lengthy) debate around the specifics of the dates.[3] Throughout this thesis the established relative chronology (Manning, 2012; Shelmerdine, 2008), as shown in table 2.2, will be used and mostly the abbreviations will be used for Early, Middle and Late Helladic (EH, MH and LH consecutively) as well as for the Late Bronze Age (LBA). As will be shown in the discussion of the Mycenaean society (see below) the main period will comprise the LH III (so roughly between 1,400 to 1,100 BCE, see table 2.2), while the fortifications themselves are mostly constructed in LH IIIB (see chapters 3 and 5).

2.2 Mycenaean society

The context in which a study is done is important because it influences how data are interpreted. The fortifications, which are the objects of study, are part of a Mycenaean context. The term Mycenaean comes from the site in

3 There are extensive discussions on the difficulties of dates in the Aegean Bronze Age, see for an overview Manning 2012 or Shelmerdine 2008.

Relative Chronology			High date in years BCE	Number of years	Low date in years BCE	Number of years	Difference of date in years
LBA	Early Mycenaean	LH I	1700-1600	100	1600-1500	100	100
		LH IIA	1600-1470	130	1500-1430	70	100-40
		LH IIB	1470-1410	60	1430-1390	40	40-20
	Mycenaean	LH IIIA	1410-1315	95	1390-1300	90	20-15
		LH IIIB	1315-1190	125	1300-1190	110	15-0
	Late Mycenaean	LH IIIC	1190-1050	140	1190-1050	140	-

Table 2.2 The relative and absolute dates that apply to the Late Bronze Age in Greece (based on Manning 2012: 18; Shelmerdine 2008: 5).

the Argolid, Mycenae (see figure 2.1 and chapter 5). Subsequently, the name refers to two other meanings: 1) a period, such as described above; 2) the Mycenaean society or culture, describing a group of sites on the Greek mainland that share many similarities. In this section the Mycenaean society will be discussed. This will be done by way of considering four specific elements:

1. Two models of interpretation of the Mycenaean societal structure;
2. The social stratification within the society;
3. The role of the palace as a social institute;
4. The size of Mycenaean communities in terms of demography.

These four elements provide information on how Mycenaean society functioned at various levels of detail. The first component (section 2.2.1) provides a general view on Mycenaean society. The second (section 2.2.2) zooms in on the existence of social stratification. Subsequently, the third element (section 2.2.3) elaborates on the specific role of the palace within that social stratigraphy. Finally, the size of Mycenaean communities (section 2.2.4), in terms of demography, is considered as this can have both social as well as economic implications. Moreover, the population numbers are crucial to be able to conclude anything in regards to the potential impact that the construction of the studied fortifications has on Mycenaean communities. This refers in particular to the question whether a community had a sufficient population to mobilize a large enough workforce. The importance of the social stratification and the role of the palace have to do with the organisation of the labour forces, required for constructing the fortifications.

Information available on Mycenaean society and its organisation comes from various sources. Besides archaeological data in many forms, such as architecture, articles of everyday use and burials (*e.g.* Shelton 2012: 139),[4] inscribed clay tablets have also been found. These tablets are inscribed with a script referred to as Linear B (Palaima 2012: 356-7). These tablets are only preserved in those cases when they were accidentally fired and are thus limited in number. Furthermore, their scope is also restricted as they were intended for administration of mostly economic matters (Palaima 2012: 359). Despite these restraints, they provide useful information, as will be shown in the sections below.

2.2.1 Socio-political organisation of Mycenaean society

Two main models on how Mycenaean society was structured exist. These models focus in particular on how the state or states in the Mycenaean world were organised. One model describes the various citadels as centres of small inter-related states (*e.g.* French 2002: 17; Pantou 2010: 381). This is, in a way, not very different from the later Classical city-states. Another interpretation sees the various citadels as vassals to the primary centre at Mycenae, where a so-called "Great King" resides (*e.g.* Kelder, 2008). This model relies heavily on parallels from the Near East and Egypt as well as the original description of Mycenae in Homer's Iliad and Odyssey. In both cases, the citadels are seen as centres of a specific region (see for example figure 2.2). To what degree specific regions were controlled by certain centres is still difficult to ascertain. Suffice it to mention that the core of both models is that there was a centre that had (some) control over a (defined) region. For some regions, like that of Pylos, the Linear B tablets have provided information that is more detailed. For example, that the region was divided into a number of separate districts for administrative purposes (Bendall 2003: 206). However, the amount and detail of information from the tablets varies per citadel and such data are thus localised.

The idea of a king-like figure was confirmed by the presence of palatial structures (*e.g.* Schliemann 1878; Schliemann and Dörpfeld 1886) and the decipherment of the Linear B by Ventris (*e.g.* Ventris & Chadwick, 1956). On the Linear B tablets there are various officials mentioned that are part of the palatial organisation. The two most

4 This list of archaeological data is by no means complete, but serves as a short list of examples.

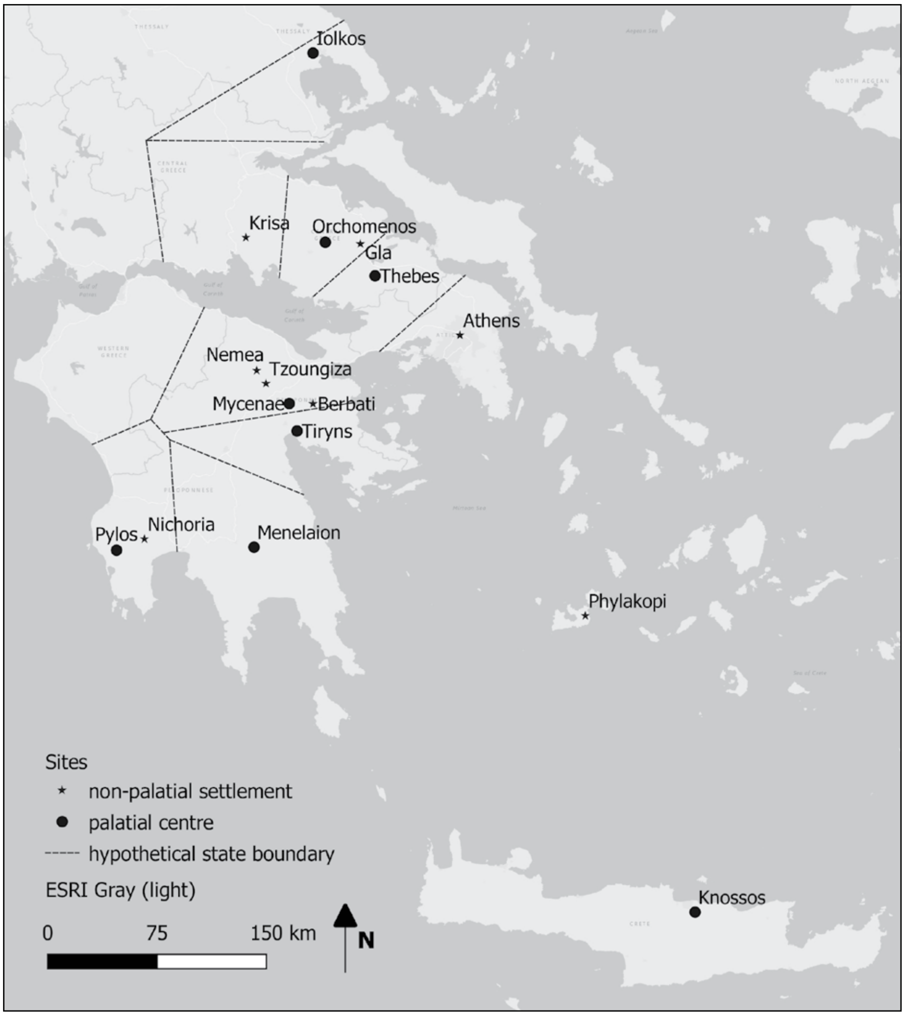


Figure 2.2 Map of part of the Aegean showing important sites (Galaty & Parkinson, 2007, pp. 2; figure 1.1; after Renfrew, 1975, 15; figure 3). Note in particular the "hypothetical state boundary" lines and the lack of potentially important sites in Achaea.

prominent ones are the wanax ("king") and the lawagetas ("leader of the host") (Killen 1998: 21) (see also the schematic overview in figure 2.3). Depending on the model of a unified Greece or a number of independent states, the wanax is seen as the "Great King" at Mycenae, or the ruler of the local/regional state, respectively. The lawagetas has also been identified as someone of considerable power, but subjected to the wanax (Kelder 2008: 50). Two other important social institutes that are represented on the Linear B tablets are the damos and the sanctuaries (Lupack 2011: 207). The damos refers to "political and geographic entities that are commonly called 'districts' or 'district centres'" (Lupack 2011: 212) or are considered to be a "community" (Killen 1998: 20; Halstead 1999: 36). The damos is thus subordinate to the central palaces (Killen 1998: 20), as will be further explored in section 2.3.1. The sanctuaries are an element of a religious sphere. They are mentioned in the Linear B tablets in relation to goods, and possibly land, being allocated to them (Lupack 2011: 207). Although the sanctuaries as such, are not mentioned in the schemes that display the structure of Mycenaean society (see figure 2.3), they are clearly interwoven with the various officials. This is made clear from the fact that the wanax, the lawagetas, and the heketai / eqetai (followers) all have some religious role (*e.g.* Nakassis 2013: 6-7). These roles are not explored further, as they are not of immediate importance for this research. However, the role of the religious sector on the economy is shortly discussed in section 2.3.4.

As an advocate of the view that Mycenae ruled a unified Greece, Kelder (2008, 2016), has argued that there are two reasons why the opposing concept of a "fragmented Mycenaean Greece" is inaccurate. First, he argues that this idea only came about to denounce the 19th and early 20th century idea of a unified Greece in the LBA. Secondly, and supposedly a more thorough argument, is that Hittite and Egyptian texts indicate a large political entity in Greece (Kelder 2008: 50). Eder and Jung argue that the uniformity of the Linear B and the administration system as whole, used in Mycenaean Greece, indicate a singular driving force in the form of a dominating "Great King" (Eder and Jung 2013: 116).

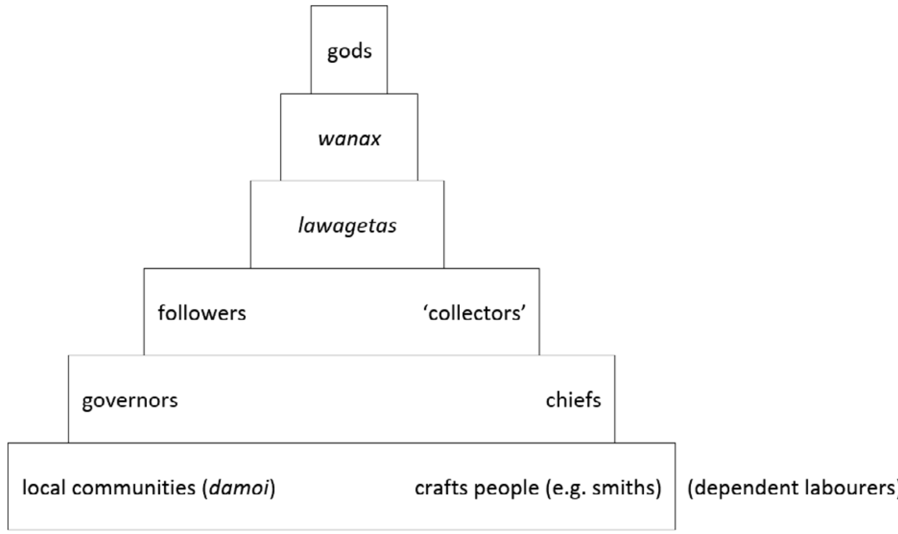


Figure 2.3 Schematic overview of the traditional view on the social structure of Mycenaean society as based on the titles on the Linear B tablets (based on Killian 1988 and Nakassis 2013).

To what extend Mycenae controlled regions is thus difficult to ascertain, but Cherry and Davis (2001: 155-156) stated, for example, that it was possible that Mycenae cultivated the nearby Nemea valley by creating hydraulic works to drain the valley for agricultural use. The views described here, are not without critique though. As will be shown for Teichos Dymaion below, which was not the capital of Mycenaean Greece, not even a palatial site, it had thriving contacts outside its own region. Furthermore, even without a clear palatial elite, some form of leadership existed who organised the construction of the cyclopean fortification there. Moreover, there are scholars, such as Sherratt (*e.g.* 2001), who argue that Mycenaean Greece is nowhere near as important as is thought. She points out that there was, for example, no written communication between Mycenaean and Hittite lands (Sherratt 2001: 218). Moreover, Sherratt (2001) downplays the ingenuity and power of the Mycenaeans, by explaining their society and, more importantly, their sites, as mere nodal points on a larger Mediterranean (trade) network. So whether Mycenae is just another LBA citadel, albeit seemingly rich and possibly powerful, or the seat of a ruler who controlled a larger Greek kingdom, is part of a lively and interesting debate. It is, however, beyond the scope of this research to determine what it may or may not be. This discussion is brought up to highlight how the assumption that there is a great king affects the way Mycenae is seen and its possible role within and beyond the region in which it lies. As such, Mycenae will be, in this book, treated as a singular site, rather than a major capital, in order to make comparisons with other sites more relevant.

Mycenae was not the only citadel in the region. The Argolid has several fortified centres such as Tiryns and Midea. This has led to enormous amounts of data as well as far-reaching interpretations about the individual sites and the region as a whole. In particular the core-periphery distinction is based on this, in which the Argolid is seen as the core of the Mycenaean world with other regions as mere peripheral zones. While more and more contested, much of what is known about Mycenaean society is based on finds from the Argolid.[5]

It is, in light of such comparisons, useful to look at another region as well: Achaea. This region is also located in the Peloponnese, but on the other end, in the north-west (see also figure 2.1). Archaeological research in Achaea has thus far not produced any palatial sites. This has given rise to the hypothesis that there were none. This in turn has been taken to imply one of two things: Achaea was a peripheral region, which was interacting with, but not an integral part of, the Mycenaean world. Alternatively, Achaea was, in its entirety or in parts, a territory of palaces in neighbouring regions. Arena (2015) has argued that Achaea was indeed a peripheral region where, in the absence of palaces, a network of local "chiefs" ruled the area. These local chiefs or elites are mainly attested through the elaborate graves that are present in various areas in Achaea (Arena 2015: 3). Despite the lack of a palace, the concentration of sites around Patras might indicate a "network of close, interrelated small chiefdoms, perhaps developing in a hierarchy of sites centred on something like a 'primary centre'" (Arena 2015: 36). The latter is, however, currently just a hypothesis. Nevertheless, Arena argues strongly against control by a palace "faraway" (2015: 37). Especially for western Achaea, Arena reasons that due to the geographical position as well as the chronology of local ruling sites, Mycenae would have never controlled the area (2015: 19). His other arguments are based on the

5 Although most Linear B tablets are found elsewhere (mainly at Knossos and Pylos).

lack of specific finds (*e.g. kylikes*[6] deposited in dromoi of chamber tombs), that are associated with the rise of the palaces (Arena 2015: 29). Furthermore, Achaea saw a rise in population and a steady settlement pattern throughout the LH IIIC period, despite being affected by destruction at the end of LH IIIB like the rest of the Mycenaean world. Arena takes this as an indication that the collapse of the Mycenaean centres improved the situation for sites in the peripheral regions. It may, therefore, be seen as an indication that (some of) these regions were autonomous since they were not dragged down with the palaces (Arena 2015: 30-31).

Van den Berg (2015: 30) provides additional indications of a more autonomous Achaea. In her analysis of Bronze finds in Achaea and the Argolid, she identifies an important difference in distribution in these regions. Looking at these finds from a network-analysis point of view, she (2015: 27) notices that in the Argolid, Mycenae and Tiryns are clear "hubs" based on the large concentration of finds at these sites. Yet, in Achaea, the bronze finds are more distributed and van den Berg (2015: 30) identifies as many as six "hubs". Similar to Arena, van den Berg (2015: 31) reasons it is local elites in Achaea who play an important role in the exchange with Italian sites and that the Achaean settlements where these elites were located can be seen as "non-palatial hubs".

How Achaea thus fits in the larger Mycenaean world, is not entirely clear. It is apparent though, that Achaea was part of an elaborate exchange network with palatial regions and other contemporary regions (Eder, 2003). This is mainly proven by the presence of specific pottery types (*e.g.* Jones et al. 2014), as well as certain bronze objects (like the Naue II swords; *e.g.* Arena 2015; van den Berg 2015; Gazis 2010) and amber (Eder, 2003). The fact that these finds date, in large parts, to the LH IIIC period and are thus post-palatial, seems to indicate that there was no need for a palace to facilitate (long-distance) exchange (van den Berg 2018: 31; see also section 2.3.3). Interesting in this instance is in particular the exchange with settlements in the Italian peninsula. There has been no proof of palaces of any kind there either (Eder and Jung 2005: 485), which indicates a type of exchange that is not palace-driven. However, Eder and Jung make a case that there was palatial involvement and that the exchange was done by lower level officials like the *qa-si-re-we*[7], who were involved in the palatial bronze industry. Moreover, they argue that it was palace officials like qa-si-re-we that may have filled the space left by the collapse of the palaces (Eder and Jung 2005: 486).

6 Kylikes are a specific type of pottery used for drinking (e.g. Immerwahr 1971: 42).

7 q*a-si-re-we* is a term from the Linear B tablets, which is interpreted as a title of a palatial official.

Another possible explanation for the lack of a palace in Achaea so far, is that it is still buried under a modern city: Patras. Hypothetically, there could be a Mycenaean palatial site located there, perhaps underneath the local fortress, which is located on a high place within the city, just like the hilltops on which the Mycenaean citadels were placed. However, this cannot be tested presently, and neither is there any other evidence to support such a claim.

The fact that there is at least one fortified site (Teichos Dymaion) shows that there was some form of elite capable of organising a workforce large enough to construct it. The results of this research might, therefore, also shed light on this issue since the necessary work force will be calculated in chapter 7.

In the sections below, the various institutions are used to further review how Mycenaean society functioned. In particular the social stratification that existed in Mycenaean society is explored. Although few of the titles as displayed in figure 2.2 are explicitly discussed in depth, the overall rise of social stratification and the role that elites may have played will be the focus.

2.2.2 Social differentiation in the Mycenaean world

It is useful to explore briefly the existence of social stratification within Mycenaean society. As pointed out above, this can aid in understanding the organisation of the work forces, involved in the construction of the fortifications. The overview presented here is by no means complete, however, it shows some influential considerations, some of which tie in together quite well, on how this social stratification came into existence within the Mycenaean context (and slightly before). Out of this stratification, eventually grew a society that is characterised, in part, by a centralised organisation. This centralisation of power, however it came into existence, is a fundamental concept of how Mycenaean society is seen (see 2.2.2). The physical representations of this centralised power are the palaces (see 2.2.3).

First, the concept of conspicuous consumption as a concept within the Mycenaean context needs to be explored, as multiple explanations of social differentiations are based on this concept. Conspicuous consumption is mostly seen as a social or societal mechanism for expressing and maintaining social hierarchy (Fitzsimons 2006: 19).[8] The display of wealth in

8 A modern equivalent of conspicuous consumption can be seen in the phenomenon that rich (sometimes totalitarian) leaders use vast resources to attempt odd record attempts, just to be holder of a *Guinness Book of World Records* achievement. This is perceived, by some, even if only by the leaders themselves, as a way to show what they can achieve due to their status and resources (e.g. HBO's *Last week tonight with John Oliver*, aired 11/08/2019).

any form by elites drains resources and thus may have an impact on the economy. It can also be tied, therefore, to the economic organisation of a society. Mycenaean examples of conspicuous consumption are quite varied and include, in the Early Mycenaean period, the acquisition of luxury artefacts (although this continues through the later periods (*e.g.* Voutsaki 2001)), extensive burial types and, later on, monumental architecture (Fitzsimons 2006: 20; see for the latter also section 3.2). Voutsaki (2001: 206) explains conspicuous consumption as a method to create status, in which wealth is transformed into prestige. The gained prestige means that alliances are sought with the elites which, according to Voutsaki (2001: 206), results in a "steady supply of prestige goods", as reciprocity (see also below) is centralised due to this process. It is difficult to define when this supply of goods is still part of a reciprocal exchange and when it becomes a tribute, or in other words, when it becomes institutionalised (Voutsaki 2001: 207). The aim here is not to find the line between the two, but rather to show that this view on conspicuous consumption, as an elite strategy to gain and maintain power, also provides an explanation as to how a form of tax may have come into existence in Mycenaean society. This is essential as economic systems, based on redistribution and mobilisation, thrive on a form of tax to finance the endeavours associated with them, as well as to mobilize labour and military forces (see 2.3.1). Conspicuous consumption can thus lead to a (steady) form of income with which the elite can afford certain ventures that may be in themselves a form of conspicuous consumption.

There are clear signs of growing social stratification from the end of the MH onwards. This is most noticeable in the mortuary evidence, which shows an increase in elaboration, evident from large cist graves, shaft graves and tholos tombs (Bennet, 2013; Dabney & Wright, 1990; Voutsaki, 2010b; J. C. Wright, 2008). Moreover, the deposition of more elaborate grave goods, another form of conspicuous consumption (see above), also increases (Voutsaki, 1995). As Voutsaki (2010a) has shown for the Argive Plain, both categories (elaborate graves and grave goods) increase dramatically after the MH, reaching a peak just before the LH IIIA period, after which they decrease in LH IIIB. Voutsaki (2010a: 97) also argues that local variations between sites in the Argolid can be seen since wealth concentrates in and around Mycenae and less on other sites in the region. This is an indication of the variety that existed between the Mycenaean polities.

Such expressions of conspicuous consumption (see above) can be used to identify social stratification, but can also be seen as part of a mechanism to create that stratification. According to Voutsaki (1995: 59) wealth itself is not enough to gain power, but it can be transformed into prestige and authority by "ostentatious disposal, public acts of generosity or worship". This is in line with Kilian's (1988: 294) thoughts that the Early Mycenaean burials show extravagant richness that can be linked "to what are quite clearly insignia of political, and possibly other forms of leadership". This is, according to Kilian (1988: 294), evidence that early on claims were made to socio-political leadership in these stratified communities. These claims were later expanded beyond burials and included features like complex architecture (Kilian 1988: 294). It should be noted that rising elites may have comprised kin-groups rather than just individuals (*e.g.* Dabney and Wright 1990; Voutsaki 2010a; Webster 1990). Voutsaki (2010a: 92) has argued that these kin-groups were the main organisational principle in the MH period. In subsequent periods, in particular from the MH III onward, there are clear indications in the mortuary evidence (as mentioned above) that status difference becomes important (Voutsaki 2010a: 97). Yet this is tied to a rise in importance of kinship and descent, visible through the reuse of tombs (Voutsaki 2010a: 97). This trend continues and by LH II the conspicuous consumption associated with these burials can be seen as a "strategy of social aggrandizement and political competition between emerging elites" (Voutsaki 2010a: 97). Taking all this in account, a picture emerges that shows that people may have used the displaying of wealth and linking themselves to (important) ancestors to gain influence. This ultimately led to the rise of a dominant elite. From the Linear B tablets, it is clear that at least during the Mycenaean period (LH IIIA-B, see table 2.2 above) there was a central figure called the wanax. Regardless of the fact whether the ruling elite consisted of a single person or a group, this model on conspicuous consumption shows how people could thus gain power through extravagant spending in burials and monumental architecture (see also section 3.2).

Besides conspicuous consumption, another concept that may be important for understanding the emersion of social stratification is that of reciprocity. Reciprocity is most famously studied in the form of gift-exchange by Mauss (1990 [1925]).

In the Aegean Bronze Age, there are two aspects of society in which reciprocity can be used as an explanatory factor. The first is in the rise and maintenance of the power of palatial centres where "negative reciprocity" created gift-debts that resulted in host-guest relationship (Pullen 2016: 82-84; section 2.2.1). The second type is the gift-exchange between elites in- and outside of Greece through which elites maintained reciprocal relations and facilitated trade (Burns 2016: 89).[9]

Concerning the first type of gift exchange, Sahlins (1972: 193-5) describes three points on a "continuum of reciprocity": generalized reciprocity, balanced reciprocity and negative reciprocity. In generalized reciprocity, a gift is given without the expectation of an immediate return or of a return of equal value and thus a gift-debt is created (Sahlins 1972: 193-4; Pullen 2016: 81-2). Balanced reciprocity describes the situation in which the obligation of reciprocity is immediately released or the return is of equal value. This type of reciprocity is usually associated with "commodity-exchange" (see also Roller 2001: 132) or trade. Finally, negative reciprocity is a situation in which someone would try to gain something for nothing (Sahlins 1972: 195-6; Pullen 2016: 81-2). When gift-debts are created, the recipient becomes "socially subordinate and inferior to the giver" (Roller 2001: 132 in Pullen 2016, 83) and thus a vertical differentiation is established. Not only does Pullen show how manipulation of reciprocity can be used to create social stratification, but subsequently this model could also explain how corvée labour can be the result of a reciprocal system (see above). Acquiring fealty among people does not only provide one with a possible workforce, but also brings about extra prestige. This manipulation of reciprocal obligations may have given some people the opportunity to rise to power and tie lesser exchange partners to them. Goods, services and alliances subsequently "flow" towards a figure or centre and this thus establishes the basis of a centralised structure (Voutsaki 2016: 76). Gift-debts are also created when elite exchange gifts, on whatever scale. However, a gift-debt does not necessarily result in a (lasting) subordination of the receiver, as this state only lasts until the gift has been reciprocated (Pullen 2016: 82-3).

The loyalty to a certain group, as highlighted above in relation to the kin-groups, is also a central theme in another model that describes the rise of a centralised form of power. Sherratt (2001: 229), for example has argued that the Mycenaean palaces, as a form of centralised power, formed out of a warrior society in which "communal drinking and libation rituals" as well as a clientele linkage to larger sections of the population, bound people together. Although not based on kin necessarily, this model seems to suggest that the act of communal activities created certain loyalties as well. According to Sherratt (2001: 229), this social structure was still visible in the palatial society, albeit hidden underneath the palatial bureaucracy and its associated titles.

2.2.3 The role of the palace

The physical manifestation of elites within the Mycenaean world can be found in the palatial structures that are discovered at a number of sites. Furthermore, in a number of studies, the palace is not just seen as such a physical structure, but also as the centralised place of power, a social institution that was in control over certain aspects of Mycenaean society (*e.g.* Shelmerdine and Bennet 2008: 290). This section describes both the physical structure of the palace as well as the palaces as social institutions. As such, this section has close links to the previous section on the presence of social stratification and the next section on Mycenaean economy.

Palaces can be described in architectural terms as monumental, having a complex plan and using specialized techniques in their construction (Dabney and Wright 1990: 47; see also chapter 3 on monumentality). The core of a Mycenaean palace was the megaron; a large rectangular room with a central hearth encircled by four columns (*e.g.* Bennet 2013: 243, see also figure 2.2). The megaron shows that Mycenaean society developed its own ideals, since the nearby older palaces on Crete and in the Near East are centralised around a main court, rather than a megaron-type structure (Sherratt 2001: 228).

Although there are plenty of variations between the individual sites, this megaron was a common denominator among Mycenaean polities, as can, for example, be seen at Mycenae, Tiryns and Pylos (Rehak 1995: 95) and also more recently found in other regions like Thessaly at Dimini (Pantou, 2010). The basic layout of this structure can, according to Kilian (1988: 295, 298), be traced back to the MH period, exemplified at Eutresis, in central Greece (see also figure 2.4). Mansion 1 of the Menelaion in Laconia from the LH IIB period is also considered a precursor of the later megara (Kilian 1988: 295; Maran 2015: 280). However, there is no evidence for actual megara in the final "monumental palaces", before LH IIIA1 (Dabney and Wright 1990: 48). Considering the early predecessors though, it is clear that the palaces did not suddenly appear,[10] rather they developed in places where there were already communities in earlier periods (*e.g.* Voutsaki 2010b).

According to Shelton (2012: 140), LH Greece saw "more uniform developmental stages and material culture out of complex and heterogeneous processes", due to internal indigenous growth and closer interactions

9 Even in modern days the basis of reciprocity still exists. This is portrayed with some humor in the American sitcom *The Big Bang Theory* (CBS 2007-2019), in which a character, upon receiving a Christmas gift from his neighbor, states the following: "I know you think you're being generous, but the foundation of gift-giving is reciprocity. You haven't given me a gift, you've given me an obligation. […] I now have to go out and purchase for you a gift of commensurate value and representing the same perceived level of friendship as that represented by the gift you have given me".

10 Unlike birds, when you are near (Carpenters 1970).

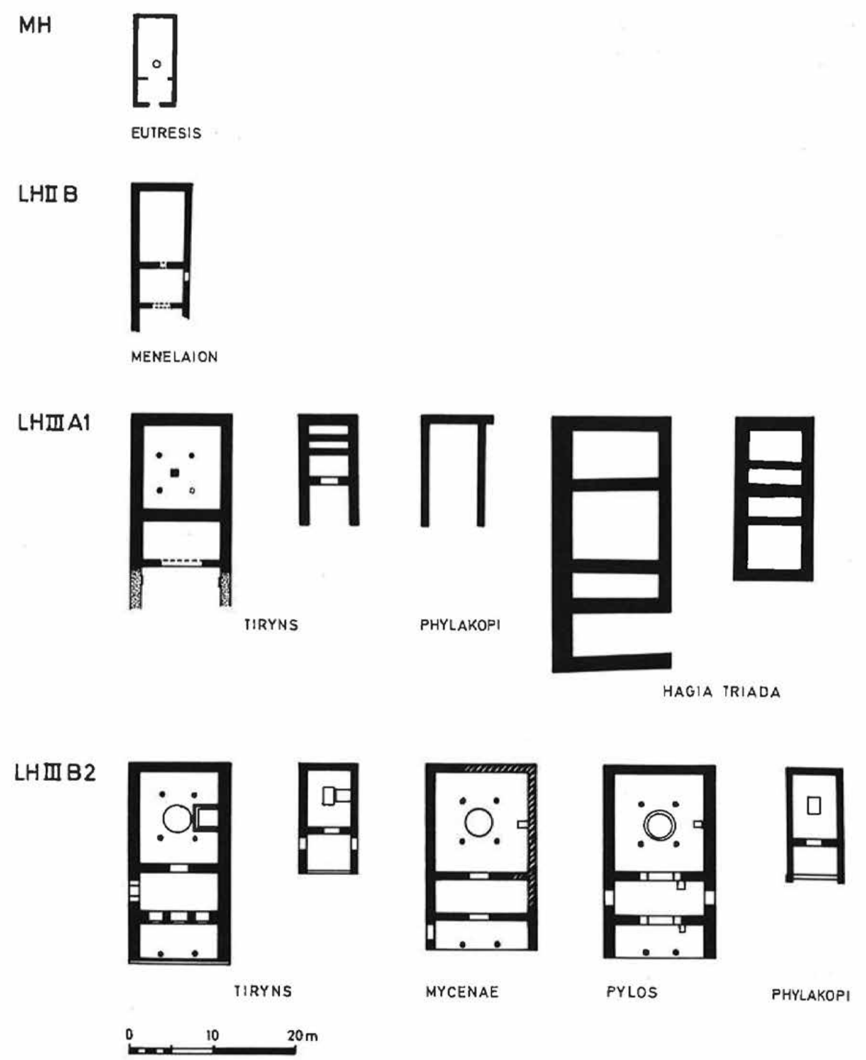


Figure 2.4 Architectural layout of residential nuclei in Mycenaean palaces (Kilian 1988: 295, figure 2, reproduced with permission of the publisher).

with Minoan Crete and the Cyclades. However, palaces are not found in all regions or in the same density. This is shown very well in the regions in which the case studies of this research lie (the Argolid and Achaea, see chapter 4). While there is a concentration in the Argive Plain, with Mycenae, Tiryns and Midea, in Achaea no palatial site has been found to date (Dabney and Wright 1990: 48; Shelmerdine and Bennet 2008: 295; Shelton 2012: 142; see also chapter 4). The rise of the palaces may therefore not be a linear development towards increasing complexity, but rather a local solution to demands for some sort of administrative institution (Dabney and Wright 1990: 48). Intensive contacts between the various centres must have been in place, as the many cultural and architectural resemblances show. The control of production, resources and/or labour at a central location seems to be crucial to the origin of palatial sites in Mycenaean Greece and it is fundamental for understanding the Mycenaean economy. When there is a reference to a palace in the following sections, this should therefore be understood in the way Broodbank (2013: 356) described Mediterranean palaces:

> "It serves as the shorthand for a physical and organisational structure dedicated to large-scale farming, storage and processing, skilled multimedia manufacture, technological know-how and innovation in hothouse conditions, literate supervision of the complex flows of materials and labour demanded by such tasks, as well as trade and gift giving (often deploying its own high-value products), both internally and with peers beyond the palace's rule."

To what degree the palace was in control over all these matters can be questioned though. Even though the existence of a central place is fundamental to our understanding of Mycenaean society, its authority was not absolute. This will also be shown in section 2.3 below.

2.2.4 The size of Mycenaean communities

So far, in discussing the societal organisation of Mycenaean Greece in this book, the focus has been largely on social differentiation. This is a key characteristic and important for understanding the construction of the fortifications in its proper context. Another essential aspect of understanding social organisation is the size of the discussed population (Drennan et al. 2015: 1). Besides the potential understanding about the settlements that population size can provide, for this particular study the population size is crucial for interpreting the calculated labour costs. The aim here is to study the impact the construction of the fortifications had on a community. Hence, it is necessary to establish the amount of people that were needed. This is subsequently compared to how many people there may have been. Only then, can conclusions be drawn about the possible impact. Therefore, it is shortly discussed how many people are thought to have been living at various Mycenaean communities and/or regions.

Determining population sizes from past societies is complicated and inherently approximate (Drennan et al. 2015: 1). There are various methods to calculate past populations, based on different sources of data. Chief amongst these sources of data are settlement size (*e.g.* Carothers and McDonald 1979; Hanson and Ortman 2017; Russell 1958), number and size of domestic structures (*e.g.* Bogaard et al., 2009; Casselberry, 1974; Cook & Heizer, 1968; Naroll, 1962), number of graves and/or size of cemeteries (*e.g.* Alden 1981; Bintliff 1989; Roberts et al. 1989), the carrying capacity of the land surrounding a settlement (*e.g.* Bintliff 1977, 1985, 1989; Timonen: in prep.) and finally, specific for Mycenaean times, extrapolations of the number of individuals mentioned on Linear B tablets (*e.g.* Chadwick, 1972). Each of these datasets and associated approaches, have their merits and their faults. Furthermore, the difference in approach means that for the same site or region different approaches lead to different population size estimates. For example, calculating the carrying capacity of a region results in the maximum number of people that could have lived off the produce of that region. In contrast, calculating the number of people per site based on settlement size uses an average population density over that area (*i.e.* a number of people per area, often hectares). An issue with determining the population based on grave finds is that there are various uncertainties: for example, it is not always sure to what settlement a cemetery might belong; if there is a clear cemetery it is uncertain if it contains all or at least most deceased individuals; whether the cemetery and the researched phase of the settlement are contemporary and the actual number of individuals that is found per grave (*e.g.* Alden, 1981; Bintliff, 2019; Roberts et al., 1989).

One area that has seen extensive studies on the population sizes in the Late Bronze Age is Messenia (south-western Peloponnese). Estimates for this region have ranged from a minimum of 50,000 (McDonald and Hope Simpson 1972: 141), to ranges of 80,000 to 120,000 (Chadwick 1972: 112-3), to 178,000 (Renfrew 1972: 251) and finally to as many as 235,800 people (Carothers and McDonald 1979: 435, extrapolated from Renfrew 1972).[11] For the latter two estimates, the population density at settlements is estimated to be as high as 300 people/ha (Renfrew 1972: 251; Carothers and McDonald 1979: 435), while for the lowest estimate the density is estimated to be 130 people/ha (McDonald and Hope Simpson 1972: 128).[12] For Knossos (Crete) the population has been estimated between 1,000 – 1,250 people during the Mycenaean period, based on a density of 200 – 250 people/ha (Whitelaw 2000: 225). Another often quoted population number comes from Mycenae where a comparable density of 200 people/ha is assumed and the site is estimated at 32 ha, resulting in a population of 6,400 people (*e.g.* French 2002: 64; Bennet 2007: 187). Hence, basic population densities for urban areas in the Late Bronze Age Aegean seem to have been estimated between 130 – 300 people/ha.

Since the approach of estimating the population size through settlement size is already available for one of the case-studies in this research (Mycenae), this method will be used to determine the population size to put the labour costs into perspective. The many uncertainties with using cemetery data and the difference between carrying capacity and actual population figures, mean that the population based on settlement size seems more appropriate in this study. This is also because at least for both sites an extent of the settlement has been determined (*e.g.* French, 2002; Gazis, 2010), whereas some of the required information for the other approaches is not available. It must be pointed out, that these calculated population sizes cover only the sites themselves. Surrounding hinterlands with farming communities that may be tied to, or even controlled by, the fortified settlements, are not unpopulated. This means that the potential labour pool from which workers could be drawn for the construction work could be larger than just the settlement population. A more detailed determination of the population sizes at both case-studies is presented in chapter 4.

11 Part of the reason for all the discrepancies in total population estimates has to do with the fact that different sized areas were used for the calculations in some cases (e.g. Carothers and McDonald 1979: 435).

12 The range provided by Chadwick (80,000 – 120,000) for the population of Messenia during the LBA is not based on a density. Rather, he extrapolates a number of individuals per settlement based on Linear B inscriptions and multiplies that by an estimate number of settlements (Chadwick 1972).

2.3 The Mycenaean economy

Archaeologists tend to categorise all their finds, whether it is pottery, architecture or weapons, to name but a few types of artefacts. Categorising helps to distinguish one group of finds from the next to highlight differences or similarities, which, in turn, will help to gain a deeper understanding of the past. The same applies to the more abstract, theoretical matters in archaeology, such as states, societies and ancient economies. These social institutions are extrapolated from the available archaeological data and, where it is available, written sources. In this section the Mycenaean economy is discussed. An understanding of how the Mycenaean economy may have functioned is fundamental, as it will have an impact on the interpretation of the results from the labour cost studies (see chapter 8). This is because of the economic nature of this study (labour costs) and the close link between the economic and socio-political organisation of the society. This will also be shown in the sections below.

The overview presented here is not complete, however an attempt is made to discuss a variety of economic models that may properly describe (parts of) the Mycenaean economy. To structure this discussion the four sub-sections below coincide with four inter-locking sectors of "Bronze Age Aegean economies" as described by Earle (2011: 241):

1. The political economy of palaces;
2. The subsistence economy in local communities;
3. The trading economy of entrepreneurs;
4. The religious economy of sanctuaries.

Within this structure, various modes of exchange, different institutions and the control of production factors are discussed. In particular how these fit with certain (theoretical) economic models and how these are relevant for the Mycenaean context is explored. The focus is mostly on how the various economic models intertwine with the social stratification as described in 2.2. It will be shown that many of the models need or strengthen such social stratification and that the palace takes a central role in most instances. However, it will also be shown that, despite the heavy presence of the palace in these interpretations, its control was not absolute (*e.g.* Halstead 2001: 38; Nakassis 2013: 2-3). While it is by no means the aim to provide a complete overview or a final determination about what is or is not under direct palatial control, the influence the palace had is important. This is relevant as it provides understanding about how the palace may have had enough influence to order the construction of the fortifications as well as how the influence of the palace was build-up. Hence, the emphasis will be on the political economy. The other sectors will only be described shortly.

2.3.1 Political economy

Political economy within the context of this study, is about the political institute, the palace (see 2.2.3 above), and its influence and/or control over (parts of) the economy. A political economy is: "the material flows of goods and labour through a society, channelled to create wealth and to finance institutions of rule" (Earle 2002: 1). The palatial influence over, and the interlocking of that sector with, certain other institutes or sectors have also been mentioned in the sections above. In accordance with the argument in section 2.2, a form of centralisation was not only fundamental to Mycenaean society, but has also been seen as elemental to its economic system. Below, a number of characteristics are discussed that underline the central role that an institution like a palace may take within an economic system.

Mycenaean (and Minoan) palaces used to be viewed as being similar to Near Eastern redistributive centres that controlled production, storage and distribution (for an overview see *e.g.* Morris 1986). This was often tied to the existence of a powerful religious or priest class and/or having a redistributive system in which the temple takes in large contributions and redistributes them to its followers (Morris 1986: 12; Bendall 2007: 4). This thus puts the palace in a primary role within the economic system. The similarities to the Mycenaean economy are also described by Killen (1985: 241):

> "economies, in the two areas, in which the key role in the movement of goods and the employment of labour was played, not by a market or money, but by a central redistributive agency: in the Near East, by a central palace or temple; in the Mycenaean world, by a central palace".

This has been challenged over the last few decades (*e.g.* Nakassis et al. 2012; Bendall 2007). In a redistributive system, there is a central institution collecting goods from groups and individuals and subsequently redistributes these goods (Pullen 2011: 186). The term is somewhat problematic, as it has been used to describe a variety of systems, but it indicates a form of movement of commodities characterised by centricity (Nakassis et al. 2011: 180). Characterising an economy as redistributive denotes that the central institute has power over all transactions within said society. However, recent research has focussed on the complexity of redistributive systems and views them as consisting of multiple types of exchange, intersecting with each other and running on different scales (Nakassis et al. 2011: 180). It is therefore misleading to characterise an economy as redistributive, when only parts of it would function in this manner (Earle 2011: 241). In line with these thoughts, current scholarship tends to view the influence of the palace as being far more selective and only controlling a part of the goods that were exchanged (*e.g.* Nakassis et al. 2012: 244; Halstead 2011: 233).

A number of people relied on rations from the palatial centre as payments in kind, for example (and most relevant for this study) labourers carrying out construction work (Nakassis 2010: 275). Nakassis' study on the tablets from Pylos, shows that payments were made to various people with different ranks within the construction work and that the amount was tied to this rank (Nakassis 2010: 275-8; see also below). While this is in itself important for our understanding of the building processes researched in this dissertation, it also provides a look into the economic organisation of palatial centres. The payment of labourers in kind could perhaps be characterised as part of a redistributive system. If so, it suggests that sections of the Mycenaean economy were redistributive in nature. Clearly, redistribution has its complications when applied to the Mycenaean economy, but in its simplest form, parts of the Mycenaean economic organisation are redistributive (Halstead 2011: 233).

This dependence, however, could also be characterized differently. Broodbank (2013: 356), for example, argues that the whole designation of redistribution is no longer valid. He argues that the initially social aspect of redistribution in which products are taken or taxed in (economically) good times by the palace and aid is provided by the palace in bad times is no longer tenable. Instead, he views the palaces as "extractive institutions that mobilized wealth from taxes, estates, share-cropping, compulsory labour, trade", whose elite inhabitants validated their position through traditions, "kinship and other social alliances" which they retained by use of force if necessary, as the palaces "jealously guarded a military monopoly" (Broodbank 2013: 356). In this view, there is thus little to no distribution back to the populace. In following Broodbank, redistribution may not be the best description of how the palace-controlled economy was organised.

As shown above, the widespread use of the concept of redistribution for a variety of institutional forms may have led to some confusion amongst scholars (Halstead 2011: 233). Several scholars therefore advocate moving away from redistribution, and presenting an alternative in the form of mobilisation (see also the quote from Broodbank (2013: 356 earlier). In this model commodities move upwards supporting elites and their dependents and thus can be seen as a strategy adopted by elites to strengthen their control and prestige (Nakassis et al. 2011: 180). This upward flow consists of the collected surpluses that were used to finance the operations of the state (Earle 2011: 239; Nakassis et al. 2012: 245). These operations consist of enabling "dependent workers to involve themselves in highly specialized craft activity" (Killen 1999: 88).

The mobilisation of goods consists of two possible finance systems: staple finance and wealth finance. The first is the procurement of subsistence goods (*e.g.* grain, livestock) by the state. The second involves the production and obtainment of special, valuable goods (D'Altroy and Earle 1985: 188). The palatial organisation around raw material acquisition and craft production focused on only a few industries that enabled a large degree of specialisation. Furthermore, palatial products may have been intrinsically more valuable due to their tie to the palace (Burns 2016: 90; section 2.3.2). This large degree of specialisation and the added value of palatial products formed the basis of Mycenaean wealth finance (Halstead 2011: 233).

Although mobilisation is said to focus on the upward flow, there is always something flowing back down. For example, the palace would attract craft specialists who would be paid in rations of staples, which would thus indicate redistribution (Earle 2011: 243). Earle argues that the same is true for craftsmen like architects, stonemasons and painters, but also unskilled workers (Earle 2011: 243). The focus in a mobilisation economy is on the financing of operations of the state, rather than distributing goods, yet there is a certain goods come in and go out system. The characteristic of mobilisation that is helpful though, is the differentiation between staple and wealth finance, since it shows what the focus of the palatial administration was on (see also below). It is important to realize that one type (staple finance) enables the second type (wealth finance). Moreover, as will also be shown, it is clear that the palace was not only concerned with raising staple for food supplies, but also, perhaps even more important, the mobilizing of raw materials for luxury and exotic goods production, and labour forces for a variety of work. These three aspects are crucial to the success of the palace-driven parts of the economic system.

It has become increasingly clear that the palace only had control over a portion of commodities that were being exchanged in the Mycenaean economy (*e.g.* Bendall 2007; Pullen 2011, 2013; Schon 2011; Halstead 2011; Bennet 2013; Parkinson et al. 2013). It seems that the palace mostly concentrated its administration on products of status and prestige, like precious metals, ivory and the textile industry (Schon 2011: 220; Pullen 2013: 439; Voutsaki 2010b: 101). Alternatively, as Bennet states, the state took over when it was "advantageous" (Bennet 2013: 248). This idea fits well with the mobilisation model in which the palatial elites use staple goods to enable the acquisition of raw materials and subsequent creation of valuable goods (see 2.3.3). Bendall, however, questions the amount of control of the elite, even in industries that are well attested in the Linear B tablets. She writes that although the tablets show the incoming goods and the internal circulation of goods, they almost never show what was finally done with those goods, except in the case of donations to the religious sphere (Bendall 2007: 291). This is important for two reasons: firstly, it confirms that the Linear B tablets have very limited administrative range, since even for a rather well-documented industry like the textile one, the simple out-go of the products is missing.[13] Secondly, the religious sphere seems to represent a special domain within the economy (see below in 2.3.4).

The interpretation of elite control leans mostly on evidence from the tablets and the assumption that if it is mentioned in the tablets, the palatial administration found it worthy of recording and thus the palace was involved. Besides various crafts, land was another subject that comes up on the tablets. Killen (2008: 163) concludes that the reason for the palatial interest in tracking land ownership did not have to do with some cadastral survey, but rather that landholders were expected to contribute tax, based on the size of land. However, land was seemingly not under complete control of the palace, because as Lupack (and others) have pointed out, a dispute between a religious figure and the damos about the taxation of a plot of land is recorded on Linear B tablets (Lupack 2011: 213).[14] Lupack (2011: 213) argues that the fact that this dispute exists in the first place shows that both the religious sphere as well as the damos were, to a certain degree, independent and legitimate entities. However, the taxation under dispute is still to be paid to the palace. This and the fact that it is recorded on the tablets make it obvious that it was of palatial interest. It thus seems that the palace leased out the land to people or groups and that these gained certain autonomy on how to organize things locally. This is shown on one of the Pylos tablets (Er 312), on which four classes of landowners are recorded (Killen 1998: 21):

1. wanax (the king);
2. lawagetas (leader of the host);
3. telestai (landholding supervisors);
4. wrokion (an individual (collector), likely a member of the elite).

Moreover, both Lupack and Killen argue that proximity is a factor in the palatial influence and assume that the amount of control lessens with increased distance from the centre (which in this case is Pylos, but Killen states that the same goes for other centres) (Killen 2008: 165-6; Lupack 2011: 213). Halstead argues that in the Mycenaean context staple grains were produced near the centres just as fully dependent textile workers were located there (Halstead 1999: 39). Resources for craft production were acquired within and beyond the territory of the palaces. Similarly, the finished goods, like perfumed oil and jewellery were distributed through exchange on a comparable scale. Halstead concludes that this is all intertwined: locally produced staples financed the creation of craft goods, which in turn created wealth. This enabled a wider range of resources to be generated in greater quantities and mobilised over larger distances (Halstead 1999: 39). This shows again that the palatial control varied between industries.

One of the contexts where palatial influence is apparent, however, is that of (corvée) labour. Various forms of labour and associated workers are specified in the Linear B tablets (Killen, 2006; Nakassis, 2010). Individuals mentioned in the tablets are usually only designated by title or profession. These vary from potters to goldsmiths and from bow makers to architectural labourers (Killen 2006: 84; Nakassis 2010: 275, 2013). This is informative for a number of reasons: firstly, it shows that some of the work is clearly of interest to the palace, which can often be linked to the overall interest of the palace in the creation of high-value crafts.

Secondly, as Killen (2006: 77) argues in the case of the Pylos tablets (designated "Ac"), which are designated as "taxation records", men are recruited from various taxation districts. This implies that the palace conscripted people to work as part of a taxation that was collected in a larger area than the settlement of Pylos itself. Corvée labour was thus part of the Mycenaean economic system as Nakassis also confirms as he describes that corvée as a tax was the main method for raising labour (Nakassis 2010: 273). The taxation itself was likely tied to landholding (Nakassis 2010: 273; Killen 2008: 463; also above). Since it is possible that craft specialists worked mostly in their own communities but were occasionally ordered to work for a certain amount of time in a centralised location (Killen 2006: 85), these labour obligations seem temporary in nature.

Thirdly, the fact that architectural labour is mentioned in the tablets shows the palatial involvement in construction work. More importantly, they show that the palace used differentiation in payments for different tasks (this was likely the case when work was not part of a taxation). Based on work by Melena (1997), Nakassis (2010: 275), discussed the various types of professions associated with construction. These include "wall-builders" (masons), "all-builders" (most likely some sort of supervisor) and "sawyers". Furthermore, two named individuals are mentioned in relation to architectural work that Nakassis identifies as those who organized part of the labour force. He argues that the large amount of rations these individuals were paid were used

13 One explanation could be the so called 'clearinghouses' as identified at Pylos (Bendall 2003) and Mycenae (Shelmerdine 1997). Clearinghouses act as intermediary between buyers and sellers. If the denotation of these structures as clearinghouses is correct than this could perhaps explain the missing of such an 'out-go' of products as it was an intermediary, not the palace itself that presided over the transaction. However, this has not been definitively proven as of yet.

14 "The term *damos* refers on the tablets to the political and geographic entities that are commonly called 'districts' or 'district centres'" (Lupack, 2011: 212). See also above in section 2.2.1.

to hire the unskilled labourers involved in the construction (Nakassis 2010: 277).

Besides professional crafts and unskilled labour, the palace also conscripted people for military service, which, again, seems to have been tied to landholding (Killen 2008: 170-1; Nakassis 2010: 270-1). Nakassis (2010: 271; see also Chadwick 1987) points out that it was possible that those required for services could send others on their behalf. These others may be dependents of the high-ranking individuals or they were persons hired by the named individuals on the tablets (Nakassis 2010: 273-4). In any case, it is clear that landholdings were important for the palace to assure ready access to sufficient numbers of military and labour personnel. It could be argued that labour by dependents can ultimately be seen as a form of reciprocity (see 2.2.2) and can only be maintained if both parties keep up their end of the bargain (one party supplying land and perhaps stability, the other labour and surplus). Since the Mycenaean economy seems to have been composed of different sections that were all intertwined, a refusal of labour by the dependents could have easily disrupted the system. In a reciprocity system, those to whom the most debts are owed get hit the hardest once the system comes to a halt (Galaty et al. 2016: 69). The palatial organisation would thus be hard pressed in such a case.

Based on the literature, it is safe to conclude that the reach of the palace was restricted. Surely, the palatial elite must have controlled certain industries or movements of goods, since they would have had to have access to those to mobilize people, not in the least for the construction of the citadels. That being said, it seems clear that they were not all-controlling in all aspects of the Mycenaean economy. This opens the possibilities for modes of exchange not directed by the palace, for example, the earlier mentioned market exchange.

2.3.2 Subsistence economy

This section will not explore the exact subsistence strategies during the Mycenaean period. It suffices to note here the livelihood was provided through agriculture and animal keeping (*e.g.* Halstead, 1987, 1989, 1999a; Margomenou, 2008). Rather, in this short section the importance of the generation of surplus within the subsistence economy is underlined. It was stated above that the Bronze Age Aegean economies can be seen as having four interlocking sectors. However, none of the economic sectors and models described in this chapter can exist without the occurrence of surplus production (Halstead, 1989; Margomenou, 2008; *e.g.* Renfrew, 1982). Researchers like Allan (1965) and Halstead (1989) have convincingly argued that any form of farming has a "normal surplus". This normal surplus is required to ensure enough food in a poor yield season (Halstead 1989: 70). It was, in essence, a form of risk management (Margomenou 2008: 207). Moreover, the normal surplus could be used for various social, ritual and economic circumstances, as shown for the Tonga in East Africa in the 1940s (Allen 1965: 44-5). Similarly, it was found that in some other (African) communities there existed an "obligation to offer customary gifts to political superiors, in acknowledgement of the right to hold or allocate land, [which] sometimes amounted to a form of taxation which diverted part of the normal surplus to the maintenance of elaborate social and political hierarchies" (Allan 1965: 45).

The creation of surplus as a buffer for bad times is only useful if it can be stored properly. The way the surplus was stored, either physically or through social storage (foodstuff is exchanged for "tokens" that can in the future be returned for food) (Halstead 1989: 74-5) can subsequently be used by persons or groups to appropriate surplus.

The various models for the emergence of social stratification (see 2.2.2 above) and the subsequent ideas on the influence of elites on society (2.3.1) thus rely heavily on the existence of some sort of surplus. Similarly, the types of exchange of goods (see 2.3.3) and the ascribed roles of sanctuaries to Mycenaean society (2.3.4) also require the existence of surplus. After all, if there is no surplus there is nothing to exchange or to offer to sanctuaries. The subsistence economy is thus clearly interlocked with the other economic sectors. Similarly, the influence of the elites is constantly interwoven with all the sectors and the explanatory models, as will be shown below.

2.3.3 Trading economy

There is substantial material evidence to suggest that there was interaction between regions in and outside of the Greek mainland (see below and sections above). The focus should therefore be on what kind of interaction there was, especially in the period of the MH into the LH period and subsequently, what this can say about the relations that existed between those parties involved. In this section, the nature of exchange with other centres, within and beyond mainland Greece, is further explored.

Continuing on the earlier mentioned involvement of reciprocity in the Aegean, one type of exchange is elite gift-giving (see also 2.2.2). The circulation of gifts between "brother kings" (Burns, 2016) represents a way for the elites to elevate themselves. The biography of these objects, the distant places they come from and their overall infrequent nature would imbue the gifts with value (Burns 2016: 90).[15] The latter may include, for example, not just material

15 For the Near East, some information is available from the 'Amarna tablets'. On these clay tablets the exchange of goods and people is mentioned between various elites (outside Greece), dating to the Late Bronze Age (e.g. Monroe 2011; Burns 2010; Burns 2016; Pullen 2016).

goods, but also persons in the form of craft specialists. However, gift giving would only amount to a small number of finds pointing to inter-regional exchange. As Sherratt and Sherratt also note, the quantity of Mycenaean finds in the Near East or the procurement of metal in the Aegean cannot be explained by mere gift exchange (Sherratt and Sherratt 1991: 353). Haskell argues that LBA "trade" is visible mostly through prestige goods, but implies that only a portion of this is through the palace (Haskell 2004: 151). He notes that almost all large stirrup jars, intended for the transport of oils, originated from Crete (Haskell 2004: 158). These large jars found throughout various regions in the Mediterranean were supplied by different producers. Jars from west Crete dominated the Greek mainland, while jars from central Crete seem to have been moved to the East, to Cyprus and into the Levant (Haskell 2004: 157). Only a small number of these are found to be designated to the wanax, though (Haskell 2004: 153). It has been argued that such designations indicate products that are directed by the palace, but are not "royal" (Palaima 1997: 411). As such, out of all the oil being transported, only a portion went to the palace, and this may have been given as offerings (Haskell 2004: 153). Hence, even for those products that the palace is involved, which is often based on the mentioning of these products on Linear B tablets, the palace might not have directed the entire industry.

The quantities of exchanged goods would probably only be a small portion of the total production, but their importance should not be overlooked as these high-value products motivated "the intensification of local production and the extraction of surplus, in order to provide goods for exchange" (Sherratt and Sherratt 1991: 354). This coincides with Halstead's (1999) description of staple and wealth finance systems (see also previous sections). Sherratt and Sherratt observe in the relationship between manufactured products and raw materials the "fundamental reason for long-distance trade" (Sherratt and Sherratt 1991: 355, 366). However, they also argue that the long-distance trading routes were not direct journeys, but rather involved travelling bazaars going from harbour to harbour. This argument is mainly based on the idea that sea travel was still quite dangerous so ships hugged the coasts, and the winds and currents dictated much of the routes as well (Sherratt and Sherratt 1991: 357). Furthermore, the large variation of type and origin of the finds on shipwrecks like the Uluburun wreck (*e.g.* Sherratt and Sherratt 1991: 372-3; Pulak 1998: 188-92) also confirm the likeliness of indirect routes. Harbour-hopping is also suggested by Burns, although he based this on the finds of metalworking tools on the Cape Gelidonya wreck, which seem to suggest that crafting was, at least in part, an on-board activity, selling the products at the various ports (Burns 2010: 15). Moreover, Tartaron points out that the long-distance trade is dwarfed by the local and regional connections when it comes to quantities (Tartaron 2013: 5-6). While the exotica found at the Mycenaean polities show long-distance connections, there is, according to Tartaron, no direct proof that Mycenaean ships sailed to the locations to acquire the foreign goods (Tartaron 2013: 5). He seems to suggest, like Sherratt and Sherratt, and Burns, that smaller, more localised trade routes formed the mechanism through which goods were circulated in the Mediterranean.

Over time the exchange networks grew and, within this network, one node that became increasingly important is the Argolid as it was a point for traveling to and from Troy and the entrance to the Black Sea (Sherratt and Sherratt 1991: 370).[16] Sherratt and Sherratt argue that this happened between 1700-1400 BCE, which thus coincided with the Early Mycenaean period (Sherratt and Sherratt, 1991). Without being explicit, they seem to imply that this might be (one of) the factor(s) of the rise of the palaces in the region. Susan Sherratt elaborates on this in her 2001 article in which she claims that the Mycenaean centres are located on nodal points of longer-distance route networks (Sherratt 2001: 226). Only later, during the LH IIIA, when the palaces were consolidated, did these centres start adding their own specialised crafts to the flow of goods along the network (Sherratt 2001: 226).

Another approach to exchange might be provided by looking at how these networks and routes operated. As mentioned earlier, it seems likely that long-distance routes between various centres via sea travel was achieved by hopping from one place to another rather than the use of direct routes (Burns, 2010; Sherratt and Sherratt, 1991; S. Sherratt, 2001). Pursuing this model, it seems that the trading system may have consisted of separate units. One unit would be a major, long-distance international route in the east Mediterranean with large cargoes that were partly state dependent (Sherratt and Sherratt 1991: 372). A second unit would have comprised a series of smaller exchange "cycles" on the western side of which some were controlled by mainland centres, but many were not (Sherratt and Sherratt 1991: 372). Knapp and Cherry also advocate the existence of various smaller, overlapping, interlocking, but separated exchange systems (1994: 165-6). They described it as follows:

> "Mediterranean exchange systems were flexible, overlapping, and in a state of continual dynamic transformation; consumer or supplier demand and maritime technology enabled regional exchange networks to be linked to a wider circulation system that moved high-value goods, [...] between participating units" (Knapp and Cherry 1994: 165).

16 The Argolid is taken as a single entity by Sherratt and Sherratt, instead of dealing with the individual centres in the region.

While the Mycenaean centres of the Greek mainland were certainly part of these routes, as is clear from the finds, it is interesting to try to understand how they were part of it. Sherratt (2001) argues, as mentioned, that the Mycenaean palaces were merely places on nodal points within the network, controlling segments of the network. Furthermore, she mentions that these palaces were small in comparison to the Cretan centres, let alone the centres in the Near East (see also Dickinson 2010: 485). Hence, the Mycenaean centres were only able to take part in, and to some extent add to, an already existing network, controlled by their larger counterparts to the East and South (Sherratt 2001: 238). Regardless of their relative size, Burns also considers the Mycenaean centres part of a system of Mediterranean exchange involving gift-giving among elites (Burns 2010: 13). He agrees with Sherratt in suggesting that the Mycenaeans were certainly involved with the Near Eastern centres, but they never became true equals and "remained essentially peripheral to their elite gift exchange and political intimacy" (Burns 2010: 18).

Even though it is clear that "scale of activity and level of involvement in interregional contacts increased during the Late Bronze Age, as the palace-based economies of the Levant and the Aegean expanded" (Knapp and Cherry 1994: 166), it is unclear to what degree this involved gift-giving or trade. Moreover, as is discussed earlier, the palatial control over goods varied greatly and only a portion of it can be traced on the Linear B tablets. One could therefore argue that perhaps a merchant class was active in trading with Near Eastern regions (Knapp and Cherry 1994: 166). The difficulty with this stance is that most scholars, based on the Armana letters (see also 2.2.2, above), argue that trade with others was mainly based on gift giving (and thus circumventing merchants) and involved high-value goods, like textiles and perfumed oils. These products are relatively well represented in the tablets. However, the scope of the texts is obviously limited and it would certainly be possible that goods were traded without being recorded on (palatial) documents. Moreover, as Bendall has shown, the tablets do not represent a proper in-and-out kind of administration of goods and therefore any lack of evidence on the tablets is not necessarily a reason to dismiss non-palatial trade. It would therefore seem that a combination of small-scale gift giving and a somewhat larger scale trade-type of exchange took place in the Mediterranean during the Late Bronze Age, between the various centres in and around the Aegean.

The concept of non-palatial exchange provides opportunities for other concepts such as market exchange. However, the focus here is on palatial control, so this concept is not discussed here further (but see others who have discussed this extensively, also for Mycenaean Greece: Polanyi et al. 1957; Killen 2008; Parkinson et al. 2013; Aprile 2013; Pullen 2013; Shelmerdine 2013; Feinman 2013; Knapp and Cherry 1994: 165).

It is thus important to point out that the palatial elites were not in absolute control and there were people who were able to create a livelihood outside palatial control. This could influence the potential labour pool from which the palatial elites drew their workforce. However, it is also beyond the scope of this research to estimate how large this part of the population would be. Nevertheless, this notion as well as the fact that not all goods were controlled by the palatial elites are important considerations: if those matters that were outside of palatial control were substantial, then overstretching the palatial economy by large constructions may not have led to the 'collapse' of the Mycenaean centres (see also 2.4).

2.3.4 Religious economy

From Linear B offering tablets it has become apparent that the palace sent various offerings to sanctuaries, deities and religious personnel (Bendall, 2007; Lupack, 1999, 2011). Owing to these offerings, the idea developed that the religious sphere was included into the palatial structure of redistribution. Yet, religious institutions seem to have been subordinated to the palatial elite and its administrative system (Lupack 2011: 208). The mentioned offerings were considered to sustain the religious personnel (Lupack 2011: 209). However, Lupack has shown that most of the offerings from the palace to sanctuaries would not have been able to sustain the religious personnel. She argues that the oil and spices that were offered would have been primarily used in cultic settings, not to feed personnel. The livestock and other food supplies would most likely have been for festivals and would be consumed by the entire community rather than the religious personnel (Lupack 2011: 210-11).

Besides holding land and flock of sheep, Lupack (1999: 27) has found further evidence for an independent religious economic power in the form of workers that were ascribed to sanctuaries. She concludes that because of the possibility to produce economic viable commodities, the religious sphere did so, and it did it on such a scale that it became an economic power in its own right (Lupack, 1999, 2011). As such, it might have been, at least economically, not fully subordinate to the palace. Halstead (2011: 231) points out that the limited amount of offerings sent to the sanctuaries could also be explained by the hypothesis that the personnel only worked at the sanctuaries part-time, during periodic festivals. The fragmented state of the information from the tablets makes it difficult to ascertain which the right interpretation is. It does show, in any case, that the sanctuaries played an important part in Mycenaean society. Bendall, in her study of the religious sphere and its impact on the economy of Mycenaean society has three important remarks. Firstly, there seems to have been a bias in the tablets towards religious offerings (Bendall 2007: 291). Secondly, which supports Lupack's interpretation, is that the amount of goods that the palace donated to the religious sphere was but a fraction of the total wealth of the palace (Bendall 2007: 290; Lupack 2011: 210-11). Finally, Bendall concludes that, because the percentage of products disbursed to the religious sphere is so low, yet the frequency with which religious expenditure is mentioned in the tablets is so high, religion was "economically unimportant, but culturally, symbolically and politically significant" (Bendall 2007: 290).

The role of the religious sector in the Mycenaean economy remains a difficult matter to grasp. The over-representation of religion in the tablets might impose a more economically important role on the religious sphere than was actually the case. Furthermore, the tablets seem to be missing a basic in-and-out administration of goods circulated through the palace and, therefore, had a limited economic scope. However, it is certainly possible that sanctuaries were not dependent on the palace for their livelihood and were, therefore, able to sustain themselves. How big their economic value was and how much this affected ordinary people remains extremely difficult to prove. Nevertheless, Lupack (2011: 211) concludes that the religious sphere "would naturally have become involved in the economic life of their communities" and that the sanctuaries "may have been able to accumulate real material wealth from their endeavours" and therefore became a "constituted and economic force in Mycenaean society". Whether this was the case is beyond the scope of the study presented in this book. However, it underlines the idea that the palaces were not in absolute control.

2.4 Collapse of Mycenaean centres

In section 2.1 it was mentioned that the Mycenaean era changed at the end of the LHIII B (see table 2.2). While this change has long been referred to as a collapse (see for an overview *e.g.* Middleton 2010) it remains difficult to ascertain how this came about. Since an overarching aim of the SETinSTONE project is to study to what degree large scale building programs may have contributed to this collapse (Brysbaert, 2017), it is important to have a grasp of some of the ideas that exist about this. In this section, some of the theories and models that aim to explain this collapse are therefore discussed (see general works on societal collapse, *e.g.* Tainter 1988 and Middleton 2012).

Deger-Jalkotzy (2008) recognizes two possible reasons for the decline of the Mycenaean centres in the large-scale building programs of the LH IIIB period. The first reason is, in line with Brysbaert's (*e.g.* 2013, 2017) question, of an economic nature. The large scale of the constructions, erected in a limited amount of time, would have put serious strains on the economy as these, so Deger-Jalkotzy (2008: 389) argues, would require a large workforce paid in rations. The territories associated with the palaces were not large enough to produce sufficient staple and subsequently wealth to maintain such expenditures (Deger-Jalkotzy 1996: 717). The soil was therefore over-exploited and thus deteriorated. Heavy woodcutting damaged the environment further, and the population was suppressed through taxes and labour obligations (Deger-Jalkotzy 1996: 718). The results of the study presented in this book will thus help to understand whether this is indeed a realistic scenario. The second one, not related directly to an economic crisis, is the fact that many of these buildings are part of extensive fortifications. Especially the later additions to the fortifications of the LH IIIB2 period, as well as the restricted access to various economic quarters and the securing of access to water within the fortification are seen as a military move. On top of that, she argues, "fortifications are usually built against human attack" (Deger-Jalkotzy 2008: 388-9; see also chapter 3). This puts, unlike the recent ideas, the focus on an external threat (which could also include other, nearby, Mycenaean polities).

Other interpretations of the decline of the mainland palatial centres during the 12th century BCE are quite diverse and often tied to the various interpretations of the Mycenaean economy and society. Scholars have suggested various causes that led to the collapse including warfare, invading peoples, natural catastrophes and social uprising. The main issue with all of these is that it remains difficult to explain the widespread decline throughout a very large region. Each of the mentioned causes could certainly explain the destruction of a centre, or perhaps even the centres within a bound region. However, the widespread destruction, abandonment and overall change in a relative short period are problematic to link to any of the aforementioned causes. Recently, therefore, more and more scholars (Antonaccio, 2016; Deger-Jalkotzy, 1996, 2008; Galaty et al., 2016; *e.g.* Sherratt and Sherratt, 1991; S. Sherratt, 2001) moved away from these original explanations and look for more holistic interpretations. One is the breakdown of the economic system that, according to some, gave Mycenaean centres their power in the first place (see above).

Sherratt, for example, argued that Mycenaean centres were mere nodal points in a wider network (see 2.3.3). She links the breakdown of the system to changes in trading routes. Owing to a change in routes, caused by a shift in suppliers and/or commodities, these Mycenaean polities or states could no longer maintain their position. When the profit of being part of a trading route slipped away, the centres declined (Sherratt 2001: 235-7; Knapp and Cherry 1994: 166). Galaty et al. (2016: 69) also prefer an economic explanation for the collapse at the end of the Bronze Age. They link the decline in economic profit to the system of reciprocity in which the Mycenaean elites were involved and argue that when the balance of reciprocity is disturbed, those who are owed debts, get hit hardest (Galaty et al. 2016: 69). As a result the palatial structure failed, but the continuity of life can be seen in some places, like in Achaea where there is even a rise in population in the LH IIIC period (*e.g.* Arena, 2015; see also chapter 5). According to Antonaccio certain elements of the Mycenaean palaces survived (warrior elites, the basileus), while others did not (wanax, writing and monumental architecture) (Antonaccio 2016: 110).

Despite the recent shift towards economic explanations for the decline of Mycenaean centres throughout Greece, the changes in the economy are, in and of themselves, still unable to fully account for the scope of the collapse (Deger-Jalkotzy 2008: 391-2). More likely, a combination of factors has played a role and perhaps the internal crises laid the groundwork after which later events followed to come to the destructive finale that ended the palatial centres (Deger-Jalkotzy 2008: 392). Moreover, as pointed out in 2.3.3, the amount of the control the palace had over the people and the economy will be a major influence on whether such economic explanations should be considered realistic.

It is also important to keep in mind that there were large variations between the centres. This variation is particularly notable in the way these continued to be occupied after the collapse, if at all. Moreover, the term collapse remains somewhat problematic for multiple reasons. For one it suggests a sudden change, yet in reality, it would seem that the change took place over a prolonged period of time (Deger-Jalkotzy 2008; Dickinson 2010; Middleton 2010). The research presented in this book can, to some extent, add to this discussion since its results aim to provide some insights into whether or not the building of the fortifications (mentioned as possible reason for the collapse above) may have had a substantial impact on the (economy of) communities in which these were built (see also chapter 1).

2.5 Concluding remarks on Mycenaean society

The aim of this chapter was to provide a background of Mycenaean society, its rise, economic structure and ultimate decline.

Mycenaean society is characterized by social stratification. As shown, this is achieved and maintained by tools such as conspicuous consumption. Moreover, due to this stratification, there was a centralisation of power and wealth, which thus also heavily influenced the economy. However, it is also shown that the palatial control was not absolute. Nevertheless, palatial elites were able to mobilise people through their wealth and influence. This mobilisation seems to consist partly of paid positions as well as forms of taxation based on landholding. These insights do not only show the potential influence over these matters by the palatial elite, but also where the labour force came from. Their exact location is unknown, but it is clear that at least part of the labour force were subjects of the palatial elites. The context presented in this chapter will therefore be used in chapter 8 to put the results of the labour cost analyses into its proper Mycenaean framework and as such interpret these results appropriately.

In the next chapter the focus will be on the fortifications themselves. This comprises primarily matters like the function of the fortifications, how the fortifications are perceived and the deconstruction of the construction process of the fortifications. Moreover, it will be discussed whether the fortifications themselves should be seen as a form of conspicuous consumption.

Chapter 3

The fortifications of Mycenaean Greece

This chapter provides background information on the fortifications of the Mycenaean Age in Greece. There are two main parts to this chapter. The first deals with three characteristics of the fortifications. First some general observations of the fortifications; second, the perception of the fortifications, as these walls have been described as monumental (*e.g.* Brysbaert, 2018). Such a 'modern' perception of these ancient walls may colour the way in which they are approached. Therefore, this ascribed characteristic is analysed and it is assessed to what degree such a concept is useful in relation to the present labour cost study and whether this may indicate a secondary function for the fortifications as well. Third, the style in which the walls are built. This so-called cyclopean style is used to denote some physical features present in the studied fortifications. Since it is considered such a defining feature, a study of the style is presented. This is important as it describes the type of material used, which is crucial to understand for a comprehensive labour cost study. In the second part of the chapter, the general construction processes of the fortifications under study are examined and broken down into various stages, each of which can be studied in terms of labour costs. Such a study provides essential parts of the framework in which the data can be placed (chapter 7) and subsequently interpreted (chapter 8).

3.1 The practicalities of the fortifications: when, where and why

It may, at first glance, seem odd to discuss the function of fortifications, as this would be obvious. The definition of a fortification is "a defensive wall or other reinforcement built to strengthen a place against attack" (Oxford English Dictionary), after all. Its function is thus primarily to protect oneself from an attack. However, it is worthwhile to take a closer look at when, where and why these fortifications were built within the Mycenaean context and what kind of information can be taken from these considerations (the how is explored in section 3.4).

To start with the question when the fortifications were built: they are built throughout the LH III period, but the final phases of the fortifications were built towards the end of the period. Most fortifications are thus dated to the LH IIIB (*e.g.* Iakovidis, 1983, 1999), which, as can be seen in the overview in chapter 2, is the final century of the Mycenaean era. While earlier fortifications exist, it is not until this period that the extensive fortifications are built in the cyclopean style (see section 3.3) and take on the form still visible today. Some researchers see the late date of the construction as a possible explanation for the later collapse (see section 2.4). This argument has two possible implications: 1) the need for fortifications shows that there was a threat against which protection was required and/or 2) the construction was such an investment that it destroyed the economic system on which the Mycenaean society depended. Both these points will be taken into consideration when the results of the labour cost analysis are discussed (chapter 8).

As for where the fortifications were built, they are located in different provinces of mainland Greece. The Argolid contains a concentration of such places at Mycenae, Tiryns and Midea, whereas in other regions they are more dispersed. There are well-known places in Boeotia, such as Thebes as well as Athens in Attica. Other, similarly fortified sites that do not have palatial structures, also exist, like Gla in Boeotia and Teichos Dymaion in Achaea, in the north-western tip of the Peloponnese (see also figure 2.1 for a map with all the mentioned sites). All fortified sites are located on an elevated position making attacking such a place even more difficult (*e.g.* Winter 1971).

This brings the matter of why the fortifications were built into the picture. Fortifications are by definition meant as structures of defence; their physical placement, circling a set of structures as well as their large size, seems to support such a function. The fact that the fortifications only encompassed certain structures and not the entire site can be explained in various ways. First, it could be a matter of costs as encircling the entire site might simply be too costly an endeavour. Second, it might be that only the elite were worthy of being protected by such a structure. A third explanation is that even though a limited area was fortified, it still provided ample room for (most of) the population to seek refuge, even if their houses were not protected. This has been suggested for Mycenae (Spyropoulou et al. 2013: 3) and in the past it was argued that the Lower Citadel at Tiryns was built for this reason, although this view has been challenged since the findings of extensive "palace-associated buildings" in that area (Deger-Jalkotzy 2008: 388). Finally, it might have to do with the fact that these fortifications were indeed protecting important structures inside (such as workshops (*e.g.* Brysbaert 2013: 57)), but were also meant to show the capabilities of those residing within to actually build such fortifications (see also below, 3.2). However, at some sites there are no palatial structures (see above). Care must thus be taken with projecting the perceived grandeur of the fortifications from well-known sites such as Mycenae, on to sites that were also fortified in a similar style, but lack some of the characteristics (such as elite palatial buildings, *c.f.* Gla) on which the above mentioned interpretations are based. Thus, whatever additional reasoning there may have been to construct these fortifications, their defensive capabilities are clear (Iakovidis, 1983; Loader, 1998; *e.g.* Winter, 1971).

Other arguments for the defensive or military character of the fortifications can be seen in additional finds at the sites. Iakovidis (1999: 199, 201) states that simple gates comprised an opening in the wall which at that point was thicker than elsewhere. Yet, a "second generation of gates" was more elaborate and included a bastion or a secondary wall parallel to the fortification, creating a narrow passageway in which any assailant could be attacked from multiple sides (Iakovidis 1999: 202; see also section 4.1.1). He (1999: 202) gives the gates of Mycenae, the main gate of Tiryns, the west gate at Midea and Athens as examples of such later gates. However, this does not mean that the other type of gate was no longer in use during this time. One other thing to consider would be if these "second generation" gates were part of the militarisation that can be seen at the LH IIIB2 period at various sites, according to Loader (1995: 23). If so, this argument might be further substantiated by the concern for water availability within the fortified areas during the late LH IIIB period (see also below).

Accessibility to water is crucial to withstand an enemy during prolonged sieges. Subterranean water reservoirs have been found at multiple sites, such as Mycenae, Tiryns, Teichos Dymaion and Athens. At Tiryns, there are two parallel tunnels dug under the lower citadel wall, heading west (Verdelis, 1963). These tunnels had, like the galleries at Tiryns, corbelled roofs (*e.g.* Iakovidis 1983: 12). At Athens, the underground cistern was originally a naturally formed cleft (Broneer 1939; Iakovidis 1983: 83-84). By constructing flights of stairs within the cleft, the lowest portion was reached, from which water could be drawn (Broneer 1939; Iakovidis 1983: 83-84). All the underground water systems belong to the final span of the LH IIIB period. Arguably, the defensive capability is therefore the primary function of these structures. Supplementary functions or goals are also explored in the section below on how these fortifications were perceived.

3.2 Perceiving architecture: the fortifications as tools for consolidating power

The Mycenaean fortifications are impressive to behold (see for example figure 3.1). Most fortifications are a few hundred meters long, up to 10 meters high and several meters wide. It is, therefore, not hard to understand that even in ancient times these walls were considered imposing (*e.g.* Apollodorus 2.2.1; Pausanias 2.25.8). Considering this, the walls are often called monumental in modern times (*e.g.* Brysbaert, 2018). However, as Brysbaert (2018: 22-23) points out, monumentality is a matter of perception. As such, whether something is perceived as monumental, is specific for regions, periods and cultures (Fitzsimons 2006: 21). The importance for this research of the denotation of the fortifications as being monumental has two aspects. First, monumentality is seen by some researchers as an explanation for building on a large scale as a form of conspicuous consumption to show off wealth (*e.g.* Fitzsimons, 2006; Trigger, 1990). In such a view, the fortifications are thus a prestige project. Therefore, it might colour the interpretation of the studied material. Moreover, as shown in chapter 2, conspicuous consumption has been seen as an important way for people to gain and maintain power. Thus seeing the fortifications as conspicuous consumption would indicate that besides (or even instead of) the tangible, practical use

Figure 3.1 Part of the fortification wall at Mycenae (West Wall section) (photograph by author).

of the fortifications as discussed in 3.1, another function existed that is of a different order: the consolidation of power by elites. Secondly, depending on the definition of the term monument(al) an opportunity might arise to quantify monumentality, when an approach such as a labour cost study is used. If the required investment of a certain structure is higher than other structures in the same region, from the same period and part of the same society, could this be an indication for its monumentality, or is the cost of something too simplistic an approach to monumentality? In order to deal with these issues the concept of monumentality is explored to show what it might mean in this research context and what it may, or may not, add to this study.

Due to the mentioned link to perception, monumentality is not an easily defined term, even though its use in archaeology is quite common (Osborne, 2017, p. 3). In his work on monumentality and monumental construction in Bronze Age Cyprus, Fisher (2014) states as follows:

> "Large size and elaborate construction are characteristics that typify many traditional views of what makes something monumental" (Fisher 2014: 357)

and:

> "While size is not a prerequisite for monumentality, often the sheer mass of monumental buildings or complexes means that even people who might never set foot inside such buildings are affected by the gravity of their presence" (Fisher 2014: 358).

These descriptions show that monumentality, or the perception of something being monumental, comes from the fact that something is seen as impressive. It seems at first glance, that in the case of buildings this is achieved mostly through size. It is therefore easy to see why the large fortifications from the Mycenaean era are often considered monumental. This fits well with the definition offered by Trigger (1990) for monumental structures. He states that a structure may be defined as monumental when "its scale and elaboration exceed the requirements of any practical functions that a building is intended to perform" (1990: 119). In a way, this defines monumentality as something that is bigger, better and over-the-top. Monumental structures should thus be easily recognisable in relation to other structures from the same (archaeological) context. However, the issue remains that there is a grey area in which it might be unclear when something is more elaborate or larger than strictly necessary and even what should be considered strictly necessary. Nevertheless, Trigger takes a very pragmatic approach to monumentality. His idea is that people in general will take the course that requires the least amount of effort, not out of laziness, but because in the long run it saves energy (Trigger 1990: 123). This means that anything that takes more effort than might be strictly necessary can be seen as conspicuous consumption. Thus, monumentality can also be considered conspicuous consumption. Trigger describes this as follows:

> "The basic concept that underlies such behaviour is as follows: if economy of effort is the basic principle governing the production and distribution of those goods which are necessary to sustain human life, the ability to expend energy, especially in the form of other people's labour, in non-utilitarian ways is the most basic and universally understood symbol of power. Monumental architecture and personal luxury goods become symbols of power because they are seen as embodiments of large amounts of human energy and hence symbolize the ability of those for whom they were made to control such energy to an unusual degree" (Trigger 1990: 125).

Such an approach tends to overlook any significance that the building had for the community, its builders, and those who commissioned it (if these were indeed all different from each other). Other researchers have likewise argued that monumentality is not just physical greatness, but also involves technical innovation, high skill levels, the large range of the required resources and the time and effort invested in the construction itself (Brunke et al. 2016: 250). Brunke et al. (2016: 255) study what they call "XXL projects", which they define as such if a majority of criteria is met. These criteria involve the size, position, permanence, investment and complexity of a structure. It is important to point out that these features of a building are all considered relative to surrounding, contemporary structures. Therefore, in each case the characteristics make it stand out against the norm (Brunke et al. 2016: 255). This is somewhat similar to the approach adopted by Turner (2020) in which he determined a norm in terms of required investment for tombs in LBA Greece. Outliers from this average value signalled tombs that required far less or far more labour input than the average tomb would have. This approach of setting it against normal structures is also proposed in determining the required investment, which is expressed as the amount of work involved (Brunke et al. 2016: 256).

Moreover, Osborne (2014: 3) points out, the word monument comes originally from the Latin word *monere*, which translates into 'to remind' and thus ties into an active approach to memorializing and commemorating something through a structure. From such a viewpoint a monument is not just a big structure, as Trigger would argue, but also has a more active role in a community. In this way, the function of such a structure would include this commemorative part and it can be questioned if such a function can be seen in a structure's form.

The form of monumentality is often tied to size, as Trigger pointed out in his definition. Yet, Osborne (2014: 1-2) poses an interesting example which constitutes the ancient statue of the Guennol Lioness,[17] which has been described with the most grand words and has been called monumental, even though it is a mere 8.4 cm tall. If this statue is considered monumental, then monumentality might be sought in other characteristics than an object's size. Yet, according to Osborne, interpreting meaning is also often skewed by a focus on size.[18] He argues that such meanings are often tied to power and an elite's control over commoners as they were made to build the monuments (see Trigger's quote above). This is then often used to show a correlation in which a more elaborate or more expensive structure illustrates that a ruler had more power (Osborne 2014: 5).

One might argue that the Bronze Age fortifications in this research were primarily built to protect its inhabitants (see section 3.1), not to commemorate a specific event. While this cannot be concluded for sure, the defensive capabilities are without question and do much to underwrite such a functional classification. However, monuments, as architectural features, also have implications in relation to power. Fisher's (2014) argument is that elites competed for power and used architecture to show authority through the use of people and resources as well as to exert control over commoners (see also 2.2.2). These theories are not new; Foucault (1977) and Hodder (1994) have proposed similar ideas in the past. The latter has written about monumental structures:

> "Their size and physical nature mean that they can be active in a direct, bodily way – direct control over people, their access, movement and interaction in architectural space. Architecture embeds certain specific meanings in society through the control of people and their encounters with the world around them" (Hodder 1994: 74).

Interestingly, both Trigger and Knapp mention that monumental architecture, as a way to consolidate power by elites is mainly an "early stage" method. Knapp (2009: 49) writes that after centralized authority was stabilized

17 The Guennol Lioness is a small ancient statuette from Mesopotamia representing an anthropomorphic lioness (Osborne 2014: 1-2).

18 Obviously, his example of the Guennol Lioness is also tied to size, although not physical size but, instead, the enormous amount of money that was paid for it (52.7 million dollars).

elites turned their attention to other ventures that were "more finite or subtle than monumental architecture". Yet, in Mycenaean Greece, elaboration of graves predates the construction of large fortifications and palaces (*e.g.* Cavanagh, 2008; J. C. Wright, 2008) and the latter replaced the former as a form of "elite display" (Cavanagh and Mee 1999: 94). Similar processes have been seen on LBA Cyprus where elites built new monumental structures, which "replaced the funerary realm as the primary arena in which socio-political and ideological dynamics were enacted" (Fisher 2007: 289). While protecting its inhabitants was their primary function, the way these fortifications were built, massive walls built with massive blocks of stone (see below), might also hold a secondary function of conveying messages like "hardness, inapproachability and unlimited power" (Maran 2006: 79).

It is precarious to use modern terms such as 'message', 'propaganda' or 'ideology' in describing the meaning of ancient structures (Thomas 2007: 150). Thomas (2007: 150) writes that in particular the latter (ideology), however, can be a useful construct to interpret ancient structures and their role in in a society. His study focusses on Imperial Rome. It is, again, important to keep in mind that comparing features separated by such a timespan is problematic. However, from a conceptual point of view, the use of forms and 'messages' or 'ideology' might be useful, for a moment disregarding their origin in time, or indeed the origin in time of the examples used.

In particular in this instance are the examples from Thomas about the use of architectural features as a manner of establishing and maintaining a relation of domination between elites and non-elites (Thomas 2007: 150). Furthermore, Thomas (2007: 153) writes that Romans may have had the inclination to use buildings to "inspire 'respect' in their allies and, in their enemies, awe and 'terror'".

> "The emphasis on buildings of great size as supposedly reflecting the eternity of the regime seems to recall the 'eternal buildings' of Ephesus and Thera, notably the explicit planning of public buildings from the perspective on how they would look in a future ruined state" (Thomas 2007: 153).

While these arguments are all based on the notion that size conveys a 'message' of power, likewise the used material was important. On this, Thomas (2007: 158) writes:

> "Buildings dedicated to the emperors were made of superior materials and workmanship, reflecting the principle, familiar from monarchist literature, that a royal body might consist of the same matter as any other body, but made by a better artist."

The use of a different material around the gates at Mycenae, as shown below and in chapters 7 and 8, might be seen in a similar light, where the material seems to be used to draw additional attention due to its deviating material and building style (see also section 3.3.3.2). This underwrites the earlier argument that monumentality is a multi-layered phenomenon that does not consist purely on sheer size.

In the Roman context, as described by Thomas (2007), the construction of monumental buildings "encouraged a belief that the stability and unity of the Empire had been enhanced by a new prosperity under the divine Antoninus Pius."

In regards to the first aim of this section on monumentality (see start of this section), it can be concluded that the characteristic of monumentality of the fortifications and tying this to the concept of conspicuous consumption, means that the fortifications' existence does not only show that elites could muster the labour forces required to build them, but that they are used as a tool to keep the elites in their seats of power. After all, as shown above and in chapter 2, conspicuous consumption is considered an important tool to consolidate power.

In regards to the second aim of this section, it is shown above that, the concept of monumentality might be tied to an approach such as labour costs studies, as this is a good way to differentiate costs involved in construction between different types of buildings. The problem with this is, though, that when things are quantified there is a need for a threshold value of some sort to denote the various classes from each other. In other words, how much more expensive does something need to be in comparison to a mundane object to be considered monumental? One way to determine such a threshold is to study a wide variety of structures and see if certain classes exist, based on required investment. An attempt is made on a small scale studying certain domestic structures, besides the fortifications. This creates at least some form of scale on which the calculated labour cost can be plotted. This way an opportunity is created to try to say something meaningful about the monumental status of the fortifications based on the required investments.

Finally, this also means that if the fortifications are considered monumental, then it is considered an elite-driven endeavour and the construction is thus a top-down organised project. As will be discussed in chapter 8, the required organisation for building projects would benefit from not just horizontal, but also vertical configuration: in other words, not just the amount of people involved is important, but also the way these workforces were organised and who ordered the construction in the first place. The status of a monument allows the recognition that a structure has more than one function: not multifunctional in the sense of a large room that can be used to host parties as well as funerals and lectures, but in a far less utilitarian manner. As pointed out, the original Latin word ascribes an active approach to memorializing and commemorating to something that is monumental and specific messages may be conveyed through such structures. Whether modern scholars can ever hope to translate these messages can be questioned, but it would be wrong to discount the idea that monuments had a secondary function besides their primary function as defence work.

3.3 The building style of the fortifications

There has been a long history of categorizing architectural styles in Greek archaeology (*e.g.* Lawrence, 1957; Scranton, 1941). These categories help to define styles, their dates and the recognition of ancient wall types at different sites. The style used for the fortifications during the Mycenaean age on mainland Greece, is called cyclopean. The use of the term cyclopean in relation to architecture comes from the mythical, one-eyed, Greek Giants called Cyclopes. According to the myths, the Tiryntian ruler Proetus had called upon these Cyclopes from Lycia to build the walls of his citadel (Apollodorus 2.2.1). Only these giants would have been strong enough as each stone is so large and heavy that not even a pair of mules could move the smallest one (Pausanias 2.25.8). The size of the individual blocks and their carriers thus originally defined the construction style as cyclopean.

In recent times, the term cyclopean is still useful in relation to the size of the blocks (not the giants). The definition is expanded though, with the description that the blocks are generally unworked and that small stones are used to fill gaps in between the large blocks (see figure 3.2) with the possible addition of clay here and there (Iakovidis, 1983; Loader, 1995; J. C. Wright, 1978). This seems generic, but it is nonetheless an accurate description. However, Küpper (1996: 31) points out that there are flaws in this description. He mentions that the ashlar masonry that surrounds the Lion Gate at Mycenae was considered cyclopean due to the size of the blocks (*e.g.* Schliemann, 1878, who followed the description by Pausanias (Paus. II: 16.5)), but that the large blocks used in some of the tholoi are not considered cyclopean (Küpper 1996: 31).[19] Küpper's main point here is that the description leaves a lot of room for personal interpretations and he stresses that it is the careful addition of the smaller stones in between the large blocks that make cyclopean stonework stand apart from simple rubble masonry. More importantly, he argues that the insertion of the smaller stones is largely for technical reasons, as it compensates even the smallest irregularities between the larger blocks (Küpper 1996: 31). Thus, in creating the most stable wall possible, one needs to ensure that the load of these larger, heavier stones is well spread out. In other words, for Küpper, it is the technical use of smaller material that defines true cyclopean construction.

Loader (1998) also explored the nature of this type of construction, but in a different manner. In her study (1998: 23-38), she defines the variations within cyclopean constructions as different types (labelled I-V). These types only comprise what she calls "true cyclopean stonework". Other constructions are merely called cyclopean due to the use of large blocks, but do not share a similar construction technique (Loader 1998: 23). While the definition of this true cyclopean construction remains a bit vague, Loader seems to imply that it comprises stonework from the Greek mainland and the use of the smaller stones (and occasionally clay) in between the large blocks. This is not unlike Küpper's definition, although he does not seem to specify the Greek mainland. Loader's various types of true cyclopean constructions are actually variations in the shape of the blocks and the small stones. However, with mostly unworked stone, which remains the case for cyclopean constructions, the shape of the blocks is largely dependent on the characteristics of the geological layers from where the stone is quarried (*e.g.* Wright 2005b: 6). The fortification walls at Teichos Dymaion (Achaea) are a good example of this. Here many of the blocks are relatively rectangular or slab-like. This has mostly to do with the local limestone layers as these determine how the quarried blocks split from the bedding. Moreover, the shape of the blocks is sometimes determined by their location in the structure. Corner sections of cyclopean constructions are often built in more regular courses than elsewhere in the wall. This, on occasion, results in the use of rectangular (and thus cut) blocks to achieve coursing. This is a structural feature to keep the wall in place and to counter the weight of the wall that pushes on these corners (see section 3.4.3). It, therefore, seems that the types, as defined by Loader, are subjective and not necessarily add anything to the study of these constructions, as both dates and geographic spread (within Greece) are not delimited.[20] At many sites, several of Loader's types are employed. Therefore, the available material, the position of the material in the construction and the difference between groups of builders are more likely to be responsible for the differences. This seems more probable than a conscious differentiation of types of blocks resulting in various types of cyclopean construction.

19 *Tholoi* is the plural of the word *tholos,* which comes from the Greek word θολος, meaning dome or vault. In this context it refers to the beehive shaped tombs from the Mycenaean era.

20 Except for her Type V, which only occurs in the Isthmian wall (loader 1998: 32) of which it is now known that the date is actually not Mycenaean (e.g. Morgan 1999).

Figure 3.2 Top: Cyclopean-style wall. Part of the fortification at Mycenae. Bottom: difference between the cyclopean-style section (left) and the later Hellenistic polygonal-style section (right). Note the well-fitting blocks in the Hellenistic section. Each block had to be cut specifically to fit. Also, note that many blocks on the left are quite a bit larger than those on the right (photographs by author).

The definition of cyclopean as the use of large blocks with smaller stones and sometimes clay in between is a useful one. When distinct variations occur these can be described, but there is, at this time, no need, nor a reason to create these different types. As such, this definition is the one used for cyclopean constructions throughout this study. It also means that the sections at the Lion Gate and North Gate at Mycenae are considered not to be cyclopean. These can be better described as a "massive pseudo-ashlar" construction (Küpper 1996: 33).

3.4 Constructing the fortifications

In the following section, the various steps of the building processes are examined and described to get a proper understanding what these processes entailed from start to finish. These are broken down in quarrying, transportation, and construction, each of which with various subsections.

3.4.1 Quarrying

3.4.1.1 Choosing the quarry location

Due to the nature of cyclopean stonework, which involves the use of largely unworked stones, there was little time spent on dressing the blocks to a certain finish (*e.g.* Grossmann 1980: 496). It could therefore be argued that blocks were simply moved from the quarry, as they were when they broke apart from the bed. The stone itself had to have certain qualities, though, to be suitable for building these enormous walls. At most sites, the used material consisted of locally available limestone, sometimes cut from the very hill the site was located on, for example at some sections at Tiryns and Mycenae (Iakovidis, 1983; J. C. Wright, 1978). There was thus a conscious decision to get material from nearby (supporting Trigger's argument that people will try to do things as efficient as possible). This also explains the difference in stone types between various sites because different sites lie in different geological zones in Greece and nearby layers of limestone have varying characteristics. A clear illustration of this is the difference in limestone at Mycenae and Teichos Dymaion. Disregarding the special sections of the ashlar masonry built in conglomerate stones at Mycenae,[21] it is clear that the material was quarried nearby at an accessible location (*e.g.* Loader 1995: 37). Furthermore, because the blocks were mostly unworked, it meant that harder, but more difficult to shape, stone types were used for the construction of the cyclopean-style walls. The harder limestone types are indeed more difficult to shape, but they also lack the porosity that would make them susceptible to cracking under the enormous weight of subsequent courses in a wall.

3.4.1.2 Splitting block from rock

Quarrying stone is hard work and even more so in the past, when the available tools were less efficient then nowadays. The study of ancient quarries, especially in Greece, is mostly focused on quarries from the Classical period and more specifically on the extraction of marble (*e.g.* Fant 2010; Waelkens et al. 1992). For Bronze Age quarrying it is often argued that subsequent stone extraction in later periods erased any signs from earlier eras (Loader 1995: 40-41). There are traces of quarrying in the form of tools though. The most common tool found in the Aegean from the Bronze Age is the chisel (Loader 1998: 47; Blackwell 2014: 453). However, for quarrying the pick as well as hammers would be crucial, although both have rarely been found (Loader 1998: 46-48). Other equipment like wedges, borers and saws would also be helpful but are not, or hardly, encountered. The equipment used for extracting the stone from its bed is largely dependent on the method used. Loader describes two such methods: the deep channelling and the wedge-and-feather method. The first comprises the digging of deep channels around the desired block and subsequently prying it loose. These channels would be ideal to cut with a pick (Loader 1998: 50). In the wedge-and-feather method holes are made around the desired block in which two feathers are placed. Between these feathers a wedge is placed that is subsequently hammered down. This causes the pressure to increase and eventually the stone will split (Loader 1998: 52). Because cyclopean stonework is built with blocks of varying sizes and shapes, there is no need to be very precise during the quarrying. The major objective would be to split the rock in such places that the blocks would be as large as possible. This method of extraction would also arguably leave very irregular traces, unlike the channelling method of regular, straight cuts. In particular after several thousand years of weathering, it should be expected that such quarry sites are difficult to locate.

From Crete various examples of Bronze Age quarries exist and they share a number of characteristics. Firstly, quarrying was done by deep-channelling. Secondly, most of the used stone comprised softer stone types than were used on the mainland. Thirdly, where tool marks are found, they mostly consists of marks from (bronze) picks (Waelkens 1992: 8-11). The grid-like quarrying, associated with channelling to extract the stone (Waelkens 1992: 11), as well as the fact that the quarried stone was relatively soft, makes it easier to create rectangular blocks. Soles (1983), who studied the Bronze Age quarry near Mochlos, in eastern Crete, reports similar findings. His study focusses on a quarry within a small ravine near the coast. Within this quarry, rectangular blocks were quarried using the channelling method (Soles 1983: 42-46). Similar to Waelkens' findings, Soles (1983: 40) concludes that near Mochlos, the material comprises sandstone and most likely picks or adzes and chisels were used to cut the stone. Devolder (2013), in her work on Minoan architecture on Crete, comes to similar conclusions. She argues that the ashlar is only used on specific locations within buildings; the rest is built in rubble masonry (Devolder 2013: 20, 23). About the latter she argues that the material was often collected (simply picked up) near the site, but some may have been indeed quarried (Devolder 2013: 14). Her research on quarried material though, focusses only on extracting the ashlar blocks. Also similar to Waelkens and Soles, she has found that mostly sandstone and soft limestone or *poros* was used and that this was similarly extracted as it was in the entire Mediterranean region, particularly as in Egypt (Devolder 2013: 21). This is thus quite different from the hardly shaped cyclopean blocks employed on the mainland.

From the mainland there are very few quarry sites published from the Late Helladic era. While quarry sites have been located at Tiryns (*e.g.* Varti-Matarangas, Matarangas, & Panagidis, 2002) and Mycenae (*e.g.* Brysbaert 2022; Brysbaert et al. 2020) none have been studied for extraction methods. Another quarry site has recently been investigated, located in Laconia near the LH site of Vapeheio-Palaiopyrgi (Hitchcock, Chapin, Banou, & Reynolds, 2016). However, the very small quarry site

21 These sections might have been built differently for a specific reason, which ties to the discussion on conveying messages through architecture and monumentality in the previous section. See also chapter 8.

(a little more than 20 m^2), only featured possible column bases of a conglomerate stone type (Hitchcock et al., 2016). This means that the stone quarried here was used for very specific architectural elements and does not constitute a large-scale quarry as would be needed for cyclopean-style fortifications. Since very few quarry sites exist from this period though, any information might give insights. Unfortunately, only very few tool marks are found, and of these the authors are hesitant to pinpoint what tools were exactly used. They assume these were chisels, adzes or axes (Hitchcock et al. 2016: 76).

Blackwell (2011), who has dedicated his PhD research to the use of (metal) tools during the Bronze Age in the Aegean, confirms that these tools were likely used. His extensive comparative work shows that on mainland Greece, the majority of the used tools were chisels and after that axes although, he mentions that it remains obscure if these were used for wood or for stone as well (Blackwell 2011, 2014: 453). Similar findings are presented by Shaw (2009: 38-53) and Evely (1993) for Late Bronze Age stone working on Crete. Considering the work by Shaw, Loader, Waelkens, Hitchcock et al. and Blackwell, it seems that chisels, picks and axes would have been the obvious tools for quarrying stone during the LBA. Atkinson (1960), referring to Stonehenge and Dworakowska (1975) discussing Cretan finds from the Middle Minoan period, both also identify hammers being used to roughly shape blocks where necessary.

It remains problematic to be conclusive, as most of these studies do not focus on large-scale cyclopean quarrying. However, short of experiments, they form the best sources for reconstructing the quarry stage of the building process. Two main quarry techniques are considered for the labour cost analysis: the deep-channelling for the material used at the conglomerate façades at the gates at Mycenae and the more casual method of breaking material from the bedrock following natural faults (perhaps using the described wedge-and-feather method) for the cyclopean-style walls.

3.4.2 Transportation

After the extraction of the stone from its bed, it needed to be transported to the actual building site. The location of the quarry as well as the terrain between the quarry and the building site would have influenced the manner of transport greatly. This section will explore the various types of transportation possible, mainly over land. For transportation over land there are, basically, four main methods: (1) dragging the block over the ground, (2) moving the block over rollers, (3) transporting the block placed on a sledge (with or without rollers), (4) transporting the block placed on a wagon. In theory objects can be carried, but considering the weight of the cyclopean blocks (averaging between 1.8 (Loader 1995) and 3.8 tonnes (Harper 2016)), this seems farfetched. All four modes of transport can be done by using persons and/or animals for traction.

3.4.2.1 Rudimentary movement of objects

The most basic mode of transporting blocks of stone would be pushing/dragging it over the ground with no tools or machinery, other than perhaps a rope. There are two main issues with this method: first, the friction would be by far the greatest in comparison to the other ways of transporting the stone. Second, the block would likely be damaged or broken in the process. While this may seem less of an issue when it does not concern carefully hewn blocks (unlike the ashlar blocks), it seems unlikely that damaging the blocks would be desirable. However, for short stretches or particularly difficult to reach places, moving the stones over the ground may have been the only way. This would apply, for example, to moving the block out of the quarry area and perhaps also moving it into its place in the wall at the building site. Particularly over longer distances, though, it seems that the extra effort in creating and using sledges, rollers and/or wagons would pay for itself because less force was needed to move the stones (see example calculations below).

The amount of force needed to move a block of stone depends on a number of factors. The force involved in moving anything (momentum) is defined by Newton as the product of the mass of the object and its velocity (*e.g.* Cotterell and Kamminga 1990: 23). The rate of change of momentum is, therefore, defined by the object's mass and the rate of change of velocity (acceleration), which can be formulated as F=ma ('F' is the force, 'm' the mass of the object and 'a' the acceleration) (Cotterell and Kamminga 1990: 23). This might seem as if there is no force applied to any static object, however, there is of course the gravitational pull of the earth. Galileo showed that although heavier objects reach a higher velocity when dropped than lighter objects, their acceleration is similar. Through Newton's universal law for gravitational force, it has been calculated that the constant acceleration due to the gravitational force (g) of any object in free fall, is 9.81 m/s^2 (meter/second-squared) (Cotterell and Kamminga 1990: 26). The gravitational pull on any static object is thus its mass multiplied by the constant g.

To move an object horizontally on a level surface it is the friction that needs to be overcome (de Haan 2009: 4). Friction is determined by the normal force (F_n that in the case of a level surface is equal to the gravitational force) and thus the object's weight, and the friction coefficient. The friction coefficient is dependent on the material of the two surfaces that move over each other. The friction force (F_f) can therefore be determined as follows: $F_f = \mu F_n$ in which 'μ' is the friction coefficient and 'F_n' the normal force. An example illustrates the two basic formulas mentioned above. A block of stone, weighing 1,000 kg has just been quarried and needs to be moved horizontally from its bed to outside the quarry. It concerns a limestone block and the path is even and straight over remaining limestone. F_n = 1,000 × 9.81 = 9,810 N. The friction coefficient for limestone on limestone used here is 0.60.[22] F_f = 0.60 × 9,810 = 5,886 N. This number represents the maximum friction force, therefore a force greater than that is needed to start moving the block.

Since blocks of stone were obviously not only moved horizontally, but also on slopes it is important to see how this would influence the required workforce. Atkinson (1961: 297) estimated that a slope of 9 degrees meant an increase of required workers by a factor 4.5 (from 2 to 9 people per tonne). However, this seems very drastic for such a slope. A similar calculation as above can be made for the same block on a slope. So rather than moving the block on a level surface, the block is now moved, on limestone, on a slope of 9 degrees.[23]

In this case, F_n is not equal to F_g, since the block is on a slope. The force is divided between F_n (which is always perpendicular to the object) and F_h which represents the gravitational pull along the slope (see figure 3.3). While the gravitational force F_g remains 9,810 N, F_n is determined by $F_g \times \cos(\alpha)$ in which α represents the slope in degrees (9 in this example). F_n is thus 9,689.2 N while $F_h = F_g \times \sin(\alpha)$ = 1,534.6 N. With an increase in slope, F_h will increase, while F_n will decrease. The friction is determined by F_n and μ: F_f = 0.60 × 9,689.2 = 5,813.5 N. Note that the friction force is larger than the force pulling the block along the slope and, therefore, the block does not slide down. When the people start to pull the block up along the slope, both F_h and F_f need to be overcome and thus a force greater than 1,534.6 + 5,813.5 = 7,348.1 N is necessary to start the block moving up the slope (see also figure 3.4).

The required workforce is not as straightforward, as it depends whether the workers are not just dragging the block upwards (hauling in the weight, while standing at the top of the slope), but are also moving along the slope. In the case of the latter, their available force would be diminished by the force that is needed to walk up the slope. Nevertheless, a slope of 9 degree thus results in an increase in required force by a factor of roughly 1.25 (7,348.1 vs 5,886 N). This factor is a lot less than the factor of 4.5 advocated by Atkinson. This is also shown by de Haan (2010: 18-19), who did a much smaller experiment, yet showed the difference in required force between hauling on a level surface and hauling on a slope. In his experiment the difference in force was a factor 1.17, which is much closer to the value of 1.25 mentioned above. He also points out that this is the force exerted on the sledge, and that the actual total force is higher since the person pulling the sledge also lifts one's own weight up the slope (de Haan 2010: 19; also Hodges 1989: 10-11). This would bring the difference between hauling on level ground and a slope to a factor of 1.7. Although this is higher than the earlier calculated factor of 1.25, it is still far off the 4.5 mentioned by Atkinson. While Atkinson did groundbreaking work, which provided great insight into transport of heavy material in pre-industry societies, it remains difficult to compare his research 1:1 with more quantified work. This is partly due to the descriptive nature of his work and sometimes unreferenced assumptions. What may be an additional factor in this, is the loss of efficiency when using more people or animals for traction. Already Xenophon points out that multiple yoking creates a dramatic loss of efficiency from a carrying capacity of 640 kg per yoke to 380 kg per yoke over 8 yokes (DeLaine 1997: 108; Cyr. 6.1.52). While this seems excessive, DeLaine (1997: 129) assumes a 20 % loss of efficiency when using multiple yoking. Although the amount of required force may only

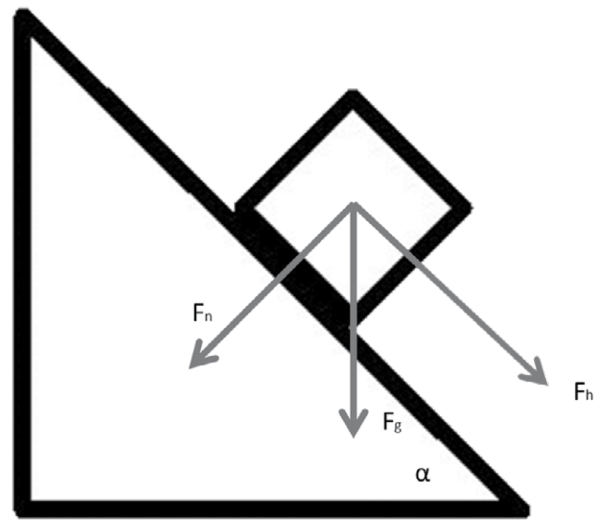


Figure 3.3 Forces that work on an object on a slope with angle α (drawing by author).

22 The friction coefficient of materials varies between sources and is dependent on surface roughness and pressure. De Blasio (2011:26) writes that friction force is comparable for materials of similar properties, which for rocks is about a half of the weight, thus 0.5. Ohnaka (1975) has shown that the friction is highly dependent on the surface and in the case of limestone, the coefficient can vary between 0.46-0.80. Some online tables show values of 0.75, but these are unverifiable (e.g. http://www.supercivilcd.com/FRICTION.htm last accessed 02/12/2019). Zhu (2016: 1) (2016) states that for rocks the friction coefficient varies between 0.5 and 0.8 and that a value of 0.6 is a safe number for general use. A friction coefficient of 0.6 may seem high, but due to the large range it does seem to be a safe value to use.

23 The results are not directly comparable as the cited increase of 4.5 by Atkinson is based on the use of rollers. When rollers are used the overall needed force is lower, but the increase in force when the slope increases is much higher in comparison to a situation where rollers are not used.

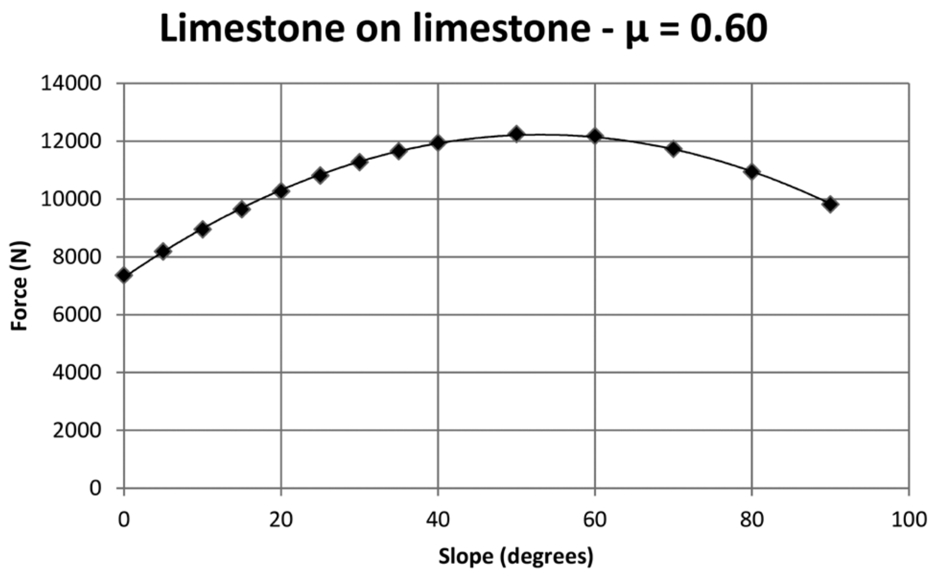


Figure 3.4 The distribution of required force on different slopes when hauling a 1 tonne block over the ground, with friction force μ=0.60. Note that the total required force lessens after a 60 degree angle, as the friction force becomes less on such steep slopes even though the friction coefficient is a constant (graph by author).

be increased slightly, the use of a larger number of people/animals may thus decrease the efficiency, creating a need for even more creatures to pull the load. However, the factor of 4.5 that Atkinson mentions remains high, even when traction efficiency drops by 20 %.

The two examples show the impact of slope and friction on the amount of force needed to move stone blocks. Similarly, it has been shown that friction has an incredible influence on the necessary force. It would thus seem sensible that people would have looked for ways to decrease the friction between the surface and the object to move.

3.4.2.2 Friction

Friction is the result of two forces perpendicular and parallel between two bodies, and various factors influence this. Amongst these factors are the contact geometry (how well do the surfaces fit together, but also the surface roughness), lubrication, applied forces and stiffness of the contact surfaces (Blau 2001: 587). The reduction of friction can be achieved by changing or improving these factors. For example, the surface on which a sledge is moved can be altered by using wooden beams, placed parallel to the runners like a track, lubricating the surfaces with water or grease or the use of rollers placed perpendicular underneath the sledge (see also figure 3.5). All three of these measures have the effect of lowering the friction due to a lower friction coefficient. The friction coefficient of wood on wood can reach values below 0.2, especially when some sort of lubrication is used. Lubrication creates “friction-altering films” (Blau 2001: 587) that generally lower the friction although in some cases (like sand) this depends on the ratio of material and water (Fall et al., 2014). Rollers have the advantage that rolling friction is generally lower than sliding friction. Cotterell and Kamminga have calculated that the friction involved in moving the Vatican Obelisk to its final location, was as little as 0.002-0.008 (both extremes, so a value in the middle of 0.005 is more likely), due to the use of rollers on a wooden track (Cotterell and Kamminga 1990: 223-224). This type of result is only achieved on level ground and with a complete wooden track and (perfectly) round rollers.

Wheels and rollers thus provide less friction than objects that slide. A number of factors determines the frictional resistance of wheels and rollers. The size of the wheel is of influence, larger wheels provide less resistance than smaller ones. Furthermore, the nature of the surface over which the wheel moves is of great importance: the harder the surface the less rolling resistance there is (Cotterell and Kamminga 1990: 198-204). Finally, the friction caused by the movement between the wheel and the axle influences the overall resistance. Other factors that have an effect on this are those of the wheels themselves. The diameter and the width of the wheel determine the rolling resistance that, in turn, determines the amount of force necessary to move the wagon: the larger the wheel size, in general less force is required. The range of measurements of wheel sizes is limited, the diameter seems to be roughly between 0.50 and 1.00 m, while the width is between 0.03 and 0.09 m (see table 3.1).

3.4.2.3 Sledges

One way to reduce friction between the object that is moved and the ground it is moved over, is the use of a sledge. The runners (see figure 3.5) underneath the sledge provide a smoother surface that reduces friction (Cole 1954: 710). Sledges had been used for a long time, dating back to at least the fourth millennium B.C. in Mesopotamia

Literary reference	Wheel Diameter	Wheel Width	Axle Diameter	Wheel Type	Location	Dating
Piggot 1979	0.75-0.90			single-piece	Holland	2900-2500 BCE
Crouwel 1981	0.87-1.00			Spoked	Aegean	2nd Millennium BCE
Cotterell and Kamminga 1990	0.99-1.45	0.083		Spoked	Britain	19th century AD
Childe 1954	0.50			Tripartite	Kish	2750 BCE
	0.60-0.80			Tripartite	Ur	2500 BCE
	1.00			Tripartite	Ur	2500 BCE
	0.66-0.83			Tripartite	Susa	2500 BCE
	1.05			Tripartite	Susa	2000 BCE
	1.15				Trialeti (Georgia)	1500 BCE
	0.7				Yelista (S. Russia)	1200 BCE (?)
	0.54				Dystrup Mose (Denmark)	200 BCE
	0.92				Tapper (N. Germany)	200 BCE
van der Waals 1964	0.54-0.92	0.04-0.09	0.065-0.085	single-piece	Holland (11 samples)	1990-2150 BCE
	0.65-0.70	0.03-0.05		bi- and tripartite	Holland (2 samples)	before 200 AD
	0.7-1.00	0.032-0.051	0.14-0.16	Tripartite	Holland (5 samples)	450 BCE-100/200 AD
Clark 1878; Eastons and Anderson 1874	0.99-1.45	0.064-0.102		Spoked	Britain	19th century AD

Table 3.1 Overview of wagon wheels from various regions and periods as possible parallels. All measurements are in meters.

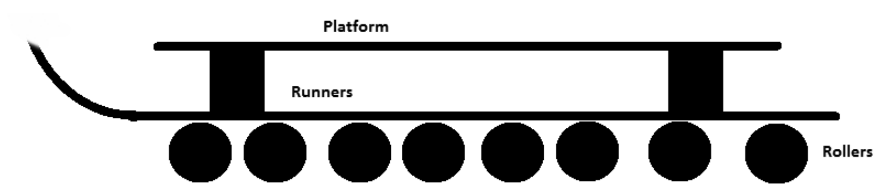


Figure 3.5 Schematic drawing of a sledge. The runners are the bottom part of the sledge actually sliding over the ground or rollers. In some cases, like a fork shaped sledge, the runners are also the platform on which the load is placed (*e.g.* Atkinson 1961; Shimotsuma et al. 2011) (drawing by author).

(Cole 1954: 710). The use of the sledge in ancient times is mainly attested on reliefs from the Near East and Egypt (Cole, 1954; Cotterell & Kamminga, 1990). Moreover, for the transport of particularly heavy materials, the sledge might actually be more suitable than a wagon (4 wheels) or cart (2 wheels). Too heavy a load would strain the axels too much and causes the wagon to collapse (see also the section below). On sledges, the weight is spread out over the length of the runners and thus the weight is more distributed than it is on a wagon. Due to the (in theory) simplistic design of sledges, the ability to withstand enormous weights and the reduced friction in comparison to dragging stones over the ground, sledges have been used to move megaliths as recently as the 1990s (von Saher, 1994). Saher's accidental discovery of the use of a sledge to move a 46 ton megalith on the island of Sumba (Indonesia), shows a wedged sledge made of two tree trunks forming an A-shaped platform with a raised front end (von Saher 1994: 69-70, figures 5 and 7). No real proof for sledges is known for Greece in the Bronze Age, but there are indications of sledges throughout prehistory and up to modern times in the Near East, the Mediterranean, Asia and Europe (Cole, 1954; Cotterell & Kamminga, 1990; Harper, 2016; Loader, 1998; von Saher, 1994). It seems, therefore, likely that sledges were known in the Aegean.

In order to understand the effect that a sledge has on the force that is required to move heavy stones, a similar calculation can be made as above. The main difficulty lies in determining the friction coefficient of the material of the runners (wood) on stone. Friction coefficients are usually taken from tables, based on experiments, presented in handbooks. The friction coefficient for this specific circumstance is not in such tables. However, Cotterell and Kamminga implied that the friction coefficient of an Egyptian simple sledge on bare ground would be 0.55 (Cotterell and Kamminga 1990: 219).[24] This is on par with what was found in research on the use of water as a lubricant for moving sledges on sand (Fall et al., 2014). This research team found that the friction coefficient of a sledge on dry sand was around 0.56 – 0.59 (Fall et al. 2014: 2). Moving the 1,000 kg limestone block used in the previous example over a level ground using a wooden sledge can then be calculated. $F_f = \mu F_n$, the load is on level ground which means that $F_n = F_g = 9{,}810$N. The friction force is then $F_f = 0.55 \times 9{,}810 = 5{,}395.5$ N, which is an 8.3 % decrease from the 5,886 N necessary to move the block without the sledge. This in itself is not an impressive reduction of the necessary force, which is unsurprising seeing the similarity in friction coefficient. However, this is in dry sand, not hard limestone, hence the friction on the former would be higher. The friction force of wood on stone can be as low as 0.2 – 0.4 [25] which would mean a force between 1,962 – 3,924 N or a 67 – 33 % decrease in required force.

3.4.2.4 Wheeled transport

Another viable option for the transport of the stone material from the quarry to the construction site would be by wagon. Cavanagh and Mee (1999: 96) also assumed the use of wagons for the transport of stone material during the LH III construction of the Treasury of Atreus.[26] The wagons could be simple wooden platforms under which two axles and a draught pole would be attached. To this draught pole, a yoke was fastened so the wagon could be pulled by animal power. Wheels could be either spoked or solid. The latter, in turn either could be single disc wheels or built up in a tri-partite manner (*e.g.* van der Waals 1964: 71; Littauer and Crouwel 1979: 18; Loader 1998: 47). The spoked wheel was mostly used for chariots. Their lower weight and "springy" nature made them stable at higher speed (Cotterell and Kamminga 1990: 198), but the large weight of cyclopean blocks might be too much for such wheels (Loader 1995: 47). The transport of such large blocks by wagon would be a slow endeavour in any case, since most likely the draft animals involved oxen (see below: 3.4.2.5). The axles were fixed to the undercarriage, with the wheels turning freely (Littauer & Crouwel, 1979; van der Waals, 1964).

Based on data from the 19th century, Cotterell and Kamminga (1990: 37) have calculated that to move a four-wheeled wagon on hard arable land, requires 920 N per tonne. This coincides with Clark's (1878: 962) figure of 927 N per tonne.[27] In order to move the block of stone of 1 tonne (as in the examples above) with the wagon, the weight of the wagon is of course also important. From the example of Cotterell and Kamminga, the wagon weighs 3,260 kg, bringing the total to 4,260 kg. A total of 4.26[28] × 920 = 3,919.2 N is thus necessary to move the wagon with the block on level ground. This is a similar force in comparison to the force that was necessary moving the block with the sledge and a 33 % decrease compared to sliding the block over the ground. These figures are based on different surfaces though, and therefore not directly comparable because moving the wagon on hard surfaces such as limestone would decrease the rolling resistance. Even less force would thus be necessary to move the wagon.[29] It could also be argued that a 1 tonne block does not need such a large wagon weighing over 3 tonnes. This would lower the necessary force even further. If, for example, the weight of the wagon matched the weight of the load, the total weight would come down to 2 tonnes. The necessary force would then be 2 × 920 = 1,840 N, a 69 % decrease from dragging the block over the ground (or even more if moving on a hard surface (see previous note)).

The maximum load a wagon could have been able to carry depends on a variety of factors, but ultimately it is the weakest point that determines the maximum load. Arguably this is either the wheels or the axle as these are most likely the thinnest sections of the wagon. Wright (2005a: 41) argues that it is the axle load and that this can never be more than "several tons". While this seems a plausible statement, the strength of wood is based on the surface area of the section. In the case of a circle (assuming a round axle) the surface area increases by a factor x^2 in which x is the factor with which the radius increases. In other words, if the radius of the axle doubles, the surface area quadruples (2^2). If the radius triples, the surface area increases by a factor 9 (3^2). The pressure that can be withstood can be expressed in N/mm², thus the difference between an axle of 25 or 75 mm, means a difference in surface area of a factor 9 (1,963 vs 17,671 mm²) and thus

24 Implied because they mention the following figures: maximum force a person can exert for a reasonable time is 300N and it would have taken 18,000 persons to move a 1,000-tonne statue. Thus it can be calculated that $F_t = 18{,}000 \times 300 = 5.40$ MN, $F_n = F_g = 1{,}000$ ton × 9.81 = 9.81 MN. $F_f = F_n\mu \rightarrow 5.40 = 9.81 \times \mu \rightarrow \mu = 5.40/9.81 = 0.55$. The friction coefficient is actually lower as this calculation does not take into account the weight of the sledge.

25 https://physics.info/friction/ (18/09/2018) and https://www.engineeringtoolbox.com/friction-coefficients-d_778.html (18/09/2018).

26 The Treasury of Atreus is a large tholos tomb near Mycenae (e.g. Mylonas 1966).

27 Clark mentions that on a field (similar conditions as Cotterell and Kamminga use) the draft per tonne gross is 210 lbs., which is roughly 927 N.

28 4,260 kg / 1,000 = 4.26 tonnes.

29 If for example the friction coefficient is used that is given by Cotterell and Kamminga for a hard gravel road (0.019) then the required force drops to 174.4 N per tonne, which would result in a total force of 174.4 x 4.26 = 743 N. A decrease of 87 % of the required force to move the 1 tonne block by dragging it over the ground.

the amount of pressure that can be withstood also differs by a factor 9. The span of diameters of axles found in the literature lies between 0.065 – 0.16 m (see table 3.1 above), which gives a range of cross-section surfaces of 3,318 – 20,106 mm^2. Thus, the range of possible loads is huge and heavily depends on the measurements of the wagon and specific elements in particular, and of course the type of material used. Which is also expressed by Russell (2013: 101-102): different wagons were used for different loads. The variety shows two-wheeled carts for small loads, to large 12-wheeled wagons for large unusually heavy loads (Russell 2013: 102).

Finally, the loading and unloading of the material needs to be considered. It would seem likely that some sort of ramp would be created to accommodate pushing/pulling the massive blocks onto and off the wagons and sledges, as there is no proof of hoisting machinery being in existence at this time. Coulton assumes that it was not before the end of the 6th century BCE that pulleys and winches were being used for heavy lifting (Coulton 1977: 48). Blocks could have been moved onto the ramp, possibly with the use of rollers, as suggested by Wurch-Kozelj (1988: 63). Alternatively, the use of levers could have helped in the loading. This methodology has been thoroughly explored for use in the construction of the Egyptian pyramids by Hodges (1989). He showed that a 2.5 tonne block could be lifted using levers by four men with two additional men inserting supports. Using this setup, Hodges and his team lifted the block 0.813 m in 200 seconds. Considering the fact that the diameter of early wagon wheels varied between 0.50 and 1.00m, it could be argued that such a method means that the loading of a wagon could potentially be achieved in mere minutes.

3.4.2.5 Traction

As shown above, the required force to transport material is dependent on a variety of factors. One of the great challenges to overcome in this work is to ascertain what is and is not plausible in terms of transportation and which factors are known and unknown. The available literature on transportation, and more accurately, on the forces involved in transportation range from early engineering manuals to 20th century experiments and more modern interpretations of these numbers in more objective figures. Some figures are more comparable than others, for example, Rankine's figures (Rankine, 1866) from the late 19th century can be relatively easily compared to modern-day standards. More abstract figures like Atkinson's results from field experiments based on the stones of Stonehenge (Atkinson, 1960, 1961), are more difficult to interpret. His trial of moving a block of stone on a sledge by senior school boys provides some useful insights into what kind of numbers should be considered, but no real objective figures (*e.g.* pulling force of the boys, weight of the sledge, friction coefficient) are provided. While in some texts these kind of figures can be determined if at least some of them are given, in his texts hardly any are offered. This means that the figures considered below are based on various works which range from manuals, to hear-says, to experiments in various periods of time. An attempt is made to convert the variety of figures into a comparable form.

Pulling large weights on wagons or sledges can be done by humans, as shown through Egyptian murals and the experiments by Atkinson in the 1950s and 1960s. However, it is likely that draught animals were used whenever that was possible (*e.g.* Russell 2013: 98). Crouwel (1981: 32) argues that bovids were used for this task well before 3000 BCE in the Near East. Building accounts from Greece show that oxen were used in the Classical period for the transport of heavy building material (Burford 1960: 5-6). Burford also mentions in relation to the Late Bronze Age in Greece that oxen are referred to as "working oxen", which she interprets as the oxen being the main animal used for work.[30] In both eras the oxen were the primary animal used in agricultural settings and it is argued that, when they were not needed within this situation, they could be and were used for heavy transport (Burford, 1960, 1963).

While very strong and sturdy, oxen are also very slow going at an average speed of 0.8 m/s or 2.9 km/h. In comparison, horses will go 1.1 m/s or 4 km/h on average, when pulling weight (Cotterell and Kamminga 1990: 36-38). The latter is on par with Clark's figure for horses (2.5 m/h = 4 km/h) (1878: 962) as well as Rankine's figures for horses (3-3.6 ft/s = 0.9-1.1 m/s) and oxen (2.4 ft/s = 0.7 m/s) (1866: 251). Although horses are faster, they cannot be harnessed to a yoke in the same fashion as oxen due to their physiology. The proper harnesses for horses were invented much later. Furthermore, ancient horses were a lot smaller than modern horses and provided less power (Cotterell and Kamminga 1990: 37). Donkeys may have been used, but they lack the draught strength that oxen have and the donkeys were thus most likely used as pack-animals (Loader 1995: 50). Oxen can be yoked quite easily with the yoke resting on their broad neck just in front of the withers (Cotterell and Kamminga 1990: 206).[31] Another advantage of the oxen over other animals is that they are superior on rougher terrain. Here its slow but steady pace is far more useful than the quick and light step of a horse (Cotterell and Kamminga 1990: 206; Crouwel

30 Faunal evidence from Knossos (Crete) has shown that from the Neolithic onwards cattle in general were used for, amongst other things, traction (Isaakidou 2006: 108). Thus, traction was not solely provided by oxen. However, there are two reasons to focus on oxen in this study: 1) most studies concerned with traction force of cattle focus on oxen (see references throughout) and 2) oxen were mentioned on the Linear B tablets (e.g. Killen 1993).

31 This is the ridge between the shoulder blades.

1981: 32). Considering that in Mycenaean times roads were scarce, horses never really replaced oxen as the working animal. Horses remained an elite commodity, for the most part (Burford, 1960; Crouwel, 1981) and it seems that oxen would be used for heavy transport since they were available when not used for agricultural purposes.

An obvious source for information on the use of draught animals in construction work would be DeLaine's (1997) dissertation as this is one of the first and most thorough labour cost studies in the Mediterranean, though focused on the Roman Baths of Caracalla. However, her analysis of the amount of effort oxen can provide is not very useful here. First, she focusses on the use of oxen carts (instead of wagons) which, as she writes are limited to carrying a maximum weight of between 400-500 kg (DeLaine 1997: 108). This is based on the Price Edict (8.5.30) and the Theodosian Code (17.3, 14.8) respectively. This is problematic for two reasons: 1) this is probably not the maximum possible load, but the maximum allowed load and 2) she does not consider the weight of the cart in this, and therefore it is difficult to ascertain how much weight the oxen are truly moving in her examples. As Russell (2013: 95) points out, the Price Edict is restrained in both time and geography, and therefore difficult to extrapolate to other situations. Furthermore, most of the material DeLaine considers consists of dividable loads, unlike undividable loads such as the massive blocks used in cyclopean stonework. On the transport of the heavier marble used in her study, she states "The size of many of the blocks and the difficulty of loading and unloading them, as well as any special preparations which may have been necessary for moving them, make calculations of total requirements very difficult" (DeLaine, 1997, p. 129). While her work is a great inspiration for many energetic studies in the Mediterranean, the difference in construction material (she deals mostly with bricks), makes that it is not the most suitable source for this study.

Similarly, the figures that Harper (2016: 522) uses for transporting materials in his energetic study of Mycenaean structures have some issues. He uses the same figure of 2,100 kg as Devolder who has come to this figure based on Raepsaet's figure of 630 N of pulling force for oxen (see below). However, like Devolder, Harper does not take into account the weight of the wagon in establishing a maximum pulling force of oxen. This may seem negligible, but wagons can weigh up to several tonnes themselves (*e.g.* Cotterell and Kamminga 1990: 204) which means that there would be a large increase of necessary force to pull wagon and load. Even if the wagon is only 500-1,000 kg[32] this makes up 25-50 % of the weight Devolder assumes an ox can pull thus increasing the necessary trips to transport the material by a factor of almost 2 in the worst case scenario, and using only one ox.[33] Moreover, Harper (2016: 522) has made an additional assumption and has taken this weight of 2,100 kg as the maximum load a wagon can support, on seemingly no other basis than the fact this figure was mentioned by Devolder. Any weight above 2,100 kg would thus not be moved by wagon but by other means of transportation (*e.g.* rollers or sledge). It is thus imperative to first come to a useable draught force of oxen. Furthermore, the weight of the wagon must then be included in the calculations of the necessary trips for transporting the material.

The draught force of oxen is variable, which is reflected in the range of figures presented in the literature. Cotterell and Kamminga (1990: 38) cite a relatively low value of 410 N, based on Rankine (1889: 251), yet Rankine mentions an effort of 120 pounds (~ 534 N) in his 1866 paper. Raepsaet (1993: 260) comes to the highest mentioned effort in relation to ancient oxen of 630 N. How Cotterell and Kamminga come to their low number is somewhat unclear, although it might be because they try to incorporate the fact that in ancient times the operation of draught animals was less efficient than nowadays. Loader (1995: 56) has simply accepted their figure and uses this in her analyses. The other figures are taken from experiments with (relatively) modern animals. However, Raepsaet (1993: 260) comes to his figure based on the assumption that an ox, when pulling a wagon, can pull about 1/7 (~ 14.3 %) of its bodyweight and that an ox from ancient Greece can weigh roughly 450 kg.[34] This ratio between bodyweight and maximum pulling force is similar to what Akinbamijo et al. (2003: 113) state, which is a workload of 14 % of the bodyweight of the oxen. O'Neill and Kemp (1989:41) also mention that oxen can pull a maximum of 10-15 % of their bodyweight. According to Devolder (2013: 27 n143) ancient oxen are, based on their weight, comparable to modern light bovines from Africa weighing between 350-400 kg.[35]

32 In their article, Wooley and Jones use two different wagons that weigh 544 kg (with no driver) and 1,839 kg (with 2 drivers) respectively (Wooley & Jones, 1925).

33 Devolder gives an example for the Gournia palace in which she uses that number of 2,100 kg to divide the total load of stone into loads that could be drawn and thus calculate the number of trips. If a wagon weighed 1,000 kg, the maximum load would be 1,100 kg, the number of trips would then be 102,160 (the total weight of the stone material) / 1,100 = 92.87 = 93 trips at least, which is almost twice as many as she calculates (49). The person hours would then be 0.36 x 93 = 33.48 instead of 17.64 in her example. The number of 0.36 (person hours) comes from the distance of 594 m at a speed of 1.67 km/h.

34 450 x 1/7 = 64.3 kgf which is 64.3 x 9.81 = 630.6 N.

35 It is odd that Devolder argues that the maximum pulling force is 630 N, based on Raepsaet who assumes that oxen weigh about 450 kg, yet in a footnote on the same page argues that the weight of oxen in the Bronze Age is likely between 350-400 kg. Despite this discrepancy, she continues to assume a maximum pulling weight of 2,100 kg, which is based on a pulling force of 630 N.

If 14 % of the bodyweight is taken as the average draught force, then this would mean that for ancient oxen the force would be roughly between 491 and 549 N.[36] These numbers will be used later on for calculating the required number of oxen to transport the material to the site.

Humans were obviously involved in moving heavy material, but cannot provide the same amount of force as oxen (or other draught animals for that matter). Rankine (1866: 252) notes that pushing or pulling horizontally, humans can produce 26.5 pounds of force, which is roughly 118 N. Hertzberg (1972: 552) writes that while pushing horizontally against a stationary object, a human can exert 40 pounds of force, or 178 N. While moving and actually performing mechanical work, this high output cannot be reached. Hertzberg (1972: 574) writes that over a full day, an average man can put out 0.14 hp or 104.4 W. This is close to de Haan's (2010: 17-21) figure of 70-100 W per day. If Hertzberg's figure is used and a person would have been walking at a pace of 3 km/h (0.83 m/s), this would mean he would have been exerting a force of roughly 125 N. Clearly, it makes sense to have animals involved in the transport of heavy material as an average ox can exert 4-4.5 times the amount of force a human can and, more importantly, over a prolonged period of time. It can, however, be argued that in tight places, like the quarry or at the actual construction site, there was no place for oxen and thus human force was necessary to move the stones into place. In these instances the short bursts of a greater force that men can exert can be utilized, which can reach up to 300 N (de Haan, 2009).[37]

3.4.2.6 Final comments on transport

It is thus clear by the examples presented above that an investment in building transportation devices like sledges and wagons provides solid returns in the form of a great reduction of required force. The costs of transport will also depend, in large part, on the length of the route as well as the state of the terrain through which the route goes. Whether the latter was adapted to ease the transport is difficult to research. There are roads known from the Mycenaean era (Brysbaert et al. 2020; Harper, 2016; Jansen, 2002; Steffen, 1884), but the close proximity of the quarry locations (see also chapter 7) might make these obsolete for this objective or at least unlikely to be solely built for the construction of the fortifications. The work force needed to move the stone onto the wagon obviously depends on the weight of the stone and this will be further elaborated on in chapter 7.

3.4.3 Design of cyclopean stonework

The material and its possible modes of transportation have been presented. In the following section the various parts, which form the actual fortification walls, are discussed. These parts entail the foundation, the wall faces, and the fill and finally there are some considerations presented in relation to how the blocks were put in their place in the wall.

3.4.3.1 Foundation

While the walls at one of the case studies (Teichos Dymaion) have no additional foundation layers (Gazis 2010: 239), it should be noted that some LH III fortifications are built on foundations, like certain stretches at Athens (Iakovidis 1983: 88). For Mycenae, there are various opinions on the matter of possible foundations (see below). Thus, for the general understanding of cyclopean stonework it is worthwhile to discuss it shortly. The foundation of cyclopean stonework can come in various forms and depends largely on the ground on which the construction is placed. Due to the overall high weight of the walls, a firm basis is needed. Wherever looser soil was present foundation trenches would be dug until bedrock was reached or a layer of debris was laid in such a trench (Wright 1978: 11; Loader 1995: 18-19). However, foundation trenches are often difficult to trace archaeologically, especially when the walls are still present on top. Furthermore, trenches were not always necessary, as for example is the case at Mycenae. The fortification wall at Mycenae follows the outline of the bedrock and could therefore be built straight onto it with no need of additional foundation trenches (Iakovidis 1983: 27). Similarly, at Teichos Dymaion, the fortification wall is also built straight onto the bedrock (Gazis 2010: 239). The bedrock may have been cut slightly to provide a level surface to build on.

A level surface could also be achieved by bedding. This is, in its simplest form, providing a layer of mud mortar and, in a more elaborate form, consists of slabs in mud mortar (Wright 1978: 20-21). Another form of foundation are actual foundation walls that often stepped out from the face of the superstructure. Due to this greater width, the weight of the wall on top was distributed over a larger area (Wright 1978: 23-24). However, these foundations were not necessary if structures were built straight onto the bedrock, as this would provide enough stability for the large walls (Loader 1995: 18-19). Iakovidis writes that for the first fortifications at Mycenae, there was no separate foundation layer, but the bedrock was hammered to create a level surface. Any remaining irregularities were overcome by laying down small stones to make sure that the first course of the wall had optimal contact

36 350 x 14 % x 9.81 = 481 N and 400 x 14 % x 9.81 = 549 N.

37 It seems that an obvious source is missing in this section, namely, Atkinson's (1960 and 1961) work on megalithic transport. However, his figures are more descriptive and no real numbers of force are given. This makes it more difficult, if not unreliable, to compare those figures with the ones from other studies where methods that are more precise are used.

surface (Iakovidis 1983: 29). For the later additions of the fortification at Mycenae, some variations in the use of foundations occur. Besides the use of smaller stones to counter any irregularities in the surface (as supposedly is the case at the Lion Gate, and sections of the walls at Athens and Gla), a layer of clay was sometimes used on which the lowest courses were put (Küpper 1996: 34). A similar use of clay can be seen at the lower courses at Midea (Küpper 1996: 34).

There is thus some variation in the foundation layers at various sites and in various sections at sites. The most important thing is that a more or less level surface was created before the actual walls were built. Like the use of the smaller stones set in between the larger blocks, the creation of a level foundation layer is meant to create a stable surface over which the weight of the blocks is properly spread out, thus creating a stress-free and optimal placement of the large, heavy blocks. While there was thus no or no extensive separate, foundational substructure, the preparation of the bedrock before the laying of the first course is nevertheless part of the building process. It therefore needs to be taken into account in the calculation of the labour investment in the structure. For the case-studies it can be argued that this comes down to hammering down the bedrock to a level surface, or the laying of a foundation layer of clay and/or small stones. Additionally, where necessary, earlier structures or ground needed to be removed to reach the bedrock (Küpper 1996: 49).

3.4.3.2 The wall faces

The impressiveness of cyclopean stonework comes from two main characteristics: the size of the structures themselves and the size of the used stones. The wall faces, in which these enormous blocks are visible, are only two parts of the entire structure, though they do form the most visually impressive sections. Cyclopean stonework is a rather general term (see section 3.2); it comprises various styles that are often the result of local circumstances (Loader 1995: 22; Iakovidis 1983). One feature that various authors have tried to fathom is the stepped sections of, or offsets in, walls that are visible at various sites. This can be described as “a vertical joint that marks a change in the course of a wall, such that one section of the wall is not aligned with its neighbour” (Wright 2005b: 191). Küpper (1996: 33) argues that, since it is more difficult to construct straight angles (see below), there is no technical need for such offsets and thus it is done for purely aesthetic reasons. On the other hand, Loader (1995: 73) argues that these “stepped” sections are the result of the building process of constructing the wall in separate units. She argues that this building approach is meant to accommodate building on “slopes and cliff edges” and speeds up the building process (Loader 1995: 73), most likely because various groups could work on different units simultaneously. Grossmann also argued that the fortification walls were built in sections because the wall had to be built level to accommodate the fill (see below) and this could not have been done over the entire length of the fortification (Grossmann 1967: 99). Scoufopoulos (1971) and Iakovidis (1983) also note that the offsets are the result of construction of the walls in sections. Wright (2005b) points out that although the use of offsets is widespread, it is not universal among Mycenaean sites and at some sites, offsets are not used at all to bond various sections (like Midea). He argues that the use and style of offsets is largely depended on the material. As different types of limestone are bedded differently and thus break away differently, this determines the size and shape of the blocks used. Therefore, this feature influences the way techniques such as offsets are employed (Wright 2005b: 6).

A specific form of wall facings that is worth mentioning shortly here is ashlar. It is more common on Crete (*e.g.* Devolder 2013; Shaw 2009; Soles 1983) than it is on the Greek mainland during the Bronze Age. Yet, there are a few sections built in this style and therefore it is worth exploring what it is and adds to the study of fortification walls in this research. Ashlar constructions are built in (well-cut) rectangular blocks. This difference in style is especially interesting from an energetics perspective as the use of cut blocks increases the amount of time invested in the preparation of the blocks and thus in the overall building time. The prime example would be the façades surrounding the Lion Gate at Mycenae, built in conglomerate stone. However, Küpper (1996: 32) argues that these blocks do not fit as well as or are as regularly shaped as real ashlar constructions as can be found on Crete, in Pylos (*e.g.* Nelson 2001: 108-17; Wright 2005: 1) and in some of the tholos tombs (Küpper 1996: 31). He states that the conglomerate sections at Mycenae and some of the sections at Gla, comprise “pseudo ashlar” constructions (Küpper 1996: 32). It is clear that sections in this style require additional time and skill to shape, compared to other cyclopean style walls in which the blocks used are hardly shaped at all. Furthermore, the use of smaller stones set in interstices is not executed and thus it might be best to consider these sections as non-cyclopean (see above section 3.3), despite the fact that some of these blocks are quite large. At least for Mycenae it is clear that the sections built in the pseudo-ashlar fashion in conglomerate are façade walls and are not integrated with the fill or wall that they cover (see figure 3.6). Moreover, these pseudo-ashlar sections are often built in highly-visible places and should be considered as a display of craftsmanship and perhaps power (see also Chapter 2.2.2 and Wright 1978). Others have argued that the specific use of ashlar masonry was for the sake of protecting the

Figure 3.6 View on the backside of the bastion at the Lion Gate, Mycenae (textured 3D model by author). The cut blocks on the left form a separate façade around the wall (note that this section of wall is not cyclopean). It also shows the somewhat irregular shape and size of these conglomerate blocks, as mentioned by Küpper, which makes that he does not consider them as true ashlar.

vulnerable sections of the fortifications (Loader 1998: 22). Loader bases her argument on Lawrence (1979: 232) who argued that because ashlar blocks fit together so well that they are more difficult to dislodge than in other types of stone construction. In and of itself, this argument seems solid, yet, when the position as well as the difference in material for the (pseudo-) ashlar sections at Mycenae are considered this seems less likely. If it was a mere structural choice, the ashlar sections would not have needed to stand out as much as it does now. In the current positions, it provides an impressive and dramatic approach to the likewise impressive Lion and Northern Gate.

3.4.3.3 The fill

Besides the foundation that was used for some structures, the faces are separated by another important part of the wall, the fill. This core was usually a dense fill of stones and earth (Loader 1995: 22). Küpper (1996: 33) describes the core as smaller blocks than those used in the shell walls, with larger blocks in the exterior shell wall than in the interior one. It is important to point out that the fill was not a completely separate unit within the wall. Blocks used on the walls encasing the fill would often go into the fill, creating a whole entity, and thus increasing its overall strength. This being the case, it makes sense that fill was built up at the same time as the walls, keeping the overall wall at an even level. Not only would this ensure proper bonding of the wall faces and the fill, it would ease construction as blocks could be moved over a broader area, since the fill was (roughly) on the same level as the wall faces. The latter is also concluded by Küpper (1996: 50) and ties in with Grossmann's (1967: 99) argument for building the fortifications in sections.

3.4.3.4 Putting the blocks into place

Proper coursing only occurs at a few places within cyclopean stonework and Iakovidis (2001) has argued that any form of coursing could not be maintained for prolonged sections due to the uneven blocks used. As for corners, there are a few rounded sections, but it is argued by some (Grossmann 1967: 95) that the stepped way in which some walls are built are the result of the inability to build rounded sections. Wright (2005b: 4) has pointed out that more precise recording would be helpful to test whether there are rounded sections present in cyclopean stonework. It is clear, however, that there are multiple sites where rounded sections appear (*e.g.* Teichos Dymaion, Tiryns and Mycenae). Moreover, Küpper (1996: 32) argues that creating sharp corners is much more difficult, as it requires skill and knowledge about selecting the right blocks to execute these corners. He further states that some of these straight corners were reinforced with particularly large blocks (Küpper 1996: 33).

Putting the blocks into place would have become increasingly harder as the height of the wall grew. Since pulleys and winches were most likely not yet in use at this time, some form of ramp thus seems to be the most likely solution of getting the material to the appropriate height (*e.g.* Coulton 1977; Loader 1995; Küpper 1996). Heizer (1966: 827) points out that (earthen) ramps are the simplest and possibly the most used method of elevating heavy stone material in ancient times. The downside of using ramps is the large amount of space that is needed to accommodate such ramps. Loader (1995: 59) writes that for a ramp 10m high with a 20 % gradient, the ramp would need to be 50 m long.[38] Besides the issue of the long ramp, a 20 % gradient (= 11.5 °) is rather steep, especially when moving large, heavy blocks. Obviously, the gradient would be preferably less, but that would further increase the size and especially the length of the ramp. Space is thus an issue, especially when considering on which side of the wall the ramp would ideally have to be placed. Since most Mycenaean citadels are built on outcrops, it would be far easier to have the ramp on the inside of the wall, reducing the required height. However, as many of the citadels were already in use long before the construction of the fortification walls, there most likely was little to no room for such ramps on the inside of the fortification.

The main parallel for the use of ramps in the construction of large structures comes from Egypt, where the use of ramps is researched extensively (*e.g.* Hodges 1989; Arnold 1991; de Haan 2009, 2010, 2014). There are, however, a number of differences between circumstances in Egypt and Greece that need to be taken into account. First, the Egyptian pyramids are not built on rocky outcrops, which means that the ramp does not need to overcome an additional height. Secondly, space seems to be less of an issue, considering the location of the pyramids. Thirdly, the pyramids are built in stepped courses, which makes that each course provides a working platform on which material can be moved and additional ramps for the next level can be placed. No ramps can be placed on cyclopean-style walls as it is not stepped and thus the ramps would be in the way of the actual construction. This means that there would need to be a ramp for each section of cyclopean-style wall, or at least for a small number of sections. Alternatively, the ramp would level out at the appropriate height and encase the entire length of the wall on that level to accommodate transport to all sections in construction. De Haan (2014: 154) has shown that the latter method would be highly impractical for pyramids and therefore rejects this "spiral ramp" theory. Arguably, such a ramp would seem an excessive structure to build and, would take up an enormous amount of space, which could not be accommodated on many sections. Even if the fact that Mycenae's walls were not built in one go and, therefore, there would not have been a ramp around the entire citadel, the ramp for the individual phases (see chapter 4) would still be massive. It seems more practical that while building sections of wall, individual ramps were constructed for these sections (see also chapter 7).

38 A 20 % gradient means a 20 m rise over a length of 100 m, a 10 m rise thus needs a 50 m long ramp.

3.4.4 Conclusions regarding the building processes

In the sections above the various stages that make up the general construction processes are explored. In each phase a number of factors play a crucial role in relation to the workload involved. The stage of quarrying is heavily depended on the type of stone that is quarried as well as the method of extracting and the tools involved. During the stage of transportation the distance to the building site is key as is the landscape since both slope and friction have a great impact on the necessary workforce and on the amount of time it takes. At the building site itself, there are various sub-phases, starting with the preparation of the site where necessary. In case no foundation structure is being built, the underground needs to be levelled to a certain degree to provide a stable base for the walls. Most likely, the large fortification walls are then built in sections to accommodate a steady work pace in which outer walls and inner fills are built simultaneously to create a wall that is as strong as possible. This is achieved by linking the outer blocks into the fill. Furthermore, such a section-type construction allows a constant working platform to accommodate the movement of the blocks into their proper position. For loading the blocks onto transport vehicles as well as getting the blocks to the top of the wall, either ramps or a form of levering or both was used. In the case of ramps, it must be explored how big these needed to be to be able to get to the proper height, while still maintaining a feasible slope for hauling. At various places such as the Lion Gate at Mycenae, special care was taken in creating visually attractive shell walls in the form of (pseudo-) ashlar stonework. These sections are built differently and their cost must be calculated separately as they do not just differ in material, but also in workmanship and construction. In the analysis chapter (chapter 7), the above described processes are used to break down the labour cost for the various stages. This leads to realistic ranges of necessary workforce figures for the construction of these fortifications.

3.5 Concluding remarks

As set out in the introduction, the aim of this chapter was to provide crucial insights into the fortifications that are studied for this research. Two characteristics that are often mentioned in relation to the fortifications of the Mycenaean era are to do with how these fortifications were perceived (monumental) and the style in which they were built (cyclopean). Monumental or monumentality remains a difficult term because so many connotations are associated with it. In its core, the discussion evolves around the meaning of a structure, it seems. Since it is difficult, if not impossible, to ascertain the meaning or intention of a structure's builders and commissioners from prehistoric times, it is perhaps best to follow a more quantifiable set of characteristics. Although such an approach has its own challenges as a way to make structures comparable in terms of work investment it is most applicable to the current study. Thus, by comparing the cost of the fortifications to the cost of domestic structures there will be at least a scale on which to place the calculated investments. Whether a characterisation as monumental is useful in this context will be discussed further in chapter 8.

Cyclopean-style building is best described as a stonework construction in which large, mostly unworked, blocks are used with smaller stones placed in between. The latter are used to create a greater stability of the entire structure. Stylistic variation within this type of construction between sites is largely due to the characteristics of the local stone. While there are sections built in large, more carefully cut, stones such as the Lion Gate at Mycenae, these sections miss the use of smaller stones and might, therefore, not be considered cyclopean.

A breakdown of the construction process of the fortifications helps to understand how the fortifications were built, but also provides the steps that need to be quantified in terms of investment to come to a proper estimate of the total costs. Each of the separate stages within the construction processes poses their own challenges. By studying these stages separately (as far as possible as some of these stages are interrelated), a proper assessment of the investment in terms of workforce can be made. This chapter thus provides insights into key aspects of the research into the energetics of monumental cyclopean construction and forms part of the base on which the labour cost calculations will be interpreted, in chapters 7 and 8.

In chapter four the case studies will be discussed. These sites, Mycenae and Teichos Dymaion, have provided the data on fortifications that is used in the subsequent analyses. The next chapter will thus provide a general overview of the sites and their fortifications. Furthermore, a short overview of the estimated population for both sites, which is crucial for understanding the calculated labour costs, is presented.

Chapter 4

The case studies

Within this research, two case-studies are used to analyse the labour costs of cyclopean fortifications: Mycenae and Teichos Dymaion. To be able to put the data from these case-studies into the proper context, this chapter provides background information on these sites. For both Mycenae (section 4.1) and Teichos Dymaion (section 4.2) (see their location in figure 4.1) the following key aspects are discussed: first, a short description of the site and its research history is provided; Second, a (very) short overview of the structures at the site; Third, the fortifications; Finally, population numbers for both sites, these numbers are crucial to properly interpret the calculated labour costs. All this contextual information is crucial to be able to properly interpret the data and labour cost analyses and will thus prove fundamental in the interpretations presented in chapter 8.

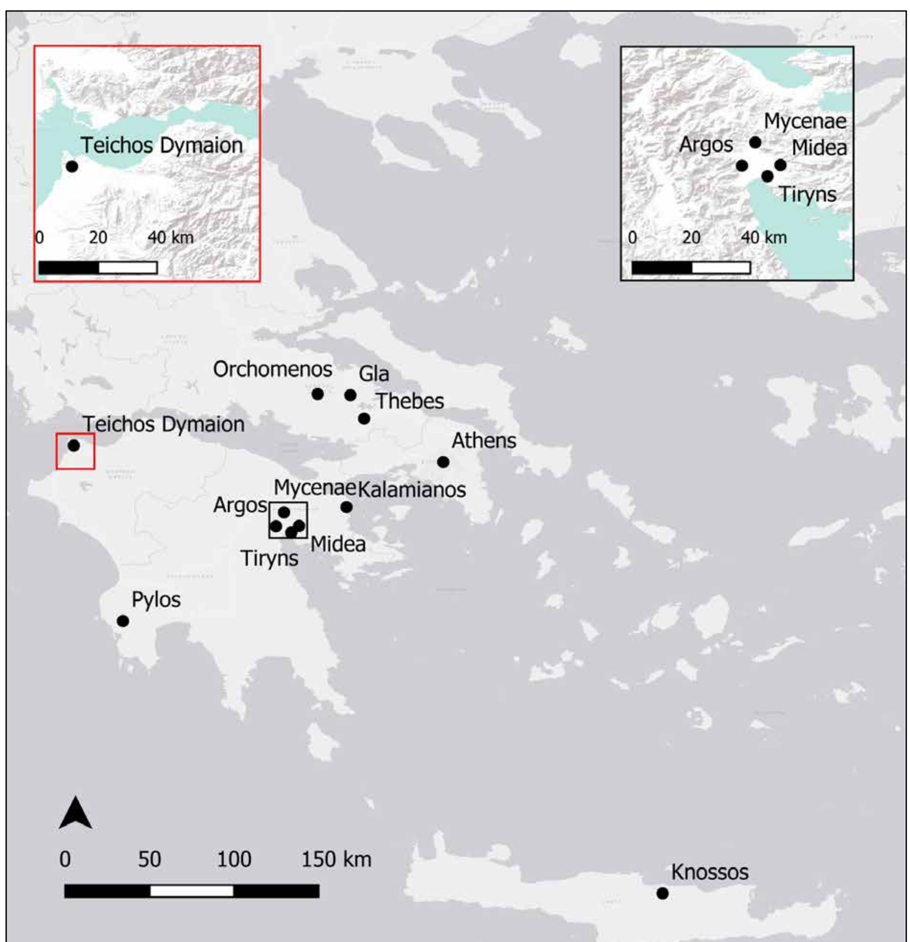


Figure 4.1 The location of the case-studies as well as other sites mentioned in the text (World Terrain Base map by ESRI ArcGIS) (map by author).

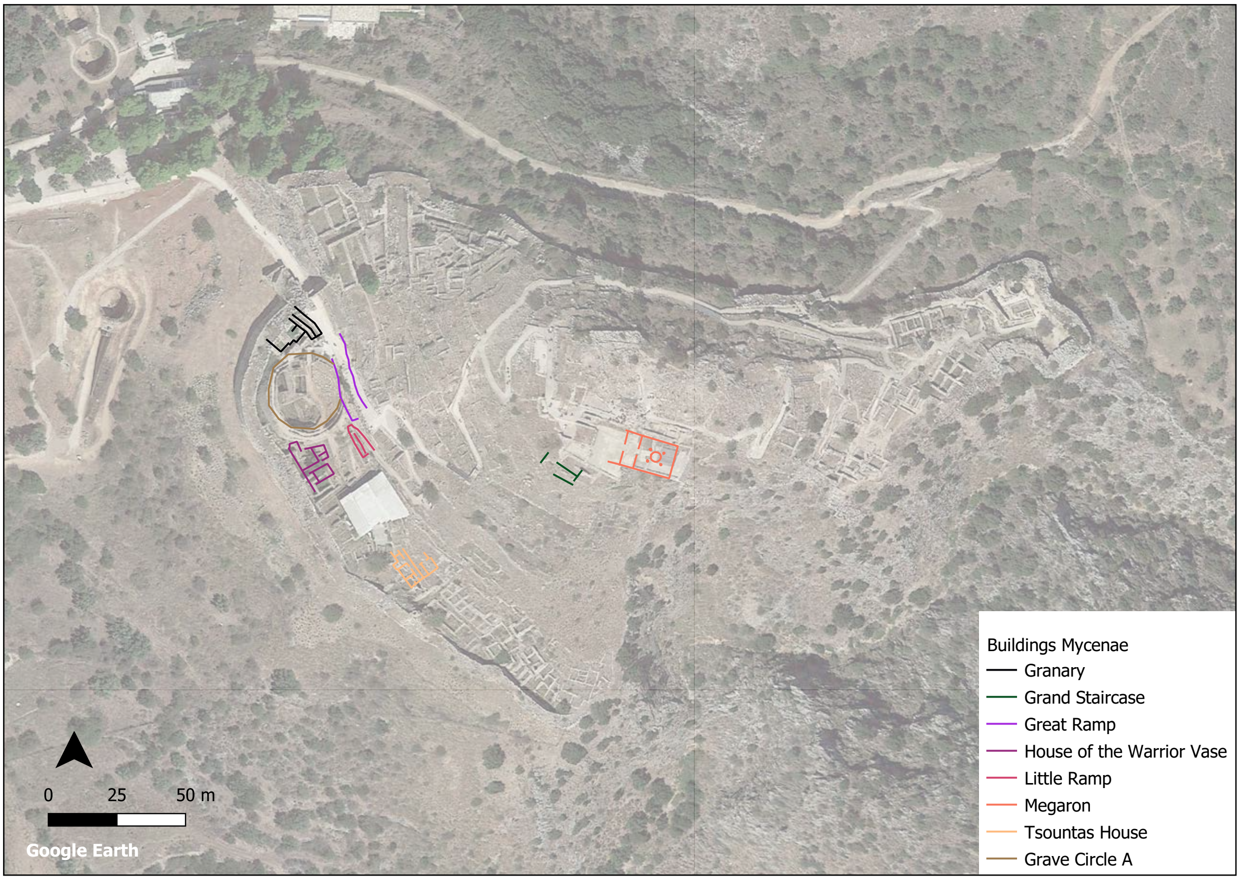


Figure 4.2 Satellite image of Mycenae, showing numerous buildings within the fortified area (base map by Google Earth). Highlighted in the image are some of the buildings mentioned in the text (based on Küpper 1996: Beilage 3 and French 2002: Plan 19).

4.1 Mycenae

Mycenae is the most famous site for the Aegean Late Bronze Age on the Greek mainland, lending its name to an entire society as well as an era in Greek prehistory. The site is located on a hill, which rises some 40 metres above the surrounding land. Although two nearby peaks are higher, the hill is a natural strong point. It lies near the pass connecting the Argolid with Korinthia and it is thus perfectly situated to control any movement between the two plains (Iakovidis 1983: 23). The site was famously excavated in the late 19th century by Schliemann who had set out to prove the validity of Homer's epics.[39] Homer in his renowned poem the Iliad, described Mycenae as a city "rich in gold" (Homer, Iliad: 11.45) and home to the king Agamemnon. The status that was ascribed to the site so early on by Homer meant that the site has always been well-known. This is both a blessing and a curse, because it means that a lot of research has been done and, therefore, a lot of information has come to light. However, biases may be lurking and the most obvious one is seeing Mycenae as the seat of a king of kings or "Great King", controlling the rest of the Aegean (*e.g.* Kelder, 2008; see also chapter 2). There is still a divide between scholars regarding Mycenae's role in the Aegean and its status compared to other, contemporary states (see also chapter 2).

4.1.1 General build-up of Mycenae

Mycenae was densely built-up with a variety of structures within (see figure 4.2) and outside the fortification. The total site size has been estimated at 32 ha, based on the spread of finds (French 2002: 64). The most prominent structure would be the palace, located on the top of the hill. The central structure of the palace, the megaron (see also chapter 2), is located on the south-east edge of the top plateau (see figure 4.2). As such, parts of the original structure have eroded off the cliff. However, it had, originally, the typical layout of the megara as they are found throughout the Peloponnese (*e.g.* Mylonas 1966:

39 Schliemann was neither the only one nor the first who excavated at Mycenae (see French 2002 for an extensive overview). However, his excavations and the subsequent discoveries are widely known.

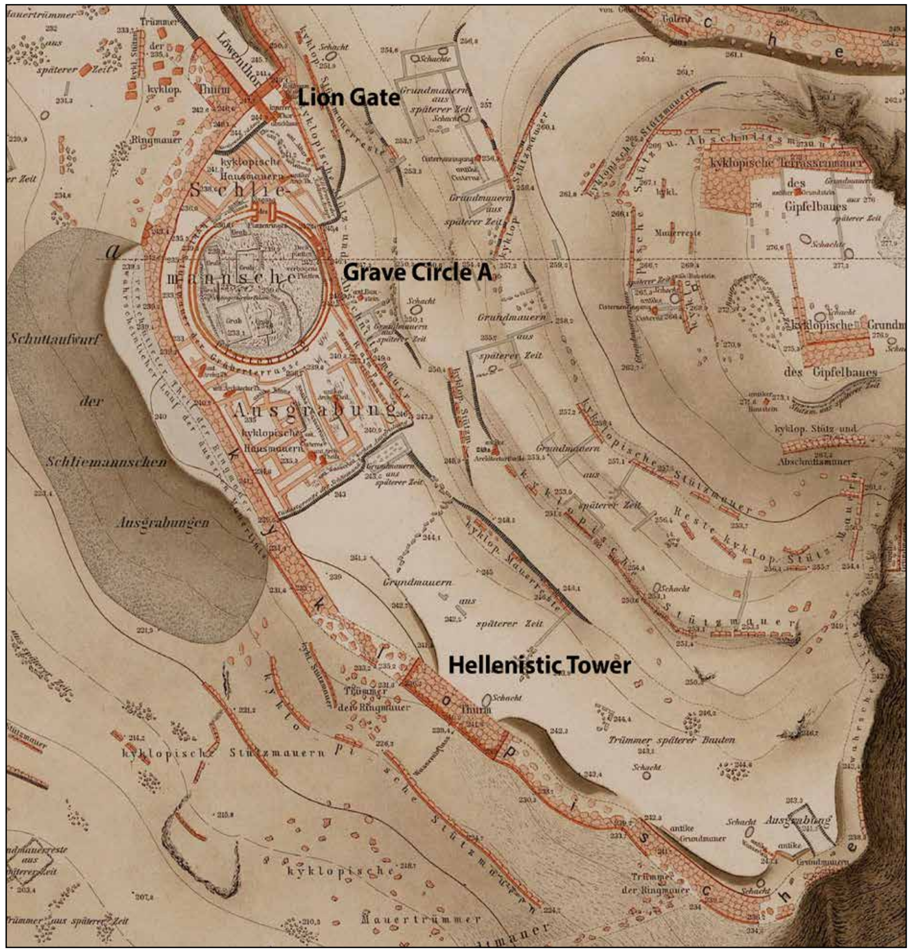


Figure 4.3 Location of the Lion Gate, Grave Circle A and the so-called Hellenistic Tower. Sections west of the Grave Circle can be seen to have partially collapsed (after Steffen 1884: Map 3).

63: figure 16; see also section 2.2). Along the western cyclopean wall, various structures have been identified, such as the “Granary”, the “House of the Warrior Vase” and the “Cult Centre” (*e.g.* Mylonas 1966; Iakovidis 1983 and figure 4.2). The general construction of these buildings consisted of a stone foundation, which also outlined the first floor or basement. On top of these, mudbrick walls were built which formed the upper storey(s) (Iakovidis 1983: 42-50). As can be seen in figure 4.2, structures can be found throughout the fortified area, all along the slopes of the hill leading up to the palace with its megaron. While not all the structures are from the same period, the space within the enceinte was well used as most buildings had multiple phases. Furthermore, Mycenae had multiple terrace walls to accommodate construction on the slope of the hill (French 2002: 51). Constructions like the “Great Ramp”, the “Little Ramp” and the “Grand Staircase” allowed movement up the slope towards the palace proper (French 2002: 54-55, 57-61, see also figure 4.2).

Mycenae was occupied since the Neolithic period and continued to be occupied until at least the 2nd century AD when it was mentioned by Pausanias (Iakovidis 1983: 23). In the Hellenistic era (323 – 146 BCE) some construction work took place, amongst which some repairs on the fortification walls (see also table 2.2 for a chronological overview). The most prominent example of this is the Hellenistic tower located in the western section of the fortification, but there are two more sections with such repairs (French 2002: 92). One such section is located just outside Grave Circle A and one consists of repairs to the bastion on the outside of the Lion Gate (Wace 1921: 9-10; Boethius 1921: 416; see figure 4.3). These sections are easily recognisable as they are constructed in polygonal masonry (see also Wace 1921: 9), which sets a stark contrast to the cyclopean stonework of the Mycenaean period (see also chapter 3, in particular figure 3.1). Within the enceinte there were also a number of structures dated to the Hellenistic era. Unlike Teichos Dymaion (see section 4.2), though, there is no mention of it being occupied after the 2nd century AD and it was not mentioned thereafter until the early travellers in the 18th and 19th century looted the site for antiquities (Iakovidis 1983: 23). It was described and located on various maps from the 15th century onwards by travellers, though (French 2002: 18-19).

4.1.2 The fortification

The fortification wall at Mycenae is 900 m long and encompasses a 3 hectare area (Iakovidis 1983: 23). The walls are built in the cyclopean style using limestone blocks, likely cut from the hill itself or other nearby locations. At specific locations (see also below and chapter 3) a façade of regular, ashlar-like blocks of conglomerate stone was built against the cyclopean wall (Iakovidis 1983: 26).

The fortification was constructed in various phases (see also figure 4.4). The first phase was a lot smaller than what is visible today and encompassed the top of the hill and sections to the east and west (Mylonas 1966: 22-28, 33). This first enceinte followed the outcrop of the harder limestone (Mylonas 1966: 24). In a second phase, a tremendous extension was created to the south, which encompassed Grave Circle A. Among the extensions were also the Lion Gate and the North Gate, although the latter is thought to be built slightly later than the Lion Gate (Mylonas 1966: 28-31, 33). The wall extended to the west and south and thus beyond the limestone outcrop and onto the softer conglomerate stone. Mycenae also has a subterranean cistern. This was part of the final phase of construction, when the North East extension was being built. As part of this extension a cistern was dug into the softer conglomerate bedrock just outside the wall with a staircase descending into it, which started on the inside of the enceinte (Mylonas 1966: 31-32). The cistern secured water in case of a siege (Iakovidis 1983: 27-37). Considering the fact that the extension built in this final phase only adds roughly 600 m^2 to the fortified area (Iakovidis 1983: 34), it seems that it was almost exclusively built to accommodate access to a water source. This seems a particular valid explanation when the 600 m^2 the extension adds, is compared to the 11,000 m^2 that the expansion of the second phase added to the fortified area (Kalogeroudis 2008: 288).

Mycenae also has several drains to expel excessive water from the citadel (Wace 1921: 62). Wace discovered several of them and one of these runs under the Granary (see also figure 4.2). It was built on the bedrock and had an inverted V-shaped roof. Due to its location under the building and as it avoids the Shaft Grave it seems that it is earlier or contemporary with the Granary and later than the Shaft Grave. Wace (1921: 62-63) therefore

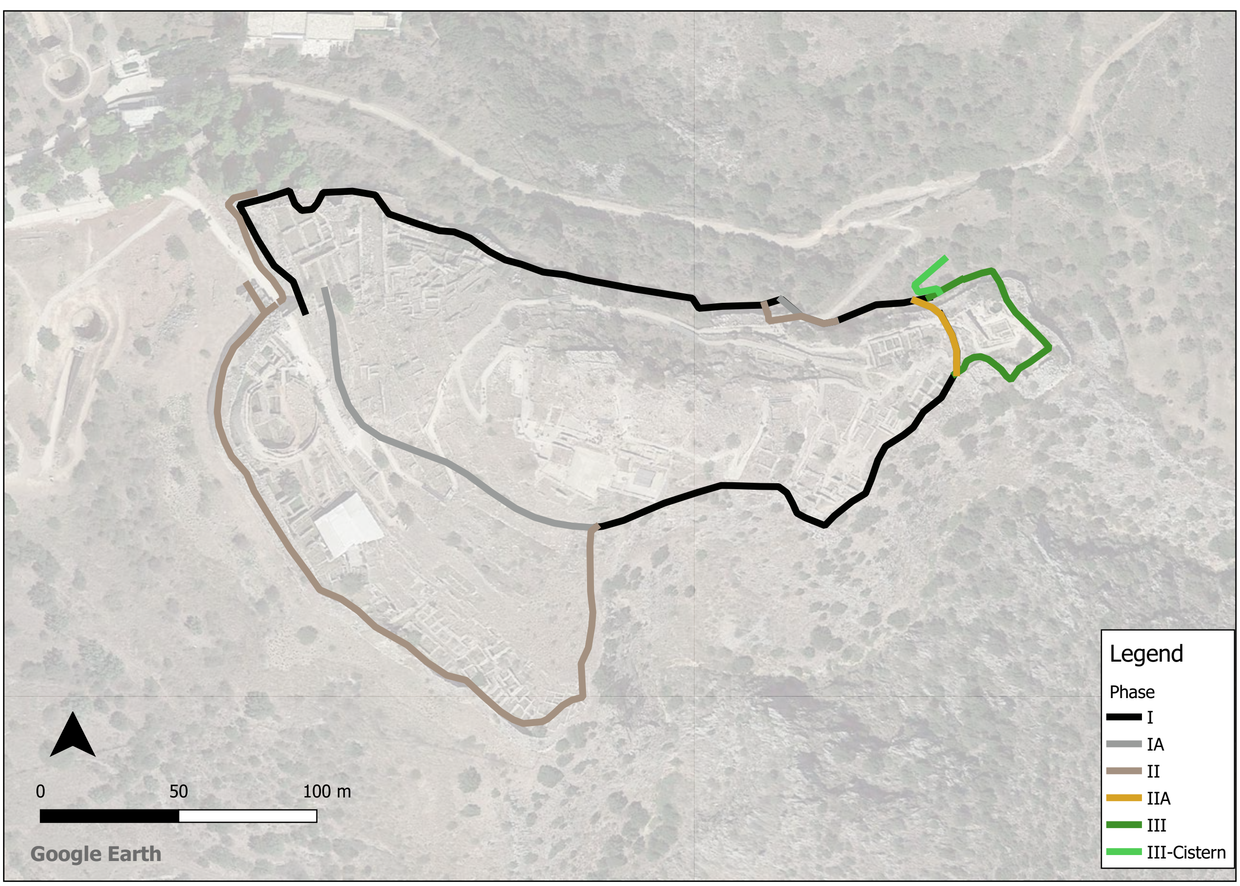


Figure 4.4 A schematic overview of the three phases as mentioned in the text. The zig-zag in the north-east, outside the fortification, represents the underground staircase to the cistern (after Mylonas 1966 figures 3, 5 and 7).

concluded that the drains are part of the second phase of construction. As for the dates of the phases, Mylonas tied the first phase to the late LH IIIA period, phase two to the "advanced years" of the LH IIIB era or at least the second half of that era, while the third phase is placed near the end of LH IIIB (Mylonas, 1966, p. 33).

The first and third periods are thus at least 100 years apart (see also table 2.2). This is important to realize, for the fortification at Mycenae does not constitute, therefore, one big project, but several. Not only does this mean that the labour costs are spread out over these various projects, but also that the experience of building in this way cannot be present in the form of the same persons on all projects.

The two gates that are present in the fortification at Mycenae are thus, in their present form, part of the later phase. However, Mylonas (1977: 18, fig. 5) assumed gates at roughly the same location for the earlier phase I (see above) of the fortification. Similar to the east gate at Teichos Dymaion (see below), the approach to the two gates at Mycenae is built in such a manner that one is forced in a corridor between the wall on one and a bastion on the other side. Both the Lion Gate and the North Gate have such a specially built bastion (Iakovidis 1983: 33). This meant that the threat of an attacking force was diminished; firstly, the corridor caused a reduction in the number of people that could attack the gate simultaneously. Secondly, defenders could attack any force from both the wall on the left as well as from the bastion on the right (Mylonas 1977: 12). This setup, using a corridor-approach to protect the gates of a fortified site, was used throughout Greece during the LBA period. It is apparent at Midea (west gate), Athens and, although to a lesser degree, Gla (south gate) (Iakovidis 1983).

Particularly interesting is that seemingly, except for Mycenae, only one such gate was built at each site. The other gates were simple openings in the wall where the end of the wall may or may not be strengthened. The middle gate at Teichos Dymaion has, for example, strengthened wall ends, but the small openings in the North East extension at Mycenae are just that, small openings in the wall, small sally-ports. The one on the south-east side of the extension is built with a corbelled roof, while the one on the north-west section, next to the entrance to the cistern, is roofed with large stone slabs (Iakovidis 1983: 35). Excavations at Midea have uncovered a similar passage through the fortification wall. This passage also has stone slabs making up the ceiling (Demakopoulou et al. 2009: 19). It is little over a meter high and 0.65 m wide and dated to the LH IIIB2 phase (Demakopoulou et al. 2009: 20). Although the opening on the outer face was not located due to reconstructions later, Demakopoulou (2015: 187) argues it very much resembled the northern "sally-port" at Mycenae.

4.2 Teichos Dymaion

The site of Teichos Dymaion lies on a hilltop (see figure 4.5) of the (lower-lying) southern point of the so-called Black Mountains, which are located in the north-western tip of the Peloponnese, in the region of Achaea (see figure 4.1). The upper part of the hill is fortified with cyclopean-style walls on three sides, while the fourth (south-west) side is unfortified, but protected by a steep cliff towards the seaside. Teichos Dymaion is at present the only known fortified Mycenaean site in the western part of the Peloponnese and as such, forms an excellent case-study for inter-regional comparisons. The site itself has seen only a few (small) excavations. The earliest, by Mastrokostas, date to the 1960s and give a preliminary idea about the site and its long history. While the massive walls originally date to the LH IIIB period, Neolithic pottery was also found

Figure 4.5 The fortification wall of Teichos Dymaion seen from the north (photograph by author).

and the fortifications were later repaired/extended in the Middle Byzantine period (see table 2.2). Even during the Second World War, Italian forces used it as a stronghold (*e.g.* Gazis 2010). This in itself shows that the location played a prominent role in the construction of the fortifications. While over the years further research has taken place at Teichos Dymaion and, as a site, it has been incorporated in a number of regional and inter-regional studies, it has not seen extensive studies on its status during the Mycenaean period (but see the current research by M. Gazis). However, the work by Kolonas and Gazis (Gazis, 2010, 2017; Kolonas, 2009; *e.g.* Kolonas & Gazis, 2006) at Teichos Dymaion and in the wider Achaean region is crucial in understanding the role of the site within the region.

4.2.1 General build-up of Teichos Dymaion

Structures from various periods have been found, but the focus in this research obviously lies on the Late Helladic period. Successive building phases have been found that show an intensive use of space in this period, particularly in the LH IIIB and C (Gazis 2010: 238). The settlement was quite small, with its total size estimated at 4.9ha (Gazis 2010). Excavations have unearthed houses built with stone foundations and superstructures of perishable materials like mudbricks (Gazis 2010: 242). The structures typically had two rooms, one might have been a storeroom and there were narrow alleys between the structures to allow movement of people (Gazis 2010: 242). Late Helladic structures, possibly houses, were also found outside the fortifications on the north and north-east slopes (see figure 4.6). The only possible non-domestic structure (based on its large size) found at the site consists of an EH II building, which was in part built over by the north-west corner of the fortification wall (Gazis 2010: 243).

Besides domestic structures, there is little evidence for other types of buildings from the LH III period. There are no large storage buildings, nor any palatial or administrative structures. Gazis (2010: 244) argues that the site is not large enough for any such larger, more elaborate buildings to begin with. It is interesting that there is no palace in Achaea at all. However, it could be that a potential palace in Achaea is simply not found yet (see also 2.2).

4.2.2 The Fortification

The impressive fortification wall at Teichos Dymaion (see figure 4.5 and 4.7) is built in cyclopean style and was described by Polybius as being a stade and a half long (277.5 m) and no less than 30 cubits high (13.3 m) (Pol. IV.83). Currently, it still stands up to a height of 8.40 m in the north-western corner and over the length of the wall, the width

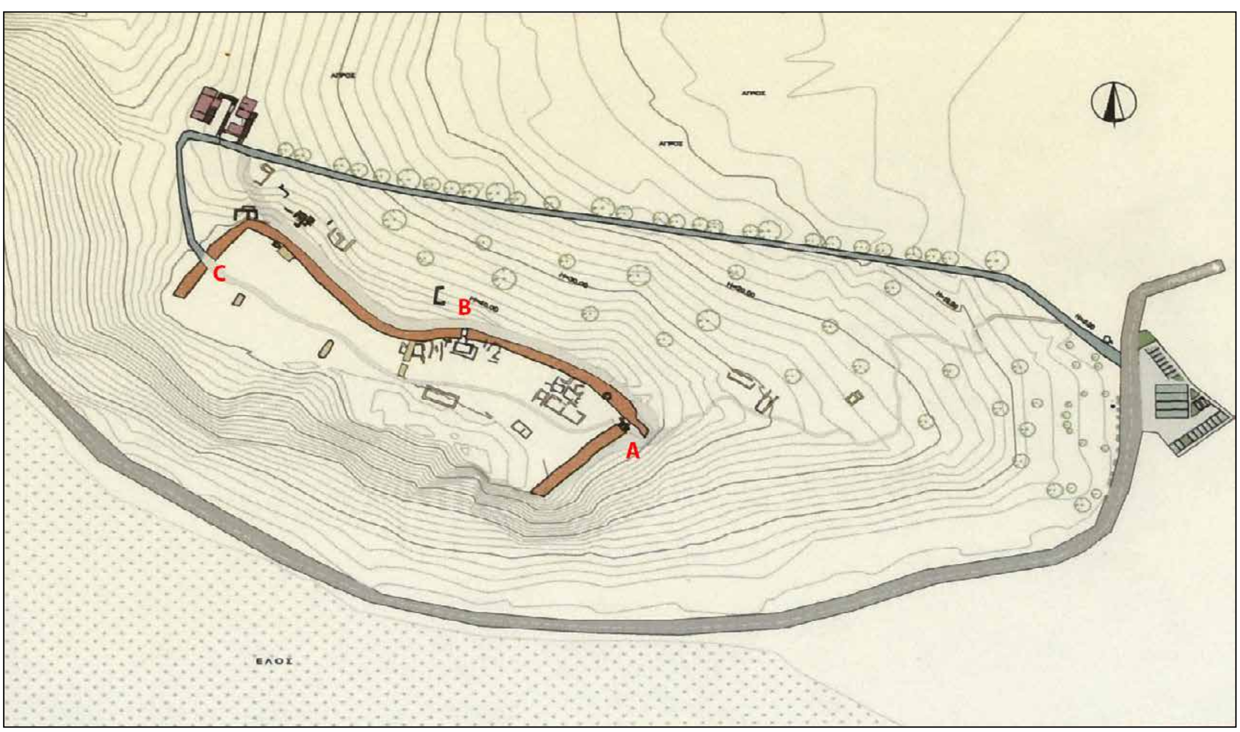


Figure 4.6 Overview map of Teichos Dymaion. The brown line represents the fortification wall, the grey lines modern roads. The various smaller shapes are architectural remains of various structures (after: Kolonas et al. 2002). The letters A, B and C, represent the locations of the eastern (potentially main) gate, the middle gate and the north-western gate, respectively.

ranges from 4.50-5.50 m (Gazis 2010: 240). The wall is built with large, slab-like, blocks of stone. The shape of the blocks, which is somewhat similar to that of the blocks in the walls at Gla and Midea, is likely dictated by the nature of the stone, rather than by any conscious choice (Gazis 2010: 239, n4) (see also section 3.3). The fill of this fortification consists of stones and earth (Gazis 2010: 239). The walled area comprises an area of about 0.8 hectares (Gazis 2010: 240). In comparison, Mycenae has a walled area of ± 3 hectares, Tiryns ± 2.3 hectares, Athens ± 3.4 hectares and, unrivalled in size, Gla ± 20 hectares (Iakovidis 1983; Hope Simpson and Hagel 2006; see figure 4.8). Teichos Dymaion is thus a relatively small site and interestingly, so far no palatial structure has been found at the site. This is uncommon as currently Gla is the only other site where cyclopean fortification occurs, but a palatial structure is not present (*e.g.* Iakovidis, 1989, 1998, 2001).

The fortification of the hill has a number of noticeable features. The first feature is that the long north-east section of the wall curves halfway. Rather than straight sections accommodating the topography, the wall curves inwards (towards the south-west) and then outwards again. Other curved sections in cyclopean style can be seen at the extension around Grave Circle A at Mycenae and the extension around the Western Staircase at Tiryns, both dating to the late LH IIIB period. Similarly, the fortification at Teichos Dymaion is dated to the late LH IIIB (Gazis 2010: 239). However, other than those examples, curved sections are not common in Mycenaean fortifications.

The second feature that stands out is the Γ-shaped tower-like structure on the eastern corner, protecting the gate at this location. While Mastrokostas (1962) does not provide a different date for this projecting structure than for the rest of the fortification, it might be a later addition.

The third feature is the presence of three separate gates in the fortification. The gates are spread out over the length of the wall with one at the eastern corner, protected by the Γ-shaped tower (see above). This is said to be the main gate (Mastrokostas 1962: 129; Giannopoulos 2008: 24; Gazis 2010: 240), although Papadopoulos (1979: 24) has argued that it was the second gate, located in the middle of the long north-east stretch of wall, which

Figure 4.7 Section of the fortification wall at Teichos Dymaion. Just left of the middle, the section with smaller stones can be seen, this is the walled up Middle Gate. Furthermore, the image shows how much of the interior face of the fortification wall is still buried (photograph taken by Ann Brysbaert and Jari Pakkanen).

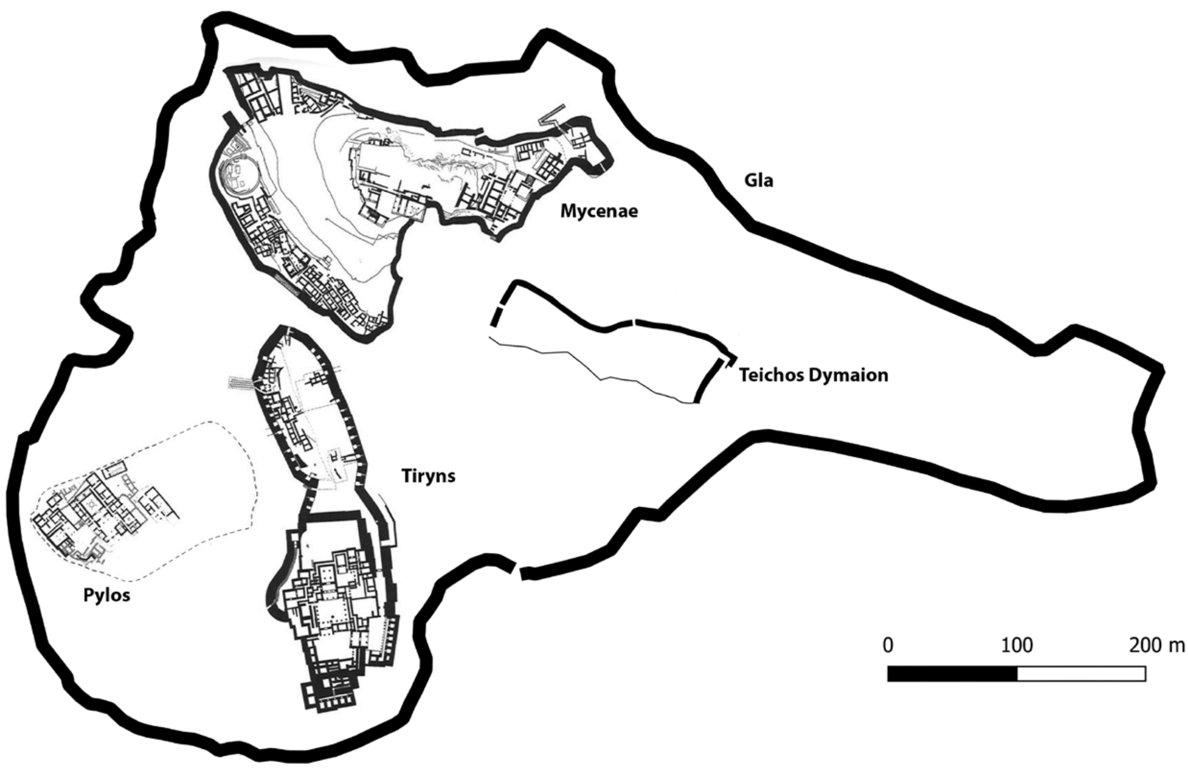


Figure 4.8 The sizes of several Mycenaean sites compared (after Iakovidis 1983). Gla can encompass all four sites with plenty of room to spare.

functioned as the main gate. He gives no arguments for this conclusion, though, nor do those arguing for the east gate to be the main gate give any arguments. The latter seems simply implied by the projecting tower structure as well as the monumentality of the gate as pointed out by Gazis (2010: 240). He argues thus that the primary importance is proven by the presence of an altar within the gate structure. It is clear that the east gate is the most elaborate gate of the three. The final gate is located in the northwest stretch of wall. Since this gate was used by the Italian occupation forces during WWII, the actual gate is destroyed as it was widened to accommodate the entrance of vehicles (Papadopoulos 1979: 24; Giannopoulos 2008: 25; Gazis 2010: 241).

Similar to Mycenae, Teichos Dymaion also has possible presence of water-related structures; a subterranean water reservoir near the Middle Gate. Accessibility to water is crucial to withstand an enemy during prolonged sieges. Similar subterranean water reservoirs have been found at other sites as well, such as Mycenae (see above); Tiryns and Athens (see also section 3.1).

Another potential water-related feature at Teichos Dymaion entails a drain 15 m north of the Middle gate. Although this interpretation has been contested by some researchers (*e.g.* Mastrokostas 1966: 158-9; Giannopoulos 2008: 25-6) who interpreted the opening as a passage. However, others (Küpper 1996: 64-5; Mylonas 1966: 32) have argued that it (and similar openings elsewhere, see Mylonas for Mycenae) is too small for a passage and that the interpretation of the opening as a drain makes more sense. The opening under discussion at Teichos Dymaion is less than 50 cm high. Although accessible, this can hardly be considered the size of “a small doorway” and it fits comfortably in the range of drains up to 70 cm (Mylonas 1966: 32). It seems therefore more likely that this was indeed another drain. Two additional channels exist that go through the wall at a right angle, one in the south-west and one in the north-west (Gazis 2010: 239). Gazis (2010) has argued that these were put in place during the original construction of the wall and are meant to channel excessive water from the acropolis. As shown in section 4.1.1, similar features were also found at Mycenae.

A final similarity between Mycenae (Iakovidis 1983: 31) and Teichos Dymaion (Gazis 2010: 240) is the possible presence of some sort of shrine near the entrance of the gates (Lion Gate and North Gate at Mycenae and Eastern Gate at Teichos Dymaion). Although in both cases either the date (Teichos Dymaion) as well as the actual function of the room (Mycenae) is questioned, it would be an interesting notion that some sort of shrine is located

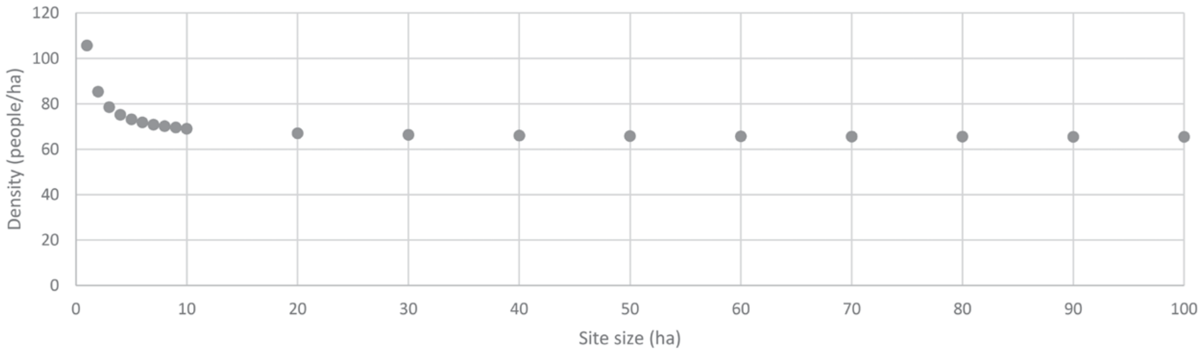


Figure 4.9 Relation between site size and population density (after Carothers and McDonald 1979). Note that it is the density that is decreasing, the actual population size increases for larger sites.

right at the (main) entrance of a fortified site. According to Iakovidis (1983: 31), similar "gate shrines" have been found at Tiryns (see also Kilian 1981: 51), the Athenian Acropolis and at the gate of Troy VI.

4.3 The size of the population at Mycenae and Teichos Dymaion

As was discussed in section 2.2.4, the population size at the case-studies is very important to be able to interpret the results of the labour cost analysis properly; the larger the population, the smaller the potential impact of fortification construction, as a smaller part of the population was required for the entire production process. Moreover, in order to say anything about the impact of the building projects at all some idea must be presented on the population numbers. If the required workforce is beyond the estimated population size, it must be considered whether the necessary workers came from beyond the settlement itself and what this may imply about the socio-political organisation of the settlements. After all, this means that the elites at the settlements were powerful enough to order people from further away to perform construction work, or wealthy enough to hire them.

It was also pointed out in section 2.2.4 that there are various ways of determining past population numbers and that in this dissertation the choice was made to base the calculation on site size and population densities, as for both case studies the site size is established (as best as possible). Other methodologies for calculating the population sizes require additional information that is more problematic or incomplete for either or both case studies.

In a study on the population density in medieval cities in Europe in the thirteenth to the sixteenth century an average of 100-120 people per hectare was calculated, with a maximum of 200 people per hectare (Russell 1958). However, the range was actually much larger, as pointed out by Wallace-Hadrill (1994: 95) as it encompasses values between 40 and 289 people per hectare. He rightly pointed out that it may be problematic to project medieval population figures onto his study of Roman cities. The same can be said for prehistoric societies like the Late Bronze Age in Greece. However, it seems unlikely that Mycenae was as urbanised as those medieval cities that are considered very densely populated; after all, 200 people per hectare is towards the high end of the range provided by Russell (1958).

Nevertheless, this density of 200 people/ha is an often used number to calculate past population sizes based on site size, including for LBA sites such as Mycenae (*e.g.* Bennet, 2007, 2013; French, 2002) and Tiryns (*e.g.* Brysbaert, 2013). French (2002: 64) has pointed out in this regard that the surface finds indicate that a site size of 32 hectare is a realistic estimate for Mycenae, but that the density of 200 people per hectare seems too high. In comparison, modern-day Holland is one of the most densely populated areas in the world and even there the average population density for built-up areas is 180 p/ha (Erwich & Vliegen, 2001). Thus, even though the number is often used by a variety of scholars, care should be taken when applying it. Hence, two other approaches using site size to calculate population sizes are also presented here.

In a study on the population size and density of Late Bronze Age Messenia, the distribution and population density of modern villages was used for the reconstruction of the ancient population (Carothers & McDonald, 1979). The reconstructed density depended on size but it was calculated that each village had a "starting population" of 40.64 and each increase in size (1 ha) would increase the population by 64.99 people (Carothers and McDonald 1979: 436).[40] This means that a 1 ha site had 105.63 (106) people, a 2 ha site had 105.63 + 64.99 = 170.62 (171) people and so on. This in turn means that smaller sites were more densely habited if the density per hectare is considered;

40 Based on their observations on population and site size in modern villages (n=68), a correlation was found. This correlation could be summarized in the formula y = 40,64 + 64,99(x) in which y was the population, based on the size of the site/village x.

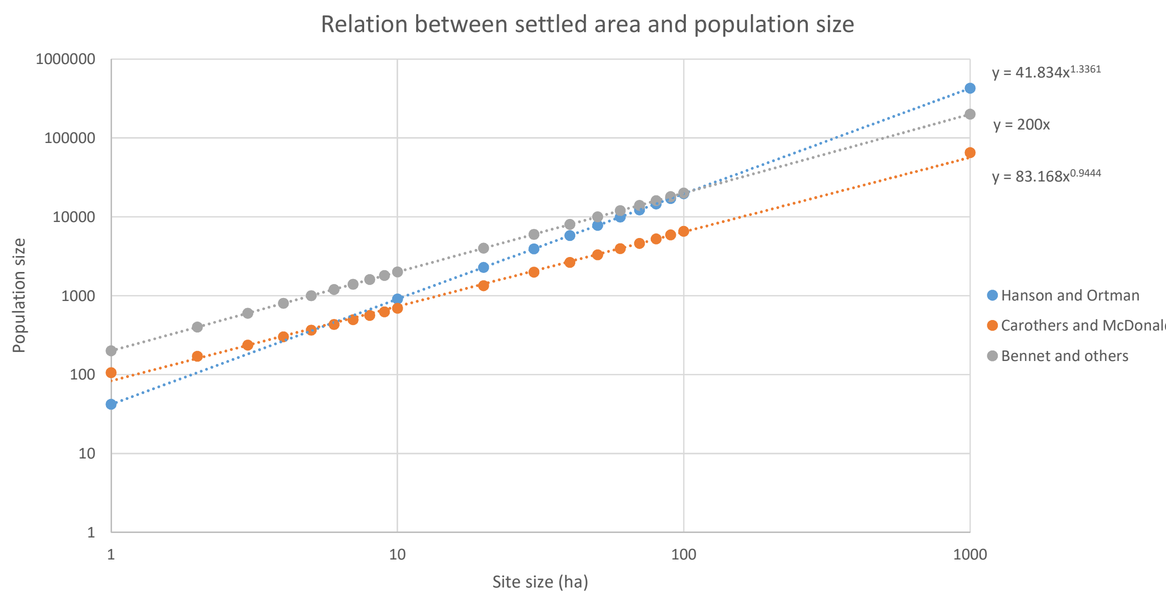


Figure 4.10 Relation between site size and population size, based on the various population densities. Note that both axes are on a logarithmic (log) scale (after Hanson and Ortman 2017; Carothers and McDonald 1979; Bennet 2007).

Source of model	Mycenae		Teichos Dymaion	
	Population size	Population density (p/ha)	Population size	Population density (p/ha)
Bennet 2007	6,400	200	980	200
Carothers and McDonald 1979	2,120	66	359	73
Hanson and Ortman 2017	4,291	134	350	71

Table 4.1 Overview of the estimates of the population size and density based on the three described models.

106 p/ha and 85 p/ha for a 1 or 2 ha site respectively. For larger sites this density would decrease to, not quite, 64.99 p/ha, which is the increase factor in the formula (see figure 4.9).

However, the research by Carothers and McDonald focused on rural villages. In contrast, a study by Hanson and Ortman (2017), focused on the relation between population density, population size and site size in urban contexts in the ancient world. They found that for urbanized sites, the population density increases as the site size grows. Using data from 52 sites from the Greco-Roman world between 4th century BCE and 6th century CE, they calculated the size and density of the population related to the site size (Hanson and Ortman 2017: 314). Of course there was some variety, but an overall trend was established which could be summarized in the following formula: y = 41.834 x ^ 1.3361 (see figure 4.10), in which y is the population size and x the site size in hectares (Hanson and Ortman 2017: 317 in particular figure 3).

When the three methods described above are applied to the case studies, Mycenae and Teichos Dymaion, the methods produces quite different population sizes (see overview in table 4.1). Moreover, when reverse calculating the average densities at the sites based on the population sizes, each method thus produces a very different density. Additionally, it shows that both dynamic models; the methods by Carothers and McDonald as well as the method by Hanson and Ortman, produce different average densities for both sites, unlike the fixed density of 200, as used by Bennet (and others). Both these models also confirm that the used fixed density of 200 p/ha seems to be too high, as they produce far lower densities: 66 and 134 p/ha for Mycenae and 73 and 71 p/ha for Teichos Dymaion. Obviously, the used methods suffer from the same chronology issue as Russell's (1958) average number. However, Hanson and Ortman use a long chronological spread and a large geographic area and they take into account that larger sites may be more urbanised which means that the density increases. It may not be a perfect fit for Mycenaean sites; however, it is a much more comprehensive approach to population numbers than the estimates that have been used so often before. A more thorough and in-depth study into

Mycenaean populations would be beneficial, but is beyond the scope of this study.

For Teichos Dymaion both dynamic models produce very similar population numbers. However, the model by Hanson and Ortman has no case studies in its own study below 11 ha. For Teichos Dymaion, which is only 4.9 ha, the produced population number is thus an extrapolated figure. Whereas, in the study by Carothers and McDonald, the smallest case study is less than 1 ha.

In contrast, Mycenae, which is, as mentioned above, estimated to have been about 32 ha, fits within the range of site sizes as studied by Hanson and Ortman. Unlike the model by Carothers and McDonald, though, in which the largest site is just over 18 ha. For Mycenae, the model by Hanson and Ortman seems to be more applicable as the calculated population size is an interpolation.

It is well outside the scope of this study to formulate a definitive population number for the case studies. Therefore, the presented numbers here will be used in the analysis in chapter 8. However, where applicable the population numbers as calculated with the model of Hanson and Ortman will be used for Mycenae and the result for Teichos Dymaion as calculated by the model of Carothers and McDonald. This is because Mycenae is a far larger site and presumably more urbanised, whereas Teichos Dymaion is much smaller and fewer structures were found. Hence, the two models seem to be more applicable to either site. Finally, it must be noted that these population numbers only cover the urban areas of the sites. The rural population that lived further away from the settlement is not taken into account in these calculations, but could provide a serious increase to the potential labour pool. Reconstructing the potential rural population is, unfortunately, beyond the scope of this study.

4.4 Concluding remarks

This chapter has introduced the sites of Mycenae and Teichos Dymaion. While Mycenae's first fortification is dated to the LH IIIA period, Teichos Dymaion was not fortified until the late LH IIIB period, coinciding with Mycenae's second phase of fortification. Mycenae has been fortified in three stages, while the fortification of Teichos Dymaion was built in a single phase. Mycenae is often seen as the capital of its region, and by some even as the capital of a larger Mycenaean kingdom. Teichos Dymaion, on the other hand, is the sole fortified site found within its region to date, but has no substantial architecture, apart from its fortifications, that might point to a palace of any kind. Both sites seem to have been capable of being part of inter-regional trade networks (see also chapter 2). These potential (inter-)regional contacts might also indicate that workforce or expertise for large construction projects could be imported from beyond the community itself. Finally, for both sites the population estimates were presented, which are estimated between 2,120 and 6,400 for Mycenae and between 350 and 980 for Teichos Dymaion, depending on the used model. It is argued that the population for Mycenae is more realistically around 4,291, following the model by Hanson and Ortman and around 359 for Teichos Dymaion, using the model by Carothers and McDonald. The next chapter will focus on the used methodology for studying these ancient fortifications and how relevant data are collected and processed.

Chapter 5

Methodology

In this chapter an overview of the used methods is presented, to make clear why these approaches are useful for the study presented in this book and how they are implemented. First, the method of studying ancient building processes is discussed. The research presented in this book is a labour cost study. In section 5.1 it will be discussed what this approach comprises and for what goals it is used. The data that are required in this type of study are quantitative, namely, the amount of material that is required to construct the studied buildings. Parts of these data were collected through fieldwork. Hence, the used methods for gathering these field data is considered in section 5.2. Finally, section 5.3 is devoted to describing the process of producing the appropriate data for the labour cost studies. The data that are the result of these methods are subsequently presented in chapter 6.

5.1 Studying building processes: labour cost studies

The study presented in this book deals with the potential impact that the construction of large fortifications may have had on communities. Hence, it is not only the building itself, but also the construction process that is being studied. In this section the studying of the construction process is being considered by means of the concept of labour cost studies.

5.1.1 The way labour cost studies are used

Labour cost studies are a way to quantify the cost of buildings in terms of labour. This quantity is expressed in person-hours, or the number of people needed for how long in order to do a task. Architectural energetics is another term for labour cost studies, and was coined by Abrams, but the method of quantifying construction in terms of labour cost is older (Abrams and Bolland 1999: 269; Pakkanen 2013: 2). Andrews (1877: 57), for example, who studied mounds in Ohio, calculated the number of small loads that were necessary to create one of these mounds to get an idea of "how much labour entered into the construction of the mounds". The amount of labour or costs represent, as Abrams and Bolland (1999: 264) put it; "… the analytic unit of measurement upon which comparative assessments of power or status within and among archaeological societies are based". In other words, the calculation of labour costs of construction allows the comparison of different buildings. As a comparative tool, labour cost studies do not represent an absolute answer to the invested time and energy: rather, the figures that result from such an exercise allow the measuring and comparing of one structure against another. Thus, the relative costs provide the most useful information. Furthermore, exploring the size of the necessary labour-input can be used to estimate how many people needed to be taken from their other tasks (such as herding and farming) to complete a building project (Brysbaert 2016: 10). Even though the range might not be absolute, at least it provides a scale of the labour-input. As such, the impact of a structure on a community or society might be grasped, or at least hinted at.

In order to calculate the necessary labour input, two elements are required: the volume of material (*e.g.* Abrams & Bolland, 1999; Brysbaert, 2015a; de Haan, 2009;

Harper, 2016) and the rate at which work was done (labour rate).[41] These two basic parameters can be further subdivided into various types of material, different tasks and the method that was used to perform these tasks. For example, building a house in ancient Greece required (at least) stone, wood and mud. The paces at which these can be procured are different, not only due to the material itself, but also depending on the used tools and the distance of the source to the building site. Furthermore, the construction of such a house is carried out in a certain sequence, as the roof cannot be installed before the walls are up. To accommodate all these different tasks, materials and the sequence of the construction process is divided into various sub-processes (Abrams and Bolland 1999: 266, fig. 1). The number and types of sub-processes depend on the type of structure and the level of detail that is known about the construction process. This also influences the result of the cost analysis. While coarse calculations are quicker and still allow comparisons between structures, data that are more detailed allow a more thorough study of the building process itself. One is not inherently superior, but depending on the intended goal of the study, one might be better suited than the other.

In order to determine the quantity of the material and labour rates, several assumptions need to be made. In case of the labour rates, for example, the average speed with which stone was quarried, or with what speed a cart or sledge filled with material was moved can be estimated through certain analyses (see also chapter 3) and experiments. More importantly, these need to be used consistently to be beneficial. It is obvious that labour costs for structures can only be comparative if similar rates and variables are being used. It has been pointed out that for example a workday is highly variable in terms of length (Abrams and Bolland 1999: 264-265, but see also for example Voutsaki et al. 2018: 174).

In order to determine what a usable rate is, researchers (*e.g.* DeLaine 1997; Devolder 2013) often use pre-mechanical era building manuals, such as those by Rankine (1866), Pegoretti (1869), Clark (1878) and Hurst (1905). The upside of such manuals is that they provide actual figures in terms of what a man could carry or quarry in those days. The downside is that some of the used characteristics are not always quantifiable. An interesting example of this can be found in Clark's manual (1878: 719, table 251), in which he describes how much power can be exerted over a stated time, dividing the workers into categories like "stout Englishman" and "sturdy Irishman". Such categories are meaningless to this study, as they are not quantified. If, for example, such categories would imply an average weight, they might be useful. This would have shown how a person's weight and accompanied possible exerted force are related (see this link for oxen in chapter 3). Ignoring such categorisations that have little meaning in this particular research, the data themselves are useful to create a range in which feasible figures for a task can be discerned (see also chapter 3).

Labour cost studies attempt to "objectively quantify" the (energy) investment into a construction (Devolder 2015: 242). Obviously, the earlier mentioned assumptions about rates mean that any attempt is never truly objective. However, by using a systematic approach and comparative works, an as objective as possible result can be achieved. Thus, consistency is essential in creating useable results that allow comparisons between various structures.

Once the labour costs of a structure are calculated, they need to be interpreted. Abrams and Bolland (1999: 269) describe possible interpretations based on labour cost studies as follows, explaining the cost of a building as an expression of power:

> "Collectively, architectural energetics represents a powerful quantitative method for the holistic and dynamic study of power, authority, and specialization in past societies from varied paradigms."

A somewhat more nuanced way of looking at the results of labour cost studies is by viewing differences in costs as deliberate choices. Thus, when labour-cost studies show that one building needed significantly larger investments than another, such choices should be studied. They can provide insights into what was deemed important, or worthy, for such extra investments to be made. It thus visualises choices. Only when the question arises how and why these labour forces were put onto the task of building these structures, do concepts such as authority and power come in to play. However, this is only at a later stage of such analyses. It can be argued that there are phases of quantification and interpretation in the process of labour cost studies.

5.1.2 Critiques on labour cost studies

The four main critiques on labour cost studies below, target either the quantification of an object or the interpretation of such a quantification (see 5.1.1).

The first critique regards the issue of "the unknowable specifics of volume, behaviours, and costs in the past" which makes the reliability of the calculated total cost of a building questionable (Abrams and Bolland 1999: 266). Secondly, calculating labour costs for construction is based on the assumption that people will choose the path of least effort to achieve something (*e.g.* Abrams and Bolland 1999: 274; Osborne 2014: 5; Trigger 1990: 122). This can be criticised as a modern, industrial, economical view on the past.

41 Even if some labour cost studies refer to weights, these are often derived from volume as well.

A third critique of conventional labour cost studies concerns all the assumptions that are being made throughout the process of calculating the labour costs. This results in essentially each researcher creating their own methodologies and therefore, the outcomes of different studies are not comparable (Voutsaki et al. 2018: 176). This is an understandable critique; if a very different rate for transport is assumed for two structures, for example, the contrast in the calculated final labour cost might be (entirely) due to this difference in assumption, rather than due to any difference between the buildings themselves. After all, as mentioned, the strength of labour cost studies lies in their comparative character.

Other critiques of labour cost studies concern the implied connection between higher cost and power of the person or group of persons who ordered the construction (Osborne 2014: 5; Marcus 2003: 134). Osborne argues that by calculating the labour costs for "monuments" the only thing that can ultimately be said is that one structure may be more expensive than another. In other words, the concept of monumentality (see chapter 3), is then nothing more than a matter of size. His critique is that this is the only product of labour cost studies and a direct consequence of seeing "architectural scale as directly correlated with power and with the social and political control of commoners by elites" that is often associated with monuments (Osborne 2014: 5). His critique is thus that the mere quantification does not do justice to what may or may not be considered monumental (see also 3.2). This is in large parts tied to the idea that monuments are seen as a way for dominant figures to show their influence by mobilising labour-force (see also the discussions in chapters 2 and 3). Although this also likely has to do with the way a society is organised (see also chapter 2), it would seem that an organisational party must have been involved and a group of people (elites) could perhaps coordinate this collectively in the absence of a single king-like figure. Osborne's critique thus focusses mainly on labour cost studies of monumental structures, rather than the method in general.

5.1.3 Justification for using labour cost studies

Against the first critique (on the many unknowns in labour cost studies) Abrams and Bolland (1999: 266-267) argue there is no need to have "perfect knowledge" of the structure, but rather a general knowledge of the building elements and the most costly activities of those elements. An alternative argument against this critique is given above; the absolute numbers matter less than the scale and comparability that are the result of labour cost studies.

The second criticism against labour cost studies (the assumption that people did things as efficiently as possible is a modern projection on an ancient context) can be countered as well. There are definitely examples in Greek stone architecture that provide evidence for economical approaches to construction: the limited use of well-cut conglomerate stone at highly visible places at LBA Mycenae and Tiryns rather than around the entire site and the way ashlar blocks in the Classical and Hellenistic era are cut neatly only on those sides that are visible on the outside, while the invisible back side is left as it was quarried.[42] There is no question that dressing blocks requires extra time over leaving blocks in a quarry-state and by dressing only those sections that are the most visible, the visual effect is maximized in an efficient manner.[43] It is therefore realistic to assume that for many (sub-)processes, the most efficient method was used.

Besides pointing out the incomparability of different labour cost studies, Voutsaki et al. (2018), try to come up with an alternative to counter this issue. However, in their method of creating relative values based on the differences of material, location and build quality (Voutsaki et al. 2018: 176-180), they still create the problem of incomparable values. This is due to two issues: 1) the values given are still subjective, which Voutsaki et al. criticise other labour cost studies for doing and 2) due to the nature of using just relative appraisals with no intrinsic value, the numbers cannot be combined in a total cost, nor does it mean that a characteristic with a value of five is five times as costly as a value of one. Their effort is commendable, and their initial critique just, but their solution still provides a methodology that is only usable in an enclosed context (in this case a single cemetery).

Turner (2018) has also addressed the issue of comparability of labour cost studies. He has shown the value of using multiple scenarios that can then be compared, even between sites by using the same rates. The use of multiple scenarios allows the exploration of multiple variables, like rates, build-up of the structure and number of workers available. Hence, the relative costs of the researched structures are eventually more telling and thus more important than the absolute costs. Labour cost studies would therefore benefit from a consensus about rates. While some efforts are being made to consolidate such data (*e.g.* Abrams & McCurdy, 2019), there is still a long way to go. Hence, currently the best practice is to justify the used rates, which for this study is done in chapter 7.

Finally, in response to the fourth criticism: regardless of the societal organisation, labour costs as a comparative

42 For Tiryns also elaborate studies have been done on the meaning of the use of the conglomerate at specific points within the citadel, see Maran 2006 and Brysbaert 2015b. It is beyond this study to go into this, it suffices to state that whatever reason or meaning there may have been, the conglomerate is still only used sparingly.

43 The term "quarry-state" is a description of the state of dressing of a block of stone. As the name implies, the stone is not dressed beyond the work that was done to the block to quarry it.

tool is still more informative than a simplistic higher cost = more power conclusion (see also 3.2). It can inform us about the choices made during the building process and provide starting points for researching why these choices were made. For example, it will be shown that the size of stone material influences the labour input needed for transportation due to the constraints to the way stone can be transported. It might thus give insight to how the wall is built up and provides a possible answer as to why as well.

5.1.4 The use of labour cost studies within this research

Labour cost studies are a useful way of studying the impact of construction projects. The discussed comments (5.1.2) on the methodology should be taken into account in order to make the results of such a study valid. The labour cost study in this research, therefore, explores multiple scenarios to give a proper overview of what the possible ranges in costs were and to accommodate many variables involved in large scale construction projects such as those of the citadels of Mycenae and Teichos Dymaion. Such scenarios comprise material acquisition, methods of transportation of the material, the build-up of the studied fortifications and the way the structures were assembled.

It has been pointed out above that the strength of labour cost studies lies in their comparative nature. In order to utilize this strength and to be able to answer the research questions, comparisons are being made on a number of levels. First, the use of two case studies (Mycenae and Teichos Dymaion) allows a comparison between two fortifications from the Mycenaean era. Having such different types of settlements (see chapter 4) that both have fortifications, makes for, potentially, highly interesting comparisons as they portray a possible core-periphery dichotomy. Not only to see how the actual costs compare due to the difference in site size (and assumed population size), but also how that influences the potential impact that these large building programs may have had on these communities.

Furthermore, by comparing the costs of the fortifications to another type of structure, in this case domestic buildings, it can be assessed what the calculated labour costs mean in terms of alternative projects. If, for example, a given fortification wall takes 100,000 person hours to build it is difficult to grasp how this relates to what people could ordinarily built. However, if, again for example, a (simple) house can be built for 2,500 person hours, a lot more can be inferred from the calculated costs of the fortification wall by comparing the two figures. Hence, in order to say anything about the potential impact large constructions may have had, it is also important to understand the cost of these constructions in relation to other buildings.

Moreover, the study of different types of structures also enables the comparison of the cost of the building style or technique. As shown in chapter 3, the fortifications during the Mycenaean period were built in a specific way. This cyclopean style may seem as a laborious method of constructing due to the use of the large blocks. By comparing the cost of the fortification and the domestic structures per volumetric entity (the amount of person hours per 1 m^3 for example), one can gain insights into the cost of the way a structure was built, rather than the cost of the structure itself.

Furthermore, it is not just the structures but also the construction process that is being studied. Hence, the various stages in that process are also compared to each other. This will give insight into what steps require what amount of investment as well as where potential bottlenecks may exist during construction.

Finally, the intrinsic relative values of the results of the labour costs are acknowledged, but actual figures like size, volume, slopes and force are used to calculate the labour costs, to allow real comparisons. Only then will any interpretations regarding the structures and their costs be made, to avoid a predetermined notion of power-relations involved in large scale structures. In this manner, this research provides a valid evaluation of the structures.

5.2 Data gathering

The previous section and the descriptions of the various construction processes in chapter 3, make clear that a number of data are required to calculate labour investments for the construction of the fortifications and domestic structures. In this section it will be discussed how the data for the various processes are gathered.

For most processes there is only the need for the volume (or surface area) and a work rate. This is the case for the following steps:

- Material acquisition
- Levelling of the terrain (site preparation)
- Dressing of the material
- Building the earthen ramps for constructing the walls
- Assembly of the walls

The remaining studied process is the transport of the material. This process is reconstructed in a systematic manner and the required labour costs calculated that way, rather than using a fixed rate. For the assembly of the walls a similar approach is used next to the fixed rates, to show the range of required investment for that process (see chapter 7).

To gather the required metric data (volume and area) of the studied walls, fieldwork was conducted. The labour rates were taken from literature, which varied from pre-industrial building manuals (Clark, 1878; Hurst, 1905; Pegoretti, 1869; *e.g.* Rankine, 1866), to ethnographic studies (*e.g.* Heizer, 1966) and results of (archaeological) experimental research (*e.g.* Atkinson, 1960, 1961; Kelany, 2015; Lehner, 1997).

In contrast, for the calculation of the transport costs and the costs for the assembly of the walls, additional information is required. For the transport this includes the distance between the quarry and the building site (and thus quarry locations), the traction force of animals and people (see also 3.4.2), the weight of the material and the slope of the terrain. In order to calculate the costs for the assembly, the possible force that people can exert as well as the weight of the material is important.

Similar to the labour rates, the potential amount of force that animals and people can exert was based on a variety of literature (*e.g.* Bobobee, 2007; Eastons & Anderson, 1874; Goe & McDowell, 1980; Hertzberg, 1972). However, the distance between the quarries and the building sites is a different matter. First, it had to be determined where the quarries were located. For Mycenae and Tiryns this was partly studied by Brysbaert et al. (2020). In contrary, little is known about quarry sites near Teichos Dymaion. At that site, the regional geology was studied which showed that the used material was available in the near vicinity. Hence, at Teichos Dymaion the area within a 100 m radius around the site was taken as a possible extraction area.

5.2.1 Landscape data

As is shown in chapter 3, the landscape greatly influences movement of people and goods. Moving the building material from its source to the building site is thus made more difficult when the terrain is rugged or when steep slopes need to be scaled. In order to investigate 1) what kind of route would be feasible and 2) how much labour this would require, a study of the landscape is essential. Both Mycenae and Teichos Dymaion lie on hilltops (see also chapter 4) and any material thus had to be moved up that hill.[44] In order to be able to reconstruct the transport cost there is thus the need for the source location and data on the landscape in as much detail as possible, in particular the inclination of slopes (see chapter 3.4.2.).

One approach is using a Digital Elevation Model (DEM) (see figures 5.1 top and 5.2 top) in a GIS, visualising the height (elevation). In slope maps the steepness of the terrain is visualised, the higher the value the steeper the terrain is (see figures 5.1 bottom and 5.2 bottom). It is a good way to show 3D data in a 2D setting and immediately shows the difficulties that some parts of the terrain may pose when moving through the landscape.

44 This is true for most if not all Mycenaean citadels, such as: in the Argolid (Argos and Midea and, to a somewhat lesser extent, Tiryns), the larger Peloponnese (Pylos) as well as beyond (e.g. Gla and Haliartos in Boeotia).

Due to the close proximity of the quarry sites, the resolution of the DEMs will influence the usability since a low resolution DEM would mean that changes in the landscape within a limited area would go unnoticed, while these changes could be of great influence of the required force for moving the loads. However, very high resolution DEMs might give a false sense of accuracy for determining the exact route that might have been taken, due to the presence of modern features such as roads. In order to circumvent this issue, as well as the lack of skills by the author in properly reconstructing such routes with specialised applications, it was decided not to reconstruct Least Cost Paths. Rather, based on a more rudimentary study of the slopes surrounding the two sites and where applicable, using possible quarry locations, very generic routes are contemplated for the labour cost analyses. As pointed out, the terrain influences the transport costs. However, if routes can be established that would fall within the capabilities of the method of transport, the exact route is less important than the parameters of that route, in particular the slope and distance. For example, if a certain traction force is determined for human or animal as well as a friction coefficient or rolling resistance, such parameters can be used to indicate maximum slopes (see also chapters 3 and 7). Hence, the acquired data, which consist of the height and slope maps and the parameters set for the transport, will prove sufficient for determining an approximate route for calculating a satisfactory accurate investment in terms of the transport of the material between quarry and building site. This is done by using the parameters for transport as explored in chapter 3, regarding animal traction, wagonloads and rolling resistance as specifications for wagon transport. Through this approach it has become clear that oxen can produce a traction force of roughly 14 % of their body weight but this can increase to as much as 50 % in short bursts (Raepsaet, 1993; see also 7.2).

For the reconstruction of the possible transport routes through the landscape, a maximum slope of around 9 degrees (see section 3.3.3.4) is used. The DEMs were used to reconstruct rudimentary routes between quarry locations and building sites that fell within the set parameters for the transportation. The other landscape data that is gathered for the study, as mentioned above, is the geological data of the areas around both case-study sites. Mycenae lies just within an area that consists mostly of conglomerate deposits (see figure 5.3). The top of the hill itself is a limestone outcrop, although further down the slope conglomerate dominates (see also above and *e.g.* Mylonas 1966). The (sandstone-) conglomerate, which is strongly cemented on the borders of the basin, extends to the east until it reaches the Arachneion mountain range, which consists of carbonate rocks, mostly limestone. There are greyish, white, yellowish and crystalline beds

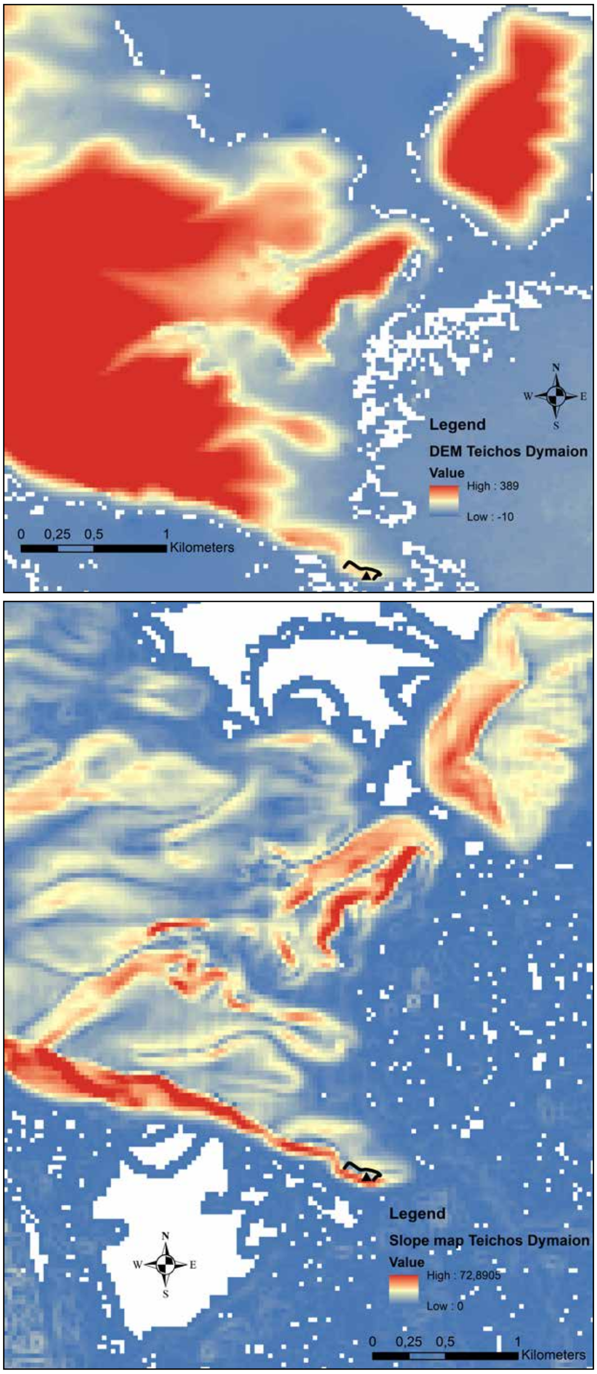


Figure 5.1 Digital Elevation Map (DEM) (top) and slope map (bottom) of Teichos Dymaion (black triangle) area. Based on data from ©JAXA (section of N038E021 tile) with a spatial resolution of 30m. The colours represent the value (in meters in the DEM and in degrees in the slope map) and immediately this shows the difference between the two maps: the DEM shows the area around TD as red (high) because this is a relatively high area, whereas in the slope map, only the cliff on the south side of this same area is red (high value) and thus shows that that area is steep (maps by author).

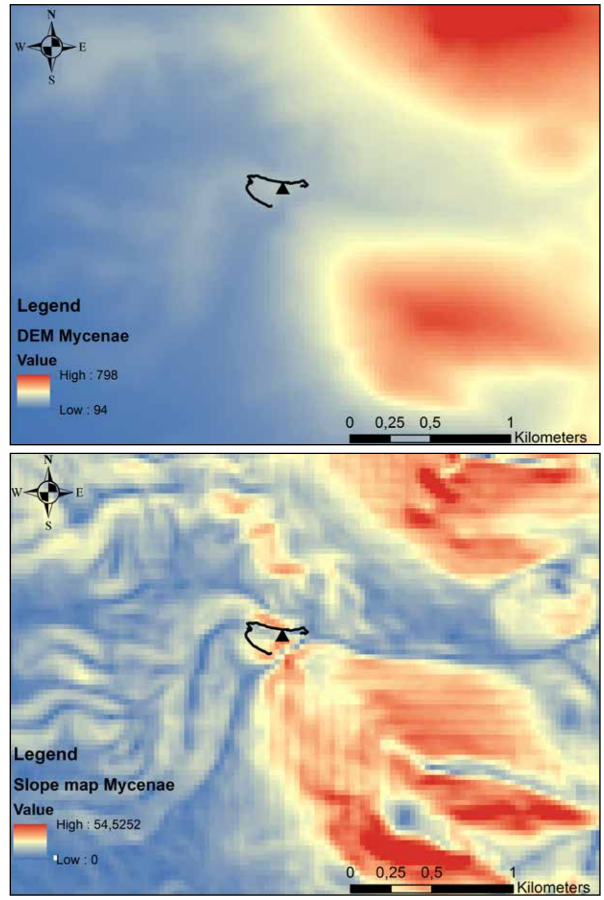


Figure 5.2 Digital Elevation Map (DEM) (top) and slope map (bottom) of Mycenae (black triangle) area. Values are in meters in the DEM and in degrees in the slope map. Based on data from ©JAXA (section of N037E022 tile) with a spatial resolution of 30 m (maps by author).

of the carbonate rocks as well as hard types of limestone, although these beds are relatively thin. To the west, the conglomerate continues after the alluvial deposits that dominate the valley to the north and the plain to the south. West and south-west the conglomerate deposits are bound by limestone mountain ranges, the Artemision and Parnon ranges (French 2002: 13; Higgins and Higgins 1996: 45-49). These types of limestone vary in colour from white to yellow grey and red. The beds vary in thickness from a few centimetres to several metres. The Argive plain itself, which continues south till it reaches the Gulf of Nafplio, consists of alluvial deposits (Geological Map of Greece; Argos, Nafplion, Nemea and Korinthos sheets) (Papastamatiou et al., 1960). Both the used limestone and conglomerate are thus locally available for the construction of the fortifications.

Teichos Dymaion lies in a zone of limestone that covers the entire area between the sea on the west, the Kalogera lagoon on the east and the marsh on the south

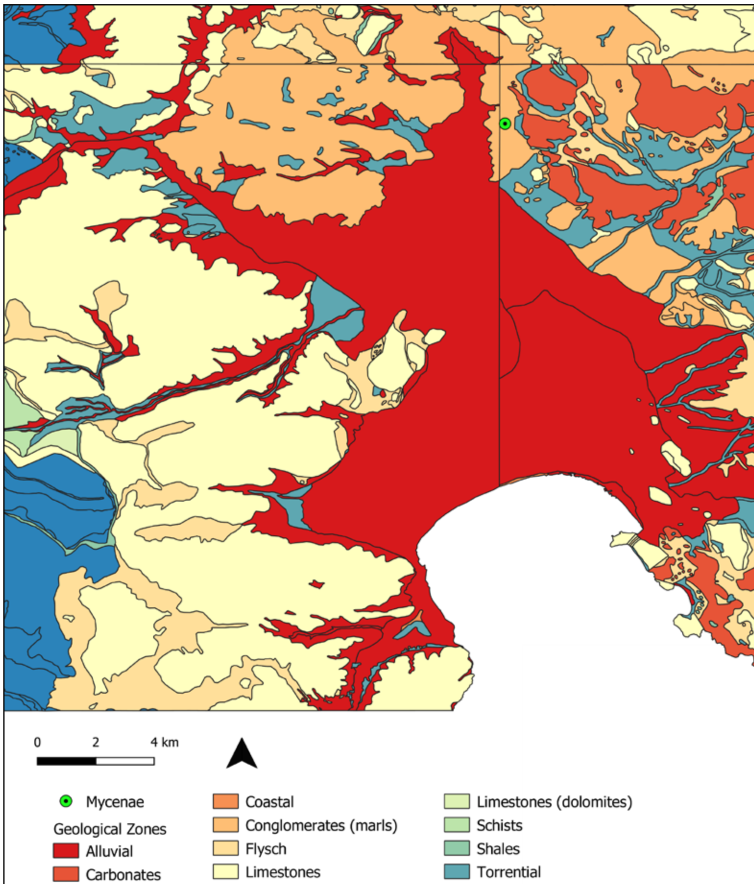


Figure 5.3 Geological map of the region around Mycenae (green dot) (based on IGME maps).

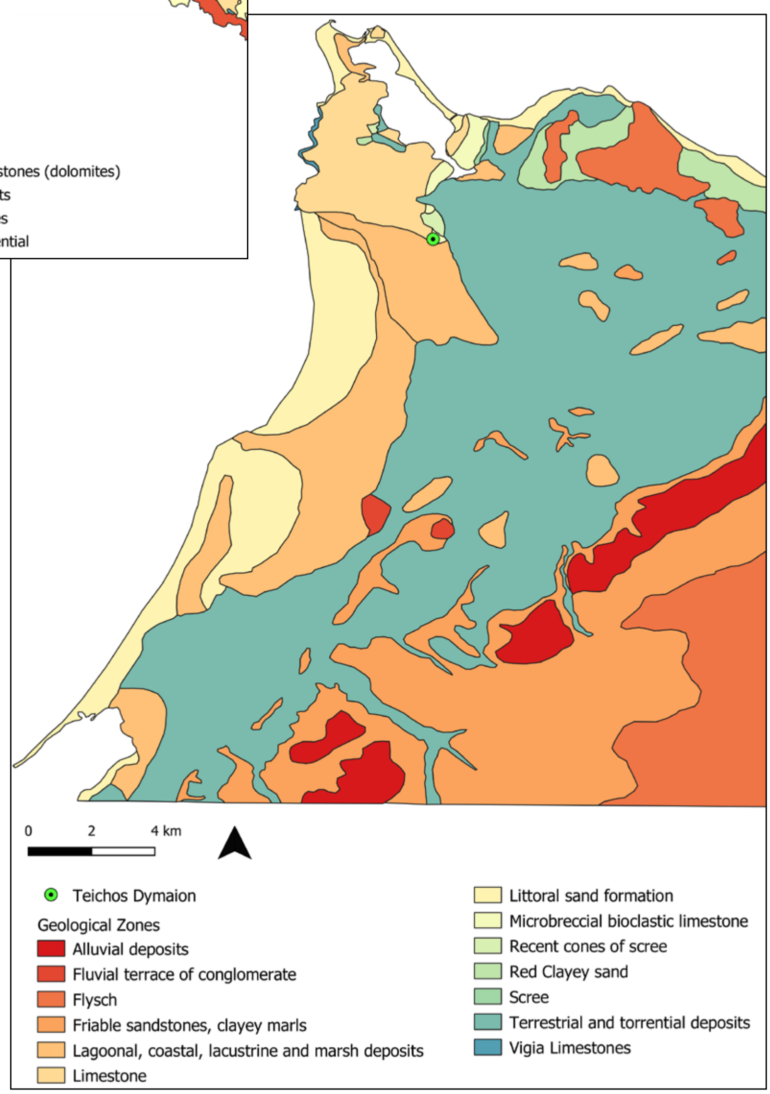


Figure 5.4 Geological map of the region around Teichos Dymaion (green dot) (based on IGME maps).

(see figure 5.4). It consists of mostly pelagic limestones, coloured white to light brown. Immediately to the east lies a region of microbreccial, bioclastic limestone. The region is surrounded by alluvial deposits and in the south, there is a large region of sandstone, while in the east, a region of flysch is located. Beyond the sandstone in the south, there is also flysch, which makes up the start of the mountain range extending eastwards (Geological Map of Greece; Nea Manolas, Patrai, Vartholomion, Amalias and Goumeron sheets (Papastamatiou et al., 1960)). In a 20km radius around Teichos Dymaion, the only limestone is thus in the immediate area of the site itself. It seems that the material comes from close by, which will be taken into account when looking at the labour costs of the construction of the fortifications (chapter 7).

5.2.2 The need for volumetric data

To determine the volume of the used stones, some previous studies on labour costs of Mycenaean fortifications, like Loader (1998) and Harper (2016) simplified the matter by taking the total volume of the wall and using an average stone size in their calculations. They referred in particular to Wright (1978: 159-160) for the size of the material, who stated:

> "The usual block size at all sites,[45] however, ranged between 0.70 m. and 1.20-1.50 m. in length and between 0.60 and 1.00 m in height (average course height from 0.60 m. to 0.80 m.). Most blocks are 0.80-1.00 m. thick."

Loader (1995: Appendix 4, n5) simplified Wright's measurements by taking an average stone size of 1.025 m long, 0.90 m wide and 0.80 m high. Harper (2016: 210) took Wright's maximum measurements as average and thus used hypothetical blocks of 1.5 x 1.0 x 1.0 m. He made the mistake of equating this to Loader's average weight of 1.845 tonnes (Harper 2016: 210). Of course Loader's weight was based on her (smaller) average sized stone, which is 1.025 x 0.90 x 0.80 = 0.738 m^3 and at 2,500 kg/m^3 this comes to 1.845 tonnes. Harper's use of Wright's maximum sizes, however, produces 1.5 m^3, which would weigh 3.750 tonnes and thus be more than twice the weight Loader uses.

However, there is a large variety in the size of blocks and it can be questioned whether simplifying that variance to a single figure, does justice to the real build-up of the studied walls. Therefore, an approach is used which can accurately document the fortification walls. This accurate documentation allows the recording of the large varieties in size of the used building material. The results of this approach represents the actual build-up of the walls, in terms of the variety of the size of the material, far better than a single average. Moreover, the size of the material and in particular the weight (the two are interrelated) is of potential influence on the labour cost.[46] In particular the labour cost of the transport and the assembly of the walls is dependent on the weight of the blocks (see also 3.4.2 and above 5.2.1). Therefore, a more nuanced understanding of the build-up of the wall through properly acknowledging this large variety in size could seriously alter the result.

Since the weight is an important factor for certain steps in the building process, yet weighing the stones is impossible, the best way to determine the weight is then through the volume. Determining the volume of the walls is achieved by documenting the fortification walls in 3D. By applying certain steps in this 3D documentation, a high accuracy was achieved to be able to deal with the variety of stone sizes.

The usefulness of 3D models for taking measurements depends on the accuracy of the model and the intended accuracy of the study. If, for example, a model is only accurate to a few centimetres, it cannot be used to take measurements with millimetre accuracy. An advantage of measuring digitally is that it is sometimes easier than taking measurements from the real thing. For example, determining the surface area of irregular shapes can be a matter of a few clicks on the computer, while doing so in the field is either rather bothersome if some accuracy is warranted, or it becomes a crude guesstimate by simplifying the shape to a rectangle or triangle. Furthermore, if the object of study is large (like a building), taking measurements becomes much more manageable when using a scaled computer model instead of doing this in the field. Additionally, 3D models allow easy access, long after their original creation or even after the original excavation, which may not have left the structure or other types of find, intact (Roosevelt, Cobb, Moss, Olson, & Ünlüsoy, 2015).

3D recording of surviving structures allows for a digital replica, and can be achieved through various methods. The preferred methodology comes down to, as with so many other matters, time, accuracy and funds. Millimetre accurate recording is possible with a Total Station, but may take a substantial amount of time and will likely result in a low resolution recording. Faster recording can be achieved through photogrammetry, which will result in

45 Wright refers in this section mainly to Mycenae, Tiryns, Midea and Gla.

46 Calculating the weight, based on the volume is depended on the specific weight for a given material. For example, the specific weight for limestone is roughly 2,500 kg/m^3. A volume in m^3 can thus be multiplied by 2,500 to obtain the weight of that particular volume.

a high resolution, but individual point data may not be as accurate.[47]

However, millimetre accuracy would be excessive for the aims of this research. After all, the calculated weight of the blocks will not alter significantly if the block is a centimetre larger or smaller. The potential of sufficient accuracy in photogrammetry has been shown in previous studies (*e.g.* El-Hakim et al., 2008; Remondino & Campana, 2014; Remondino, 2011; Stylianidis, Georgopoulos, & Remondino, 2008; Suwardhi, Menna, Remondino, Hanke, & Akmalia, 2015). Furthermore, since the photographs document the actual surface of the blocks rather than, for example, the outline that is recorded when a Total Station (TS) is used to document architecture (*e.g.* Pakkanen 2009), the resolution of the photogrammetry models is much higher. Originally, the documentation of the walls included photogrammetry and TS drawings to gain higher accuracy data (Brysbaert et al. 2018: 22-4). However, the photogrammetry models proved to be of sufficient accuracy and additional work on the TS data proved more difficult. Hence, photogrammetry models are used as the means of analysing the walls (see 5.2.3). The TS drawings, made by digitizing the outlines of the blocks with the TS in reflectorless mode (Brysbaert et al., 2018; *e.g.* Pakkanen, 2009) and subsequently processed by software (TS2DXF) provided by the Finnish Institute at Athens,[48] were only used to check the overall accuracy of the photogrammetry models. The TS models are not used for any further measurements for the labour cost analyses. By using accurately measured Ground Control Points (GCPs) the created photogrammetry models can be properly scaled (see above). This allows sufficiently accurate measurements to be taken from the models.

The main advantage of using a Total Station (TS) for recording the GCPs is the high accuracy that can be achieved. By creating a network of fixed points from which the location of the TS can be determined, the coordinate position of the TS can be determined within a 1 mm accuracy (Pakkanen 2009: 4-5; Olson et al. 2013; Sapirstein 2016: 138). Within this project, a differential global positioning system (DGPS) was used to set out an initial grid of reference points, which had a general accuracy of a few centimetres.[49] Subsequently, some of these points were used to setup a TS,[50] after which the points were remeasured with the TS and recorded in the Greek national grid coordinate system (GGRS 87). These new coordinates were then used to recalculate the position of the TS and with the new position with an improved accuracy, the rest of the points were measured with the TS. In this way, a number of fixed points were in place to help setup the TS at certain sections.

5.2.3 Photogrammetry / Image-Based Modelling

Large sections of the fortifications were documented through photographs, which were then used to create 3D models using photogrammetry software. At Teichos Dymaion all visible sections of the fortification were documented, which entails the entire outer face of the wall and those few sections of the inside face that are still visible (most of the inner face is still buried). These segments are located at the south-east and middle gates, and between these two areas. At Mycenae, there are various sections where it is difficult if not impossible to document the wall properly. Furthermore, it takes a considerable amount of time to document a wall that is over 5 metres high and has a total length of 900 metres, as is the case at Mycenae. So rather than attempting to document the entire wall, only sections were recorded, as was arranged in the fieldwork permit (see figures 5.5 and 5.6 for an overview of the analysed sections). Slightly problematic is the West Wall, where two sections of the exterior face seem to be modern reconstructions. At least, this seems to be suggested by Steffen (1884: map 2), who drew those sections of wall as being disturbed at the time (see also figure 4.3, in chapter 4).[51] However, judging by the style and material (distinctly different from the Hellenistic reconstructions in polygonal style, see also 4.1.1), it seems that mostly original material was used in the reconstruction. Hence, stone size and most likely the wall size is still reliable enough for the labour cost analysis.

In order to geo-reference and scale the models generated with the photographs, TS measurements were taken of marked locations which feature in the photographs. These coordinates can be loaded into the modelling software to secure an accurate model. These

47 Note the difference between accuracy and resolution: accuracy is a measure of trueness (how close is it to the actual thing), resolution in this instance refers to the amount of data points. Thus the TS will have high accuracy (very close to the actual point one is measuring), but low resolution (only a limited number of points are measured), while photogrammetry has a lower accuracy, but a very high resolution.

48 The current version of the software for converting the total station documentation into a three-dimensional CAD drawing was developed as part of the Three-Dimensional Development Programme of the Finnish Institute at Athens (Pakkanen, 2018).

49 A Leica Viva GS08 Plus system was used. Also note the accuracy difference between the TS (millimetres) and the DGPS (centimetres).

50 Both a Leica T1000 and a Leica T500 were used.

51 Moreover, a number of sections of the outer wall were repaired during the Hellenistic period (323-160 B.C.E.) (French 2002: 92) in a distinctive polygonal masonry. A particular section, called the “Hellenistic Tower” stands out in the Western wall, being wedged between two still standing sections of LBA stonework (see also figure 4.3).

Figure 5.5 Map of the documented sections at Mycenae (map by author).

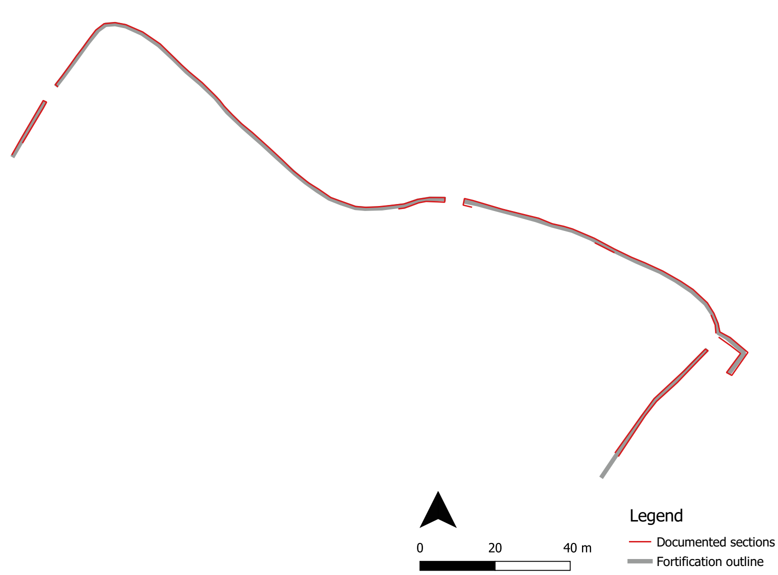


Figure 5.6 Map of the documented sections at Teichos Dymaion (map by author).

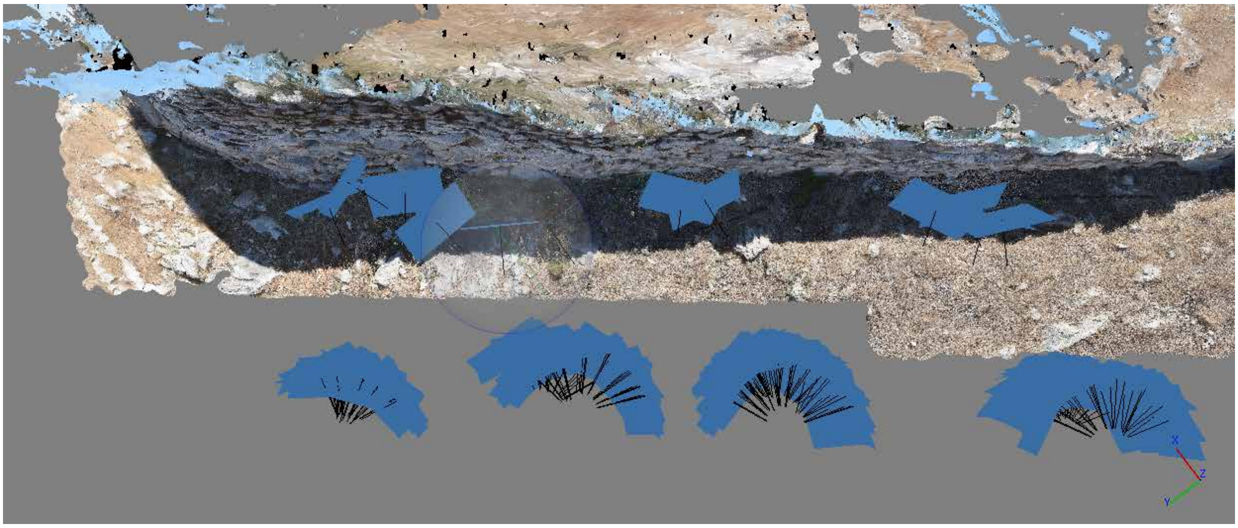


Figure 5.7 The position from where the photographs were taken for a section of wall at Teichos Dymaion (textured 3D model by author). Also, note the close-up photographs, taken to document the location of the reference points to ease processing. This image also shows the large amount of photographs (over 900) taken. It is likely far fewer photographs are necessary to accommodate the level of detail needed.

"Ground Control Points" (GCPs) (*e.g.* Suwardhi et al. 2015: 418) were similarly used as the fixed points for the TS, as described above, by using loose pebbles which were wedged into the wall. At Mycenae and Teichos Dymaion, the first points set out with the DGPS were put on bedrock and concrete patches on site, on which it was allowed to put markings. Subsequent TS points were marked on loose pebbles that were then wedged in the walls. This way, the walls were not marked or damaged, yet the marked points would stay in position long enough to be used over a period of two weeks at each site. Only those points that were positioned this way at the Lion Gate at Mycenae were subject to close inspection by tourists or guards, who occasionally also removed the pebbles. However, due to putting in many such points at each section to be recorded, it was still possible to set up the TS with enough reference points to secure a reliable and accurate position. At Teichos Dymaion, it was possible to use the pebbles again, but in order to secure the position of enough reference points, that were not on one line, throughout the period of working, iron stakes were also used. These stakes were hammered into the ground some distance from the wall and each held a marking, which was measured. This way a good spread of fixed points was created.

Data were gathered in the morning and modelled in the afternoon, to assure that the models worked. If the models were satisfactory, the GCPs could be removed the next day (and be used in the next section if necessary). Photographs were taken from various heights and angles to assure that enough vertical and horizontal overlap existed between the photographs. Therefore, from each position photographs were taken while in a crouching position, while standing and finally by holding the camera overhead, totalling several hundred photographs per section (the total number of photographs depends on the size of the section).[52] This resulted in a vertical variation of roughly 0.30 m to 2.4 m above ground level.[53] Since no ladders, balloons or drones were available, there are no photographs from a higher perspective.[54] Horizontal overlap was secured by taking a few photographs from each location and having only a few metres (between 2 and 5 metres) between each photograph location (see figure 5.7).

For the creation of the 3D models Agisoft Photoscan is used. It has an easy systematic workflow, which starts by adding the photographs of a section to the program. Subsequently, the coordinates of the GCPs are loaded into the program as a text file. On a number of photographs that contain any or multiple of these reference points the

52 A Nikon D7200 DSLR camera was used for all photography.

53 As a seasoned volleyball player, I know the top of my fingers reach above the top of a men's volleyball net when stretching out, which is at a height of 2.43m. Thus holding the camera in that position would put it slightly lower, at roughly 2.3-2.4m.

54 At least there are not for Mycenae. At Teichos Dymaion, drone photography was carried out by Pakkanen and Brysbaert in 2016 (Brysbaert pers. comm.). However, due to the height from which the photographs were taken and a lack of accurate GCPs, the resolution and accuracy of the subsequent models are not adequate for measuring individual blocks and are therefore not used as such in this study.

coordinates are linked to each other.[55] The program will then align the photographs and create a first, rudimentary model. From here, the program can create a dense point cloud, a mesh (a network of small polygons) of the surface and ultimately a texture layer can be draped over the 3D model. This will result in a photo-realistic representation.

5.3 From model to measurement

As pointed out above (5.2.2) some earlier labour cost studies simplified the calculations by using an average stone size in their calculations. However, there exists a large variety in size and it can be questioned whether simplifying that variance to a single figure, does justice to the real build-up of the studied walls. It was therefore decided to reconstruct the depth of the individual blocks, based on the hypothesis that there might be a relation between the size of a block's surface and its total volume.

Software, in particular Agisoft Photoscan allows the creation of an orthophoto from the constructed model. An orthophoto is extremely useful in this matter as it creates a rectified view on the surface, whereas ordinary photos are (slightly) distorted due to the shape of the lens (*e.g.* Jaklič et al. 2015: 144). By creating the orthophoto, any curvilinear distortions are rectified and thus any measurements (in 2D) are more reliable. Although this seems counterintuitive, going back from 3D to 2D, the acquired 3D data was, as pointed out, inadequate. There is no way to measure the actual volume of the blocks, since only one surface of each block is documented (the face that is part of the wall's face).

The manner of data recording in the field, through the use of the Ground Control Points (GCPs), meant that the subsequent data, in this case the orthophotos, are already georeferenced and scaled.[56] Thus, any measurements taken from these are real-world dimensions. This was tested by taking some measurements from the projected orthophotos and comparing these two dimensions taken from both the photogrammetry and TS data sources. This proved to be within centimetre range, and was thus found acceptable. To get the size of the blocks surfaces, the orthophoto is loaded in a GIS (ESRI ArcMap). This software allows to extract measurements easily, like surface area, based on the geometry fast and accurate. The TS drawings of the individual blocks were not used for this because:

1. the simplicity of extracting the required data in a GIS;
2. the TS drawings were not 2D, but also followed certain cracks in the blocks, which makes it more difficult to subtract the required data;[57]
3. the obtained data in GIS can more easily be quantified, grouped and visualised.

5.3.1 Volume of individual blocks

The way the data are collected makes it difficult, if not impossible in most cases to document the depth of individual blocks. The few sections in which the third dimension is visible, showed that there is as much variation in this dimension as there is in the surface area (see figure 5.8).

In the example from figure 5.8, blocks one and two have a surface area of roughly 0.37 m^2. Yet, block two is twice as deep as block one and thus its volume is twice as large.[58] Hence, extrapolating volume from surface area proves to be problematic. However, since this project does not have the means to record the depth of the blocks within the wall (*e.g.* radar), the use of the surface area is the best solution available. The question then rises how to come to volume when only two-dimensional data is present? The solution chosen in this research is to use those few instances where three-dimensional data is available (broken sections of walls, wall ends, and corners) to determine a range of ratios between measured surface area and measured block-depth. These ratios are subsequently used to calculate the volume of blocks of which only the surface area can be measured.[59] The extrapolated figures are determined by calculating the ratio between the depth and the surface area (see figure 5.9) and calculating the size difference between the blocks in the various sections, then using those ratios on the blocks of which only the surface area is known. This allows the creation of ranges that fit within reasonable dimensions based on the observed sizes (see table 5.1 below).

As exemplified the stones are far from uniform in shape (figure 5.8), therefore, a number of alternative ratios have been used (see table 5.2) to create a realistic spectrum of labour costs. Due to this approach, the volumes of the wall's faces vary according to the used scenario. This affects the volume of the fill since the total volume of the wall is fixed. This is taken into account in the calculation of the labour costs. The scenarios make use of size classes based on the measured surface area of the blocks, created through various means.

55 Although the program can align the photographs and create a model without the reference points and coordinates, such a model would not be georeferenced and scaled, and no real-world measurements could be taken from the model.

56 Georeferencing means that the models are connected to real-world coordinates (e.g. Eitljorg 2008: 229).

57 This has also to do with the limited skill of the author in AutoCAD.

58 This is obviously dependent on the shape of the block.

59 This assumes a constant shape of the block along the entire depth of the block. While this will in most cases not be so, it still approaches the proper volume far better than the previously used alternatives of one standardized average size.

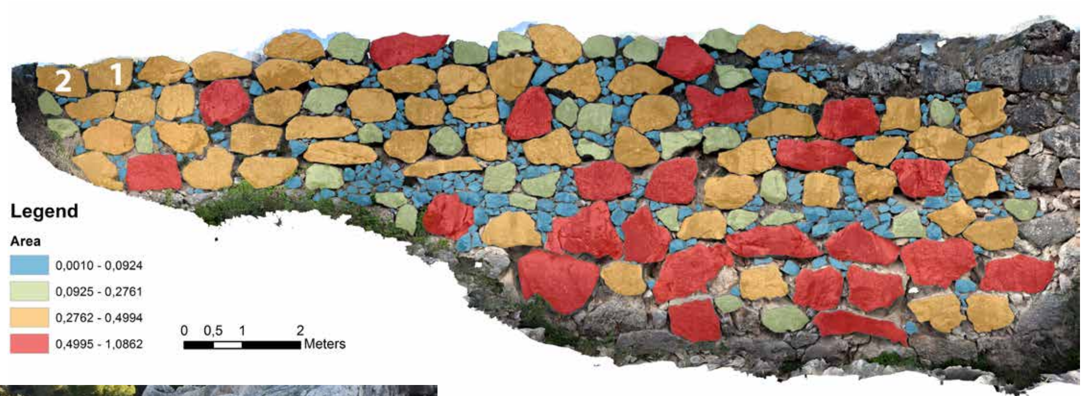


Figure 5.8 Two blocks with similar surface area, but very different depth and thus different in volume (images by author).

Size class	Maximum surface area (m^2)	Observed depths (m)	Maximum volume (m^3)
1	0.0079	0.001-0.05	0.0004
2	0.0132	0.05-0.1	0.0013
3	0.0518	0.1-0.4	0.0207
4	0.6755	0.4-1.0	0.6755

Table 5.1 Example of the ranges and ratios, from a section at Teichos Dymaion, between the measured surface area of blocks, the depth of these blocks and the associated maximum volume. Note that in this example maximum values are used.

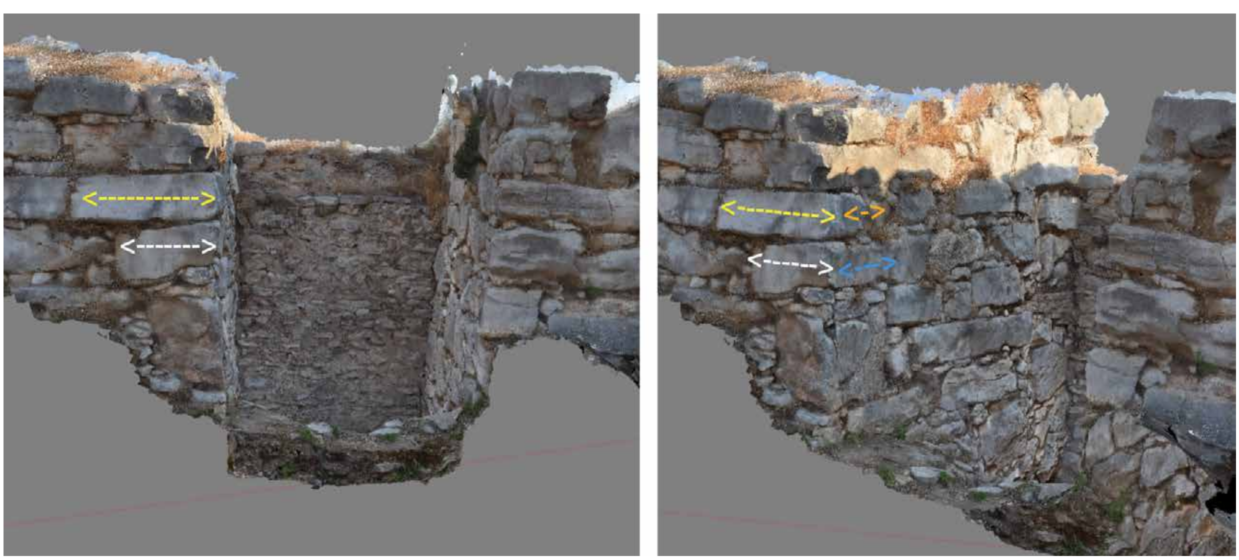


Figure 5.9 An example of a section of wall at Teichos Dymaion where a block is visible from two sides (textured 3D model by author). On the left the wall is viewed straight on its surface, on the right image on a slight angle. The yellow and white arrows indicate the same faces of the blocks in both images. The orange and blue arrows indicate the second face of the blocks that is visible. By measuring a number of such instances, certain ranges could be determined of ratios between a block's surface and its depth. Due to the variability of these measurements, it is important to use these ranges, rather than singular values.

Scenario	Description
I	Each group represents 25 % of the number of blocks. Depth is based on the ratio between the surface area of the stone and the depth, calculated by using those instances where the depth was documented.
II	Each group represents 25 % of the number of blocks. Depth is based on the weight percentage of the group in comparison to the total weight from scenario I. Then use the weight that is the result of the volume of the wall face, if the wall face is taken as a set width (*e.g.* 1-1.5 m wide as suggested by Wright (1978)).
III	The size of each group is based on the percentage coverage it provides in the wall. This is then multiplied by the volume of the wall face (same as used in scenario II) which gives the volume per group and thus the weight per group (not per stone).
IV	Each group represents 25 % of the number of blocks. The depth is reconstructed as a maximum of twice the root of the surface area. This means the depth is a maximum of twice the average length or height of the blocks in a group.
V	Each group represents 25 % of the number of blocks. The depth is reconstructed as the root of the surface area. This means the depth is a maximum of the average length or height of the blocks in a group.
VI	Each group is based on using Jenks Natural breaks. Depth is based on the ratio between the surface area of the stone and the depth, calculated by using those instances where the depth is documented.
VII	Groups are identical to scenario VI. The depth is reconstructed as a maximum of twice the root of the surface area. This means the depth is a maximum of twice the average length or height of the blocks in a group.
VIII	Groups are identical to scenario VI. The depth is reconstructed as the root of the surface area. This means the depth is a maximum of the average length or height of the blocks in a group.
No size differentiation	The total weight is divided into 1,845 kg blocks (as suggested as average block by Loader (1998)) or, in the case of transport divided over 5,000 kg loads per trip.

Table 5.2 The used scenarios for reconstructing the volume of the stone material, based on the surface area of the stones in the wall's faces. A scenario in which no differentiation is made in stone size is also used.

The first method divides the entire dataset into four groups in which each group contains 25 % of the blocks. Each group has thus the same size, but the meaning of the groups themselves is vague, at best, since the threshold values are completely arbitrary. It is useful to show the spread of the block size, though, and it shows how a relatively small group covers a large portion of the wall's face.

The second method used to create the size classes is Jenks Natural Breaks classification method. It clusters data in such a way to minimize the deviation from the mean within the class, while maximizing the difference between classes (Jenks 1967: 187-8). As such, the created groups are truly different from one another. The scenarios in which this method is used also consist of four size classes. While this number of groups seems arbitrary, it allows a comparison between the types of classes as the same number of classes are created. A more in-depth statistical approach to what would be the ideal number of classes is desirable, and further research into this would be beneficial for future studies. Finally, the creation of these scenarios already show that there are differences in the size of the material used at Mycenae and Teichos Dymaion (as is shown in chapter 6).

As for some scenarios, the resulting volumes are at odds with what is known about the walls (*e.g.* the volume of the fill being close to zero). Hence, these scenarios will not be taken into account in the calculations of the labour costs in the subsequent sections.

After creating the various classes, the number of blocks in each group is determined. Subsequently, the maximum value of each group is used and multiplied by the appropriate depth, resulting in a maximum volume of stone per group for each scenario. These volumes and associated weights are then used in the labour cost calculations presented in this chapter. This method is not used for the conglomerate façades as these have been built in a regular thickness and there is thus no need for creating these groups to calculate the thickness.

The approach adopted here allows the creation of (admittedly subjective) size categories to use in the calculation of the labour cost and hence provides a way to analyse the building process in more detail. It also creates a more realistic representation of the build-up of the wall. To assess whether this approach will indeed create a more nuanced calculation of the labour costs, it will be compared to the results of an analysis in which a simple average stone size is used.

5.3.2 Volume of the wall sections

Besides the volume of the used material, the volume of the actual structures is needed to determine the total labour cost. Due to the fact that various sections were recorded along the fortification walls at both sites, there is a good amount of information on the width of the wall in its current state. The length and height recorded at these sections are particularly accurate. With these data it is possible to calculate the volume of the individual sections to a reasonable degree. Because this involves the volume of the current remains, it provides a minimum volume, as any part that may originally have been higher or any additional superstructure (not necessarily built in stone), is not taken into account. However, due to the difference in visible height between the inner and outer face, a choice needed to be made regarding what to use to calculate the volume. This means that either one of the preserved heights is used, or both heights are used and the volume is determined by reconstructing the wall, not as a 3D rectangular box, but as a 3D polygon taking into account the height difference of the inner and outer wall face.

However, it would be safe to assume that the area, on which the wall was to be built, was cleared and levelled to a certain degree (see also chapter 3). Thus taking the bottom-most and the top-most wall height, regardless what wall face it is, seems to be a safe assumption in determining the volume of the wall as it still stands. In order to justify using a rectangular box to determine the volume only straight stretches are used of the sections being studied. These straight segments might be smaller than the total size of the recorded sections, but using these straight sections ensures two things: one, the determined volume is as true to the actual volume as possible and two, it allows the creation of usable sections to compute the volume of the rest of the wall. The volumes presented here are thus based on the sections recorded at both Mycenae and Teichos Dymaion. The total volume (and ultimately the labour costs) of the fortification walls per site can then be extrapolated from those individual sections.

5.3.3 Volume of domestic structures

In order to provide a comparison for the labour costs invested in the walls a number of domestic structures is also studied. Since there was no fieldwork permit to document any other structures than the selected fortifications, the data for the domestic structures are solely based on earlier published studies (*e.g.* Harper, 2016; Jazwa, 2016; Palyvou, 2005; Tartaron et al., 2011). There might be some discrepancy in accuracy, both between these studies and between them and the data used for the fortification walls (see above). However, to provide a scale on which to place the labour costs, these comparative data suffice.

Since no complete domestic structures are preserved from the studied regions, several assumptions will need to be made. This goes for the build-up of the structure, used materials as well as the building process. For example, how high was the stone socle on which (mudbrick) walls were placed? Was there a second storey and a pitched or flat roof? To accommodate the various options, multiple scenarios are explored for both the reconstruction of the structure as well as the labour cost analysis of these structures. Ultimately, some highly detailed matters will be omitted, as they do not influence the result, and more importantly the scale, significantly.

A number of features are hypothesized in these scenarios. The structural features include the height of the stone foundation/socle, the height of the (mudbrick) superstructure, the inclusion or exclusion of a second storey and the roofing. Some finishing labour like laying of a floor and applying a basic wall plaster to protect them against weathering are also included in the labour costs (see chapter 7). Windows, doors and other more elaborate possible finishes like murals, are not considered. In appendix 1 an overview of the various scenarios is provided as well as the effect that these scenarios have on the required material. A total of 42 scenarios are calculated. This may seem a lot, but there is a certain overlap as several combinations of characteristic are used. Hence, combinations of the following variations are tested:

1. the presence of a second storey (which influences the total height of the walls);
2. the ratio between mortared rubble and mudbrick construction in the height of the walls;
3. the ground size of the structure;
4. the width of the walls;
5. the variation in thickness of the clay plaster for the finishing of floors has been calculated for a thickness of 5cm (Murakami 2015: 273) and 20cm (Palyvou 2005: 125).

For the materials used in the wall construction (stone and mudbrick), it must be noted that this comprises the total volume of that portion of the wall. This means that it has not been taken into account whether gaps existed between the stones (which in the case of rubble walls is certainly the case), nor if these gaps were filled with a mortar. Openings in the walls for doors and windows are also not taken into account. In the case of the mudbrick, no separate volume is, in this overview, calculated for the mortar used in between the bricks, which can consist of as much as 13 % of the total volume (Homsher 2012: 20).

5.4 Concluding remarks

This chapter has presented the methods used to quantify buildings through their construction processes. Such labour cost studies allow comparisons to be made between buildings based on the required investment. This method is based on the volume of the required materials and associated work rates that describe at what rate a task can be performed. As such, there is a need for volumetric data. To gain these data fieldwork was done in which sections of the fortification walls at Mycenae and Teichos Dymaion were recorded using photogrammetry. By combining this methodology with accurate point readings with a Total Station, 3D models were created that are subsequently used to extract the dimensions of the walls as well as the individual blocks with which these walls are built. Since the used methodology did not provide a means to extract the depth of the blocks, just the surface, scenarios are created with which the depth can be reconstructed. The resulting ranges of sizes for the stone blocks are then used in the labour cost calculations. The following chapters will present the data (chapter 6), the labour cost calculations (chapter 7) and the interpretations of the calculated costs (chapter 8).

Chapter 6

The data: measurements of blocks, fortifications and houses

This chapter provides an overview of the acquired data regarding the researched fortifications and domestic structures. The acquired data form the basis for the labour cost calculations of these structures (chapter 7). As shown in the previous chapter, the data acquired through photogrammetry is used to obtain the volume of the walls and blocks of the fortifications. It is the volume, after all, that is being used to calculate the labour costs (see also chapter 4). In the sections 6.1 and 6.2, it will be shown what kind of results the used methodology yielded and how these are subsequently used to gain the required information for the fortifications at Mycenae and Teichos Dymaion. For the domestic structures, volumetric data was acquired through literature study, these data are presented in section 6.3. The use of the different types of structures will aid in providing a scale on which to place the calculated labour costs, which in turn will help to understand the potential impact the construction of the fortifications may have had on communities.

6.1 Surface area analysis

The data recording, as described in chapter 5.2, resulted in a number of 3D models of sections of the fortifications at Teichos Dymaion and Mycenae. One of the main issues with these data is how to extract the required data (the volume of the stone material) from these models (see chapter 5). As will be demonstrated, these data show interesting results in comparison to earlier studies (Harper, 2016; Loader, 1998; *e.g.* J. C. Wright, 1978) concerning the fortifications.

The method of classifying the blocks in the wall by size (see 5.3.1) shows known and unknown features of the walls. As described in chapter 3, the fortification walls are built with large blocks, with smaller stones in between to create a balanced whole. The surface area analysis shows that there is a huge differentiation in size, from tiny -less than fist sized- stones to large blocks over a square meter big.[60] Yet, the amount of smaller material seems to have a larger presence than the earlier description would suggest. In some of the analysed sections the largest category of stones only provides 43 % of the total wall surface (or rather the surface area of the wall that is actually covered by stone). This is important for a number of reasons: first, the large variety in size of the material should be taken into account in the labour cost calculations as the weight of the material impacts the labour cost greatly (see also chapter 7). Second, it changes the way one should evaluate the necessary material as the large variety shows that the build-up is not simply one category of (extremely) large blocks and one category of small, easily obtainable, filler stones. This can thus potentially affect the organisation of the building processes as well. Finally, the large variety that seemed to have been overlooked by earlier researchers could also have an influence on the average stone size employed in the walls, something other labour cost studies of cyclopean walls have often used in calculations (*e.g.* Loader 1998;

60 This is observed in sections that, as far as known, are *not* modern reconstructions. However, also at those sections where reconstructions have taken place, this variety in size has been documented.

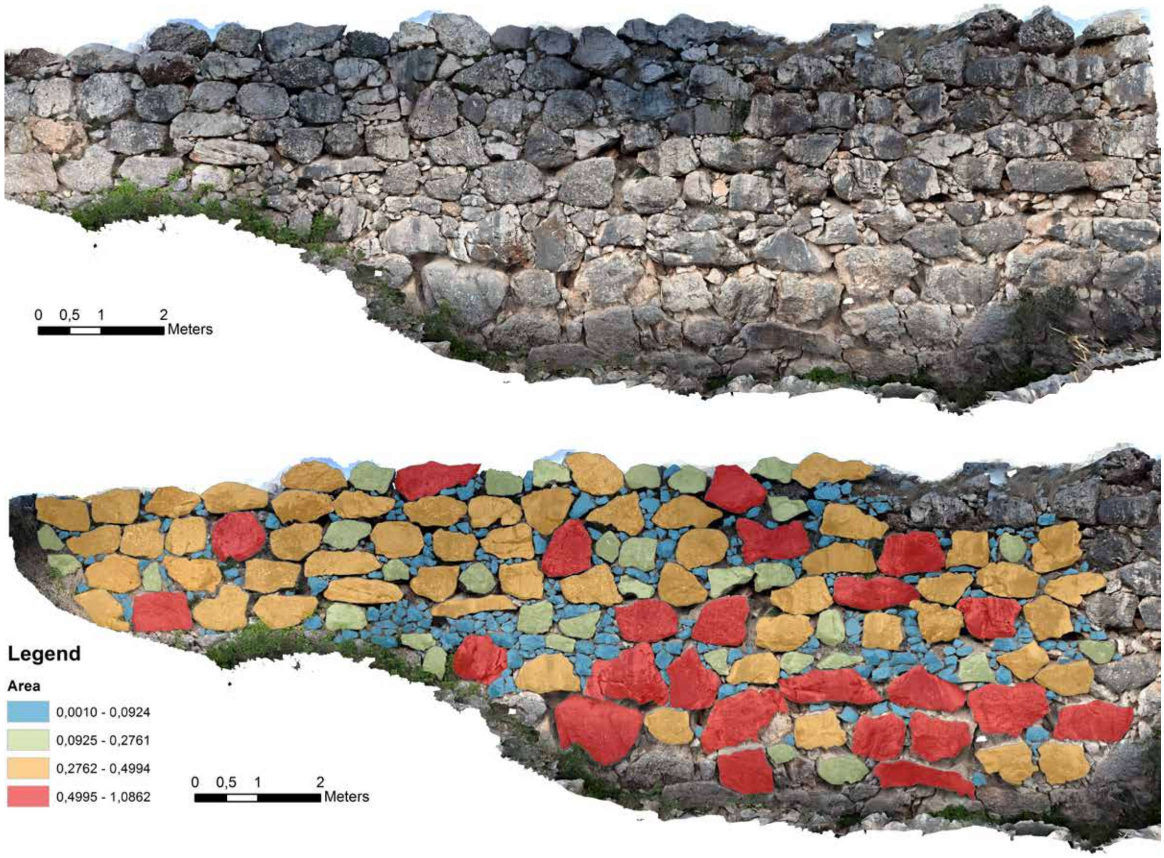


Figure 6.1 Section of the inner face of the Western fortification wall at Mycenae. The top image is the original orthophoto; the bottom image shows the individual stones digitized and coloured according to size. The size groups are determined through Jenks Natural Breaks (see 5.3.1) (images by author).

Harper 2016). Figure 6.1 shows the original orthophoto and the digitized overlay in which the stones are coloured according to surface area size. In this particular image, the four groups represented by colour are based on a Natural Breaks classification (see 5.3).

The variation in size of the used material is not only observed within, but also between sections. In other words, the size of the used stone material fluctuates in different sections of the fortifications, even within the same site (see figure 6.2).[61] All documented sections at Mycenae are part of the later phases of the fortification (see chapter 4). At Teichos Dymaion, it is assumed that the entire fortification is built in one phase. Therefore, there does not seem to have been chronological differentiation that would account for the differences in size.

The characteristics of the walls' style, built with mostly unshaped blocks, would always result in sections in which stone size varies. This is partly reflected in the graph. However, what is interesting to notice is that there are three sections in this graph that are clearly built with, on average, smaller blocks than the other sections. These bars reflect sections that are located on the inside of the fortified area, the side of the wall that is facing the citadel, rather than the outside world. The differentiation in size between the two faces was also noted by, amongst others, Küpper (1996: 33), although he never quantified it. Considering the consistency with which this is done, it would imply a conscious decision to use larger material on the outer face. This gives rise to the question whether this is due to a constructional necessity, if it is a matter of displaying the larger material to outsiders, or a

61 It is important to note that the scale in the graph is a logarithmic (log) scale. Using a log scale shows very clearly the differentiation in size, particularly for the lower figures. Because the variation in size is so large, a linear scale would only show the top box and whisker. By using the log scale, it can show the differentiation in each group of stones, with the groups each representing 25 % of the stones. This also means that some of the smaller groups might seem to have a large size differentiation, but this variation might not be more than 0.0009 m^2 (e.g. the North East section at Teichos Dymaion). Whereas the variation in the top group, represented by a slightly shorter whisker, might be as much as 0.97 m^2 (same section).

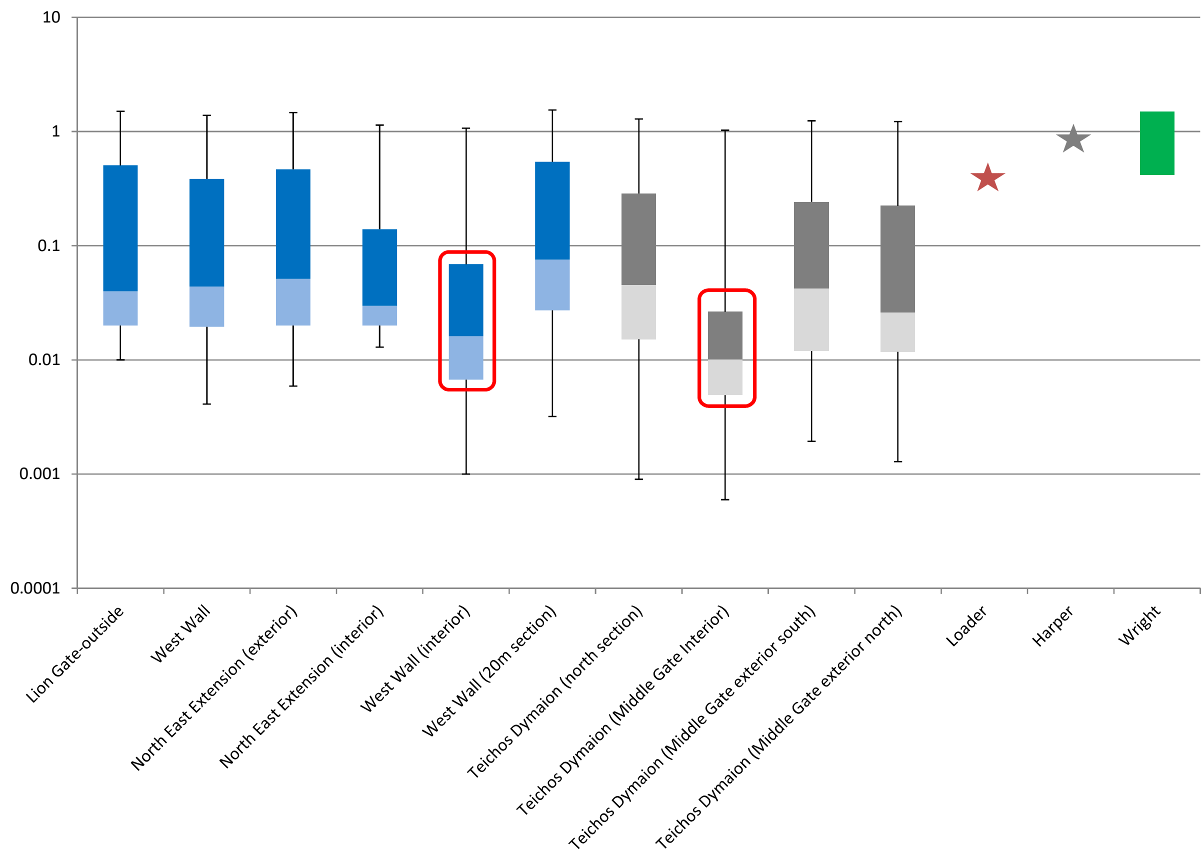


Figure 6.2 Graph showing surface area differentiation in various sections of fortification at Mycenae (blue) and Teichos Dymaion (grey). Indicated sections (red) represent sections of the inner citadel face. Those sections that include the references north or south, indicate that they are part of a longer section and two sub-sections were analysed. Also presented here are the average sizes used by Loader (red) and Harper (grey), based on Wright's average range (green). This shows that these averages are all in the top of the ranges as documented at Mycenae and Teichos Dymaion and are thus far too large (graph by author).

combination of these. Having larger material in the outer walls is not a localised or era-specific phenomenon.[62] However, since the fortification comprises a free-standing wall, it seems more likely to be an aesthetic measure than a structural need.

Finally, the analysis of the wall surfaces has shown that for the various sections being studied, on average 17 % of the surface is not covered by stone. These cavities, which are common, if not inherently present, in rubble style walls influence the amount of material that is needed. While it is possible that stones have fallen out of the wall, Mundell et al. (2009: 205) found that tightly built rubble walls have about 20 % 'voidage', while 40 % is possible in poorly built walls. The 17 % found in the surface is thus to be considered an absolute minimum. Furthermore, it needs to be taken into account that this space could have been left empty, or was filled with a clay, as suggested by Wright (1978: 160) and recorded at Tiryns (Küpper 1996: 33) and Mycenae (Mylonas, 1962) (see also chapter 3). Within the used scenarios, 17 % of the volume is taken into account as possibly not filled with stone. However, due to the large variety in possible volume as well as the lack of

62 Not only is it visible at both Mycenae and Teichos Dymaion, similar observations have been made at Koroneia from the late Archaic period (Boswinkel, 2018) as well as Hellenistic Halos (Haagsma, 2003), both sites located in Greece. Both examples represent much smaller constructions, with the first being a possible temple-like structure and the second a domestic structure and in both cases the walls are less than a meter high. Haagsma, nevertheless argues that for the structures at Halos there is a constructional reason for the difference in size between the inner and outer face of the walls. This is visible in the fact that the outer walls had to bear more pressure and weight than internal walls and if there was no structure immediately attached to a wall, it had nothing to lean against and, therefore, these outer faces were built with larger stones (Haagsma 2003: 40). This seems unlikely to be applicable to a fortification as this comprises a free-standing wall. However, the difference in size of the material is certainly present.

knowledge about how and when a form of clay was used in these walls, the clay itself is not taken into account in this study.

6.2 From surface to volume

Surface area might provide a good first step in the analysis of the build-up of the wall, but ultimately the volume is what determines the weight (in combination with the specific weight of a given material), which in turn influences the various steps of construction. Here new challenges arise, as it was impossible to assess the depth of the blocks with the available equipment. In section 5.3 it was explained how this was dealt with, first on the level of individual blocks, secondly on the level of entire walls. Below the resulting data are presented.

The façades built in conglomerate at the Lion and North Gates at Mycenae, are only that, a façade. Except for the gate itself, the façade is encapsulating a cyclopean-style wall. It is visible in multiple places that this conglomerate façade is only a single block wide. Obviously, there is some variation based on individual blocks, but this is minimal and on average this is a depth of about 0.80 m at both gate façades.

The recorded sections at Mycenae show that the wall itself is between 6 and 7.5 metres wide and preserved up to 9.5 metres high. The height is varying and this obviously influences the calculated volume greatly. Nevertheless, the volume of the studied sections provides a good sample for the later parts of the fortification (see chapter 4): the western wall, both gates and the North Eastern extension. It is possible to extrapolate the data from the documented sections and use that to calculate the volume and subsequently the labour costs for these final additions. In the table below (table 6.1) an overview of the volumes is provided. Figure 6.3 shows the location of the mentioned sections. Note that the analysed sections below are smaller than the documented sections as presented in figures 5.5 – 5.6. As explained in section 5.3.2, this is to ensure the most reliable data.

Section		Volume m3
1	Lion Gate *Façade*	237.4
2	North Gate *Façade*	48.2
3	West Wall	1197
4	North East extension	246.5

Table 6.1 Volume of recorded sections of the fortification wall at Mycenae.

Section		Volume m3
1	Middle Gate	728
2	South Wall	558.3
3	North East section	549
4	North Gate	219.2

Table 6.2 Volume of recorded sections of the fortification wall at Teichos Dymaion.

At Teichos Dymaion, no special façades are present like those at the gates of Mycenae. The wall is between 5.6 – 6.4 metres wide, although the bastion at the south gate is only 4.4 metres wide. The highest section recorded still stands 7.5 metres high. At Teichos Dymaion, a larger proportion of the wall is documented, at least of the outer face, than at Mycenae, due to the overall smaller size of the site. Height, as is to be expected, differs between sections, but overall, the wall seems to be of a relatively regular height. Table 6.2 shows the volume of the sections at Teichos Dymaion. Figure 6.4 provides the location of these analysed sections.

It is important to note for both sites that the volumes are based on the current preservation, visibility and in some cases the completeness of documentation. In figure 6.5 below, this can be observed quite well. The section in the figure corresponds with section 2 at Teichos Dymaion, which is a relatively long section, but only preserved to a low height and not the complete length was digitized. Hence, despite the length, the volume of this particular wall section that is used in the calculations is not very large. This needs to be taken into account when the labour costs are interpreted, as the actual wall was far larger than the remains that are visible today. Hence, in chapter 8 the volume and the associated labour costs will thus be extrapolated. The initial calculations are based on the actual remains though.

6.3 Measurements from domestic structures

From the various sources (*e.g.* Harper, 2016; Jazwa, 2016; Palyvou, 2005; Tartaron et al., 2011) it is clear that there is a large variety in Late Helladic houses. Houses measure a few dozen square meters up to over 300 square meters. From Jazwa's (2016) extensive study into domestic structures of prehistoric Greece, a selection of 15 structures is used. These structures were selected due to their location in the Argolid (unfortunately, none of the structures he studied from Achaea, had reliable measurements) and the fact that these are dated to LH IIIA-C. Two are from Midea, four from Mycenae and nine from Tiryns (see table 6.3). Another structure is used from the site of Kalamianos, for which the data come from Tartaron et al. (2011) and Harper (2016), bringing the total to 16 structures. Comparing these figures to those from the study on Kalamianos by Tartaron et al (2011: 589; see table 6.4 below), it is clear that three of the four structures from Mycenae are (far) larger (over 310 m^2) than the majority of the domestic buildings from this era. For one of these, the so-called West House, Jazwa (2016: 141) points out that its size, the used construction as well as exotic luxury goods indicate an "elite status of

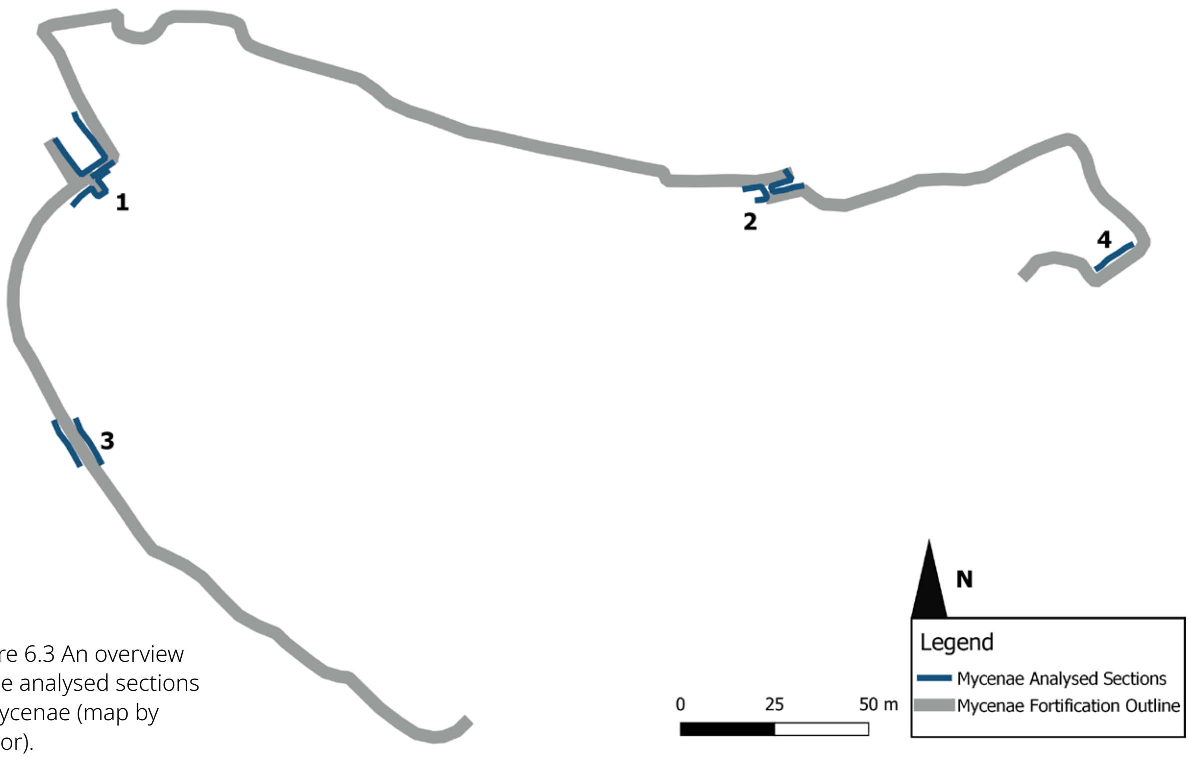


Figure 6.3 An overview of the analysed sections at Mycenae (map by author).

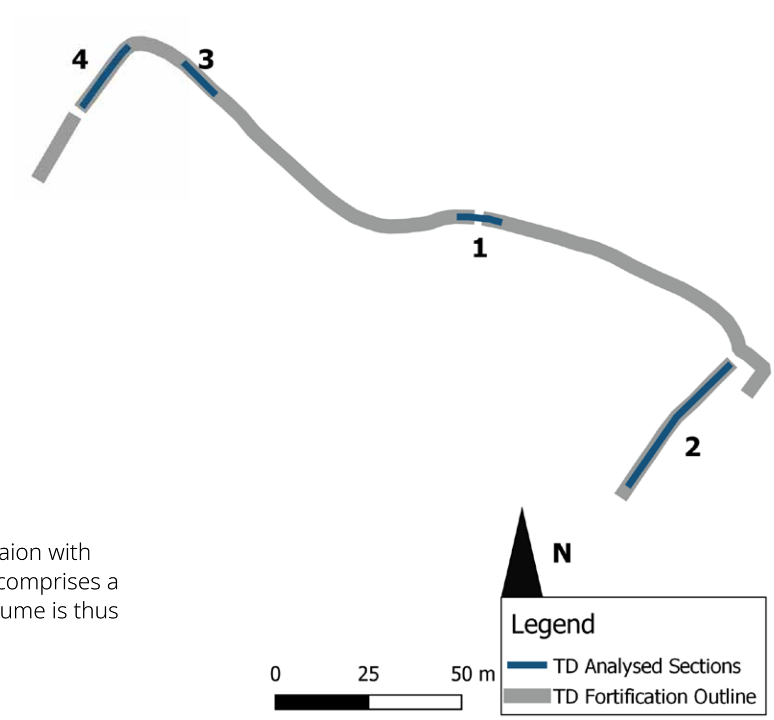
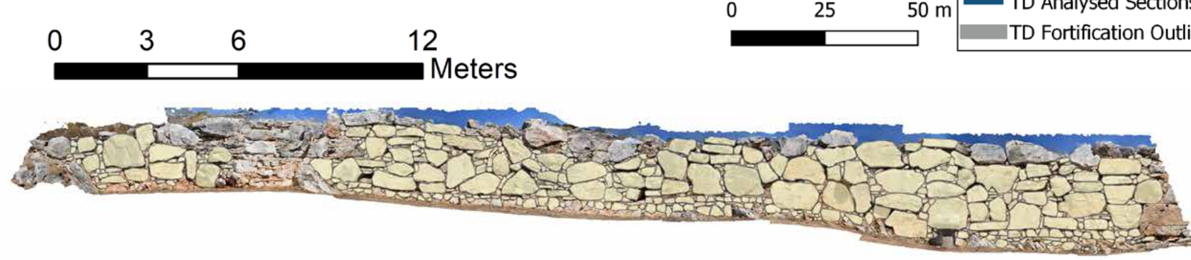


Figure 6.4 Overview of analysed sections at Teichos Dymaion (map by author).

Figure 6.5 (below) Section III of Teichos Dymaion with digitized blocks where possible. Although it comprises a long section, it is quite low and its overall volume is thus relatively small (image by author).



Site	Structure	Date	Surface area (m2)
Midea	Megaron 1	LH IIIB	161
	Megaron 2	LH IIIC	100
Mycenae	Mu House	LH IIIB	887
	South House	LH IIIA/B	357
	Tsountas House	LH IIIA/B	194
	West House	LH IIIB	377
Tiryns	A	LH IIIB	266
	II	LH IIIB	25
	VI	LH IIIB	214
	R97	LH IIIC	27
	8786	LH IIIC	46
	127	LH IIIC	90
	110	LH IIIC	10
	W	LH IIIC	177
	O	LH IIIC	24
Kalamianos	7 – X	LH IIIB	105

Table 6.3 Overview of the used houses (after Jazwa 2016, Tartaron et al. 2011 and Harper 2016).

Building size (m^2)	Kalamianos (%)	Cumulative (%)	Other Mycenaean sites (%)	Cumulative (%)
20 – 50	0	0	18	18
50 – 100	47	47	33	52
100 – 120	5	53	9	61
120 – 200	26	79	14	74
200 – 310	16	95	9	83
>310	5	100	17	100

Table 6.4 Overview of occurrence (in percentage) of houses in a certain size class (after Tartaron et al. 2011 and Darcque 2005) (please note that rounded numbers are used).

the inhabitants of the complex". Most structures are a lot smaller, with a size of 50-100 m^2 being the most common range (a third) and the majority of domestic buildings being smaller than 200 m2 (nearly 75 %) (Tartaron et al. 2011: 589). It must be noted that these figures represent the total exterior footprint of the building, including the walls. Tartaron et al. (2011: 589) have shown that for Kalamianos an average of 61.9 % of that area is actual room floor surface (their range is 48-70 %).

In the appendix of Jazwa's study (2016: 408-694) the variety of the size of the walls, in particular their width, is shown.[63] It does not only differ between buildings, but it also varies within a building. The width varies between 0.45 and 1.40 meters, but an overall average width for the walls from all 15 buildings is 0.66 m for the exterior walls and 0.60 m for the interior walls.

The height of the walls is kept consistent at 2.5 m per floor. There are only limited Mycenaean domestic structures that show a second storey to extract a reliable height from, yet from Akrotiri it seems that the height varies roughly between 2.3 and 3.3 m for the West House (Palyvou 2005: 46).[64] This is the effect of a large discrepancy of the floor level (variations of up to 1.80 m) and so the ceiling had to be at least on the height of the lower value. A height between 1.90-3.00 m is average when considering the Beta and Delta houses as well (Palyvou 2005: 128, table 1). Thus, taking into account some of the thickness of the second floor/roof, 2.5 m seems a solid figure. In table 6.5 below is a summary of the data, using average values based on the size of the structures.

6.4 Concluding remarks

In this chapter the volumetric data have been presented that derive from fieldwork in Greece (the fortification walls) or from literature on the domestic structures. The data show, first, that on average the blocks used in cyclopean constructions are (far) smaller than previously envisioned (as shown in figure 6.2), and, second, that there is a large variety in size of the blocks within the structures. Besides any influence these observations may have on the labour cost (see chapter 7), this detailed size analysis,

63 From what source individual measurements are taken in Jazwa's work is unclear. However, he does provide a bibliography per site and in some cases per house from which data are taken.
Midea: Walberg 1998, 1999, 2007; Demakopoulou 2001, 2007; Demakopoulou and Divari-Valakou 2010
Mycenae:
Mu House: Shear 1968, 235-249; Hiesel 1990, 52-54, 147-149; Darcque 2005
South House: Wace 1925, 1980; Shear 1968; Taylour 1981; Hiesel 1990, 85, 160; Darcque 2005
Tsountas House: Tsountas 1886, 1887, 1964; Mylonas 1966; Shear 1968, 226-235; Hiesel 1990, 125; Darcque 2005
West House: Hiesel 1990; Tournavitou 1995; Shelton 2010
Tiryns: Müller 1930 (Tiryns 3); Gercke and Heisel 1971 (Tiryns 5), 1-19; Grossmann and Schäfer 1971 (Tiryns 5), 41-75; Gercke, Gercke, and Heisel 1975 (Tiryns 8), 7-37; Grossmann and Schäfer 1975 (Tiryns 8), 55-96; Rudolph 1975 (Tiryns 8), 97-117; Avila, Grossman, and Schäfer 1980 (Tiryns 9), 1-88; Grossman, et al. 1980 (Tiryns 9), 89-180; Hiesel 1990, 22-23, 197; Müllenbruch 2013 (Tiryns 17); Wiersma 2013, 146-149. See for full bibliography Jazwa 2016.

64 Akrotiri is a site on the Greek island Thera and was covered by a volcanic ash in the 17th century B.C.E. (e.g. Palyvou 2005). Although it is thus older than the other studied structures, it is one of the very few locations where domestic structures from the Late Bronze Age are preserved in such a state that these kind of data can be documented.

House size category (m2)	Stone	Mudbrick		Wall plaster	Floor plaster (5cm)	Floor plaster (20cm)	Roof clay	Wood (per floor)	Small wood (per floor)
75	63.25	47.38	8.69	3.41	13.65	15.00	2.27	3.75	63.25
110	92.77	69.48	12.74	5.01	20.02	22.00	3.63	5.50	92.77
160	134.93	101.07	18.53	7.28	29.12	32.00	4.99	8.00	134.93
200	168.67	126.33	23.17	9.10	36.40	40.00	6.35	10.00	168.67
250	210.83	157.92	28.96	11.38	45.50	50.00	7.71	12.50	210.83
300	253.00	189.50	34.75	13.65	54.60	60.00	9.07	15.00	253.00
370	312.03	233.72	42.86	16.84	67.34	74.00	9.07	18.50	312.03

Table 6.5 Summary values of the various scenarios for the required materials for domestic structures. All values are averages and are in cubic meters (m^3). The size (surface area) of the structures is taken as 75, 110, 160, 200, 250, 300 and 370 m^2 respectively. The averages for mudbricks include 0-values (left column) and exclude 0-values (right column) in the scenarios with walls built completely in stone. The averages also include the scenarios with and without a second floor.

at least provides a more comprehensive insight into the actual build-up of the fortification walls. The presented data in this chapter will be used in the following chapter (7) for the calculation of the labour costs of each of the studied sections. The interpretation of these costs will be presented in chapter 8.

Chapter 7

Labour costs of fortifications and domestic structures

In this chapter, the calculations of the labour costs of the various documented sections at Mycenae and Teichos Dymaion are presented. The chapter is divided according to the sub-processes within the building procedure: material acquisition (7.1), transport (7.2) and construction (7.3-7.6). For each sub-process, the calculations of the labour costs are presented for the individual documented sections. A total-cost per section is presented in section 7.7. Section 7.8 comprises the labour cost calculations of the domestic structures, which are used as a comparison. The implications and interpretations of the calculated values are discussed in chapter 8.

Throughout this chapter the cost is expressed in person-hours (ph) or man-days (md). The latter is only applied when examples from other studies that employ this unit, are used. For the transportation, the use of oxen is assumed and their cost is described as oxen-hours (oh). Both person-hours and oxen-hours are rounded to the nearest full hour. The work rates that are discussed and used in the calculations come from various sources; some are the results of experiments (performed by others), some from ethnographic examples, from ancient texts and inscriptions and finally from nineteenth and early twentieth century builders' manuals. Each type of source has its own benefits and drawbacks and in the sections below an attempt is made to determine the best suitable rate for the discussed task. Finally, the presented numbers in this chapter are, as mentioned, often only the minimum and maximum values for that specific section or process. In the appendices, a complete overview of the costs of each step, scenario and section is presented.

The minimum and maximum cost for each scenario presented in this chapter for each process take the following variations into account: the stone size, a volume that is not filled with stone of 17 % (see chapter 6.1), whether the fill has these gaps as well and whether the fill consists of cyclopean-style blocks or rubble (an overview of the volumes of the blocks can be found in appendix 2).

7.1 Material acquisition

Quarrying stone is a slow process, yet how slow has not been definitively determined. Obviously, the used tools, the type of stone and the overall technique will influence the rate at which stone can be procured. Rates range between 0.00052 m^3/ph for quarrying granite by pounding with stones (de Haan 2009: 3) up to 0.4 m^3/ph for acquiring tufa with a pick (DeLaine 1997: 110-1). Both values are extremes (see for comparison table 7.1).[65]

It is thus a matter of choosing the right rate for the task. In this consideration it is important to keep in mind, that for the conglomerate façades at the Mycenaean gates

65 Lehner's second value in the table can be nuanced as he himself mentioned that instead of 12, it is likely an additional 20 people were needed for the task under more ancient conditions. He wrote that 12 quarrymen extracted 186 limestone blocks of 1 m^3 each in 22 days: 186/22/12/8 = 0.089 m^3/ph (as pointed out by de Haan (2009, 3) and Harper (2016)), while 186/22/32/8 = 0.033 m^3/ph. De Haan uses this value.

Task	Material	Rate (m3/ph)	Rate (ph/m3)	Method of extraction	Source	Type of source
Quarrying	conglomerate / limestone	0.089	11.236	channelling	Lehner 1997: 206-7	experiment
Quarrying	conglomerate / limestone	0.033	30.303	channelling	Lehner 1997: 206-7 (adapted for ancient circumstances)	extrapolation from experiment
Quarrying	limestone	0.033	30.303	channelling	De Haan 2009: 3 (taken from Lehner 1997)	extrapolation from experiment
Quarrying	limestone	0.03	33.333	channelling	De Haan 2014: 153	extrapolation from experiment
Breaking material from bedrock	bedrock	0.09	11.111	Wedge and lever	Devolder 2013: 43	experiment (by Abrams 1994)
Sawing	Portland stone (limestone)	0.155	6.459	sawing	Hurst 1905: 382	observation (building manual)
Sawing	hard rock	0.001	1,000.000	sawing	Devolder 2013: 43	experiment (by Stocks 2001)
Sawing	soft rock	0.041	24.390	sawing	Devolder 2013: 43	experiment (by Stocks 2001)
Quarrying	marble	0.0082	121.951	channelling	DeLaine 1997: 121 n87	ancient sources
Quarrying	marble	0.011	90.909	channelling	DeLaine 1997: 121	ancient sources
Quarrying	marble	0.0056	178.571	channelling	DeLaine 1997: 121 n87	ancient sources
Quarrying	granite	0.00052	1,923.077	channelling	De Haan 2009: 3	experiment (by Goyen et al. 2004 and Lehner 1997)
Quarrying	limestone	0.1	10.000	unknown	Brysbaert 2015: 94	experiment (by Bessac 2007)
Quarrying	tuff	0.057	17.600	Wedge and lever (?)	Abrams 1994	experiment
Quarrying	tuff	0.113	8.800	Wedge and lever (?)	Abrams 1994	experiment

Table 7.1 The various work rates associated with stone procurement and where they are mentioned.

Task	Rate (m3/ph)
Quarrying limestone blocks (cyclopean)	0.057-0.09
Quarrying conglomerate (façade)	0.03-0.048
Quarrying rubble	0.5

Table 7.2 Overview of the rates discussed in the text above and used in the calculations in the following section.

(sections 1 and 2), which are built with well-cut blocks, channelling was the most likely method for extraction. For the cyclopean-style walls a more casual method of breaking material from the bedrock following natural faults and beds (perhaps using wedge-and-feather technique) seems more likely, as the blocks are so differently shaped (see section 3.4.1). For the cyclopean-style sections present at both sites and built in limestone, the rates mentioned in table 7.1 for this type of stone seem the obvious choice, but even within that category the range is large.

To understand how the various methods differ from one another in terms of work rates, see figure 7.1. It is clear that Devolder's channelling (see chapter 3) rate (0.0099 m^3/ph) on one side and Brysbaert's rate (0.1 m^3/ph) on the other side, form the extreme values for quarrying limestone (with Abram's range (0.057 – 0.114 m^3/ph) overlapping slightly with Brysbaert's rate). Lehner's adjusted rate (see above) sits at the same height as the top of de Haan's range (same value) and Pakkanen's top is close to the lower end of Abram's range. The difference between the methods in terms of labour cost is most clearly illustrated by the rates Devolder uses. One is based on the concept of simply breaking material from the bedrock, which could mean using natural cracks and beds to break away material. The other rate is based on channelling which is thus much more labour intensive. As mentioned above, though, channelling was likely not the employed method for the cyclopean style sections of wall. Although Devolder's range is directly based on Abram's experimental data, it is an attempt to gear it towards the specifics of the type of stone used. Because Abram's experiment involved tuff, the high end of his range may be too high to be applicable to the harder limestone used in the cyclopean-style walls. Considering the discussed unworked nature of the used stone material, breaking it away in whatever shape from the bedrock seems more likely. However, over-simplifying the quarrying should be avoided and thus the range of 0.057 (low end of Abram's range) – 0.09 m^3/ph (top end of

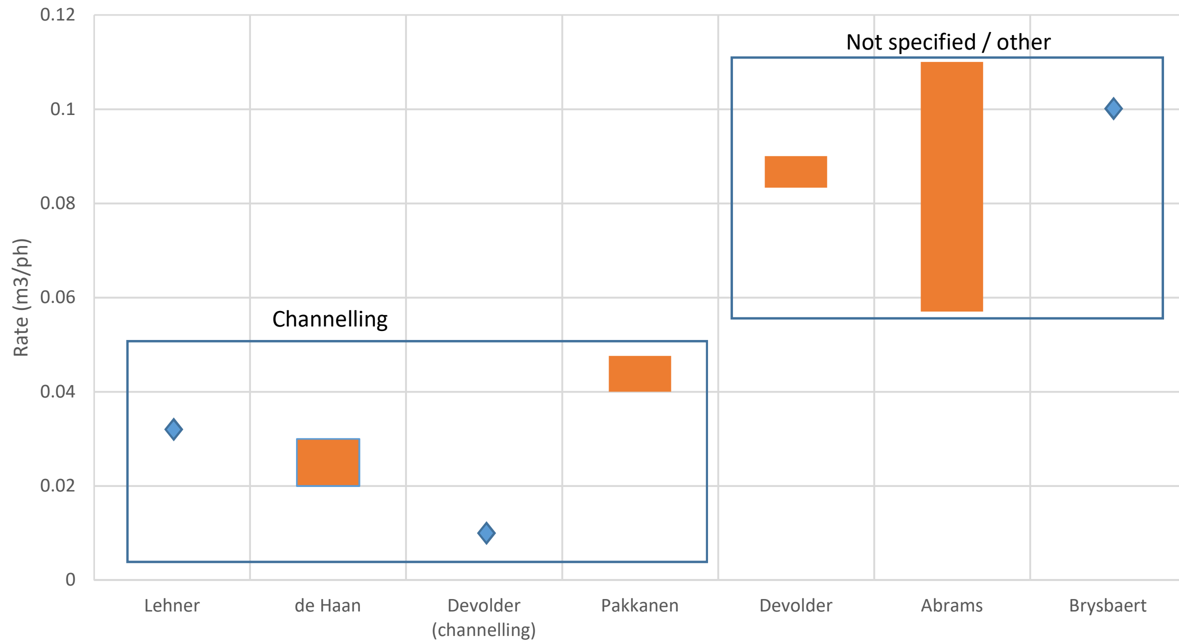


Figure 7.1 Overview of the various rates for quarrying limestone mentioned in the text. Single rates are represented by a diamond; ranges are, obviously, columns. Note that channelling was a more labour intensive method (graph by author).

Devolder's range) will be used as rate for quarrying the limestone (see table 7.2).

For the acquisition of the conglomerate material, a similar contemplation must take place in order to determine what might be a suitable rate to use in the analysis. If Devolder's quarry-rate formula is considered valid, it is important to take into account the density of conglomerate. As Brysbaert (2013: 78, n162) points out, the density of conglomerates varies widely, which has to do with their composition. Cavanagh and Mee (1999: 96) assume a density of 2.1 tonnes per cubic meter for the conglomerate used at the Treasury of Atreus.[66] This would result in a labour cost of (1 x 2,100) / 225 = 9.3 ph for one cubic meter (0.11 m³/ph). However, the conglomerate façade has quite a different build-up than the limestone cyclopean-style walls. The blocks, as pointed out before, are well shaped. It is, therefore, likely that channelling was used as a method of extraction, rather than simply breaking the material from the bedrock (as is assumed in Devolder's quarrying formula, see Devolder 2013, 43).

Channelling, as a method is well suited to create, more or less, rectangular blocks in a systematic manner. Although the conglomerate façades are not built in a true ashlar fashion and individual blocks thus had to be dressed to fit their final location in the wall, most blocks are approximately rectangular and have the same thickness. The extraction of such blocks through channelling fits much better than the rough extraction of random sized and shaped blocks used in the cyclopean-style walls. A slower rate, as shown in figure 7.1 above, associated with channelling is therefore more appropriate. The lowest value shown is Devolder's rate, which she uses for poros. This is, according to Cavanagh and Mee (1999: 97), comparable to conglomerate. However, Devolder's (2013: 21) rate is based on an average of two values, which both represent the channelling of marble, rather than the far softer material discussed here. That rate thus seems to be too low.

On the other end is the quarry rate proposed by Cavanagh and Mee (1999: 100) whose low end is on par with the high end of Pakkanen's range and the high end is slightly above the minimum of Abram's range. This thus seems to be too high as it is also unclear how they determined this range other than estimating it. A range between 0.03 (de Haan/Lehner's rate) and 0.048 m³/ph (Pakkanen's maximum) is therefore used for the extraction of conglomerate stone material. Pakkanen's rate may suffer from some issues with inscriptions as they potentially involve more than just the costs of the quarrying (see also the discussion in section 7.3). However, he argues that his cross-checking of various sources solves that issue. His higher rate also allows that conglomerate might be quarried slightly faster than limestone (which is used in Lehner's experiment) as it is considered softer (although this depends on the matrix and the inclusions of the particular conglomerate). This range thus also

66 "… some 1400 m³, say 3000 tonnes of stone" and "… a huge block (..) measuring 6.3 x 1.2 x 1.9m, which might weigh up to 30 tonnes" (Cavanagh and Mee 1999, 96). These numbers result in 2.14 and 2.08 tonnes/m³ respectively.

includes the low end of Cavanagh and Mee's rate, who do consider a softer stone type. Finally, with regard to the conglomerate sections, because these are built with blocks that are well-shaped and cut to fit, more material will have been quarried than is finally used to build the wall. It is difficult to ascertain what amount of material is wasted in this process. Devolder (2013: 32) estimated a ratio of 15 % of the originally quarried material being lost during dressing, which will also be used in this study. This is a rather low figure, but since channelling is already accepted as a quarry method, it is safe to assume that most blocks were already in roughly the right shape. The range of 0.03 – 0.048 m^3/ph is thus used as the rate for acquiring conglomerate blocks (see table 7.2).

Finally, the extraction of rubble needs to be explored. Abrams (1994: 46-47) stated that 7,200 kg of rubble can be produced by a person in 8 hrs, based on an experiment. That means an average of 900 kg/ph. If this is then translated into volume, based on the density of the rubble (between 1,535 kg/m^3 (Hurst 1905: 338) and 1,889 kg/m^3 (Rosenstock et al. 2019: 1102)) this results in a rate between 0.64 m^3/ph and 0.47 m^3/ph. Pakkanen (2013: 6, n34), however, argues that DeLaine's (1997: 111) rate for quarrying tufa and Hurst's (1905: 376) rate for excavating chalk (0.4 and 0.38 m^3/ph respectively) are representative for quarrying limestone rubble. Both rates are based on builders' manuals from the 17-18th century (DeLaine) and 19th century (Hurst). It is difficult to provide a qualitative assessment of which rate might be best suited. An average rate of 0.5 m^3/ph seems reasonable (see table 7.2). It must be noted that the acquisition of rubble as a separate task is only applicable when the fill of the cyclopean-style walls is considered a rubble fill. The small material used within the wall-faces is considered to be acquired as collateral while quarrying the larger blocks (therefore no waste is taken into account for the limestone quarrying).

Based on the above considerations the following rates are used in this research: for the quarrying of limestone a range of 0.057 – 0.09 m^3/ph. This is based on the assumption that the material is quarried by breaking it away from the bedrock in whatever shape, rather than using channelling. In contrast, the softer conglomerate, used in the façades at the gates of Mycenae is considered to be quarried through channelling, because the blocks used are far more regular than those in the limestone constructions. This means that the range for acquisition is lower: 0.03 – 0.048 m^3/ph. Finally, for the acquisition of the rubble material for the core, an average rate of 0.5 m^3/ph is used. The rates are also presented in table 7.2.

Applying the rates discussed above, the minimum and maximum labour costs of all the documented sections at Mycenae and Teichos Dymaion are presented here. The minimum cost is reached when scenario VI is used (see table 5.2) and a rubble fill is assumed which is very roughly done so that 17 % of the total volume is not filled with stone. Due to these assumptions, the smallest volume of material is required for the faces. Although the fill has the largest volume in this scenario, the rate at which rubble can be acquired is so much higher than for quarrying limestone blocks, it still results in the lowest overall cost. The maximum cost is always the highest rate times the total volume of the section. The total volume is always the same since the volume of the fill is calculated based on the volume of the wall faces, which is dependent on the scenario. The minimum and maximum values presented here are the absolute extremes, see table 7.3 (see full overview in appendix 3).

Mycenae		
Section	Minimum cost (ph)	Maximum cost (ph)
1	5,813	9,300
2	1,182	1,890
3	3,762	17,430
4	737	3,347
Teichos Dymaion		
Section	Minimum cost (ph)	Maximum cost (ph)
1	2,512	10,601
2	2,139	8,129
3	2,291	7,995
4	869	3,192

Table 7.3 Overview of the cost of material acquisition at Mycenae (top) and Teichos Dymaion (bottom). As explained above, no scenarios were used for sections 1 and 2 at Mycenae (the façades) as the thickness of the blocks is known and no reconstruction is therefore necessary.

It is important to note that the variation in total cost per section is due to the diversity in volume between the different sections. Since the same scenarios are used for all sections (except the conglomerate façades, which is why these have a smaller range), the variation is thus mostly due to the volume of the sections themselves (see also chapter 8.1.1).

7.2 Transport

A number of parameters define the transport costs (a general background on transport can be found in chapter 3). These characteristics include the steepness of the terrain, the mode of transportation and the weight that can be transported per trip. The variables each have their own effect on the necessary workforce, but all are directly influencing the amount of force (traction) that is necessary. How this then translates in the workforce or amount of person/ox hours depends on distance and speed.

The variables concerning the amount of traction are difficult to determine. They are not difficult to calculate, it mostly comes down to (basic) geometrics, but there is a lack of base values. Many literary sources keep citing each other or keep referring to a handful of old publications which are notoriously un-transparent in providing the proper relatable figures. For example: the amount of force that is lost due to multiple yoking is set by DeLaine (1997: 129) at 20 %, while Barwell and Ayre (1982: 4) state that a pair of animals have "1.9 times the tractive effort of a singular animal" which increases to 3.2 for 2 pairs and 3.8 for 3 pairs. These numbers have been corroborated through experiments (*e.g.* Goe and McDowell 1980: 13). Furthermore, it shows that the amount of extra yokes is also a factor, since the efficiency drops from 95 % for a pair to 80 % for two pairs (which coincides with DeLaine's figure) and to 63 % for 3 pairs. This is a drastic decrease and one can wonder how low this figure gets as the amount of yokes increase. However, textual sources from Classical Greece show that multiple yoking up to at least 37 yokes has been documented (Burford 1960: 7). In addition, more 'modern' examples are known in which 12-18 pairs of oxen were used in 15-18th century Italy and 60 pairs of oxen were used for moving Mussolini's obelisk in the 20th century (DeLaine 1997: 99). There are thus examples of large amounts of yoked animals (mostly oxen) to overcome the difficulty of moving heavy materials and the drop in efficiency must have some bottom value to allow these large numbers of yokes to be effective at all. It has been argued (*e.g.* Brysbaert 2015b: 97; Brysbaert pers. comm.) that using an attendant for each yoke of oxen separately (as pointed out by DeLaine (1997: 108)), might reduce the efficiency loss. Taking this into account, the maximum efficiency loss of 36 % is used in the calculations (if three or more pairs of oxen are used).

Furthermore, the amount of traction is not static. Overall, it seems that an agreeable figure for traction for oxen is around 14 % of its weight (as shown in chapter 3). However, Raepsaet (1993: 252) points out that for short periods of time and starting up, oxen can exert a force to up to 50 % of their weight (see also Goe and McDowell 1980: 8, for the difference between the required force between starting motion and keeping wheeled vehicles in motion). This may seem excessive, but for humans some researchers (*e.g.* Cotterell & Kamminga, 1990; de Haan, 2009) point to a possible (peak) draught effort of 300 N, which comprises 47 % of the body weight of a person weighing 65 kg. If a higher percentage of body weight can thus be accepted as traction force (as shown through experimentation by Sayer (1934), wagons with a rolling resistance of 0.065 and a load on a slope of 9 degrees can be draught by the same amount of oxen exerting 50 % of force of their weight, as there are needed on a flat terrain exerting 14 % of force of their weight, with an efficiency loss due to multiple yoking as a high as 36 %.

Another difficulty is determining the total weight, which relates directly to the necessary traction. From literature examples, some derivatives can be calculated. What is problematic in this is that often the weight of the load is given, whereas for proper calculation, the total weight is needed. In other words, the weight of the used transport device is also required. Very few researchers who write about non-motorized transportation deal with this. Those studies that deal with the topic, in particular in relation to building programs (*e.g.* Burford 1960, 1969; Loader 1995; DeLaine 1997; Devolder 2013; Brysbaert 2013, 2015a, 2015b; Harper 2016), ordinarily calculate the necessary traction based on the number of oxen / tonnes of weight. This results in values like 3,500 lb (1,587 kg) pulled "by 3 yoke of oxen" (Burford 1960: 5) (which comes to 529 kg load / yoke) or 19 yokes for 10 tonnes (Burford 1960: 14) (526 kg load / yoke) to 12 yokes for 10 tonnes (DeLaine 1997: 99) (833 kg / yoke). However, a load of 1,587 kg does not need the same kind of wagon as a load of 10,000 kg. Hence, the weight of the wagon will likely be different. Nevertheless, it does influence the total weight and therefore the required traction. Thus, using the figures provided in the literature (loads of 1,587 and 10,000 kg pulled by 3 and 12 yokes of oxen respectively), an attempt can be made to calculate the weight of the wagons. The oxen described by Burford and DeLaine must have comparable strength (see chapter 3, around 510 N). Furthermore, to compare them, similar routes (and thus slopes) are assumed and the same yoking efficiency drop and friction coefficient are used. If these are kept the same, only the total weight influences the necessary traction and therefore the amount of animals: If the efficiency drop is 20 % (as assumed by DeLaine (1997: 129)) and the friction coefficient is 0.05 (which is the maximum possible friction coefficient based on the figures presented by DeLaine and Burford),[67] then the wagons are 900 and 4500 kg for Burford and DeLaine. Hence, the weight of the wagon can be a large portion of the total weight that needs to be moved and should therefore be taken into account.

Not only the weight, but also the friction coefficient (or rolling resistance in the case of wagons) is problematic as there is a large discrepancy in values given by various sources. Often cited is Atkinson's (1960, 1961) work on an experiment at Stonehenge with a sledge and a large block

67 If a higher friction coefficient is used, such as 0.25 as suggested by Devolder (2013, 27), the wagons would have to weigh 0 kg (and thus be part of the weight described), there would have to be no efficiency loss and the traction force would have to be twice as high and only then, would the description of both Burford and DeLaine hold up (i.e. 3 yoke pulling a 1,587 kg load and 12 yoke pulling a 10,000 kg load). A low friction coefficient, therefore, had to be assumed in order for this to make sense.

of stone. His most important statements that are often used are: (1) a sledge on rollers requires only 100 lbs of force per tonne load (on level ground); (2) an incline of 9 degrees increases the necessary traction force by 450 % (9 versus 2 people per tonne) and (3) the use of rollers decreases the necessary force by 56 %. His first statement means that the friction coefficient is extremely low when using rollers: 0.045.[68] This implies that the rollers are very well rounded and that the surface on which they are used is quite smooth and hard to avoid extra friction. His final statement means that his sledge without the rollers has a friction coefficient of 0.19.[69] De Haan (2009) showed in his experiment that the friction coefficient of his sledge on pavement was 0.48. This is much higher, but Atkinson's experiment took place on grass, which may have a much lower friction coefficient (Cotterell and Kamminga (1990) cite a friction coefficient as low as 0.25 for grass). Other coefficients for friction (from 0.2 to 0.4 for a sledge on rollers and 0.02-0.04 for the same, but on a wooden track) (Shimotsuma et al. 2011: 176) and rolling (between 0.052 to 0.083) (Cotterell and Kamminga 1990: 204) show the large variability, yet few researchers take this into consideration. Moreover, not only does the friction influence the overall required force, but the lower the friction coefficient, the larger the impact of an increase in slope on the required force. This explains why Atkinson noted an increase of 450 % while De Haan only noted a 17 % increase (see also chapter 3) as their friction coefficient was 0.045 and 0.48, respectively. That is also why Atkinson's ratio for the increase in required labour for moving uphill should not be used as a rule of thumb for these kinds of calculations, especially when other modes of transport or conditions are considered (*i.e.* wagons instead of sledges).

As for the maximum weight with which a wagon can be loaded, G.R.H. Wright (2005a: 41) mentioned that wagons can only carry "several tonnes", but does not elaborate on what this is based. However, if the type of wood is known, the bending strength can be looked up in dedicated databases.[70] Arguably the weakest point of a wagon is its axles and with the bending strength known, it can be calculated how thick the axles need to be to withstand a certain load. Burford (1960, 1969) and DeLaine (1997) both mention examples of loads of 10 tonnes being moved by wagon. In the case of oak, the bending strength (which is the defining feature for determining the breaking point) is between 20 and 24 N/mm^2.[71] The formula for determining this is:

$$\sigma = (3F(L-L_i))/(2\pi R^3),$$

in which F is the gravitational force (weight), L the length of the entity being loaded, Li the length of the loaded area, and R the radius of the axle. Since σ is known (20-24 N/mm^2, taking 22 as a middle value), and F is known (10,000 kg = 98,100 N[72]), R can be calculated if L is hypothesized. If a wagon was 2 m wide, the axle would be longer to accommodate the wheels, so 2.40 m would be reasonable.

So, if $\sigma = (3F(L-L_i))/(2\pi R^3)$, then:
$22 = (3 \times 49{,}050\ (2{,}400-2{,}000)) / (2\pi R^3)$
$22 = 58{,}860{,}000 / (2\pi R^3)$
$44\pi R^3 = 58{,}860{,}000$
$R^3 = 425{,}812$
$R = 75.23$ mm

A wagon with axles that have a diameter of at least 16 cm would suffice to carry a load of 10 tonnes,[73] which is not an unreasonable value (see also chapter 3). It may well be as Burford (1969: 187, n1) and Cavanagh and Mee (1999: 96) pointed out that wagons were specially built for such heavy transport perhaps by using thicker timbers for the platform, axles and possibly thicker wheels as well. Hence, it is likely that the wagons used for the heavier loads were themselves also heavier (as pointed out above). In the calculations below the use of oxen wagons is presumed, first, because it reduces the amount of required force tremendously in comparison to sledges or dragging the material. Secondly, using sledges with rollers is highly unlikely in the hilly terrain surrounding the sites. A maximum load of 5,000 kg is assumed for the wagons weighing 1,000 kg

68 100 lbs is 445 N of traction. F_n = 1,000 kg x 9.81 = 9,810 N. $F_{traction} = F_n \times \mu \rightarrow 445 = 9{,}810 \times \mu \rightarrow \mu = 0.045$.

69 His example involves a sledge with a weight totaling 1,587 kg (F_g=15,568 N) on a slope of 4 °. On rollers μ = 0.045 (see previous footnote), meaning that $F_{friction}$ = 15,568 x 0.045 and F_h = 15,568 x sin 4 and $F_{traction} = F_{friction} + F_h$ = 1,785 N. Without the rollers this $F_{traction}$ should thus be, due to the 56 % decrease ascribed to the rollers, 4,057 N. Since the weight and the slope remain the same, F_h remains the same (1,086N) and $F_{friction}$ is $F_{traction} – F_h$ = 4,057-1,086 =2,971 N. Since $F_{friction} = F_g \times \mu$, this means that: $\mu = F_{friction} / F_g = 0.19$.

70 Such as http://www.houtdatabase.nl – (accessed 03/06/2019) and https://www.wood-database.com (accessed 03/06/2019).

71 This is the 'representative' value in the Dutch wood database website (http://www.houtdatabase.nl/?q=hout/gww/24/mechanisch – accessed 03/06/2019). The actual tested value is 97 N/mm^2, which is not too far from the 102 mentioned on the wood database website for holm and white oak (https://www.wood-database.com/holm-oak/ – accessed 03/06/2019). If the higher value of 102 is used then the diameter only needs to be about 9cm.

72 This is the total load, the load per axle would thus be divided by 2: 49,050 N.

73 This does not take into account the effect of rough terrain on the materials, which could lower the maximum allowable weight. However, see also note above, there is some room for additional strain due to the terrain.

and a maximum of 10,000 kg for wagons of 2,000 kg.[74] Loads above 10,000 kg are assumed to be transported on sledges without rollers. The use of rollers, as mentioned, is problematic (see also Atkinson 1960, 1961) and the use of sledges increases the friction coefficient quite a bit in comparison to wheeled transport (from 0.065 to 0.38 based on average values from Cotterell and Kamminga (1990) and de Haan (2009), respectively). Hence, it is only used for the largest blocks (in this case material used in the gate structures at Mycenae).[75]

As described in chapter 4, for Mycenae both the required conglomerate and limestone can be quarried nearby. Steffen (1884: 24) noted the greyish conglomerate comes from the modern town of Mycenae (Kharvati), where within and immediately outside the village there are numerous cuts into the rock. A yellowish conglomerate likely comes from the foot of the mountain of Profitis Ilias, which is a bit further away. Both the Lion and North Gate are built in grey conglomerate and it is thus likely that the material comes from around Kharvati. The modern town is, following the modern road, almost 2km from the Lion Gate. A recent study (Brysbaert 2022; Brysbaert et al. 2020) into quarry locations around Mycenae refers to some alternative locations. All the conglomerate quarries documented by Brysbaert et al. in the vicinity are located between Kharvati and Mycenae. It is beyond the scope of this research to ascertain which particular quarry or quarries were used for which construction. Hence, the location suggested by Steffen is considered the furthest local conglomerate source and used in the calculations. The height profile of the modern road, based on Google Earth data, shows that over the path of 1.9 km there is a steady rise from 112 to 240 m a.s.l. with a maximum slope of around 16 % (a bit over 9 °). A second route, using the, seemingly, older path slightly higher up the slope (going west of the Treasury of Atreus) is slightly shorter (1.8 km) and in places slightly steeper; up to 18 %, which is a bit over 10 °. This route is also marked on Steffen's (1884) map 1 and a route from Kharvati going north around Mycenae is marked on Pelet's (1832) map of the area. Iakovidis and French (2003) have also marked it as a Mycenaean age road on the map comprising the roads in the area. This route is thus perhaps more reliable as a 'route of old' than the modern road (see figure 7.2). An analysis of the terrain, using a slope map (see chapter 6), confirms this route to involve the least steep areas of the (current) landscape. The distance remains somewhat subjective as 'in and around the village' (Steffen, 1884) meaning that there is a variety in distance of about 600 meter around the town (based on the current size of the town). The shortest distance to just outside the town along the mentioned path would then be 1.5 km and 2.1 km for the longest distance from the Lion Gate to the other side of the town. In the calculations of the transport cost, the distance is set at 1.8km for the Lion Gate and 2.2 km for the North Gate.

The local geology shows predominantly limestone to the east (see 5.2.1). Again, Brysbaert's (Brysbaert 2022; Brysbaert et al. 2020) studies of local quarries have resulted in a number of possible locations close by to the north, east and south from the citadel. Based on the analysis of the terrain, focusing on the slope, a path from section 3 at Mycenae (the West Wall) to one of the nearby southern limestone quarries can be traced and is roughly 300 m. For the North East Extension (section 4 at Mycenae) there is a potential quarry at about 210 m away to the east. These distances will be used for calculating the cost of the transport for these sections.

At Teichos Dymaion, the quarry locations are more difficult to pinpoint exactly. Hence, a hypothesized distance is used. From the geology maps (see chapter 5), it is clear that there is plenty of limestone available in the area around the citadel. A distance of 100m is used in the calculations, which would put the quarrying activities in the immediate vicinity of the fortified hill itself, which comprises possible quarry marks (Brysbaert pers. comm.).

The transport also includes the loading and unloading of the material onto the presumed means of carrying. This could be done by either levering the blocks up and across into the wagon, or using a small ramp on which the material could be dragged onto the wagon. As Hodges'

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74 This is based on the assumption that only the bare minimum of material is used for the wagon, i.e. only a platform with axles and wheels, a yoke pole and perhaps some boarding on the sides to keep in the smaller material. There is thus no elaborate superstructure or separate bench for a driver. A more thorough study into what is required of the wagons to be successful for such endeavours would be beneficial for studies like these.

75 Alternatively, Pakkanen has calculated a transport rate of 0.7md/tonne/km, based on inscriptions which describe the wages for certain transport projects, which examples come from Burford (1969: 190). However, based on his example by Stanier (1953: 70-1), who also takes into account that going uphill requires more force and thus more animals, the price for heavier loads could increase to about 1md/tonne/km (Pakkanen 2013: 7, n45). The man-days calculated by Pakkanen are based on contract prices and thus might include more than just the time of a person (which is all that the person-hours represent). There is thus a difference between calculating the effort (ph) and the price (wages). For example, a wage for an oxen herder might be build-up of a salary for the person, rent of the oxen and money for rations for people and animals (e.g. Loomis 1998: 111, 191-2). Nor were prices, at least for transport, fixed (Burford 1969: 190). While the use of these inscriptions is certainly a useful way to get an idea about the cost, it is somewhat problematic to compare the outcomes of the various methods. It might, however, point out some of the gaps present in the reconstructed work process or costs involved in that process. This is acknowledged, but the chosen method of calculating the labour costs, based on the documented material rather than generalised rates, has its own merits and is therefore used in this study. It is good to realise though, that the cost of using oxen is thus actually higher as no maintenance costs for the animals are now taken into account.

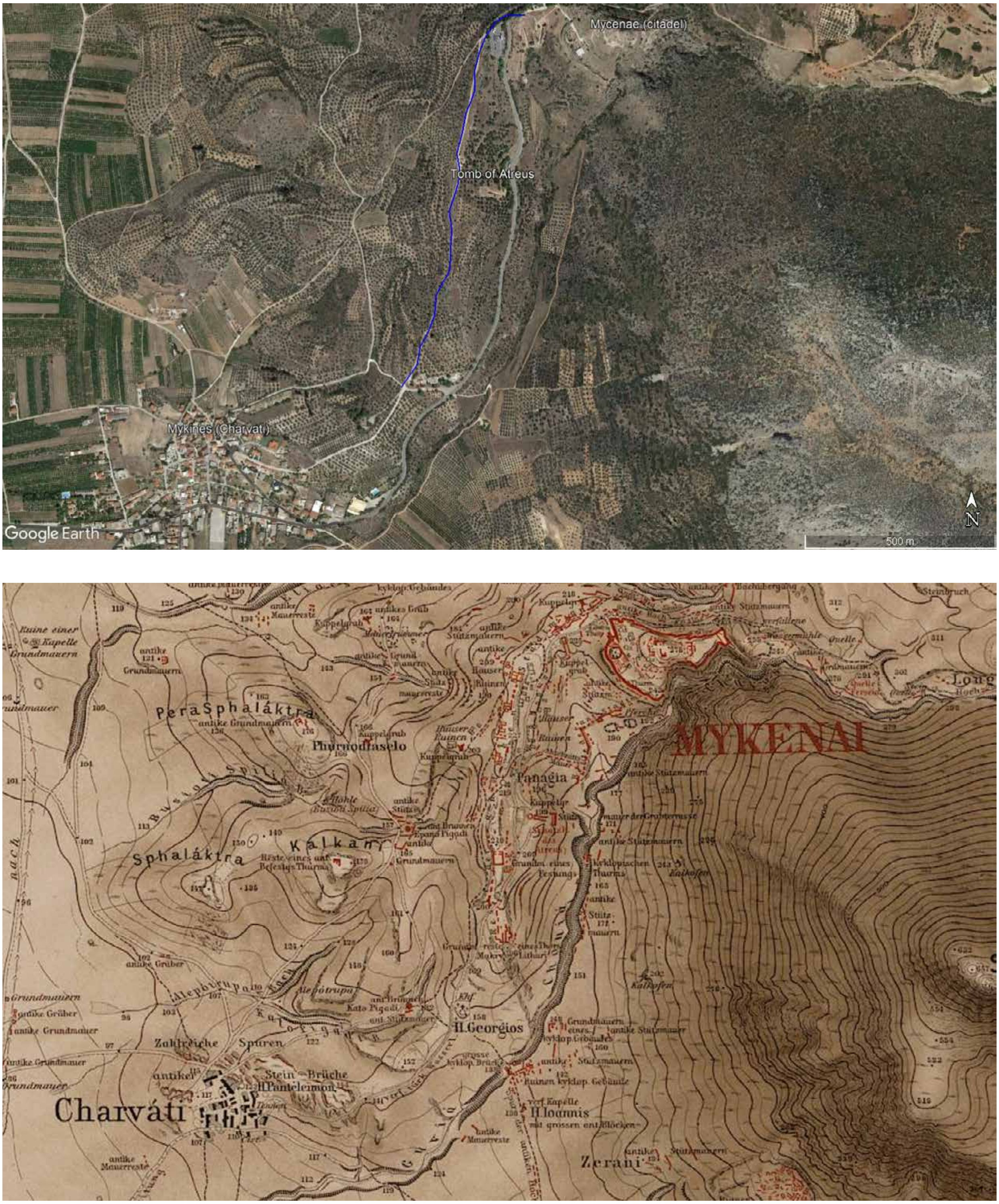

Figure 7.2 Area around Mycenae in Google Earth (top) and on Steffen's map (1884). The blue line on the satellite image (Google Earth Pro) shows the path that is seemingly similar to one of the paths on Steffen's map.

(1989) experiments have shown, a block of 2.5 tonnes can be levered 0.8 m in 200 seconds by four persons on levers, with an additional two people putting in supports (see also section 3.4.2). De Haan (2009: 7) used this rate as a basis and theorized that it would then take 20 minutes for loading to include fastening and unfastening the entire load, but admits this is rather high. Assuming 15 minutes per load of 2.5 tonnes, a wagon can be loaded and unloaded with 5 tonnes in 1 hour by 6 people, or 6 ph for loading and unloading per trip.[76] Brysbaert (2015b: 96) uses de Haan's rate, but adds two people to the levers due to the fact that "The larger blocks at Tiryns are far more irregular, both in shape and size..". There are two issues with this: first, her category containing the largest blocks (defined as blocks between 2-13 tonnes) is reduced to an average weight of 2.5 tonnes per block (Brysbaert 2015b: 99), which is the exact same figure de Haan uses. Secondly, as Hodges (1989) and de Haan (2009) mention the required force per person on the lever is well below their maximum. There is thus no direct need to increase the number of people for blocks of the same size as those assumed by de Haan. Therefore, the above-described rate (6 ph/trip), as adapted from de Haan's rate is used, rather than Brysbaert's method. Obviously, a major drawback of this method, as outlined above, is the fact that it reduces the variety in material size to one average 2.5 tonne stone. It is difficult to adjust to size or weight, as it is problematic to distil a ratio based on one figure.

An alternative way of calculating the labour costs for levering the material into a wagon is by taking the same rate for levering as mentioned above, and assuming that the material had to be levered up 0.8 m and 1-2 m across. Furthermore, if the actual stone size is taken into account the amount of people required for the levering can be equated to the ratio of 4 people / 2.5 tonnes.[77] Small material (up to 200 kg), is not levered but carried (up to 50 kg/person, based on DeLaine 1997) in that scenario. The number of person hours is depended on the size of the material and no fixed number is applicable.

Finally, a small ramp could have been used for the loading and unloading of the material onto and from a wagon. A ramp with a slope of 20 % and reaching 0.8 m (as above) is four meters long. The required labour force can thus be calculated in the same fashion as the transportation. This method also does not have a fixed rate per wagon trip, but rather is dependent on the weight of the material. Using ramps has some implications in terms of organisation, though. First, ramps would have to be built at both the quarry and the building site, which involves gathering material, transporting it to the site and constructing the ramps themselves. Secondly, because the material is mostly dragged (smaller material is carried as in the other scenarios), the heavier stones require many people at the same time (in some cases well over 100). These people would have to come from somewhere to help for a very short period of time and then move on to other tasks again. This would be highly inefficient as it would interrupt other types of work and more people would mean more organisation. The methods in which levering is used only need about a dozen people at the most. It will take longer, but fewer hands are required.

Based on the considerations described above, the costs for transport are presented here for each section at Mycenae and Teichos Dymaion. Similar to the section on the acquisition of material, the presented numbers here are minimum and maximum costs, except for sections 1 and 2 at Mycenae, as these are not depended on scenarios (see section 5.3.1). In addition, the same variations are taken into account: the stone size, a volume of 17 % that is not filled with stone, whether the fill has this lack of stone as well, and whether the fill consists of cyclopean-style blocks or rubble. A driver is assumed for each yoke of oxen (DeLaine 1997: 108), which represents the person hours in the transport. The results of the conglomerate façades and the limestone walls are shown in tables 7.4 and 7.5, respectively (see also appendix 4).

Once again, it is important to keep in mind that primarily the size of the sections dictates the difference of the costs between the various sections. The maximum number of oxen, however, says something about the size of the used material as in some sections there is material used that is so large that more oxen are required (a wagon with a maximum of 5,000 kg requires 12 oxen). A number of things stand out: first most sections have blocks that exceed 5,000 kg. This is visible in the fact that only a number of the façade sections and sections 4 at both Mycenae and Teichos Dymaion have a maximum of 12 oxen required per trip. Secondly, the large blocks used in the Lion Gate, in particular the threshold, lintel and the Lion Relief itself, are much heavier. If wagons could be built that could withstand such loads, the required number of oxen would already more than quadruple from a, projected, normal maximum load of 5,000 kg. Moreover, it has been argued that loads over 10,000 kg cannot be transported with a wagon, but are transported with a sledge. The increase in friction is such that the number of oxen that is required for moving the heaviest blocks (the threshold and lintel), rises to 166.

Besides the number of required animals and people, the labour costs are of course also determined by the amount of time that is needed. This is tied to the speed with which the transportation takes place and the distance that is covered. It should be remembered that the distances used here are optimal. For each section at

76 To load and unload 5 tonnes, means that it takes 2 x 15 minutes to load and 2 x 15 minutes to unload.

77 Plus two people for inserting the supports.

Mycenae – Lion Gate						
Sub-section	**Oxen hours**		**Person hours**		**Max. number of oxen**	
External Eastern Façade	648		324		16	
External Western Façade	700		350		18	
Gate Façade	400		200		12	
Gate Structure*	313	*949*	156	*475*	54	*166*
Inner Eastern Façade	101		50		12	
Inner Bastion	262		131		12	
Total	**2424**	***3061***	**1212**	***1530***		
Mycenae – North Gate						
Sub-section	**Oxen hours**		**Person hours**		**Max. number of oxen**	
Inner Gate Façade	278		139		18	
Outer South Façade	162		81		12	
Outer North Façade	121		61		12	
Inner North Façade	32		16		12	
Total	**593**		**297**			

Table 7.4 Overview of the transport costs of the conglomerate façades of the Lion Gate (top) and North Gate (bottom). *A number of the stones involved in this section are well over 10,000 kg and are likely moved with a sledge rather than a wagon. This consideration is represented by the secondary figures in the table. Both numbers are presented though, to show the large difference in required traction between the use of wagons and sledges.

Mycenae							
Section	Minimum cost		Scenario	Maximum cost		Scenario	Max # of oxen
	oh	ph		oh	ph		
3	1,433	717	VI	2,085	1,042	IV	18
4	184	92	VI	240	120	IV / VII	12
Teichos Dymaion							
Section	Minimum cost		Scenario	Maximum cost		Scenario	Max # of oxen
	oh	ph		oh	ph		
1	272	136	VI	400	200	IV	16
2	214	107	VI	291	145	IV	16
3	214	107	VI	275	138	VIII	20
4	84	42	VI	110	55	I	12

Table 7.5 Overview of the transport cost of the cyclopean-style blocks for the sections at Mycenae (top) and Teichos Dymaion (bottom).

Mycenae, the closest documented quarry is assumed to be its source. However, there is no proof that the quarry was used during the time of the construction of that particular section close by. The same is true for Teichos Dymaion,

Loading/unloading Mycenae	Rate of 6ph/trip ph	Levering ph	Ramp Loading ph
Section 1	558	821	31
Section 2	108	284	8
Section 3	1,881 – 2,584	1,392 – 2,759	158 – 341
Section 4	434 – 527	513 – 1,174	31 – 33
Loading/unloading Teichos Dymaion	**De Haan ph**	**Levering ph**	**Ramp Loading ph**
Section 1	1,482 – 1,818	1,713 – 3,018	97 – 104
Section 2	1,129 – 1,422	1,313 – 2,091	79 – 86
Section 3	850 – 1,368	1,260 – 2,429	74 – 81
Section 4	547 – 552	410 – 1,439	31 – 52

Table 7.6 The ranges of costs for loading and unloading the wagons used for the transport of the stone material for Mycenae (top) and Teichos Dymaion (bottom). For sections 1 and 2 at Mycenae (the façades), the weight of individual blocks is known and thus no scenarios are used. Therefore, there is only one value per method, in contrast with the other sections where the scenarios are used to calculate the volume and subsequently weight of the blocks.

where the source location is set at 100 metres. However, besides some quarry marks (as pointed out above), there is presently no way of knowing what material came from where exactly. It could thus be that the transportation costs were higher if sources were located further away.

There is a large variance in the costs for loading and unloading the wagons (see table 7.6). While using a ramp to do this might seem a lot cheaper, there are organisational matters to consider (as pointed out above). In particular the large variance in the number of people required based on the weight of the blocks makes it quite inefficient. Moreover, the costs may be lower, but the number of people that are needed simultaneously are much higher.

7.3 Levelling the terrain

As described in section 3.4.3), the cyclopean-style walls were built straight on to the bedrock. Levelling the terrain to the bedrock would not require much as it is close to the surface at both sites (Gazis, 2010; Iakovidis, 1983). Hence, the cost of preparing the terrain for the construction is not very high. Harper (2016: 226) assumed for the North East extension at Mycenae, that there was only a need to hammer the exposed bedrock to a more or less level path to build on. He (2016: 445) uses a rate of 0,232 m^2/ph, using the wall's ground surface area to calculate the costs. Devolder (2013: 13, 44), on the other hand, considers clearing to be excavating soils and uses three rates, depending on the type of soil. For a hard and stony ground, she assumes a rate of 0.3-0.4 m^3/ph. Considering the statement that the bedrock lies close to the surface,

Site	Section	Surface (m2)	Labour cost (ph) at 0.3 m3/ph	Labour cost (ph) at 0.232 m2/ph
Mycenae	1	26	88	114
	2	20	67	87
	3	126	420	543
	4	67	222	288
Teichos Dymaion	1	115	382	494
	2	203	677	875
	3	122	405	524
	4	108	360	466

Table 7.7 The labour costs of levelling the terrain for the wall construction. The area is limited to the surface area of the section and takes no further clearing or additional space into account.

if not being the surface, a maximum depth of 1 m can be assumed for the excavation rate, used by Devolder. Using the lower value of her range would make sense as it is close to Harper's value for hammering the bedrock. Therefore, for calculating the cost of levelling the terrain for building the walls on, the rates of 0.232 m^2/ph and 0.3 m^3/ph (max. 1 m deep) are used. This probably underestimates the costs if additional clearing was required, or if the terrain was more steep, or additional volume had to be removed. Nor does it take into account whether any material had to be transported elsewhere. However, without making further assumptions about the past terrain, any vegetation or earlier constructions, this is the most basic cost involved in this process. The results are presented in table 7.7. Since the costs are directly related to the surface area, the high costs for section 3 at Mycenae and all the sections at Teichos Dymaion are thus due to the large size of these sections.

7.4 Dressing

Dressing is not often used at the fortifications at Mycenae and Teichos Dymaion, due to the nature of the cyclopean construction. However, in case of the gate constructions at Mycenae with their well-shaped blocks, dressing was most certainly part of the working process. While some dressing may have occurred on stones used in the cyclopean sections and/or sites, studying this is beyond the scope of this research. Hence, approximating the cost for dressing is only done for the Lion and North Gates. As has been argued by Devolder (2013, 32) it would make sense to work the blocks to their final shape at the building site: it avoids that damage during the transport would render the block less useful, and it allowed the blocks to be shaped to fit exactly where they belonged. Considering the fact that the conglomerate masonry is not truly ashlar, as the blocks have different shapes, many blocks were tailored for specific positions within the wall. Using chisels and hammers (see also section 3.4.1.2), the blocks were cut into their final shape.

	Dressing volume		Dressing surface *(Hurst)*	
Amount	237 m^3		1090 m^2	
Rate	0.0175 m^3/ph *(Hurst)*	0.0162 m^3/ph *(Devolder/ Abrams)*	0.084 m^2/ph *(limestone)*	0.071 m^2/ph *(marble)*
Labour cost	13,543 ph	14,630 ph	12,976 ph	15,352 ph

Table 7.8 Labour cost of dressing conglomerate based on total volume and surface area.

Hurst (1905: 382) provides a number of observed rates for dressing stone: dressing ashlar masonry at a rate of 0.0175 m^3/ph and rates of 0.929 m^2 and 0.232 m^2/ph for dressing rubble masonry by using a chisel or a hammer, respectively (Harper uses these latter values in his labour cost study of Mycenaean structures).[78] As the type of stone influences the effort needed for dressing the blocks, Hurst (1905: 382) also observed rates for various stone types within a range of between 0.084 m^2/ph for Portland stone (a limestone) and 0.046 m^2/ph for "fine axed" Aberdeen granite. Devolder (2013: 32), basing herself on experiments by Abrams (1994) states a rate of 0.0162 m^3/ph for dressing stone. This value comes from taking 10 % of the cost of cutting tuff (according to Fotou 2016: 65) as a value for dressing. Devolder also points to rates observed by Pegoretti (1869, I: 159, 280-283) and Klapisch-Zuber (1969: 147), 0.0133 and 0.0055 m^3/ph respectively, for dressing stone. These rates are somewhat problematic as they both refer to dressing marble, which may be quite hard to work and they seem too low in comparison with the other rates.

The total worked surface area for the conglomerate material at the Lion Gate comes to about 1,090 m^2. This includes front and back faces,[79] the top, bottom and side faces of the blocks, as these were clearly cut to fit the surrounding blocks. Considering the rates presented by Hurst the amount of work for dressing a volume of ashlar or dressing the surface area of the blocks are quite comparable (see table 7.8).

The total of the worked surface area for the conglomerate material at the North Gate is roughly 157 m^2. This includes front and back faces,[80] the top, bottom and side faces of the blocks. Although the same approach has been used for the Lion Gate, it must be noted that,

78 Please note that some of these rates are in cubic meters and some are in square meters.

79 At those sections where the back is visible it seems that work was done on these back faces as well.

80 Based on those sections where the back is visible at the *Lion Gate* it seems that work was done on these back faces as well.

	Dressing volume		Dressing surface *(Hurst)*	
Amount	48 m³		157 m²	
Rate	0.0175 m³/ph *(Hurst)*	0.0162 m³/ph *(Devolder/ Abrams)*	0.084 m²/ph *(limestone)*	0.071 m²/ph *(marble)*
Labour cost	2,743 ph	2,963 ph	1,870 ph	2,212 ph

Table 7.9 Labour cost of dressing conglomerate based on total volume and surface area.

in general, the blocks at the North Gate are less finely worked than those at the Lion Gate. The results are shown in table 7.9.

7.5 Building a ramp for constructing

De Haan (2009, 2010, 2014) has shown the likeliness of the use of ramps for building Egyptian pyramids. In combination with levering (de Haan, 2009) the conglomerate façade could be built to its proper height. The courses are quite regularly built; therefore, each course could have been used as a platform for the course on top. Hence, there was no need to have ramps at multiple locations to reach the entire wall. One or perhaps two ramps would theoretically suffice. Since no traces of such a ramp now exist, for obvious reasons, the cost, mostly dependent on its volume, is a rough estimate at best. The two deciding factors in determining its volume are the height of the wall and the slope, which would be acceptable to pull/push blocks up. De Haan (2014: 149) proposed a slope of $\tan \alpha = 0.3$ (which is 16.7 °) for the ramps used at the pyramid of Menkaure for its construction.[81] Loader (1995: 59) hypothesized about a 20 % (= 11.5 °) slope for a ramp for construction, based on the same incline of 20 % of the Great Ramp at Mycenae.[82] Brysbaert (2015b: 97) assumes a 10 % slope for ramps used in construction or even a 3 % slope (2015b: 98-9) for the “all around the citadel ramp” as suggested by Küpper (1996: 50-1). As described above, using a smaller inclination reduces the required force per load, but increases the work time as well as the amount of work required for the ramps themselves. Furthermore, de Haan (2014: 147) has pointed out that ramps with inclinations of up to 26 % are possible. This might seem extreme, but it may be considered that the steep slopes of some of the Greek cities, such as Delphi, have many constructions on steep slopes. For Ephesus, it has even been suggested that building on slopes up to 30 % was no problem (Groh, 2012).

With de Haan’s figures, a ramp reaching 10m high would be 33 meters long. If the ramp was 2 meters wide, its volume would be 0.5 x 10 x 33 x 2 = 330 m³. Loader’s example would result in a ramp that is 50 m long and thus have a volume of 0.5 x 10 x 50 x 2 = 500 m³. A ramp with a 10 % incline would be 100 m long and be a 1,000 m³. Of course these volumes do not take into account the slope of the hill itself on which the ramp would be built to reach the top of the wall to build.[83] While a steeper slope means that more people would be needed to move the block up the ramp, a small gradient results in impractical long ramps. For example, a 100-meter long ramp from the Lion Gate would reach as far as the Lion Tomb. Although ramps could follow a zigzag course instead, reducing their length, in return they would require more space in width. The available space might still pose an issue. Therefore, a steeper slope is assumed here. Furthermore, allowing a wider base of the ramp provides it with a stable structure, even higher up. Thus, if a ramp, reaching 3 meters high and being 4 meters wide with a slope of 20 %, was built after the lower courses were put in place using levers, it would have a volume of 0.5 x 3 x 14.7 x 4 = 88.2 m³. As construction on the wall progressed, the ramp would have to be enlarged to reach a height of 6 meters, which would increase the volume to 0.5 x 6 x 29.5 x 4 = 354 m³.[84] Sections that reach a height beyond this would require an additional enlargement of the ramp up to 9 meters high. This would bring the volume of the ramp to 0.5 x 9 x 44.2 x 4 = 795.6 m³. These volumes do not take into account additional material that might be needed to compensate for the slope of the ground on which the ramp is built.

The amount of material required for such ramps will need to be excavated and transported to the building site. Turner (2018: 198-199) has shown the large variety in rates for excavating earth. Based on his work, the average rate of 4.2 ph/m³, or 0.24 m³/ph is used. Transportation could be done either manually with baskets or in wagons with oxen. Assuming that the material would be taken from down the hill on which Mycenae stands, the distance is about 250 m and there is a height difference of 30 m. A density of 1,500 kg/m³ is taken to calculate the weight of the material.[85] The material is either carried by person or moved by oxen-wagons. For the former a rate of 0.000444 hr/m carrying 50 kg (DeLaine 1997: 110, n7) is used. If the wagons are used, each trip would hold up to 5,000 kg

81 He (de Haan 2014, 147) even suggested that a “gradient of 21-26 %” might be acceptable for smaller blocks. Although he does not specify what he may consider a “smaller block”.

82 The Great Ramp is, as the name says, a large ramp positioned in the citadel just past the Lion Gate leading up the slope (e.g. French 2002).

83 Over a length of 50 m, the current path has a height difference of about 9 m.

84 The length (29.5 m instead of 14.7 m) increases to maintain the same slope when the ramp is heightened from 3 to 6 m. Hence, the volume quadruples as both length and height are doubled.

85 Combination of earth and clay: https://www.engineeringtoolbox.com/dirt-mud-densities-d_1727.html (accessed 03/06/2019).

		Labour costs (ph) according to height of ramp (m)	
Process	**Method**	**3**	**6**
Material gathering	Digging	368	1,475
Transport	Carrying	294	1,179
	Oxen	*112*	*451*
	Herders	*56*	*225*
Assembly	Piling up	176	708
	Compacting	132	528
Total (carrying)		**969**	**3,890**
Total (wagons) – ph		***732***	***2,937***
Total (wagons) – oh		***112***	***451***

Table 7.10 Overview of the costs involved in the building of a ramp of various heights. Note that for the transportation the material is either carried or moved by wagon using oxen and herders. Ph stands for person hours, oh for oxen hours. The costs represent the costs of building up the ramp from scratch. In order to ascertain the costs of enlarging a 3 m high ramp to 6 m, the costs for a 3 m high ramp should be subtracted from the cost of building a 6 m high ramp. Since average rates were used and the volume is fixed, there are no ranges in labour costs for these ramps.

of material which would require 12 oxen per trip and 6 herders (DeLaine 1997: 108).

Finally, the actual building of the ramp entails heaping together the earth into its shape and compact it (to make the earth more compressed again). The rate for compacting is difficult to ascertain, but Laquement (2009: 133) determined that 1,000 kg/ph is reasonable, which translates into 0.67 m^3/ph if 1,500 kg/m^3 is taken as the density for earth. Since the earth is far less dense than when it is dug up, piling up the material can be done much faster than digging it up. Therefore, a rate of 0.5 m^3/ph for piling up the material (instead of 0.24 m^3/ph for excavating the compacted soil) is assumed.[86] The results for the labour costs for such a ramp is shown in table 7.10, below.

The results here could be considered maximum costs for the parameters set. Alternatively, part of the material that is dug away for levelling the terrain (section 7.3), may have been used for ramp construction. However, there are two issues with this notion: first, earthen ramps are assumed whereas the material removed for levelling might be rockier and perhaps not suitable. Secondly, the total amount of material that is assumed for levelling is little in comparison to the material that is required for the ramps. For example, for section 3 at Mycenae, there might be enough material dug away for levelling for a 3 m high ramp, but nowhere near enough to raise the ramp higher. For smaller sections the amount of material from levelling is even less. The effect of using this scenario is therefore limited for the calculated labour cost.

These costs are considered valid for each ramp used. As there is no data on where the actual material would have been taken from, the distance of 250 m is used for all ramps, thus assuming that the material was acquired close by (around the bottom of the hills). After construction of the wall, the ramp would also have to be removed again. The material is compacted and thus would not be removed at the same rate as it was piled up, but nor is it necessarily done as slow as digging up the original material. For the removing the ramp a rate in the middle of 0.37 m^3/ph is used. This means that removing the ramp would cost 239 and 957 ph for the 3 m and 6 m high ramps, respectively. This does not take into account the subsequent moving of the material to another location.

7.6 Wall assembly

The assembly of the wall entails moving the blocks over a short stretch on the ground from where they were unloaded to their place in the wall and levering them into place, horizontally. For higher courses, it is assumed that up to about 3 courses of stones would be levered vertically, and above that, a ramp is used (see above) to drag the stones up to various heights.[87] In between the heightening of a ramp, blocks can also be levered to reach higher courses. The smaller material does not need to be dragged or levered but could be carried by individuals or small groups of people. As this would not require carrying over long distances, it seems a realistic solution and a lot quicker than either of the other options.

The required work force for moving stones up the ramp is similar in computation as the calculation of the transport cost, in that it is dependent on weight, pulling force, slope and friction. Assuming that there was only limited space around the building site, it might be more realistic to assume that human power, instead of animal power was used for this. The friction coefficient for dragging material is higher than when a wagon is used for the transport. The slope, as described above, is assumed around 20 % or 11.5 °. Hodges (1989) showed that it was possible to lever a 2.5 tonne stone with four people 0.813 m in 200 seconds and move it horizontally 0.19 m in 20 seconds. An additional two persons were required to slide in supports during the lifting. De Haan

86 This value is close to Erasmus' (1965: 285) value of 0.52, which deals with very loose material. See for a comprehensive overview of applicable rates Turner 2018.

87 Only in the conglomerate façades are there actual courses. In the limestone built cyclopean sections there is no true coursing. However, it can still be argued that up to a certain height it makes sense to lever the blocks before the construction and use (and later heightening) of ramps as it takes a lot less time and effort.

(2009: 6) calculated that blocks of 2.5 tonnes could thus be moved at a speed of 0.0041 m/s vertically and 0.0095 m/s horizontally.

Thus, the basic process for the construction of the wall would involve the following steps:

1. Dragging stone material to their approximate place or to a ramp;
2. Levering stone material another 2 m (horizontally). This step is used to allow for more precise placement of the blocks;
3. Levering stone material between 0.8-1.0 m per course (vertically);
4. Dragging stone material up a ramp 3 m high;
5. Dragging stone material up a ramp 6 m high.

It is important to note that these steps do not apply to each individual stone. Material used in the first few meters (vertically) is not dragged up a ramp, nor is material higher up dragged up a 3 m ramp and subsequently up a 6 m ramp, for example.

Furthermore, the following matters are taken into consideration for the above-mentioned steps:

1. The force required for dragging material is calculated in the same manner as the transport, but the friction coefficient is higher: 0.38, which is in the middle of de Haan's (2009: 6) estimate of between 0.25-0.50. This is a relatively low value for dragging stone on stone;
2. Levering stones horizontally for two meters can be done in 211 seconds (0.0095 m/s), which is 0.0586 hr. With four people at the levers, this means that it costs 0.23 ph/block;
3. Levering the stones vertically (an average of 0.9 m) at a speed of 0.0041 m/s, means that it takes 220 s or 0.061 hr. It requires four people on the levers and an additional two for inserting the supports, 0.37 ph/block;
4. A three-meter high ramp with a 20 % slope has a length of 15 m. The force calculation is similar to step 1;
5. A six-meter high ramp with a 20 % slope has a length of 30 m. The force calculation is similar to step 1.

An alternative to trying to reconstruct the individual steps in the assembly is the use of construction rates. Harper (2016: 447) uses Hurst's (1905: 381) rate for building in rubble masonry (0.159 m^3/ph) for the cyclopean construction. The main issue with this is obviously the sheer size of the blocks used for the cyclopean construction, which would make the construction quite hard in comparison to building with rubble-sized material (which in general would be light enough to be handled by a single person). Devolder (2013) uses rates of 0.1 m^3/ph for ashlar and 0.1274 m^3/ph for rubble. Both of these are problematic for the size of the material used in cyclopean-style construc-

Rate (ph/m3)	Source	How the rate was determined
0.159	Hurst (1905)	Observed
0.1274	Devolder (2013)	Based on experiment by Abrams
0.1	Devolder (2013)	Based on experiment by Abrams
0.034	Mayes (1862)	Observed
0.024	Mayes (1862)	Observed
0.019	Mayes (1862)	Observed
0.8375	Murakami (2015)	Experiment
0.4625	Murakami (2015)	Experiment

Table 7.11 Overview of rates for construction and how these were determined.

tions. Mayes (1862: 24) presented rates for building ashlar, differentiating between block size in the following categories: up to 0.2 m^3 (0.034 m^3/ph), up to 0.5 m^3 (0.024 m^3/ph) and blocks over 0.5 m^3 (0.019 m^3/ph). Furthermore, there are also separate building rates for the fill of walls. An applicable rate depends on the build-up of the fill itself. While it has been often described as a rubble and earth fill, there are also researchers who argue that the fills of the cyclopean fortifications are actually much more similar to the build-up of the wall's faces (thus with large blocks and smaller stones in between) (Brysbaert, pers. comm.). If the former is the case, possible useful rates are presented by Murakami (2015: 269), whose rates come to 0.8375 and 0.4625 m^3/ph for 'major pyramids' and 'other structures' respectively. If the latter is the case, the building rates should be assumed the same as those for the walls' faces. The process described above as well as the fixed construction rates described here are used to calculate the labour costs. This way the total range of possible labour costs can be grasped. An overview is presented in table 7.11.

At Mycenae, the assembly of the façades at the Lion and North Gates is, at least in theory, easier than the cyclopean-style walls, as there is only one face and no fill. Furthermore, due to the use of cut stone, there are discernible courses and a stone could relatively easily be moved over these courses to its final position. The assembly of the other sections thus entails more work as there are two faces and a fill to consider. Taking into account the construction steps mentioned above the cost for assembling the façade at the Lion Gate is shown in table 7.12 below.

The differentiation between the costs including and excluding the eastern section (top table 7.12) has to do with the fact that this section is built on a stone outcrop and therefore only starts above the first four courses of the rest of the façade. Putting in the limestone threshold, lintel, posts and relief will need to be added to this for the assembly. The threshold will ideally be transported as closely as possible to its position as it comes from the

Step	Cost per course (ph)		Cost (ph)		Total (ph)
	Excluding higher eastern section	Including higher eastern section (from course 5 onwards)	4 courses	5 courses	
1 Dragging	7	10	28	50	78
2 Levering Horizontally	3	5	13	27	39
3 Levering Vertically	3	6	13	28	41
4 Dragging up 3m ramp	8	12	8	23	31
5 Dragging up 6m ramp		24		71	71
Total					**260**

Step	Cost per course (ph)	Total (ph)
		4 courses
1 Dragging	5	18
2 Levering Horizontally	3	13
3 Levering Vertically	3	13
4 Dragging up 3m ramp	8	8
5 Dragging up 6m ramp	-	-
Total		**52**

Element	Cost (ph)
Threshold	318
Lintel	479
Door jambs	146
Total	**1,219**

Table 7.12 Cost of assembly for the conglomerate façade on the outside (top), inside of the gate (middle) and the blocks that form the actual passage.

Step	Total Cost (ph)
1	10
2	9
3	5
4	122
Subtotal	**147**
Posts	**180**
Total	**327**

Table 7.13 Overview of the labour costs of building the conglomerate façade and gate structure of the North Gate.

quarry. Subsequently, like with the blocks above, it is assumed that the final 2 meters are left for manoeuvring in place, perhaps through a combination of levering and dragging (higher friction coefficient than during the transport from the quarry). Moving the threshold takes 318 persons only a few minutes once the block is near its final position and all the people are in place. Moving the lintel up an 11.5 ° slope up to a height of 3m takes 479 people a few minutes and moving the Lion relief up to its height on a ramp takes 276 people. The doorjambs need about 73 people to move them, but more to put them upright. It is safe to assume that it takes about an hour to move each of these blocks into position including putting on ropes and getting all those involved in place. Obviously, the threshold was put in first as the jambs are put on top and the lintel lies on top of the two walls flanking the gate. Overall, the assembly totals 260 + 52 + 1,219 = 1,531 ph for the wall as it stands today.

If, however, the earlier mentioned building rates are used, the assembly is much more time-consuming. Using Mayes' rates for building in ashlar (see above), the cost of assembling the façade (excluding the gate structure itself) comes to 3,201.2 ph for the outer façade and an additional 2346.1 ph for the interior façade.

The conglomerate façade at the North Gate is not as well preserved and only a limited number of stones are still in place. Using the same parameters as above, the labour cost can be calculated and the results are shown in table 7.13. Step 4 only involves the lintel and the blocks above it. Moving the lintel up an 11.5 ° slope up to a height of 4 m takes 122 people a few minutes. However, additional time is assumed for the organisation of the people and general preparations.

The posts need about 81 people to move them, but presumably more to put them upright. It is safe to assume that it takes about an hour to move each of these blocks into position including putting on ropes and preparing properly. A total of 180 ph is taken for putting in the posts. This brings the total assembly cost to 327 ph. Using the building rates from Mayes, the North Gate façade would have taken 1418.2 ph. It thus seem from the results from both sections that the labour costs calculations based on the reconstruction is too low. This has likely to do with the fact that it assumes a constant optimum performance and no idling.

For sections 3 and 4 at Mycenae, the assembly of the wall includes two faces and a fill. Due to the nature of the walls, there are no real courses present. However, the walls still needed to be built in such a way that the

	Section 3		Section 4	
Step	**Cost per face (ph)**	**Cost of fill (ph)**	**Cost per face (ph)**	**Cost of fill (ph)**
1 Dragging	20.7 – 40.3	70.4 – 138	4 – 12	16.8 – 50.4
2 Levering Horizontally	34.3 – 41.9	116.6 – 142.5	14.5 – 29.5	60.9 – 123.9
3 Levering Vertically	67.6 – 187.9	229.8 – 638.9	4.5 – 9.6	18.9 – 40.3
4 Dragging up 3m ramp	21.9 – 42.5	74.5 – 144.5	3 – 6.4	12.6 – 26.9
5 Dragging up 6m ramp	29.2 – 56.7	133.3 – 192.8	2.9 – 10.5	12.2 – 44.1
Total	**174 – 369**	**625 – 1257**	**44 – 98**	**184 – 410**

Table 7.14 The labour costs of constructing sections 3 and 4 at Mycenae. Calculated through a reconstructed process.

	Section 3		Section 4	
Rate	**Fill with spaces (ph)**	**Fill without spaces (ph)**	**Fill with spaces (ph)**	**Fill without spaces (ph)**
0.159	7,082	6,249	1,359	1,188
0.1274	8,838	7,799	1,696	1,483
0.1	11,260	9,936	2,161	1,889
0.024	46,917	41,400	9,004	7,879

Table 7.15 The labour costs of constructing sections 3 and 4 at Mycenae. Calculated through the use of different single building rates.

	Section 3		Section 4	
	Min (VII) (ph)	Max (II) (ph)	Min (VIII) (ph)	Max (IV) (ph)
Cost per face	7,115	9,609	936	2,285
Cost fill (continued from face)	33,227	34,482	5,994	5,677
Total *(2x face + fill)*	**47,457**	**53,701**	**7,867**	**10,248**
	Min (VI) (ph)	Max (II) (ph)	Min (VI) (ph)	Max (IV) (ph)
Cost per face	4,670	9,609	819	2,285
Rubble fill ‘pyramid’ rate	1,197	977	228	165
Total *(2x face + fill)*	**10,536**	**20,196**	**1,867**	**4,735**
	Min (VI) (ph)	Max (II) (ph)	Min (VI) (ph)	Max (IV) (ph)
Cost per face	4,670	9,609	819	2,285
Rubble Fill ‘other’ rate	2,167	1,770	413	298
Total *(2x face + fill)*	**11,507**	**20,988**	**2,051**	**4,868**

Table 7.16 The labour costs of constructing sections 3 and 4 at Mycenae, using Mayes’ ashlar assembly rate and Murakami’s fill assembly rates.

height gradually grew. The same kind of steps could therefore be considered in reconstructing the building process. As the steps involved in the assembly are determined by the weight of the blocks, the cost varies depending on the used scenario for reconstructing the block size. Therefore, the assembly costs result in ranges. Alternatively, the construction rates mentioned above by Hurst, Devolder, Mayes and Murakami, are also used for calculating the labour costs. These rates assume a more or less uniform rate regardless of stone size (except for Mayes’ approach). The results of the reconstructed process (top) and the various single building rates (bottom) are shown in tables 7.14 – 7.16.

The ranges of the cost for the assembly are clearly quite large. The lowest costs, presented in the top table, take only the movement of the stones into consideration and not the time it takes to tie them, or to organise the people around a block to lift it. It also assumes a constant peak efficiency. This means that every single person involved is constantly doing something, even though in reality people may have to wait for one another or take small brakes. Therefore, the actual labour rate is much higher than those applied in these reconstructions. The rates in the middle table also produce large ranges and it is difficult to ascertain what rate is the most applicable, as each rate has its difficulties in relation to the used material (see above). The lowest range in the middle table is very comparable in terms of calculated labour costs to those presented in the bottom table. The ranges in the bottom table are a lot smaller. This has to do with the fact that the size of the material is taken into account for the building rates. It provides a more nuanced view on the building process as it incorporates the actual build-up of the wall, rather than seeing the wall as a single homogeneous entity. It therefore seems that Murakami’s approach is the most realistic.

	Section1		Section 2		Section 3		Section 4	
Step	**Cost per face (ph)**	**Cost of fill (ph)**	**Cost per face (ph)**	**Cost of fill (ph)**	**Cost per face (ph)**	**Cost of fill (ph)**	**Cost per face (ph)**	**Cost of fill (ph)**
1	16 – 52	67.2 – 218.4	15 – 47	63 – 197.4	21 – 74	88.2 – 310.8	6 – 20	25.2 – 84
2	97 – 171	407.4 – 718.2	31 – 83	130.2 – 348.6	22 – 135	92.4 – 567	15 – 94	63 – 394.8
3	21 – 42	88.2 – 176.4	21.5 – 40.3	90.3 – 169.1	14 – 62.4	58.8 – 262.1	5.6 – 53	23.5 – 222.6
4	12 – 39.2	50.4 – 164.6	7.3 – 23	30.5 – 96.6	6,4 – 26.4	26.9 – 110.9	2.6 – 7.6	10.9 – 31.9
5	23.6 – 78	99.11 – 327.6	57 – 184	239.4 – 772.8	12.6 – 55	52.9 – 231	5 – 25	21 – 105
Total	**170 – 382**	**712 – 1605**	**132 – 377**	**533 – 1585**	**76 – 353**	**319 – 1482**	**34 – 200**	**144 – 838**

Table 7.17 The labour costs of constructing sections 1 – 4 at Teichos Dymaion. Calculated through a reconstructed process.

	Section 1		Section 2		Section 3		Section 4	
Rate	**Fill with spaces (ph)**	**Fill without spaces (ph)**	**Fill with spaces (ph)**	**Fill without spaces (ph)**	**Fill with spaces (ph)**	**Fill without spaces (ph)**	**Fill with spaces (ph)**	**Fill without spaces (ph)**
0.159	5,187	3,667	2,914	3,305	3,075	3,453	1,144	1,292
0.1274	6,473	4,576	3,637	4,125	3,838	4,309	1,428	1,612
0.1	8,247	5,830	4,633	5,255	4,890	5,490	1,819	2,054
0.024	34,363	24,292	19,305	21,896	20,374	22,874	7,579	8,558

Table 7.18 The labour costs of sections 1 – 4 at Teichos Dymaion. Calculated through the use of different single building rates.

	Section 1		Section 2		Section 3		Section 4	
	Min (VIII) (ph)	Max (IV) (ph)	Min (II) (ph)	Max (V) (ph)	Min (VI) (ph)	Max (II) (ph)	Min (II) (ph)	Max (VI) (ph)
Cost per face	3,584	12,424	3,307	11,358	3,522	5,052	1,393	1,182
Cost fill (build as face)	18,870	10,216	13,694	5,422	15,351	15,094	5,208	9,903
Total *(2x face + fill)*	**26,038**	**35,063**	**20,309**	**28,139**	**22,395**	**25,197**	**7,993**	**12,267**
	Min (VI) (ph)	Max (IV) (ph)	Min (VIII) (ph)	Max (IV) (ph)	Min (VI) (ph)	Max (VII) (ph)	Min (VI) (ph)	Max (I) (ph)
Cost per face	3,031	12,424	3,032	11,424	3,522	8,280	1,182	4,353
Rubble fill 'pyramid' rate	698	288	504	144	475	219	197	62
Total *(2x face + fill)*	**6,760**	**25,135**	**6,569**	**22,991**	**7,519**	**16,779**	**2,562**	**8,767**
	Min (VI) (ph)	Max (IV) (ph)	Min (VIII) (ph)	Max (IV) (ph)	Min (VI) (ph)	Max (VII) (ph)	Min (VI) (ph)	Max (I) (ph)
Cost per face	3,031	12,424	3,032	11,424	3,522	8,280	1,182	4,353
Rubble Fill 'other' rate	1,265	521	913	260	860	397	357	112
Total *(2x face + fill)*	**7,326**	**25,369**	**6,977**	**23,107**	**7,904**	**16,956**	**2,721**	**8,817**

Table 7.19 The labour costs of sections 1 – 4 at Teichos Dymaion. Calculated using Mayes' ashlar assembly rate and Murakami's fill assembly rates.

For Teichos Dymaion the same approaches can be used. This results in the labour costs estimates as shown in tables 7.17 – 7.19 (see for a complete overview appendix 5). Similar to the tables for Mycenae the top table shows the ranges of the labour costs for the reconstructed steps, which are depending on the reconstructed stone sizes. The middle table shows the labour costs calculated through the uniform building rates, discussed earlier. The bottom table uses the rates that include the variance in stone size.

The same observations that were made for the assembly costs for sections 3 and 4 at Mycenae can be made for the sections at Teichos Dymaion. The largest difference, though, is that at Teichos Dymaion the range of the costs based on the set-up with the rubble fill in the bottom table is far larger than at Mycenae. This has to do with the fact that some of the scenarios used to reconstruct the size of the stones seem to create volumes that do not fit well at Teichos Dymaion, yet these do not create illogical values at Mycenae. For example, in

			Mycenae				Teichos Dymaion			
			Section 1	*Section 2*	*Section 3*	*Section 4*	*Section 1*	*Section 2*	*Section 3*	*Section 4*
ph	Quarrying	min	5,813	1,181	3,762	737	2,511	2,139	2,291	869
		max	9,300	1,890	17,430	3,347	10,601	8,129	7,994	3,192
	Transport	min	1,212	297	716	94	136	107	107	42
		max	1,530	297	953	120	181	139	137	55
	Loading/ unloading	min	62	16	317	33	101	86	77	33
		max	821	284	2,307	946	2,126	1,470	1,367	548
	Levelling	min	88	68	420	223	382	677	405	360
		max	114	87	543	288	494	875	524	466
	Dressing	min	12,976	1,870						
		max	15,352	2,943						
	Ramp 3m	min	971	971	971	971	971	971	971	971
		max	1,208	1,208	1,208	1,208	1,208	1,208	1,208	1,208
	Assembly	min	1,531	327	1,842	283	1,562	847	694	558
		max	7,484	1,216	53,701	10,248	33,142	27,621	25,197	10,940
	Total	**min**	**22,652**	**4,729**	**8,028**	**2,340**	**5,663**	**4,826**	**4,544**	**2,832**
		max	**35,809**	**7,925**	**76,142**	**16,155**	**47,752**	**39,441**	**36,427**	**16,407**
oh	Transport stone	min	2,424	593	1,433	184	272	213	213	84
		max	3,061		2,048	240	399	297	277	106
	Transport ramp	112	112	112	112	112	112	112	112	

Table 7.20 Overview of the labour cost, expressed as person (and oxen) hours of each section at Mycenae and Teichos Dymaion. Note that the minimum and maximum costs of the various processes are the minimum and maximum of the associated scenario that resulted in the minimum or maximum total costs.

scenario IV the reconstruction of the stone sizes results in volumes of the wall faces that are larger than the volume of the fill at Teichos Dymaion,[88] whereas, the same scenario does not create that issue at Mycenae. It shows that some of the reconstruction scenarios are therefore not applicable to Teichos Dymaion (as mentioned at the start of the chapter). This is a further indication that the material used at the two sites is clearly different, in that the assumed ratios between surface area and volume is dissimilar, which might have to do with the overall difference in shape of the blocks.

7.7 Total labour costs of sections of cyclopean-style fortification

In the previous sections of this chapter the labour costs for the various steps in the construction process of the fortifications at Mycenae and Teichos Dymaion have been presented. In this section the costs of the different steps are combined and an estimate of the labour investment per section is offered. The presented estimates (see table 7.20, below) are a summary. A more comprehensive overview of the effect of the various scenarios on the labour costs can be found in appendix 6. Note that the ranges for the façades at Mycenae (sections 1 and 2) are far smaller than the others, because fewer uncertainties exist. This is because there was no need for reconstructing the depth of the blocks.

It must be noted that these figures are the absolute minimum and maximum and that the differences are largely due to the great variety in rates that are used. In the cases where more than two rates are considered, these can show a more concise range of the costs than are presented in the table when extreme values are left out. This will be further taken into account in the interpretation of these numbers in chapter 8.

7.8 Labour costs of LH III domestic structures

As explained the domestic structures form a way to put the labour costs of the fortification walls in perspective and help to assess the societal effort that the building of the fortifications required. In this section the labour costs of these structures are presented. In this quantification the

88 In this particular scenario the depth of the blocks is taken as twice the square root of the surface area (see also table 5.2).

Process	Rate	Source
Procurement		
Stone	0.5 m^3 /ph	Abrams 1994: 46-7 and others (see section 7.1)
Mudbrick	0.15 m^3/ph	Brunke et al. 2016: 260-1
Clay	0.29 m^3/ph	Hammerstedt 2005
Felling tree	0.161 ph/beam	Hammerstedt 2005: 59
Transport		
Stone	0.000444 m/hr carrying 50 kg	DeLaine 1997: 110, n7
Mudbrick	0.038 m^3/ph	Homsher 2012: 18-9
Clay	0.000444 m/hr carrying 50 kg	DeLaine 1997: 110, n7
Wood	0.8333 ph/beam	Hammerstedt 2005: 63-4
Manufacture		
Mudbrick	0.138 m^3/ph	Murakami 2010: 203
Wood	0.25 ph/beam	Windes and Mckenna 2001: 129
Assembly		
Stone	0.159 m^3/ph	Hurst 1905: 381
Mudbrick	0.1 m^3/ph	Smailes 2000: 43
Clay plaster	0.8 m^2/ph	Murakami 2010: 273
Clay floor	5.690 m^2/ph	Murakami 2010: 273
Roof	0.400 m^2/ph	Lekson 1984: 280-1

Table 7.21 The rates for each of the processes involved in building a house, subdivided by material. The same rates are used as those in the construction of the fortifications for stone procurement (rubble), carrying materials and rubble assembly.

following variables are modified to allow for the different domestic structures that existed:

1. House size: this comprises the ground surface area or footprint of the building;
2. Second storey: whether or not a building had a secondary storey;
3. The differentiation between a full stone or mixed stone-mudbrick wall construction;
4. Width of the walls;
5. Thickness of the floors.

The quantifications of the materials involved have been presented in section 6.5. The rates that have been used to calculate the labour costs are presented in table 7.21 below. These rates derive from modern experiments, interpretations from ancient texts and observed work rates in pre-industrial settings.

Some of the rates were originally published as quantity/person-day, rather than person-hour as is used as a standard in this study. Based on DeLaine (1997: 106) person-days have been taken as 10 working hours per

Surface area (m2)	Average total cost (ph)	Minimum total cost (ph)	Maximum total cost (ph)
75	4,905	2,333	7,889
110	7,201	3,428	11,578
160	10,468	4,981	16,833
200	13,087	6,228	21,044
250	16,354	7,781	26,299
300	19,620	9,333	31,554
370	24,151	11,471	38,863

Table 7.22 Overview of the total labour costs in person-hours for building a domestic structure, based on the size (expressed as surface area) of the structure. The minimum and maximum costs are based on the various scenarios (as described in chapter 5). The minimum is the result of a scenario in which the structure is a single storey structure with thinner walls, thinner floor and a complete rubble wall. The maximum cost scenario is a two-storey structure, thicker walls and floor and a mudbrick superstructure on a stone socle. Other scenarios of the house structures fall in between these two extremes in terms of costs.

day. Using the calculated volumes and the rates presented above, the costs for building domestic structures of various sizes are presented in table 7.22. Obviously, this is a very generalising method as it assumes that the costs are directly proportional to the size of the building.[89] Even though the calculated costs are thus somewhat precarious, the used sizes and rates are widely used, therefore, provide a reliable order of magnitude estimate for the labour costs of the real subject of this dissertation: the fortifications. Hence, any deviations from the suggested design, materials and sources might alter the outcome of the calculated investment required for the domestic structures. The use of the ranges adopted here, should still provide an adequate figure for comparison to the fortifications, though.

The variation in cost between the structures of different size categories is obviously caused by this difference in size. The ranges within each size categories are the result

89 Even if a number of characteristics is taken into account (see above), there is still room for variations that are not taken aboard in these calculations. There might for example be more elaborations put in the elite houses, which are also larger, meaning that the cost would be even higher. In addition, the distances used in the calculations in regards to the transportation costs are estimates as it is challenging to determine exactly what material came from where. This would have been site specific and perhaps even house specific, and does not even take into account what materials would be available in a certain area (wood and clay for example). Since the level of detail of the data regarding the domestic structures is simply not as high as for the fortifications, this section is also less detailed.

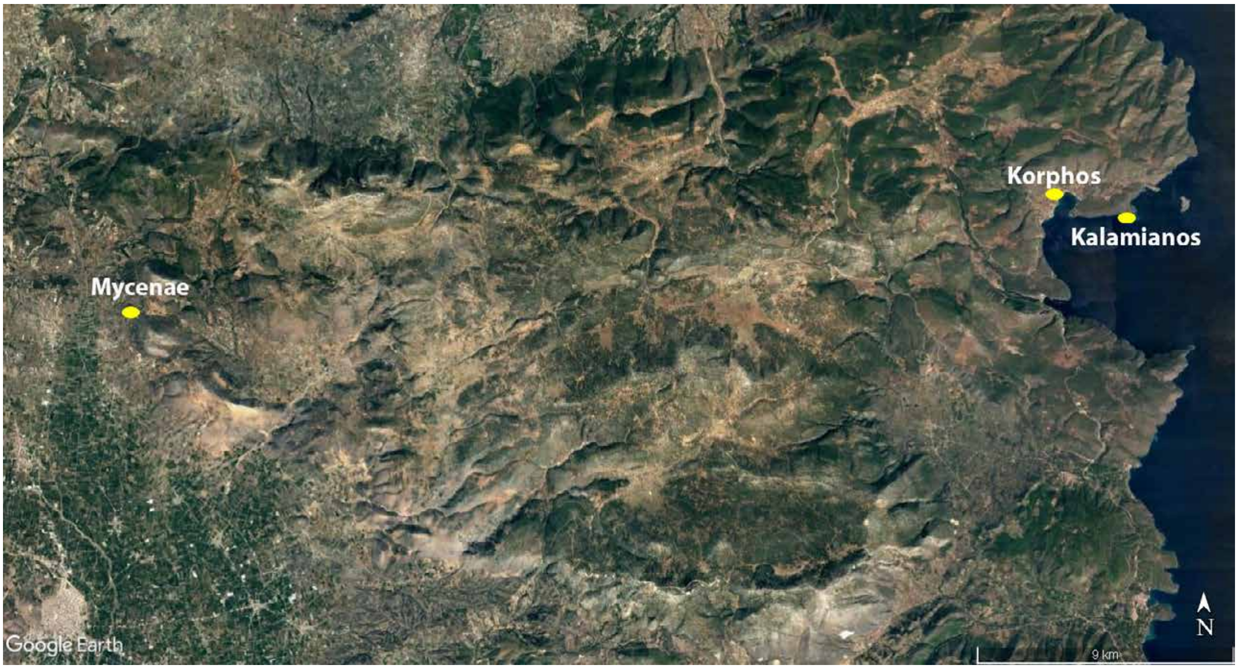

Figure 7.3 Overview of the locations of Mycenae and Kalamianos (satellite image by Google Earth) (Korphos is also mentioned in section 7.8.2).

Figure 7.4 The location of the "Ivory Houses" with rough outlines of the remaining walls (satellite image by Google Earth Pro (c), map by author).

of the variations in the scenarios presented in chapters 5 and 6 (*e.g.* number of floors, thickness of the walls and floors, and the material used for the superstructure). To show how these costs of hypothetical structures relate to actual remains of such buildings the presented rates are used on two examples. The first is the West House at Mycenae, which is considered an elitist building, due to its size, the close proximity to the citadel and the abundance of exotic luxury products (Jazwa 2016: 141). The second is a more modest structure from the site of Kalamianos (House 7-X), located on a peninsula east of Mycenae in the Gulf of Aegina (see figure 7.3). For both examples the labour cost calculations are simplified, in that any elaborations or deviations from the assumptions used in the above-described hypothetical houses are only taken aboard if they fitted in the model. Thus, the variations in the height of the foundation walls within the same building, as is the case for the West House as it is built on a slope, is not taken into account. However, the variation in the width of the walls is taken into account.

7.8.1 West House, Mycenae

The West House, just outside the citadel of Mycenae, covers an area of 377 m^2. It is part of a group of structures known collectively as the “Ivory Houses” (*e.g.* Burns 2007: 113). This group of structures is located west of the citadel, just below the modern road leading up to the parking place of the site (see figure 7.4). It consists of four structures named “House of Shields”, “House of the Oil Merchant”, “House of the Sphinxes” and “West House” (*e.g.* Burns 2007). Since the parameters used in the calculations of the hypothetical structures above are based on actual calculations taken from a range of structures from the Mycenaean era, the width of the walls at the West House (between 0.59 – 0.79 m) fit relatively well with the used range (0.5 – 0.75 m). Only the stone foundations are still in place, so any superstructure and its height will have to be estimated, as is done in the ranges used for the domestic structures above. However, traces of a possible staircase were found and a second storey is therefore assumed (Tournavitou 1995: 15). Hence, using the same rates as presented above (table 7.22), the costs for the West House at Mycenae can be estimated to be between 11,067 and 39,225 ph. Considering the second storey, though, the range should be between 19,831 and 39,225 ph, as the scenarios that assume a single storey structure are not relevant.

7.8.2 House 7-X, Kalamianos

The site of Kalamianos is located near the modern village of Korphos (see also figure 7.3, above). An extensive survey of the area has yielded numerous structures (Tartaron et al., 2011). Structure 7-X, used as an example here, is part of a group of structures built close together (for a complete overview of the site and the findings see Tartaron et al. 2011; in particular figure 11). The domestic structure from Kalamianos is much smaller than the West House from Mycenae, covering an area of 105 m^2 (Harper 2016: 170). It is quite well preserved, with some walls still standing up to 1.48m and there are even traces of a stairwell (Harper 2016: 172). Even though only the foundations remain, currently, the traces of the stairwell allows for assuming a second floor and hence a better idea about the original height of the structure. The walls are somewhat wider than those of the West House at Mycenae, reaching almost a meter in some places. Considering the wider walls and the clear indications of a second storey, the costs of this structure should be sought in the higher part of the range, calculated for this building. The overall range for a structure of this size with a second storey would be between 5,600 and 11,001 ph, with an average of 8,526 ph. The information regarding the second storey and the thicker walls eliminates a number of the scenarios used to calculate the labour costs. This means that the range of the labour costs can be narrowed to just those scenarios that fit the information of this particular structure. The costs would thus be more likely be between 8,526 and 11,001 ph.

7.9 Concluding remarks

This chapter provides an overview of the range of the labour costs involved in each of the studied building processes. It has been shown that there are large ranges for some of the steps in the construction process due to the large variations in labour rates. Furthermore, the use of the scenarios to construct the depth of the blocks used in the fortifications also creates large ranges for the costs. This means that the ranges in the total costs for each scenario are larger for the sections built in the cyclopean style than those sections built as a façade at the gates. From this it can already be deduced that a more detailed knowledge of the build-up of the wall allows more accurate estimates of labour costs to be calculated. Moreover, the scenario in which the material was not subdivided into various size categories, but rather assumed to be of one average size, never results in an extreme value (minimum or maximum). It is therefore important to evaluate whether the stone size matters when the final labour costs are analysed.

The implications of the calculated costs will be further explored in chapter 8. This will lead to a better understanding of the potential effect the construction of the large fortifications may have had on the communities in which they were built. It is important to note that the calculated costs presented here are based on the still standing remains and are not extrapolated to incorporate any past descriptions of the walls or any potential superstructures.

Chapter 8

Interpreting the results of a labour cost study

In the previous chapter the labour cost calculations of the fortifications at Mycenae and Teichos Dymaion were presented, as well as the building costs of domestic structures of various sizes from Mycenae and Kalamianos. In this chapter these numbers will be further evaluated. The calculation of the labour costs was not an end in and of itself; it is a means to try to understand what the impact was of taking on such building projects for the Mycenaean communities considered in this study. As such, the comparative strength of labour cost studies is utilised to show what these calculated numbers mean in section 8.1. Moreover, the calculated costs are evaluated by means of looking at the number of people involved and the potential number of people available at the studied sites, in section 8.2. Section 8.3 contains a broader discussion of the results in the socio-economic context of the Mycenaean world.

8.1 Comparison of labour costs

As has been pointed out in chapter 5, labour cost studies are primarily a comparative tool. In order to compare one structure or section to another, similar approaches were used for all the examined buildings, which are compared to one another here. Comparisons of the costs of various sections and structures are presented in section 8.1.1. Section 8.1.2 compares the labour investment required for the individual sub-processes, which will help to understand how these sub-processes influence the total costs and therefore what sub-processes are more expensive than others and where certain bottlenecks may be present in the process, in terms of required work-force. Finally, in 8.1.3 the building style of the fortification is studied in terms of labour cost. By distilling a building price per set volume for various building styles, one can get a better understanding of how expensive a certain style is. This will provide some insight into whether the decision to build in a particular style should have further implications in interpreting the structures themselves in relation to concepts like conspicuous consumption (see sections 2.2.2 and 3.2).

8.1.1 Comparing the total costs

As pointed out in chapter 7, the total cost for each of the studied fortification sections is largely dependent on the size of these sections. Similarly, the costs for the domestic structures are also tied to their size. The use of scenarios and ranges of rates resulted in ranges of labour costs for the various sections (see figure 8.1).[90] However, to compare the actual structures, rather than arbitrary parts of structures, the labour cost calculations done for the fortification sections need to be extrapolated to include the entire (segment of the) fortification. Section 3, for example is only a 20 m section of the much larger West Wall and section 4 at the same site is only one section of the North East Extension. Each

90 The extrapolation of the costs is done on the basis of volume. The costs for the documented section are thus multiplied by the factor that describes the volume difference between the documented section and the (segment of the) fortification.

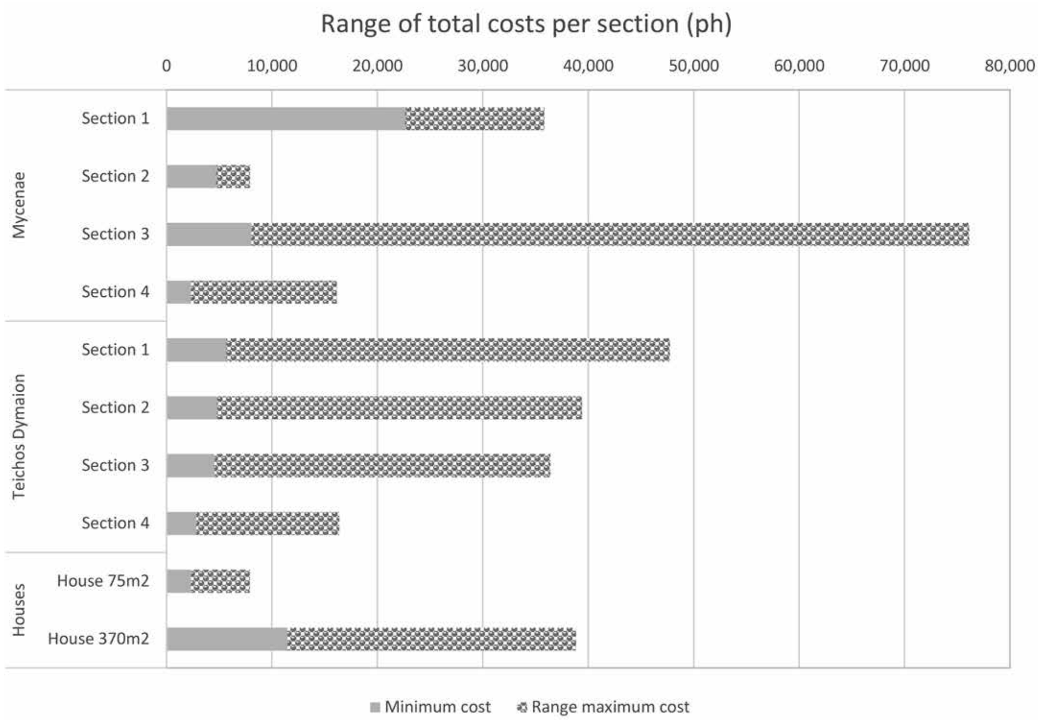

Figure 8.1 Graph of the labour costs of the sections at both sites as well as two domestic structures of 75 and 370 m^2 respectively (graph by author).

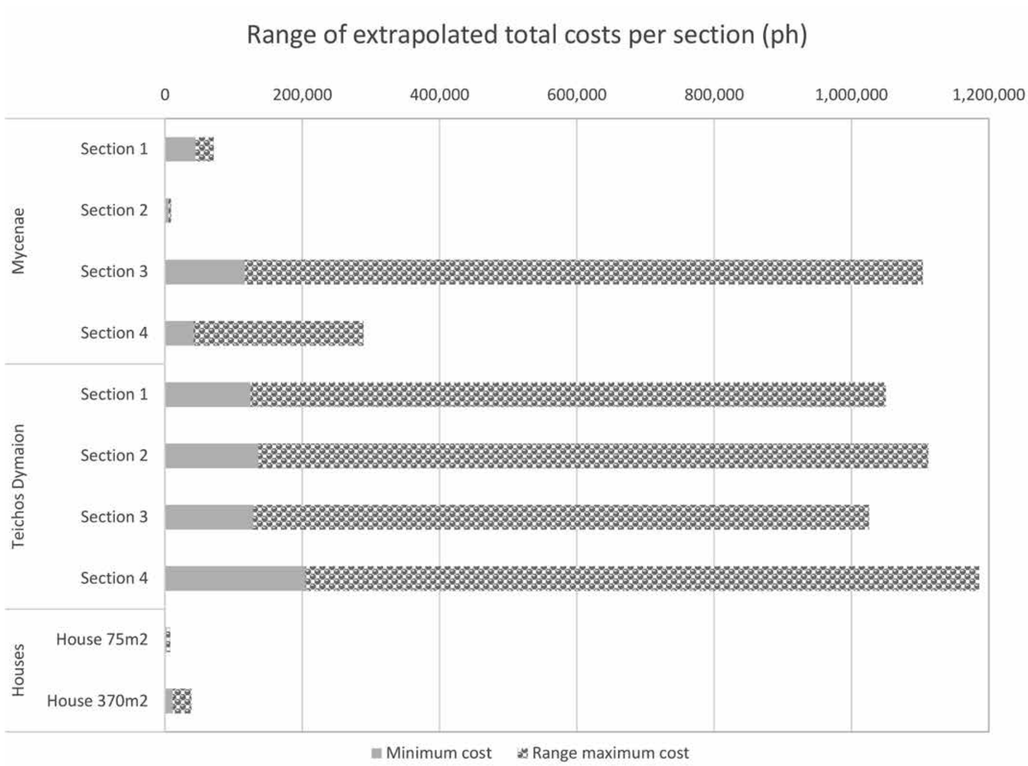

Figure 8.2 Graph of the total labour costs (as ranges) of the segments of fortifications at Mycenae and of the total fortifications based on 4 sections at Teichos Dymaion. Also the labour costs of two domestic structures of 75 and 370 m^2 respectively (graph by author).

of these larger segments is considered to have been built as one project (see chapter 4). In order to compare these projects to each other as well as to the domestic structures, the calculated costs should therefore be extrapolated to include the entirety of each of these projects. However, since they are built in sequence, they should be considered independent projects and the costs are therefore not extrapolated to include the entire fortification at Mycenae (as shown in chapter 4). For Teichos Dymaion, each of the sections will be extrapolated to include the entire fortification as this is considered to have been built in one phase (see also chapter 4). Moreover, the extrapolations are limited to the maximum preserved height, rather than any reconstructed height. The results of the extrapolated labour costs, based on the volume, are shown in figure 8.2.

Based on these graphs some observations can be made:

1. In general the larger the size of the section or structure studied, the larger the range of the costs is. This is particularly noticeable when looking at sections 3 and 4 at Mycenae in figures 8.1 and 8.2. For sections 1 and 2 at Mycenae (the façades), the range of the costs is far more restricted. This is the result of the fact that for these sections there was no need to use the scenarios to reconstruct the size of the blocks, thus reducing the uncertainties.

2. The total fortifications, or complete segments of fortifications demand far more labour investment than any domestic structure, except for the façades at Mycenae (sections 1 and 2), as shown in figure 8.2. Even if one would take the average costs of the larger sections of fortifications (which would be about 600,000 ph for section 3 at Mycenae and the entire fortification at Teichos Dymaion), rather than the extreme values of the range, the investment for the fortifications would still be many times that of a domestic structure (see also below).

3. The cost of the façades at Mycenae, despite being labour intensive due to the dressing of the blocks and the source of material being further away than for the other sections at Mycenae, is only a fraction of the cost of the larger cyclopean-style sections (see figure 8.2).

4. The cost of the entire fortification at Teichos Dymaion is comparable to the investment required for the West Wall at Mycenae.

5. The large range of the costs is not just due to the use of ranges of rates, but also due to the used scenarios; the block sizes therefore have a noteworthy effect on the labour costs. This, in combination with extrapolating the calculations to larger entities, result in variations visible in the results for Teichos Dymaion where the costs of each section is extrapolated to include the entire fortification and thus the same total volume. However, each of these extrapolations show different final costs. The small variations and the stacking of assumptions in the calculations for each section results in the shown differences for the total costs.

Regardless of any secondary function the fortifications may have had (see chapter 3), a fortification wall is used to enclose a certain area. It is therefore, informative to look also at the calculated costs in relation to the size of the area the (segments of) fortifications enclose. Since sections 1 and 2 at Mycenae are façades, these are not considered here. Rather the focus is on sections 3 (West Wall) and 4 (North East Extension) at Mycenae and the fortification at Teichos Dymaion as a whole, which enclose areas of 600, 11,000 and 8,000 m^2 respectively (see chapter 4). If the costs of these entire sections are then divided by the area they encompass, the cost of the fortification per square metre area fortified is the result (see table 8.1). This comparison thus says something about the efficiency of the fortification in terms of enclosing an area.

The results show that the West Wall (section 3) at Mycenae, in terms of efficient fortifying an area, is the least expensive section. Following closely, is the cost per fortified area of the fortification at Teichos Dymaion, while the North East Extension (section 4) at Mycenae is much more expensive. This shows that fortifying small areas is much costlier and there must have been a very specific reason to extend the fortified area at Mycenae for a relatively high price. If this extension was to secure a water source, through the use of the cistern (see 4.1.2), this would be a strong argument for a military reason for constructing such fortifications.

Considering that most houses from the Mycenaean period have a ground surface area of between 50 – 100 m^2 (Tartaron et al. 2011: 589; see also 6.5) a comparison with the costs for a, hypothetical, 75 m^2 house is justifiable. A house of this size costs between 2,333 and 7,889 ph with an average of 4,905 ph. This means that for the same kind of labour investment that it took to construct the West Wall, between 50 and 473 houses (using the lowest value)

Cost of fortification in ph/m^2 fortified.	**Mycenae**		**Teichos Dymaion**
	Section 3	Section 4	Total fortification (average)
	ph/m^2	ph/m^2	ph/m^2
Min	10.6	69.8	18.5
Max	100.4	482.0	136.7

Table 8.1 Overview of the minimum and maximum cost of the fortification per square metre fortified.

Cost of houses		Number of houses built									
Surface area (m²)	Average total cost	North Gate		Lion Gate		West Wall		NE extension		Teichos Dymaion	
		min	max	min	max	min	max	min	max	min	max
75	4,905	1	2	9	14	24	225	9	59	25	242
110	7,201	1	1	6	10	16	153	6	40	17	165
160	10,468	0	1	4	7	11	105	4	28	12	113
200	13,087	0	1	3	5	9	84	3	22	10	91
250	16,354	0	1	3	4	7	68	3	18	8	73
300	19,620	0	0	2	4	6	56	2	15	6	60
370	24,151	0	0	2	3	5	46	2	12	5	49

Table 8.2 Overview of the amount of houses that could be built for the same investment as some of the (sections of the) fortifications. In the case of 'sections', the labour costs are extrapolated to include the entire section, rather than just the documented part of it. The average cost per house is taken for each size category to allow for a variety of houses of that size to be built.

or between 15 and 140 houses (using the highest value) could be built. Alternatively, assuming that a mix of houses was built of this size and the average cost of 4,905 ph is used, between 24 and 225 houses could be constructed. There are other house sizes as well though. It has also been commented that 75 % of all Mycenaean houses are smaller than 200 m² (Tartaron et al. 2011: 589). The costs for a house of that size (200 m²) is between 6,228 and 21,044 ph, with an average of 13,087 ph. Taking these costs, between 9 and 84 houses (using the average cost) could be built for the same investment as the entire West Wall. Table 8.2 gives an overview of the amount of houses that could be built of a specific size for the same investment as was required for the sections at Mycenae and the fortification at Teichos Dymaion (considered to be built in one phase). The examples of domestic structures used in chapter 7, House 7-X from Kalamianos and the West House from Mycenae, correspond with the second size category and the final size category in the table, respectively.

From the table it is clear that when the scale (the size, in this case the volume) of the fortifications, or sections thereof, is considered, they are indeed expensive. The façade at the Lion Gate is, due to its limited size, not as expensive as one might have thought based on the elaborate dressing involved (see also section 8.1.3). The larger West Wall at Mycenae and the entire stretch of the wall at Teichos Dymaion show that their size means that it requires quite an investment, compared to ordinary houses. An average of ± 130 of the smallest (but most common) houses could be built for the investment of these fortifications.[91]

91 125 and 133 are the average values for West Wall and Teichos Dymaion, respectively.

8.1.2 Magnitude of the sub-processes

To gain a better understanding of the building processes, a comparison is made between the processes in relation to the total cost of each of the studied structures. This is summarised in figure 8.3 below. In this graph, the average cost for each process is used and expressed as a percentage of the total to be able to compare the results better. Using averages completely ignores the ranges that exist in the calculated costs due to the use of various rates and scenarios. In the graph in figure 8.4 the actual ranges of the costs of each process and section are therefore shown. They show (1) the impact that each process has on the total cost of each section (as the graph with the average values does) and (2) the large range that exists for some processes.

Immediately a few things stand out from the graphs in figure 8.3 and 8.4. First, the distinct position the conglomerate façade at Mycenae (sections 1 and 2) takes in terms of the spread of the cost over its processes is obvious. Not only are these the only sections that include dressing of the blocks, but it takes up a large amount of the total costs as well (between 37 – 57 %). Yet, the assembly, which is the most expensive process for the other sections, only makes up about 15 % for the façades.

The differences between the sections built in limestone at both sites are minimal and mostly due to size differences. This is, for example, visible in the influence of the ramp on the total costs. For each section one ramp was assumed of the same size and the absolute costs of the ramps is thus the same. However, the sections are of varying sizes, so the relative costs (or percentage of the cost of the ramp) vary depending on the total cost of the section. This is clearly visible in figure 8.4. The part of the bar representing the ramp (green) is very small for section 3 at Mycenae, but far larger for section 4 at the same site. The reason is, as mentioned above, that section 3 is a very large section

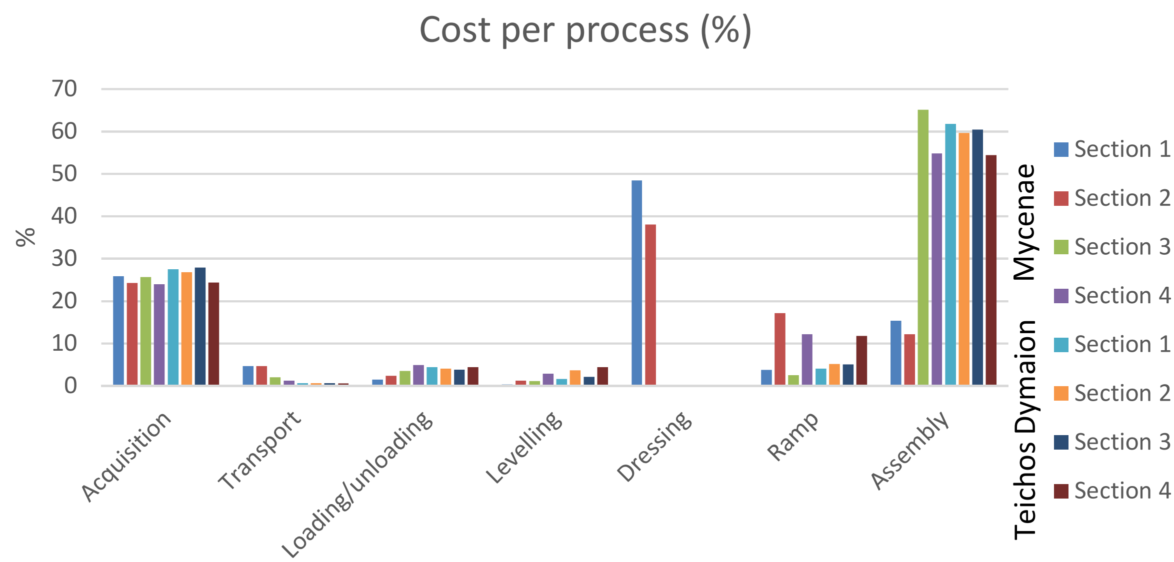

Figure 8.3. Graph of the cost per sub-building process as percentage of the total cost per section (graph by author).

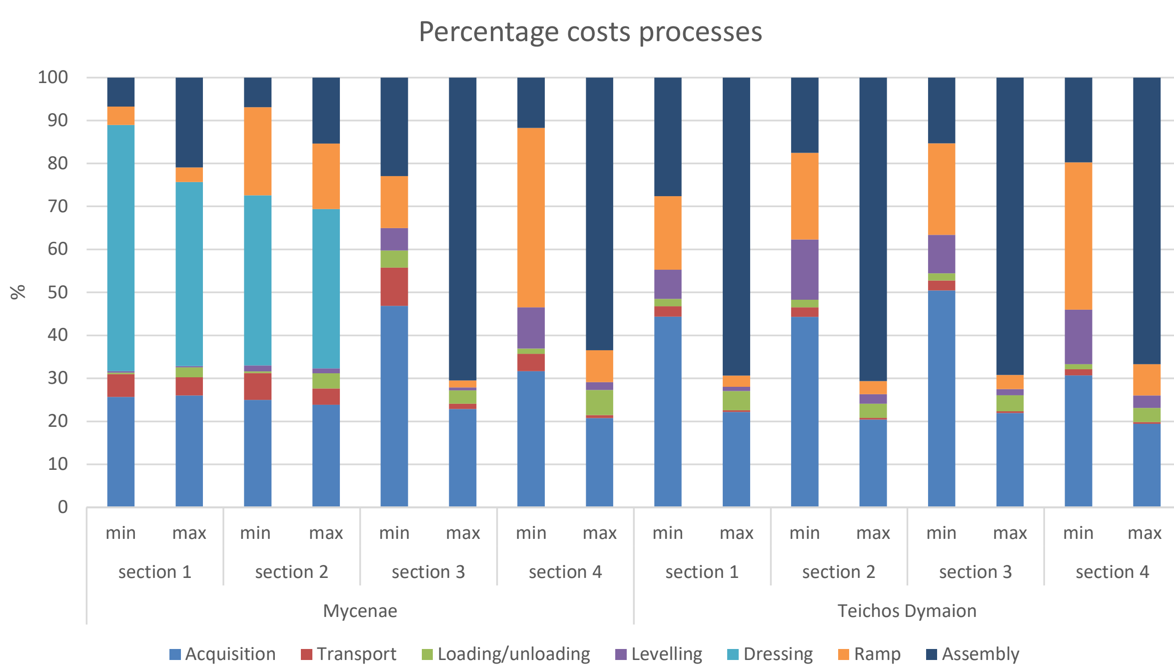

Figure 8.4 Overview of the costs of each of the processes as a percentage of the total costs of each studied section. For each section the scenario that provided the minimum total costs and the scenario that provided the maximum total costs are shown (graph by author).

(costing 43,398 ph, average), while section 4 is much smaller (8,920 ph, average). However, the cost for a three-meter high ramp is for both sections 1,089 ph and thus a much larger part of the total cost for section 4 than for section 3.[92] Obviously it can be questioned whether a single ramp would suffice for the larger section, but one should remember that this larger section is still only roughly 20 m long.[93]

The same issue with the relative costs for ramps also goes for the levelling costs, at least for some sections. For instance, the Lion Gate (section 1) is preserved to a much higher level than the North Gate (section 2). The relative costs for levelling are thus higher for the North Gate than for the Lion Gate. Moreover, the influence of the transport costs on the overall total depends on the assumed distance that is travelled. As this distance is largest for the conglomerate façades at Mycenae, these form a larger percentage of the costs. If, for example, a distance of 1,000 m instead of 100 m is assumed as the distance for the transport at Teichos Dymaion, the costs of this step increases by a factor 10 and this would, for section 1 at that site, increase the transport cost from 0.6 % to about 18 % of the total cost. Another factor is the maximum weight allowed per trip. As argued in chapters 3 and 7, it is assumed that this maximum was quite high, up to 10 tonnes (although most loads are considered up to 5 tonnes). In comparison, Devolder (2013) and Harper (2016) only allow loads up to 2,100 kg. Therefore, in their studies transport represents a far higher percentage of the total costs. In general, though, it is clear from this study that acquisition and assembly are the most costly steps in the building process of the limestone walls. As figure 8.4 shows, the range for the assembly is very large, which means that in those instances where a low rate is considered for the assembly, the second most expensive process (acquisition), whose range is slightly less, but whose overall cost is still significant for the total costs, thus takes up a much larger part of those total costs. In the graph in figure 8.3, which uses the averages, these variations are less extreme. This has to do with the fact that for the assembly process three sets of rates are considered (see chapter 7). Two of these sets are relatively close together, whereas the third (in which the rate is determined by attempting to consider the cost for each sub-process of the assembly separately), is much lower. In the average costs for each section, these lower figures are therefore only marginally taken on board, as they are, in a way, outliers. Another noteworthy detail in figure 8.4 is that for most processes the range for the conglomerate façades at Mycenae (sections 1 and 2 at that site) is quite small. The cause of this is the lack of the use of scenarios for reconstructing the depth of the blocks at these sections. This means that there is a lot less uncertainty resulting in less variety and smaller ranges. The largest varieties for these façade sections are in the processes of dressing and assembly. For both these processes, this has to do with the relatively large variance in the used work rates.

8.1.3 Comparison of the investment per cubic metre

Similar approaches and parameters were used in the calculations of the various sections. However, because these sections have different dimensions, comparing the values presented in chapter 7 shows mostly the difference in scale and thus allows the comparison between buildings themselves (see 8.1.1). By calculating the average cost per cubic meter for each of the sections, something can be said about the way something was built and thus what the costs were of using certain methods. It says therefore more about the activity, and the cost of a building style. This is particularly interesting in light of Pausanias' descriptions about the construction in cyclopean style (see chapter 3). He mentioned that the blocks are so heavy that a lot of force is required. This also implies the difficulties imagined for building in such a style. Therefore, by calculating the costs per cubic metre for the cyclopean-style sections, the conglomerate façades and the rubble/mudbrick construction (used in the domestic structures), the price for each of these building methods can be evaluated. The result for the fortifications is shown in table 8.3.

The most notable feature is the fact that the conglomerate façades (Mycenae sections 1 and 2) are much more expensive per cubic metre to build than the cyclopean-style walls. This underlines the idea that these façades were a special feature and therefore only used at specific, very visible, locations (see chapter 3). Other than that, the cost per cubic metre is quite similar for the various sections, as is to be expected, considering the fact that the same rates and assumptions are used for all of them although the costs for section 4 (especially the minimum costs) at both Mycenae and Teichos Dymaion are higher. This is because these are both relatively small sections, yet some costs (the ramps) are considered the same for all sections (see also section 8.1.2 above). The costs are then divided over the total volume, which means that for smaller sections the costs per cubic metre is higher.

In comparison, the domestic structures cost between 11.3 and 19.1 ph per cubic meter. Of course the volume of the houses involves a lot of non-built space (the rooms themselves) so the actual cost per cubic meter of

92 For the building of ramps, only 2 scenarios are used: one where the transport is done by humans and one, which involves oxen transport. The average cost of these two methods for a 3m high ramp is 1089 ph.

93 One ramp is considered per *documented* section. This is smaller than the actual wall section, as described in chapter 4. This means that for the extrapolated costs, the costs for additional ramps are also included.

		Mycenae				Teichos Dymaion			
		Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4
Total (ph)	**min**	22,652	4,729	8,028	2,340	5,663	4,826	4,544	2,832
	max	35,809	7,925	76,142	16,155	47,752	39,441	36,427	16,407
Size factor		1.98	1.1	14.5	17.9	1.1	2	1.6	5.2
Total (ph)	**min**	44,851	5,202	116,399	41,882	6,229	9,651	7,271	14,728
	max	70,902	8,717	1,104,056	289,175	52,527	78,882	58,283	85,318
Volume (m3)		469	52	17,357	4,409	784	1,117	894	1,134
Cost/m3 (ph)	***min***	95.7	99.5	6.7	9.5	7.9	8.6	8.1	13.0
	max	151.2	166.7	63.6	65.6	67.0	70.7	65.2	75.2

Table 8.3 Simplifying the cost of the studied sections to a cost per cubic meter to make the results comparable. All costs are in person-hours (ph). The size factor shows by what number the costs of the documented part are multiplied to come to the total cost of a particular section. For example, the documented part of section 3 at Mycenae is part of a larger section (the so-called West Wall), which is 14,5 times larger than the documented section.

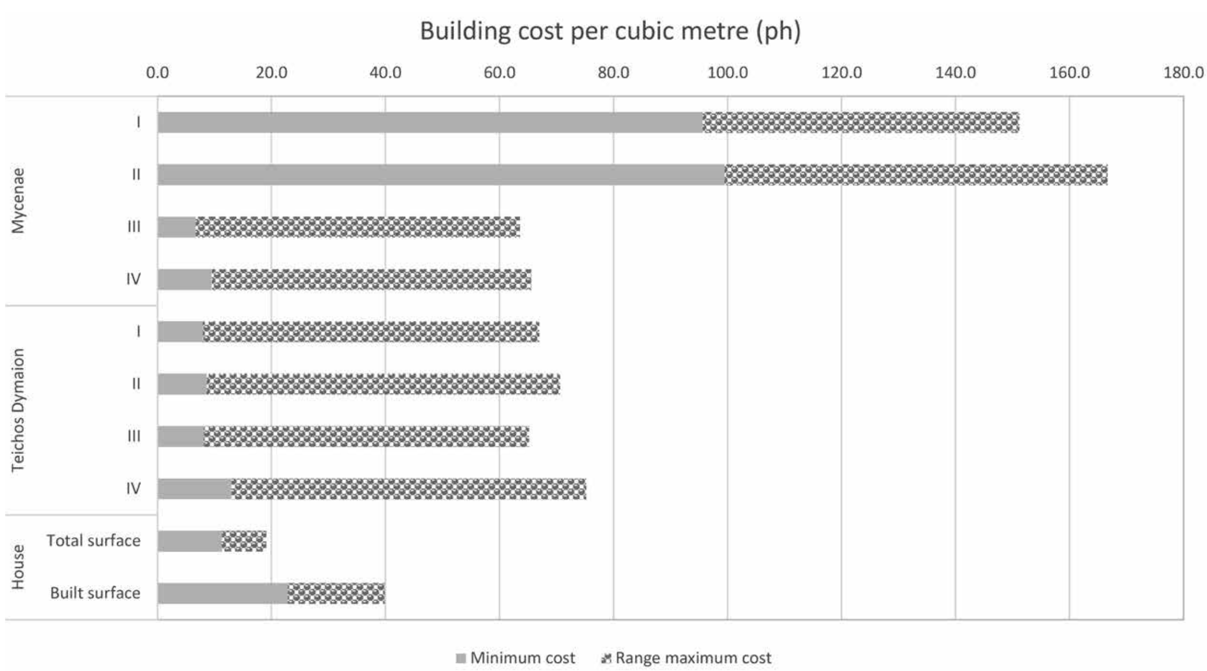

Figure 8.5 Cost per cubic metre of the various sections and the domestic structures (graph by author).

construction is higher (22.9 – 39.9 ph/m3).[94] This may seem counter intuitive, in that the costs then become more comparable to the large fortifications (see also figure 8.5). However, it must be noted that (1) the construction of houses involves certain very labour intensive tasks (*e.g.* mudbricks, making wooden roofs) and (2) the total costs of the fortifications were many times those of houses due to the enormity of the walls themselves (see 8.1.1). Thus, the results of comparing the cost per cubic meter between houses and the fortifications should be interpreted carefully. As mentioned above this difference has to do with the fact that the price per cubic meter says something about the way something was built and thus what the costs were of using certain methods. It says therefore more about the activity, while the total costs inform about scale.

94 The difference is due to the used volume: for the first range (11.3 – 19.1 ph/m^3) the volume is taken as the total volume of the house as a cube (surface area x total height). The second range (22.9 – 39.9 ph/m^3) is the result of adding up the volume of all the individual materials used in the construction. This second method thus represents the actual built volume better and because it is a smaller volume, the cost per cubic metre is higher.

Based on the cost per cubic metre (see again, figure 8.5) it can be stated that building with larger material might require some extra effort, but depending on the used strategy and the build-up of the wall (especially the fill), it may not be as expensive as perhaps assumed beforehand, based on Pausanias' description. Of course, building with larger material does require more people to be present at the same time to deal with the larger weight. In contrast, building with dressed blocks requires a far larger investment per cubic metre than building with cyclopean-style stonework or constructing domestic buildings. This is partly due, in this case, to the difference in quarry technique, but mostly to the dressing of the blocks (see also above 8.1.2).

Two things are thus clear from the calculated cost in figure 8.5. The first one is that the chosen building style for the fortifications (cyclopean) did in and of itself not necessarily make the structures inconceivably expensive, in comparison to the cost/m^3 of a house. The second thing that is clear is that the conglomerate façades, present at the Lion- and North Gates at Mycenae, are expensive elaborations. The fact that the façades are, on top of that, structurally unnecessary, makes them an interesting investment.

8.2 Implications of the calculated labour costs on communities

In the previous section, the labour costs were compared to each other, between sections, between steps in the building process, and with the cost of building houses. The latter was used to put the cost of the fortification walls in perspective, since a list of numbers in and of itself says very little. In the following section, the labour costs of the fortifications will be put in other perspectives. Firstly, an attempt is made to see how long these building projects may have taken and how large a part of the population may have been involved. Based on the analyses it is evaluated what impact the construction of the fortifications may have had on the communities in which they were built.

8.2.1 The duration of the building projects.

In order to gain insight into the organisation of large complex construction projects, it is helpful to study the length of the project as well as the number of people involved. To do so, a number of assumptions will need to be made: first, the length of a workday and the number of people available for construction projects (the potential workforce). These factors are related in terms of the project's duration (see figure 8.6 below).

A variety of lengths for workdays is used in the literature. Erasmus (1965: 283) describes that workers in Latin America, generally start early and work until the heat of midday, covering about 5 hours. He (1965: 283) writes that "most writers" (not specified) apply an 8-hour workday, but that this can be somewhat ethnocentric. DeLaine (1997: 106), on the other hand, assumes a 12-hour workday, which includes 2 hours for breaks and thus works with 10 effective hours per day. She bases this on descriptions about this subject by Pegoretti (I: 13), De Marchi (Cave: 12-13), Columella (RR 11.2.90-91) and Hurst (1905), mostly founded on the idea that people worked from dusk until dawn, which would be about 12 hours in summer. Burford (1969: 247), de Haan (2009: 3) and Abrams and Bolland (1999: 264-5) argue that heavy work may perhaps only be sustained for 5 hours/day, although they use 8-hour workdays. There is thus a range of 5 – 10 hours of work per day to work with.

When considering the duration of a, potentially, long-term project, it might be more telling to consider the number of years it takes, rather than days. It is extremely difficult to say anything definitive about how many days a year it is realistic to assume people may have worked, in general, but in particular on these kind of communal building projects. Often cited in this case is DeLaine's (1997: 105) figure of 220 days per year. She (1997: 106) mentions though, that for some work, "outside the building site, such as the working of stone and timber, and for quarrying around Rome" 290 days per year are more likely. The number of days per year is limited by extreme heat, other weather conditions, which would also apply to the Greek context and specific Roman "holidays" (DeLaine 1997: 106). The latter might be particularly relevant in Rome itself and therefore influence the construction, but whether Mycenae, or in broader sense, the Mycenaean communities, had a similar concept of having days off that could influence the construction is hard to say.[95] More importantly, it is impossible to say how many of such days would be realistic. Another issue is whether people and animals were available all year, even if weather and cultural obligations allowed. This depends on whether workforce is seen as a temporary force, who would normally work the fields, herd cattle or have other day jobs. In which case, their normal jobs might require a certain amount of time each year as well (during harvest season, for example, but see also above and Timonen in prep.). If a range of 220 – 290 days is taken for construction, then the number of years it took can be determined (see table 8.4). Figure 8.6 gives an impression of the effect the number of people and the hours per workday have on the duration of the building project. Obviously, with 5-hour workdays the construction takes twice as long as with 10-hour workdays. Moreover, with twice as many people the construction takes half the time. That is why the decrease in construction time is larger at the lower number of workers, while this decrease becomes less with more workers, but will obviously never

95 There are indications that there were religious festivals, which also included communal feasting (see 2.3.4).

	Mycenae				Teichos Dymaion – total fortification			
	Section1	*Section2*	*Section3*	*Section4*	*Section1*	*Section2*	*Section3*	*Section4*
min. days	12	4	126	32	117	119	122	134
max. days	58	18	629	160	586	594	608	669
number of years								
220 days/year	0.05	0.02	0.57	0.15	0.53	0.54	0.55	0.61
	0.26	0.08	2.86	0.73	2.67	2.70	2.76	3.04
290 days/year	0.04	0.01	0.43	0.11	0.40	0.41	0.42	0.46
	0.20	0.06	2.17	0.55	2.02	2.05	2.10	2.31

Table 8.4 Overview of the amount of time, in years, it would take to build each section with the results taken from table 8.5. The minimum values thus represent 10-hour workdays and 500 workers, the maximum values comprise 5-hour workdays and 200 workers (see for a discussion on the number of workers section 8.2.2).

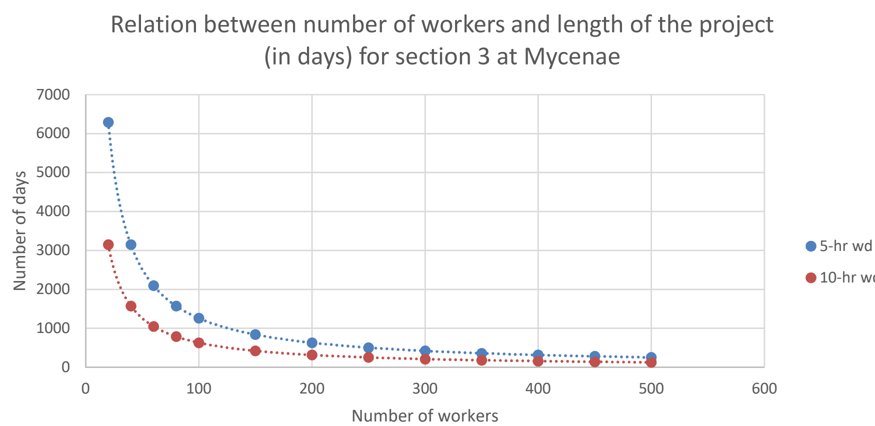

Figure 8.6 Graph of the relation between the number of workers and the amount of time (days) it would take to build section 3 (West Wall) at Mycenae (graph by author).

reach zero. Additionally, this does not take into account the actual efficiency of an increased workforce: there is only limited space, so there is a maximum number of people that could work simultaneously. Within the parameters of this research, it is not possible to ascertain this maximum. Nevertheless, the graph does show how difficult is to determine the length of the project as it is very challenging to determine the amount of people working on the project.

In order to understand whether the estimated amount of time to complete the fortifications should be considered long, it is useful to compare it to the duration of the construction of the domestic structures. The domestic structures are of a much smaller scale, and it would be strange to expect hundreds of people involved in the construction of a single house. If similar workdays are assumed for the construction of houses (5-10 hours per day), the amount of person-hours can be converted to workdays. Subsequently, if a range of 20 – 33 % of the population is potentially involved in construction, as suggested by Abrams (Abrams 1987: 493; see also 8.2.2), and 5 – 15 people are assumed per house (see below), this would mean that between 1 (20 % of 5) and 5 (33 % of 15) people would be involved in the construction. This allows making an estimate of the amount of time it took to build a house (see table 8.5). In this example, it is assumed that a household is responsible for building its own house. If, however, it is assumed that also domestic structures were built in a more communal way, *e.g.* with an extended family, neighbours or other external people not living in the house, the building time can be cut dramatically (see bottom part of the table). The latter seems to be more on par with what Harper (2016: 461) assumes for the construction of the houses at Kalamianos. He assumes a build-time of 90 days, with a varying number of people (up to 31) at any point. He estimates that house to cost 5,930 ph (2016: 436), so it is in a similar range.

Thus, besides the higher costs of the fortifications in comparison to domestic structures, there was also a much higher degree of organisation required for the construction of the fortification walls (see also 8.2.4). Moreover, due to the limited number of people involved in the construction of the houses, they take quite some time to be built. As such, the estimated number of days it took 10 – 30 people to build a 75 m^2 house may have been similar as the number of days it may have taken to build sections 1, 2 or 4 at Mycenae (although more people were

Houses	*Average* house	
ph	4905	
	5hr wd	10hr wd
workdays	981	491
5 people/house – 20 %	981	491
5 people/house – 33 %	491	245
15 people/house – 20 %	327	164
15 people/house – 33 %	196	98
Larger group of people		
10 people building	98	49
20 people building	49	25
30 people building	33	16

Table 8.5 Amount of days required to build a house, based on the described parameters. If Abrams' figures were used for calculating the pool of people from which the larger group of workers came in the bottom part of the table, this would result in a range of 30-50, 60-100 and 90-150 people respectively.

used at those sections). Building a house should therefore perhaps also not be seen as a small task.

8.2.2 The number of people involved in construction

The second issue to resolve is the number of people involved in the project. The number of people required for the various processes discussed in this study are based on the required force. For some rates that are used it is assumed that a certain expertise was present. Whether this expertise was locally available or had to be brought in is not taken into account here.

Brysbaert (2013: 82, 2015b: 98) uses 100-people strong "work gangs" for translating her calculated labour costs (in man-days) into a period of time over which the construction took place and how large a part of the population was required. For most of the tasks as described in this study, 100 people will suffice, although for some of the heavier blocks in the cyclopean-style walls up to 120 are required.[96] However, assuming that only 100 people would be working on these walls at the same time means that when it came to handling these larger blocks all other activities would have to be put on hold. That is even without taking into account the heaviest blocks used at the Lion Gate, which required between 276 (Lion relief) and 479 (lintel) people to put into place. These are obviously extremes and for most other sections there is no need for that excessive amount of people at any one moment, but it shows that 100 people as a total workforce, however useful to calculate with, is not realistic.[97]

Assuming too large a workforce though, would also cause potential issues. Due to the close proximity of the quarries, the transportation takes relatively little time. Supply of material is therefore almost immediate and too much material piled up at the building site could potentially be problematic. Perhaps a 200-strong workforce might be suitable for most sections. Moreover, the sections at Mycenae were not built at the same time, so there may also not be a need for an enormous amount of people. If a maximum workforce of 200 (for most sections) – 500 (for specific segments as described above) people is assumed for Mycenae, the maximum required people at any one moment are covered and, for most of the time, most of the activities could happen side by side, if needed. The latter is also important to keep into account, as some activities cannot happen simultaneously, whereas others are required to be done at the same time. The site preparation obviously needed to be done before assembly could begin, just as the acquisition of material had to begin before the assembly. Yet, the acquisition also had to continue during the assembly to keep up the supply of material, without cluttering the building site. Thus, if at least 100 – 120 people are required for the assembly alone, a total workforce of 200 would allow additional people be involved in the quarrying and transportation of the material.

It needs to be verified if the range of 200 – 500 people required for the construction of the fortification, is realistic in relation to the available workforce. This depends on the population size at both sites and what part of those populations might be considered part of the potential workforce. After all, for a small population 200 – 500 people might be a substantial part. Moreover, the very young and the very old might not have been part of the (potential) workforce. Brysbaert (2013: 82) for example argues that her 100 men workforce comprises 8 % of the "active workforce", of a total population of 4900. This means that the total active workforce is ¼ of

96 The number of people needed are calculated based on the same parameters used in chapter 7 in terms of strength per person, slope of ramp (if used) and a friction coefficient for moving blocks over the ground. The large group of people will have had to use ropes in order to be able to work together on moving single blocks.

97 This was also not what Brysbaert intended, however, it is used here as an example of possible sizes of workforces and how these influence the organisation and duration of the building process.

Workforce in construction	Percentage potential workforce of total population	Population	Percentage of total population	Population
200	20	10,000	4	5,000
200	33	6,000	6	3,333
500	20	25,000	4	12,500
500	33	15,000	6	8,333

Table 8.6 Overview of the workforce and population sizes when the above-described percentages are used. In the calculation of the population based on the potential workforce, the construction workforce is taken as 10 % of the potential workforce.

the population.[98] This is based on the assumption that only adult men were involved in the building process and that adult males form one quarter of the population (DeLaine 1997: 201). DeLaine further specifies that if the male population is considered the potential workforce and if this can be considered a quarter of the population, then the builders would "represent some 15-24 % of these". However, for some subsidiary tasks that were physically less demanding, DeLaine (1997: 202) also considers that women and children might have been involved. This would thus, for some tasks at least, increase the potential workforce beyond the suggested 25 % of the total population.

Abrams (1987: 493) assumes, for his case-study in the Americas, that 20 % (adult males or household heads) to 33 % (adult males as well as some females and sub-adult males) of the population may have formed the pool from which labourers were drawn.[99] In his labour cost analysis of a structure (10L-22) at Copan, Honduras, the labourers only comprised 9.3 % of the potential workforce and the full-time "specialists" only 1 % (Abrams 1987: 493). Abrams' 9.3 % is not unlike Brysbaert's 8 % suggested workforce of 100 people (but see footnote 99 for potential issues with this number). However, as pointed out above, a workforce of 100 people seems too low from a practical and logistical point of view. Nevertheless, there are thus two important considerations: (1) of the total population there is a certain percentage that forms the overall potential workforce and (2) of that potential workforce there is a percentage that may have worked in construction. This is an important consideration, as those people in the potential workforce would also have to cover all other types of work, like food production. Subsequently, it means that if a large part of the potential workforce was working on other tasks than construction most of the time (estimates for food production range from 160 – 240 days per year (*e.g.* Timonen & Brysbaert 2021)), this obviously limits the possible labour pool for the construction work. It may, therefore, not be strange to consider that only up to about 10 % of the potential workforce (which would mean 2 – 3.3 % of the total population if Abrams' 20-33 % range is used) may have been involved in construction. This is slightly lower than DeLaine's (1997: 201) figure of 4-6 % of the total population being involved in construction work. This means that substantial populations must have existed at Mycenae and Teichos Dymaion, if a 200 – 500-strong construction workforce is required (see table 8.6).

However, a different approach might be taken here as well. Perhaps it could be argued that a smaller group of people worked on the construction full-time and additional workers were drawn from the larger potential workforce pool (not unlike Abrams' (1987: 493) suggestion for construction work organisation). These additional workers would then rotate shifts and work, as it were, part-time. This could be either segments of workdays or a number of days per larger time unit (week/month/year). This way, even smaller communities could potentially provide larger construction labour pools, without necessarily encroaching on other, essential work. In table 8.7, below, an overview is provided what amount of extra people would be required, based on the population numbers provided in section 4.3 and the percentages of potential workforce as presented above, if a total construction force of 200 people is required and the construction force is taken as a fixed part of the population.

98 100 men forming 8 % of the workforce, means that the total workforce is 1250 people. This is a bit over 25 % of 4900. This population number is based on the idea that the site is 24.5 ha and has a population density of 200 p/ha. As shown in 4.3 this density seems unrealistic. Moreover, it seems that Tiryns reached this size in LH IIIC and it was smaller in LH IIIB (Maran 2010: 730). If, Whitelaw (2001:29, fig 2.10), is correct in stating that Tiryns was more likely to be around 18 ha and the population size is calculated according to the method of Hanson and Ortman, the total population would be 1990 people. Following Brysbaert's and Delaine's argument that the active workforce comprised 25 % of the population, then the 100 men workforce actually comprises about 20.1 % of the active workforce, rather than 8 %. Even if Tiryns is 24.5 ha, the population would more realistically be about 3004 people based on Hanson and Ortman, which would mean that the 100 people be 13.3 % of the active workforce (if the latter is taken as 25 % of the total population).

99 Unlike Fotou (2016: 78) states, this does not refer to construction of their own dwelling, but rather communal building activities, ordered by (an) elite(s).

Calculations below based on the idea that the construction force is a fixed percentage of the potential workforce.				
Mycenae				
Population	Percentage potential workforce of total population (%)	Construction workforce (as 10 % of the potential workforce) (# people)	Required extra people from potential workforce (# people)	Required extra people as % of potential workforce
6,400	20	128	72	6
6,400	33	213	0	0
4,291	20	86	114	13
4,291	33	143	57	7
2,120	20	42	158	37
2,120	33	71	129	31
Teichos Dymaion				
980	20	20	180	92
980	33	33	167	85
350	20	7	193	276
350	33	12	188	269
359	20	7	193	269
359	33	12	188	262
Calculations below based on the idea that the construction force is a fixed percentage of the total population				
Mycenae				
Population	Construction force as percentage of total population (%)	Construction force (# people)	Required extra people from potential workforce (# people)	Required extra people as % of potential workforce
6,400	4	256	0	0
6,400	6	384	0	0
4,291	4	172	28	0.7
4,291	6	257	0	0
2,120	4	85	115	5.4
2,120	6	127	73	3.4
Teichos Dymaion				
980	4	39	161	16
980	6	59	141	14
350	4	14	186	53
350	6	21	179	51
359	4	14	186	52
359	6	22	178	50

Table 8.7 Overview of the extra people required to get to 200 construction workers, based on various population estimates and potential workforce estimates. It shows that if the above described parameters are taken into account, what percentage of the potential workforce (top) or total population (bottom) is required on top of the assumed percentage of that group involved in the construction. It is meant to show how realistic a 200 people strong workforce is dependent on the variables discussed.

This shows the above-described approach might work for Mycenae if the population figure of 4,291 is considered (see section 4.3). Although it may seem that only for one scenario (construction force as 6 % of the total population) the desired 200 construction workers is reached, in the other scenarios for this population figure it only takes 0.7 % of the total population or between 7 – 13 % of the potential workforce, to step in to reach 200 people. These may be acceptable figures if the above-described rotational, part-time approach is used. However, for Teichos Dymaion this is a different matter. With its estimated population of about 350 (see section 4.3), reaching 200 workers is nearly impossible as that makes up 57 % of the total population. Thus, for Teichos Dymaion either the population was a lot bigger than estimated, or a large part of the construction workers came from elsewhere. The latter seems more

Average values / section	Mycenae				Teichos Dymaion – total fortification			
	Section1	*Section2*	*Section3*	*Section4*	*Section1*	*Section2*	*Section3*	*Section4*
Total (average) cost of complete section	57,876	17,589	629,263	159,668	586,499	594,106	607,996	669,359
number of 5hr wd	11,575	3,518	125,853	31,934	117,300	118,821	121,599	133,872
number of 10hr wd	5,788	1,759	62,926	15,967	58,650	59,411	60,800	66,936
Number of days								
5hr wd / 200 people	58	18	629	160	586	594	608	669
5hr wd / 500 people	23	7	252	64	235	238	243	268
10hr wd / 200 people	29	9	315	80	293	297	304	335
10hr wd / 500 people	12	4	126	32	117	119	122	134

Table 8.8 Overview of the amount of time it would take a set number of people to build the fortifications. 'wd' stands for workday. Note that for Teichos Dymaion the costs of the individual sections are extrapolated to the entire fortification. The total costs for the fortifications at this site are therefore one of the results from the sections, and should not be added up. For Mycenae, each section is considered a separate project and the costs are thus separate investments.

likely, since even with an increased population of about 980 people (if 200 people/ha is used as a population density, see section 4.3), an additional 14 – 16 % of the total population would have been required to reach that 200 people (see table 8.7 above). This also shows that a construction force of 500 people is out of the question for Teichos Dymaion, unless these are all brought in from beyond the settlement itself. For Mycenae a workforce of 500 people would bring some serious pressure on the potential workforce as it would require an additional 42 – 48 % of that pool (assuming a population size of 4,291 people), or an additional 5.7 – 7.7 % of the total population. Perhaps, such a construction force was manageable for short periods (for only putting in the largest blocks of the Lion Gate) if organised purely locally, or even for longer periods if extra workers were brought in from outside Mycenae itself. The results of using a larger 500 people strong construction force is thus taken into account in the results below, but it is important to note that this would thus mean that the project was most likely (and for Teichos Dymaion, definitively) not a local, but a regional project. The results of these assumptions are shown in table 8.8 for all sections.

To put the numbers of the potential workforce above in further perspective, it is worthwhile to study how many people could be housed for the same investment that the fortifications require. This way, something can also be said about how many people potentially could be affected by this level of investment. The number of people per house is difficult to ascertain, however various researchers have made estimates from 5 (Gallant, 1991), 5 – 7 (Bogaard et al. 2009: 566; Hansen 2006: 60; Hanson and Ortman 2017: 308) to up to 10 – 15 people (Knappett 2009: 18),[100] and

Section	Number of people housed	
	min	**max**
Lion Gate	45	217
North Gate	5	27
West Wall	119	3376
North East Extension	43	884
Teichos Dymaion	127	3627

Table 8.9 The number of people that could be housed, based on the minimum and maximum costs of each section of fortification, the number of houses that could be constructed for that investment (table 8.2) and the number of people per house.

everything in between, based on the size of the house (*e.g.* Casselberry, 1974; Cook & Heizer, 1968; Naroll, 1962).[101] Thus, using a range of 5 – 15 people per 75 m² house (and note that 15 should be considered a high maximum), and using the number of houses that could be built for the same investment as the sections of fortifications studied at the sites, it can be estimated how many people could potentially be housed for that same investment.

Thus, if the average of 130 houses that could be built for the same investment as the West Wall (section 3) at Mycenae or the entire fortification at Teichos Dymaion (see 8.1.1), is taken as an example, these would house, on average, between 650 – 1950 people for the same

100 Knappett mentions 100-150 people "..composed of c. 10 extended families..". Which implies 10-15 people/family.

101 A house with a 75 m² footprint, has 46.5 m² of floor space. Using the formulas by Casselberry (P = 1/6 x F), Naroll (P = 1/10 x F) or Cook and Heizer (1.9 m²/person for the first 6 people and 9.3 m² for any additional person), the number of people per house would be 8 – 16 (Casselberry), 5 – 10 (Naroll) and 10 – 15 (Cook and Heizer), depending on whether there was a second storey with the same floor space as the ground floor. In the formulas P stands for population and F for the floor space in square metres.

labour investment required for that fortification wall. If the minimum and maximum number of houses were considered (rather than the average 130; see table 8.2), the range would be far greater (see table 8.9).

8.2.3 The impact of building

The numbers presented in the previous section provide an opportunity to make some statements about the potential impact that the construction of the large fortification walls may have had on the communities that built them.

For Mycenae, the impact seems to be manageable. Since the sections studied in this research were built in succession, rather than simultaneously, their potential effect should also be considered independently. In chronological order, it is section 3 (West Wall), sections 1 and 2 (Lion and North Gates) and finally section 4 (North East extension) (see also chapter 4). The West Wall is the largest section studied and thus required the largest investment. It took between 0.43 and 2.86 years (126 – 629 days) to build, depending on the amount of workdays per year, amount of hours per day and the size of the workforce (see table 8.8 and figure 8.6). If only a workforce of 200 people is considered, it would take between 1.09 – 2.86 years. This seems more realistic, since even considering the larger population at Mycenae, a workforce of 500 people might be too large (see 8.2.2). If, as suggested in chapter 2, construction work such as this was ordered by some sort of elite and was executed through corvée, it means that these people had other regular jobs as well. Depending on how much time these jobs required that could not be missed (*e.g.* during harvest time, see Timonen and Brysbaert 2021), this might influence the amount of time that could be spent on the construction work. This can on one hand lengthen the total construction time, and on the other hand put more pressure on the potential workforce pool. As pointed out in chapters 2 and 4, the population figures used are based on the urban population only. Additional people from the rural hinterland could increase the size of the labour pool, decreasing the pressure of the construction projects. However, as mentioned in previous chapters, it is beyond the scope of this study to reconstruct the rural population.

Sections 1 and 2 are much smaller and as such require a lot less investment, in absolute costs. Section 1 (the Lion Gate) would take between 0.04 – 0.26 years (12 – 58 days) and section 2 (the North Gate) 0.01 – 0.08 years (4 – 18 days), depending on the same parameters as mentioned above. As described earlier, a work force of 500 might well be too large, although in the case of the Lion Gate, required. It thus seems that the higher end of the range for the time to build these sections might be more realistic (0.10 – 0.26 years for the Lion Gate and 0.03 – 0.08 years for the North Gate with 200 people). This would require a short-term influx of workers when the largest blocks of the Lion Gate had to be put in place (see 7.6). The overall building time would make that the construction should not be an issue, even when the construction crew also performed other jobs. Despite the fact that it is an expensive building method (see 8.1.3), the absolute costs seem manageable. Please note, though, that the costs presented here only cover the façades.

The final section at Mycenae, section 4 (the North East extension), sits in between the gates and the West Wall in terms of required investment. Based on the same parameters as above, it takes between 0.11 and 0.73 years (32 – 160 days) to construct. If only 200 people are considered as a workforce, it would take between 0.28 and 0.73 years. With the same factors taken into account for the other sections at Mycenae, this does not seem a problematic investment. It also shows that only the West Wall took longer than one year to construct, whereas the other sections were potentially built in less than a year. Moreover, the required workforce to do it in the timeframes constructed here, does not seem problematic for the 200-strong workforce and such a group might point to the construction of the fortification as a local endeavour.

For Teichos Dymaion the results are similar, with some subtle, yet crucial differences. First, it takes longer to build the fortification (it is slightly larger than the West Wall at Mycenae), between 0.4 and 3 years (117 – 669 days). This is based on the same parameters as used for Mycenae. However, as shown above, a 500-person workforce is too large for the assumed population at Teichos Dymaion. Even the hypothesis of 200 people would require additional people from beyond the site itself. Hence, the amount of time it took to construct the fortification will be towards the higher end of the range (between 1 and 3 years with 200 people). Besides the project itself taking longer, the limited amount of people in the potential workforce suggests such a venture had a larger impact. In effect, the fortification at Teichos Dymaion was thus relatively a larger investment than the fortification at Mycenae. If the population size at Teichos Dymaion is within the range as postulated here (around 350 people, see 4.3), and the amount of time is acceptable, then the construction of the fortification at this site is, at the very least, a regional undertaking.

One thing that must be emphasized once more is that the calculated costs and the subsequent estimated length of the building projects are a direct result of the choices made in this study. While an attempt is made to reduce the effect of these choices, by using ranges, multiple rates and a variety of scenarios, it cannot be avoided. Furthermore, some factors have not been taken into account in the current calculations. For example, the clay that may have been used in the cyclopean-style walls (see also chapter 3), is not taken into consideration. This is partly due to the unknown extent to which it was used and how it was applied. If it was used, then it definitely would have resulted in an increase in labour costs. Moreover, the choice to calculate the labour cost mostly based on the required force, particularly for transport, loading/unloading and to some degree the assembly as well, means that the resulting costs are a minimum based on maximum efficiency. It does not, for example, take into account small breaks between jobs, or people idling due to delays in previous steps in the process. This would most definitely have happened, which increases the time required and thus the labour costs. Factors like these would have influenced the calculated required investment, it is, however, very difficult to assess to what extent. Nevertheless, these results say something about the scale of the required investment, and, as such, help evaluate if the communities could have supported these kinds of investments.

8.2.4 Implications for management and organisation

Unlike the relatively small groups of people required for the construction of ordinary domestic structures, the large(r) groups necessary for the fortifications need more organisation and a certain amount of power is essential to mobilise this number of people. Considering the difference in status that existed in Mycenaean society between people (see chapter 2), an elite would likely have enough power to order or initiate the construction of these larger construction projects. If, for example, construction work was organised through corvée (see 2.3.1), people were simply drafted for the work for a certain amount of time or (part of) a project. This corvée work should be seen as a “direct ‘tax’ on communities”, which in turn was most likely tied to landholding (Nakassis 2010: 273; see also 2.3.1).

If instead, people were hired for this work, quite decent amounts of supplies (likely staple goods) would have to be saved up in order to pay the workers (Nakassis 2010: 273). Crop failures could have potentially made the construction endeavours more problematic in those cases. For both methods (corvée labour and hiring workers), it is important to realise that the Mycenaean society had a strong hierarchical character (see chapter 2) and the palatial elites had a control over the population and parts of the economy. This has been used to suggest that the mobilisation of workforces was an important part of how the elites governed (see 2.2 and 2.3). Hence, the organisation of a workforce for the construction of the fortifications may very well be an extension of this control.

As proposed above, the current figures indicate that these projects were likely regional in nature. It is thus interesting to question to what degree elites controlled surrounding territories and whether they could muster construction crews from further away. If the mobilisation of labour was indeed for an important part tied to landholding, the influence of the elites would need to reach far to be able to conscript enough workers. As shown in 2.3.1, there are indications on some Pylos Linear B tablets (the so-called “Ac records”), that there were people recruited from various “taxation districts” (Killen 2006: 77). This could indicate that people were drafted from a larger region than just the citadel of Pylos itself. Moreover, it can be imagined that not just unskilled workers were brought in from beyond the community itself, but also expertise may have been acquired from further away or even shared between the various citadels. This can be the result of hiring experts like masons or perhaps experienced overseers from other places. In the Near East and Egypt there are texts that describe that certain experts were send to friendly rulers as gifts or on loan for a project (see 2.3.3; information derived from tablets such as the Amarna letters (*e.g.* Monroe 2011: 93; Burns 2010: 18; 2016: 90; Pullen 2016: 81)).

As described in chapter 3 there are some differences in style between the fortifications in this period, but these seem to be mostly due to local geological circumstances. As it seems that at most sites the stone material is quarried locally, the limestone beds dictate a lot in terms of the shape of the used blocks (see also chapters 3 and 4). Thus, the overall style of large, mostly unworked, blocks with smaller stones in between is applied in many regions regardless of the specific local geological circumstances. Moreover, as shown in 8.1.3 (in particular figure 8.5), the estimated cost per cubic metre is very similar for the two case studies, despite the fact that on average the blocks are (slightly) larger at Mycenae than at Teichos Dymaion (see chapter 6). Expertise in the general building style and organisation of the required workforce could therefore have been applied everywhere. Considering this, as well as the necessity to bring in workers from outside the community, these building projects should be viewed as regional, or at least not solely local, ventures.

Another factor in terms of organising labour forces is the subject of supervision. Other labour cost studies such as those by DeLaine (1997: studying the baths of Caracalla in Rome, Italy) and Abrams (1987: studying buildings in Classical Copan, Honduras) have also tried to take such skilled or supervision tasks on board in their calculations. DeLaine (1997: 268), basing herself on Pegoretti’s (1869) building manual, assumed a 10 % skilled and/or supervisory task as an addition to the labour force. Subsequent labour cost studies like those by Pakkanen (2013) and Brysbaert (2015) used DeLaine’s ratio as well. Abrams (1987: 492), however assumed a much lower portion of the labour force for supervision, of only 3 %. As described in section 2.3.1, there are Pylos Linear B tablets concerned with a number of different specialties associated with construction labour (*e.g.* Nakassis 2010: 275). One of these, the so-called all-builder, has been interpreted as some sort of foreman or master builder (Nakassis 2010: 275). On the tablet containing this inscription, this all-builder is mentioned alongside 20 wall-builders (interpreted as unskilled labourers) and 5 sawyers (Nakassis 2010: 275). If this would be the work crew for a certain project, it means that one supervisor had 25 workers, which would mean that this supervisor only comprised 4 % of the workforce. There is thus quite some discrepancy between the possible impact of supervision on the overall labour costs.

If supervision and/or expertise was to be taken into account, it would be safest to add it to the total costs, rather than to each individual step. Not only would it result in the same increase, but also it would allow for the theoretical variation of the amount of supervision required for each individual step in the construction process. After all, some tasks might require more supervision or a higher percentage of skilled workers than others. The addition of any percentage, however, remains a guess. As pointed out in section 8.2.2, it has been attempted to calculate the labour costs, mostly, based on the required force, which means certain things are omitted from the calculations. Considering the potential impact as described in this chapter, adding a hypothetical percentage for supervision (which was surely part of these building projects) would not alter these interpretations, only perhaps some of the numbers themselves.

Besides the organisation of the human labour, the organisation of the oxen in the transport of the material to the building site should also be considered. The use of oxen for this type of work has been well attested for Classical times in Greece (see *e.g.* Burford, 1960, 1963, 1969; see also 3.4.2) and it has been assumed similar for the Mycenaean era as well. In Classical times, it were farmers who owned the oxen and did this transport work on the side (Burford, 1969). In Mycenaean times, the elites owned oxen, which they sometimes loaned out for agricultural work (*e.g.* Killen 1998: 20; Lupack 2011: 214). So the question then rises whether the elites owned enough oxen to cover all the required traction for the transport, or did others outside the palace also own oxen, which they may have lent/rented to the palatial elites during such construction projects? As pointed out in chapter 2, our knowledge from the Linear B tablets is limited, but gives rise to the belief that the palace controlled a restricted set of precious goods, which fuelled the palatial economy. Livestock, including oxen, seem to have been also directly owned (but not only) by the palace (Halstead 1992: 60). If the elites indeed controlled most, if not all, oxen, then allocating them for construction work may have been straightforward, as long as it did not interfere with any requirements of the beasts in agricultural settings, which would likely trump the construction work.

8.3 Discussion

As described in section 3.3, the building style of the studied fortifications is called cyclopean. This name refers back to the ancient myths in which the mighty one-eyed giants, called cyclops, built these walls. Although this is obviously considered a myth today, the name stuck and is still widely used today. Considering the analyses presented in the dissertation, it may be possible to say something about whether the costs (rather than the required force to lift a stone as the myth refers to) involved with building the fortifications are truly gigantic.

In section 8.1.3 above it has been shown that as a building style, cyclopean construction is not necessarily more expensive than other studied styles, based on the calculated labour cost per cubic metre. In comparison, the cost for the used building styles for domestic structures (a combination of rubble and mudbrick) falls within the same range, albeit with fewer extremes and a somewhat lower overall (average) cost. In contrast, the pseudo-ashlar (see chapter 3) style of the conglomerate façades at the Lion- and North Gates at Mycenae is much more expensive (see again section 8.1.3). These results show that indeed a building style can influence the labour costs, but that the cyclopean style is not overly expensive.

As structures of formidable size, the fortifications themselves do end up requiring quite an investment to be built. Although the costs per cubic metre might not, on average, differ dramatically from that of domestic structures, due to their much larger size, the fortifications as a whole cost a lot more than houses. As shown in section 8.1.1 depending on the size of the section of the fortification that is used for comparison, numerous houses could be constructed for the same investment. If these numbers are taken a bit further by using estimates of the number of inhabitants per house, it shows that large parts of the population could be housed for the same expenditure as some sections of the fortifications. This is especially the case for Teichos Dymaion, where the estimations show that the costs for the fortification exceeds the costs for building the required number of houses to accommodate the entire (projected) population.

The analyses in section 8.1.2 show that the steps in the building process that are taken into consideration for the labour cost calculations, have varying effects on the total labour costs. First, for those sections that dressing is taken into account (sections 1 and 2 at Mycenae), it is shown that this is a very laborious activity. The fact that it is used sparingly shows the conscious decision to use this elaboration only at specific locations.

Secondly, for the cyclopean style sections, the quarrying and assembly steps are the most expensive (see figure 8.4). Depending on the scenario used for reconstructing the volume of the blocks, one or the other is the most expensive. This has to do with the fact that in the scenarios in which the maximum total cost is reached the volume of the blocks is larger and thus the costs for the assembly are larger as well. This is because the assembly costs are directly related to the size of the blocks. Hence, the stone size is certainly of influence on the labour costs. Moreover, the fact that some scenarios were usable for Mycenae, but not for Teichos Dymaion shows that there is a different ratio between the surface area and the depth of the blocks for both sites. This has most likely to do with the shape of the blocks, which are more or less boulder-like for Mycenae and slab-like for Teichos Dymaion. This difference has been dealt with by the various scenarios. However, a more thorough study into the actual size of the blocks would therefore be welcome to be able to create an even more nuanced idea about the actual costs of the construction of the fortifications.

Thirdly, it is shown that the size of the documented section has a direct influence on the effect that individual steps in the building process have on the total costs. This is, however, also the effect of the assumptions made by the author to generalize certain steps. The first of those is to begin with calculating the labour costs based on the preserved section and use one ramp per such section. Since the sections are of varying size, the fixed cost of a ramp thus has a greater influence on a small section than it has on a large section. Moreover, the cost of levelling is also relatively higher for sections that have a smaller preserved height, as the cost of levelling is taken per ground surface area of the wall, regardless of height.

In line with this though, it is more economic to fortify larger areas than small ones, as shown in 8.1.1. The cost per fortified area is larger for a small section like section 4 at Mycenae than it is for the larger areas fortified by section 3 at Mycenae or the fortification at Teichos Dymaion. One thing to take into account though, is that for sections 3 and 4 at Mycenae the earlier fortification wall that was present near these locations is not taken into account in the building costs. While there were extra costs involved with breaking down the earlier wall, the available material could be used in the new walls. By doing so, the costs of transport and quarrying would be reduced. In particular having to quarry less material could have a significant impact on the total labour costs (as shown above). This might alter the cost per area for section 4.

Since the fortifications are expensive in comparison to other structures (houses), it should be explored what this signifies. In this light, it might be worthwhile to consider the monumentality of the fortifications. As discussed in section 3.2, there are two reasons for considering this: (1) what influence the monumental status might have for interpreting the fortifications and (2) how the calculated costs may say something about this monumental status.

If monumental constructions are considered a form of conspicuous consumption this may provide further insights into the construction of these fortifications. The higher cost of the pseudo-ashlar style of the façades is a good example of this. First, it is important to realize that the calculated costs cover the façade only, the actual wall it covers is not considered in the costs. Secondly, the choice to only put this type of façade in place at the two gates (thus not counting the two small entrances at the North East Extension), indicates that it is a way to show off the façades. Moreover, if the higher investment that this type of construction requires and the lack of a structural need for the façades are taken into account, it seems logical to place them in highly visible locations. Considering the features of monumentality as described by Trigger (1990; see 3.2), in particular the elaboration of a structure without structural need, the façades fit the description perfectly. Furthermore, they could thus be seen as a form of conspicuous consumption (see 2.2.2 and 3.2) and as such, the façades are used to show, and perhaps gain, power by flaunting the ability to build such elaborations. This style of building should thus indeed be labelled as monumental or monumentalizing. At the very least it can be stated that the elaborations in the form of the façades are not necessary for the primary function of the fortification (protection) as the less expensive cyclopean style was sufficient for that at all other sections of the fortification. This latter point also shows that there was a conscious decision for "economizing", or a form of efficiency in the building process (see also section 5.1.2). This thus fits very well with Trigger's considerations of building processes in which he argues people will take the course that takes the least effort (Trigger 1990: 123; see also section 3.2).

Additionally, the differences between the cyclopean style sections and the façades may indicate that the cyclopean style itself was not seen as a monumental, or special, style. This is corroborated by the fact that from a labour cost perspective the cyclopean style is not overly expensive. That being said, the total required investment for the cyclopean style fortifications are large; some sections of fortifications (or in the case of Teichos Dymaion, the entire fortification) might be over 400 times more expensive than a single house (see 8.1.1). This comparison certainly provided the scale to put the calculated costs on (see 3.2), and as such, one could argue that the fortifications as a whole were monumental. However, such a statement should be further corroborated by researching a larger sample of structures that provided a more diverse range than just two (fortifications and domestic structures).

As discussed in section 3.1 the military nature (their primary function) of the constructions is well established. In light of the discussion on conspicuous consumption, a secondary function of conveying messages as suggested by Maran (2006: 79; see also section 3.2) should also be considered. If the façades (which certainly should) and the fortifications as a whole (which might) are considered monumental and this was taken as an argument that these constructions were indeed a form of conspicuous consumption, then it should be considered what this secondary function signifies. First, if the fortifications were built to counter an imminent (external) threat, there would have been no (structural) need to elaborate the fortifications in the way they were. Second, it would suggest that there was an ongoing need for the elites to keep displaying their wealth (and with that, their power) to stay in control. Clearly though, this could be done in such a way that a very specific use of conspicuous consumption (the façades) was sufficient. If that is the case, however, what does this mean for Teichos Dymaion, where no such elaborations were found? This may signify a number of things; first, it is indeed the façades that are an elaboration and the cyclopean style was not considered an elaborate way of construction. Second, such elaborations where only worthy of palatial sites.

The first conclusion has already been discussed above. The second conclusion shows once more the limitations of what is known about Achaea as a Mycenaean region. Should in the light of these results, Teichos Dymaion be seen as an outpost of a palatial centre elsewhere in Achaea? Alternatively, was it a safe haven for the surrounding region, simply built in the style common in the period? While it lacks the, as above described, monumentalizing elements, these are lacking in most other Mycenaean fortifications. Moreover, the required investment for the fortification itself is still impressive and for a purely military function, a less massive wall would possibly suffice. Hence, to be able to be more conclusive about the status and function of Teichos Dymaion, a more thorough study of the region itself is needed. Furthermore, a more diversified study of Mycenaean fortifications including smaller (*e.g.* Tiryns) as well as larger (*e.g.* Gla) samples, could provide an even more balanced view on the labour costs of fortifications in general.

Finally, as pointed out above, the fortifications were a large undertaking when compared to the construction of domestic buildings and this difference would be even larger if the task of supervision and the use of skilled workers were also taken into account (see 8.2.2 and 8.2.4). This is confirmed when the population estimates are taken into account as well. Although it is important to acknowledge that these conclusions are based on various estimates that each have difficulties in terms of reliability, their consistent use throughout the analyses makes that their relative values are functional. It is thus important to put the labour costs in context of the Mycenaean social and economic situation.

As discussed in chapter 2, various means may have been employed by people or groups of people to gain influence over others. The existence of this social stratification within Mycenaean society is an important feature of how the large buildings are interpreted. First, the elites ordered the construction of the fortifications and organised the required workforce. As pointed out in section 2.3.1, there is evidence from the Linear B tablets that labour was organised by the palatial elite for various tasks, amongst which, construction work (Nakassis 2010: 277). Moreover, it was also described that the mobilisation of such workforces seemed to have been part of a form of tax collection by the palatial elites, likely tied to landholding (*e.g.* Killen 2008: 463; Nakassis 2010: 273). It is slightly more complicated to determine who ends up performing this form of corvée labour, since Killen (1998: 21) has pointed out that from the Linear B tablets it is clear that those who could hold land were all tied to the palace. Yet, it is difficult to assume that it was the elite that performed the actual construction work. It is therefore, more likely that these elites' subservient people executed the work. However, two other parties seem to have been able to hold land: sanctuaries and the damos (*e.g.* Lupack 2011; see also chapter 2). Based on Linear B tablets, both parties also paid taxes to the palace. From this it might follow that the damos might also have paid taxes in the form of workers for palatial driven projects. To what degree these people might also be specialists (like architects or builders) is unclear. As discussed in 8.2.2 these might be brought in from elsewhere for their expertise, or they may have been local specialists.

The social stratification, as mentioned above, also influenced the economic system of Mycenaean society. This system can be best described as a political economy, as described in chapter 2. This means that goods and labour are directed at creating "wealth and to finance institutions of rule" (Earle 2002: 1). As described above the palatial influence allowed the elites to collect taxes not just in the form of goods but also in the form of workforces. However, it has also been pointed out that this palatial system heavily depended on the production of surpluses of subsistence goods. Hence, overtaxing the people producing these by forcing them to perform labour other than farming or herding would potentially disrupt the flow of surplus products to the palace and as such undermine the stability of the hierarchical structure. Certainly, if at the same time other aspects of the economy that were important, such as trade also reduced in profits, serious harm could have been done to the economic system. Moreover, the trading of goods is only possible if primary goods, as produced by farming and herding, are kept up being produced in sufficient numbers. The calculated labour costs and the associated required workforce are therefore aimed at taking into account what part of the overall workforce at the communities are needed to actually construct the fortifications (8.2). This has shown that the local potential workforce at Mycenae might have been sufficient, but at Teichos Dymaion, people would have had to be brought in from beyond the community itself. How this may have affected the need for additional subsistence goods, though, is not taken into account.

The inclusion of the Peloponnese in Mediterranean-wide exchange networks (see 2.3.3), has arguably had a positive effect on its economy (*e.g.* Sherratt 2017: 608, 613). However, as Sherratt (2017, 602) points out that in a 'globalized' (Mediterranean) world, individual localities are linked and local events shape, and are shaped by, events occurring in other, sometimes faraway, localities. Furthermore, she argues that the reason for peoples to search for such connections comes from the desire to acquire previously unknown materials and/or products (Sherratt 2017: 603). Eventually, the exchange network changed, due to the divergence (or lack thereof) of exchanged materials and the change of routes. These might undercut certain nodes in the network with varying effects. The possible effects from events outside of the Peloponnese have not been taken into proper account here. However taking the results from this study, it is possible to put these in a Mediterranean, rather than a Peloponnesian, context, in a future study.

The question remains whether the impact of these investments would have been enough to drain the economic resources to such a degree to disrupt the way of life at the end of the Mycenaean period. The palaces were surely able to draft people from beyond the citadel sites themselves and even with a (relatively) limited amount of people, these fortifications could be constructed. Even though they might still be considered large undertakings, especially in comparison to other types of constructions, like houses, it seems to have been within the capabilities of the communities to carry these burdens. This is somewhat more difficult to assess for Teichos Dymaion, as less is known about the region and its possible connection to an actual palatial site (see chapter 4). As pointed out, the population of the rural hinterland of the settlements is not taken into account. These people may have been a serious addition to the potential labour force of both settlements and thus further limiting the effect the construction of the fortifications may have had on the communities. Further studies into reliable reconstructions of the rural populations would add greatly to the interpretations of this study.

The assumption that the communities at the citadels (and beyond) could carry the burdens of the constructions is based on a secondary assumption: that no other (large) disruptions of any kind were taking place around the same time. If there was indeed the threat of, or actual, war combined with circumstances that put pressure on the economic system (as discussed in chapter 2 and above) due to draughts and/or changes to the exchange network(s), on top of the elaborate building programmes, it might pose a credible threat to a stable society. However, as shown in section 2.4, there is no definitive proof for any of these possibilities. It is, therefore, perhaps best to follow Deger-Jalkotzy (2008: 392) in concluding that many factors probably had an influence, and that internal factors (like straining the local economies by taking on these large building programmes) laid the groundwork for a destabilisation of the Mycenaean communities, which were therefore weakened after which further complications of any kind could be enough to bring about this final "collapse" (see also Bennet, 2013; Middleton, 2010). The construction of the fortifications on their own and focussing on a Peloponnesian context, though, does not seem to have been the (immediate) cause for the large-scale decline at Mycenaean settlements.

8.4 Concluding remarks

In this chapter the calculated labour costs, as presented in chapter 7, were analysed. This was done through various comparisons, which show that various characteristics of the fortification walls have diverse effects on the required investments. Furthermore, it has been shown that the cyclopean style of construction is not an overly expensive style, while the conglomerate façade is. The latter is clearly an elaborate adornment placed in very visible locations. However, due to the sheer size of the fortifications they are serious investments, this is underlined by comparing these investments to the expenditure required for domestic structures. Finally, these results were analysed in connection to the Mycenaean social and economic structure, in which these fortifications were built. In the concluding chapter the final thoughts on the topic will be presented, the research questions, as introduced in chapter 1, will be answered and ideas for future research will be shared.

Chapter 9

Conclusions

This research has focussed on calculating the required investment to construct the fortifications from the Mycenaean era in Greece. Subsequently, the aim was to interpret these labour costs in light of the Mycenaean social and economic structure, as discussed in chapter 2. Ultimately, this was aimed at providing insights into the question whether the construction of large buildings should be considered such a high investment that it may have disrupted a community's economic system (see section 2.4). Although the latter question is part of the larger SETinSTONE project, this study will certainly prove crucial in answering the above-mentioned question.

9.1 Overview of the study and answering the research questions

In order to help answering that overarching question, the research questions as presented in the introduction will be answered. Tackling these research questions was done by executing a so-called labour cost study. Such a study aims to quantify an object, in this case fortifications, in terms of volume and apply certain rates that describe the amount of effort it takes to perform the various tasks associated with it. As described in chapter 5, this approach has pros and cons, but when used consistently and comparatively such analyses can be very informative. The case studies that were used for these calculations are Mycenae and Teichos Dymaion (see chapter 4). While they are both located on the Peloponnese and both have cyclopean style fortifications, they are also very different sites. This made them excellent for comparisons, to see if their differences affected the interpretations of the labour costs.

In order to interpret the outcomes of the calculations properly, a study into the Mycenaean context was crucial. In chapter 2 the social and economic structure of this context was therefore explored. This showed that Mycenaean society seems to have a strong social stratigraphy that is also intertwined with its economic structure. As such, both the social stratigraphy and the economic structure influence and might have been influenced by, the construction of the large fortifications (section 8.3). Moreover, to be able to perform the labour cost analyses on the structures, a proper understanding of the structures and their build-up was also required. Hence, in chapter 3 the function, the way they are perceived and their building-style and method were explored. This entailed not just the technical aspects of their build-up and stylistic descriptions of the walls and their elements but also a discussion on how the perception that people have of these walls affects the interpretations of their function and the labour costs.

The later chapters in this book deal with the collected data (chapter 6) and the subsequent calculations of the labour costs based on these data (chapter 7). In chapter 8, the interpretations of these costs were presented. It was shown that the fortifications are indeed expensive structures when compared to the more mundane domestic structures that were also studied. Moreover, some steps in the building process, such as dressing (where applicable), quarrying and the assembly of the walls, are more laborious than others. Moreover, it was shown that the conglomerate façades are an expensive elaboration, whereas the cyclopean-style construction is, as a style, not overly expensive.

Based on the assumed required workforce, the projects would not take overly long and seem to be manageable when compared to the possible population numbers: at least at Mycenae. The far smaller population at Teichos Dymaion may have struggled with the construction project and would have needed to bring in people from beyond its own community to cope with the required workforce.

As such, the research questions can be answered as follows:

1. How high are the costs (in labour) of the various stages of construction of monumental buildings in Mycenaean Greece?

This question is answered in as much that an overview of the costs for the studied sections and for the various steps within the building process are presented in chapters 7 and 8. The entire fortification at Teichos Dymaion was built in one phase. However, the fortification at Mycenae was built in separate phases and it is thus more realistic to provide the costs for the individual projects.

	Section	Minimum costs (ph)	Maximum costs (ph)	Minimum days	Maximum days
Mycenae	1: Lion Gate	44,851	70,902	12	58
	2: North Gate	5,202	8,717	4	18
	3: West Wall	116,399	1,104,056	126	629
	4: North East Extension	41,882	289,175	32	160
Teichos Dymaion	Complete fortification	124,587	1,185,927	117	669

2. What characterizes the Mycenaean fortifications and how do these features influence the labour costs?

This question has been partly answered in chapter 3, where an overview was presented about the fortifications in general and some of its specific characteristics as well. Moreover, the labour cost analyses have also provided interesting insights into some of the features of the Mycenaean fortifications. Firstly, two building styles can be identified that are used in the fortifications: the cyclopean style and the pseudo-ashlar style. The cyclopean style is widely used in Mycenaean fortifications and consists of large unshaped blocks with smaller stones in between. Moreover, the style is not overly expensive as a way of building when the costs per cubic metre are considered. The second style is the opposite: it is only sparingly used and as a building style it is very expensive. Hence, at least the latter can be seen as a form of conspicuous consumption and as monumentalizing. As such, these elaborations were likely used by the ruling elites to display their wealth and power, which in return, helped them to retain that power. Various characteristics of the fortifications thus influenced the labour costs and the labour costs also showed the differences between some of the features of the fortifications.

3. What do the costs of these monumental structures tell us about the structure of Mycenaean society and the distribution of its wealth and power?

This research question has also been mostly answered in chapter 8. Largely, this study assumes that the construction of the large-scale fortifications fits in the already existing ideas about the Mycenaean societal and economic structure. Hence, the construction of these buildings shows that a strong elite existed that had extensive control over various sectors of society, its economy and the people to be able to get these fortifications built. The elites' ability to collect surpluses generated by others as well as being able to mobilise labour forces for a variety of tasks, amongst which construction, show that at least in that regard their influence was far reaching. In other sectors, such as trade, their influence might have been less, but it can be questioned whether this has any immediate effect on their ability to muster required labour forces and finance this. Finally, this study has shown that there was a need for a strong elite that could mobilise a labour force, either through corvée labour or by hiring workers. In both cases, it shows that the elites were in control of important sectors of Mycenaean society and had the power and/or the wealth to mobilise the required workforce. The construction of the fortifications themselves, do not seem to have been the cause of the decline of Mycenaean communities at the end of the LBA.

4. Is the construction of monumental architecture in Mycenaean Greece a local, regional or inter-regional affair, when we consider the origin of the material, required expertise and workforce and construction techniques?

The final research question is mostly answered. It was assumed, based on finds by others, that the material for both case-studies was quarried locally. Even the conglomerate material at Mycenae is only a few kilometres away and is thus considered local. With regards to the required workforce, this is slightly different. For Mycenae, based on the population estimates, it could have been a local endeavour, in that it seems that the local potential workforce could be sufficient to perform the construction work. However, if a larger workforce is required, or preferred, people would have had to be brought in from beyond the community itself. For Teichos Dymaion the population estimates show that there was definitely a need to bring people in from beyond the community to be able to construct the fortification. In this case the project should thus be seen as a regional endeavour. What kind of effect the bringing in of people from the rural hinterland to the settlement may have had on this hinterland is difficult to gauge. A more thorough study into the size of the rural population in the region could shed further light on this issue (but see Timonen: forthcoming).

With regards to the used construction techniques and the required expertise, the research question is less well answered. The construction techniques have largely been assumed to have been similar to those used at other prehistoric building projects. Whether these techniques were always locally available (this is tied to expertise) is not researched. In line with this, the required expertise for building these structures is not properly studied. In particular because it is very difficult to determine where the person having the required expertise may have come from. While there are specific construction jobs being mentioned on the Linear B tablets, there is no information where the builders may have come from, if not locally available. For these two factors it is thus undetermined whether the construction projects should be considered local or regional. Considering the widespread use of the cyclopean style though, it seems fair to assume that expertise was shared (perhaps through elite gift-giving or hiring) amongst Mycenaean communities. This would thus imply that the construction could be seen as an inter-regional affair.

9.2 Evaluating the study and looking ahead

Finally, a look ahead to future directions for this type of research would be beneficial. Doing so, though, requires to critically evaluating the way the current study was executed. The two are combined here.

First, the selection of sections, particularly at Mycenae, may not have been ideal. It would have been great to incorporate a section from the very first phase (to see if there were developments over time) and to have done a more thorough study before the selection about which sections may contain modern reconstructions. While this may not have altered the results significantly, using as original as possible sections would have been preferable to avoid any possible contaminations of the analyses.

Secondly, it would have been better to do a more comprehensive evaluation of the fieldwork approaches used. The total station recording is time consuming and does not provide additional useable accuracy, within this research context. Moreover, while the subsequent use of reconstructed volumes of blocks has shown that block size does matter for the labour costs, the current model is too arbitrary. A more data-driven statistical approach to determine how many categories and of what size would greatly benefit the approach.

Thirdly, while the choice to use ranges, rather than singular fixed rates for some of the steps in the building process helps to avoid too low or too high final costs, it does show that there is no consensus about these activities. Additionally, a certain optimal efficiency is used, as no idling is assumed in the calculations here. This is somewhat problematic as was shown for the assembly process in section 7.6, where the reconstructed process produced unrealistic low labour costs. More experimental research might be a great way to get more insights about how certain tasks are organised and at what rate they can be realistically done and perhaps also for what period of time. Since one can determine a rate for a volume per person-hour, but there is no guarantee that that same rate can be maintained for a number of consecutive hours, hence lowering the effective rate over longer periods.

Fourthly, considering the reconstructed manner in which the construction processes took place, this approach could greatly benefit from simulating the processes. These types of scenarios would be very well suited for an Agent Based Modelling (ABM) approach (*e.g.* Kowarik et al. 2012). This is due to the fact that ABMs have the ability to cope with multiple variables simultaneously as well as having the potential to "model social phenomena on a very advanced level" (Kowarik et al. 2012: 17). Moreover, "the bottom-up approach inherent, ABM enables researchers to address individual actions and emergence" (Kowarik et al. 2012: 17). Thus, such an approach would allow to also factor in the social interactions, as well as model matters such as idling when one process is holding up another. Moreover, the influence of the workforce on the project as well as on potentially other societal factors can be modelled. In the case of this research, all this would even be a very manageable step, as all the information is here, but it needs to be put in a modelling software and adjusted accordingly.

Finally, this study has shown a number of interesting features of Mycenaean Greece and its fortifications, such as:

1. the enormous differentiation of size in the stones used and the effect this has on labour costs;
2. large-scale building projects might be more manageable than the impressive size of the constructions might suggest at first glance;
3. there are large regional differences in an area that is commonly referred to as Mycenaean Greece, suggesting a much more unified entity than in reality might be the case;
4. while monumentality remains a difficult label in archaeological contexts, quantification of objects might actually shed light on such a qualitative term.

Because of this, the research presented in this book adds to the knowledge and understanding of fortifications and Mycenaean Greece as a whole. While there is still much to discover, which offers a variety of future research possibilities, systematic archaeologists uncover more and more about this fascinating period and region, and this study has offered such a (small) step in this trajectory. The results of the other studies executed within the SETinSTONE project will provide similar steps towards this trajectory. The studies by Turner (2020) on the labour costs of tombs and by Timonen (forthcoming) on subsistence strategies and carrying capacity of the Argive Plain, as well as the work by Brysbaert, Klinkenberg and Vikatou, will all contribute towards the goals of the SETinSTONE project. By doing so, the SETinSTONE projects aims to gain more in-depth insights into the workings of the political and socio-economic structures of Mycenaean polities and how these were affected by various activities, such as large-scale building programmes.

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Curriculum Vitae

Yannick Boswinkel (Schiedam 1987) started his archaeological education in 2009 at the Faculty of Archaeology, Leiden University. After successful completion of the Bachelor focused on Classical Archaeology and Digital Archaeology and a thesis dealing with a Late Roman structure on the site of Koroneia, Greece, he participated in the 'Recycling a Valley' project in Jordan of the National Museum of Antiquities, Leiden. He subsequently completed the two-year research master 'Town and Country in the Mediterranean and the Near East', also at Leiden, from which he graduated cum laude in 2015. For the thesis produced during this time he focused once more on Koroneia, but this time included all the architectural remains documented at the site.

During his time as a student he had several student-assistant positions at various projects in- and outside the Faculty of Archaeology. These comprised various digitization projects, database design and student supervision during fieldwork in Greece. Moreover, he was a member of the Education Committee for two years (2010-2012) and of the Faculty Council for one year (2014-2015) during this time as well. In addition to this, he was co-organizer of the student initiated symposium 'A Theoretical Approach to Ancient Housing', as well as co-author and co-editor of the proceedings of that same symposium.

In 2016 he started his PhD project in the SETinSTONE project, led by Prof. dr. Ann Brysbaert at the Faculty of Archaeology, Leiden University. The study into the investment required for large scale fortifications in Mycenaean Greece, was finished in four years and resulted in the book before you. Within the same period, Yannick was also head of the Faculty Council at the same institute for two years (2017-2019) and an editor for the journal INTER-SECTION for three years (2016-2019).

Between 2012 to 2016 Yannick was involved in the 'Ancient Cities of Boeotia' project, led by Prof. dr. John Bintliff. Within this project he was involved in the survey and subsequent study of the architectural remains at three archaeological sites: Koroneia, Hyettos and Haliartos, all in Boeotia, Greece.

After finishing his PhD, Yannick gained a position as a project manager with an engineering firm, Econsultancy.

Appendices

Appendix 1 Overview of the calculated volumes of material for domestic structures

This table provides an overview of the volumes of the used materials according to the size of the house, its walls and the way it is build. For each size category of the domestic structure (75 – 370 m²), six scenarios are used in which different characteristics of the structure are assigned varying values (as described in chapter 4). The size categories are indicated through the colour in the column, with each size having a different colour. In the table all measurements are in metres, the surface area in square metres and the volume in cubic metres.

Scenario	Height per floor	Second storey	Height stone socle	Height Mudbrick wall	Ground size structure	% wall ground surface	Width of walls	Stone	Mudbrick	Clay plaster Walls (5cm thick)	Clay plaster floors (5cm thick)	Clay plaster floors (20cm thick)	Clay roof 20cm	Wood / floor	Twigs 5cm thick / floor
1	2.5	no	1	1.5	75	38	0.5	28.5	42.8	7.1	2.3	9.3	15.0	2.3	3.8
2	2.5	yes	1	4	75	38	0.75	28.5	114.0	9.5	4.7	18.6	15.0	2.3	3.8
3	2.5	yes	5	0	75	38	0.75	142.5	0.0	9.5	4.7	18.6	15.0	2.3	3.8
4	2.5	no	2.5	0	75	38	0.5	71.3	0.0	7.1	2.3	9.3	15.0	2.3	3.8
5	2.5	yes	2.5	2.5	75	38	0.75	71.3	71.3	9.5	4.7	18.6	15.0	2.3	3.8
6	2.5	no	1	1.5	75	50	0.5	37.5	56.3	9.4	1.9	7.5	15.0	2.3	3.8
7	2.5	no	1	1.5	110	38	0.5	41.8	62.7	10.5	3.4	13.6	22.0	3.6	5.5
8	2.5	yes	1	4	110	38	0.75	41.8	167.2	13.9	6.8	27.3	22.0	3.6	5.5
9	2.5	yes	5	0	110	38	0.75	209.0	0.0	13.9	6.8	27.3	22.0	3.6	5.5
10	2.5	no	2.5	0	110	38	0.5	104.5	0.0	10.5	3.4	13.6	22.0	3.6	5.5
11	2.5	yes	2.5	2.5	110	38	0.75	104.5	104.5	13.9	6.8	27.3	22.0	3.6	5.5
12	2.5	no	1	1.5	110	50	0.5	55.0	82.5	13.8	2.8	11.0	22.0	3.6	5.5
13	2.5	no	1	1.5	160	38	0.5	60.8	91.2	15.2	5.0	19.8	32.0	5.0	8.0
14	2.5	yes	1	4	160	38	0.75	60.8	243.2	20.3	9.9	39.7	32.0	5.0	8.0
15	2.5	yes	5	0	160	38	0.75	304.0	0.0	20.3	9.9	39.7	32.0	5.0	8.0
16	2.5	no	2.5	0	160	38	0.5	152.0	0.0	15.2	5.0	19.8	32.0	5.0	8.0
17	2.5	yes	2.5	2.5	160	38	0.75	152.0	152.0	20.3	9.9	39.7	32.0	5.0	8.0
18	2.5	no	1	1.5	160	50	0.5	80.0	120.0	20.0	4.0	16.0	32.0	5.0	8.0
19	2.5	no	1	1.5	200	38	0.5	76.0	114.0	19.0	6.2	24.8	40.0	6.4	10.0
20	2.5	yes	1	4	200	38	0.75	76.0	304.0	25.3	12.4	49.6	40.0	6.4	10.0
21	2.5	yes	5	0	200	38	0.75	380.0	0.0	25.3	12.4	49.6	40.0	6.4	10.0
22	2.5	no	2.5	0	200	38	0.5	190.0	0.0	19.0	6.2	24.8	40.0	6.4	10.0

Scenario	Height per floor	Second storey	Height stone socle	Height Mudbrick wall	Ground size structure	% wall ground surface	Width of walls	Stone	Mudbrick	Clay plaster Walls (5cm thick)	Clay plaster floors (5cm thick)	Clay plaster floors (20cm thick)	Clay roof 20cm	Wood / floor	Twigs 5cm thick / floor
23	2.5	yes	2.5	2.5	200	38	0.75	190.0	190.0	25.3	12.4	49.6	40.0	6.4	10.0
24	2.5	no	1	1.5	200	50	0.5	100.0	150.0	25.0	5.0	20.0	40.0	6.4	10.0
25	2.5	no	1	1.5	250	38	0.5	95.0	142.5	23.8	7.8	31.0	50.0	7.7	12.5
26	2.5	yes	1	4	250	38	0.75	95.0	380.0	31.7	15.5	62.0	50.0	7.7	12.5
27	2.5	yes	5	0	250	38	0.75	475.0	0.0	31.7	15.5	62.0	50.0	7.7	12.5
28	2.5	no	2.5	0	250	38	0.5	237.5	0.0	23.8	7.8	31.0	50.0	7.7	12.5
29	2.5	yes	2.5	2.5	250	38	0.75	237.5	237.5	31.7	15.5	62.0	50.0	7.7	12.5
30	2.5	no	1	1.5	250	50	0.5	125.0	187.5	31.3	6.3	25.0	50.0	7.7	12.5
31	2.5	no	1	1.5	300	38	0.5	114.0	171.0	28.5	9.3	37.2	60.0	9.1	15.0
32	2.5	yes	1	4	300	38	0.75	114.0	456.0	38.0	18.6	74.4	60.0	9.1	15.0
33	2.5	yes	5	0	300	38	0.75	570.0	0.0	38.0	18.6	74.4	60.0	9.1	15.0
34	2.5	no	2.5	0	300	38	0.5	285.0	0.0	28.5	9.3	37.2	60.0	9.1	15.0
35	2.5	yes	2.5	2.5	300	38	0.75	285.0	285.0	38.0	18.6	74.4	60.0	9.1	15.0
36	2.5	no	1	1.5	300	50	0.5	150.0	225.0	37.5	7.5	30.0	60.0	9.1	15.0
37	2.5	no	1	1.5	370	38	0.5	140.6	210.9	35.2	11.5	45.9	74.0	9.1	18.5
38	2.5	yes	1	4	370	38	0.75	140.6	562.4	46.9	22.9	91.8	74.0	9.1	18.5
39	2.5	yes	5	0	370	38	0.75	703.0	0.0	46.9	22.9	91.8	74.0	9.1	18.5
40	2.5	no	2.5	0	370	38	0.5	351.5	0.0	35.2	11.5	45.9	74.0	9.1	18.5
41	2.5	yes	2.5	2.5	370	38	0.75	351.5	351.5	46.9	22.9	91.8	74.0	9.1	18.5
42	2.5	no	1	1.5	370	50	0.5	185.0	277.5	46.3	9.3	37.0	74.0	9.1	18.5

Appendix 2 Overview of the calculations of the volume of the blocks according to the scenarios used

This appendix provides an overview of the maximum volume of the blocks in each size group for the various sections according to the scenarios (as described in chapter 4). These volumes and weights are used in the calculations of the transport costs as well as the assembly costs. In the table the surface area is in square metres, the volume in cubic metres and the weight in kilograms. Since no reconstructions of the volume are used for sections 1 and 2 at Mycenae, these are not present in the table below.

Mycenae								
Section 3								
Scenario I	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.03	0.0014	3.40	56	0.08	190.55	
	Group 2	0.08	0.0075	18.85	55	0.41	1,036.81	
	Group 3	0.54	0.4344	1,086.12	56	24.33	60,822.50	
	Group 4	1.88	2.2553	5,638.27	55	124.04	310,104.63	
	Total				222	148.86	372,154.49	
Scenario II	Size group	Max. weight / group	% of total	Max. weight / group	Max. weight / stone	Max. vol. / stone	Max. depth / stone	
	Group 1	190.55	0.0512	242.32	4.33	0.00	0.06	
	Group 2	1,036.81	0.2786	1,318.45	23.97	0.01	0.13	
	Group 3	60,822.50	16.3433	77,344.89	1,381.16	0.55	1.02	
	Group 4	310,104.63	83.3269	394,344.34	7,169.90	2.87	1.53	
	Total	372,154.49		473,250.00				
Scenario III	Size group	Max. surface area / block	Max. vol.	% total volume	Max. vol. / group	Max. weight / group	# of stones	Max. weight / stone
	Group 1	0.10	0.0048	1.35	2.55	6,368.51	56	113.72
	Group 2	0.33	0.0333	3.86	7.31	18,273.61	55	332.25
	Group 3	0.81	0.6519	22.04	41.72	104,307.23	56	1,862.63
	Group 4	1.88	2.2553	72.75	137.72	344,300.62	55	6,260.01
	Total				189.30	473,249.96	222	
Scenario IV	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.03	0.0090	22.46	56	0.50	1,257.59	
	Group 2	0.08	0.0414	103.53	55	2.28	5,694.09	
	Group 3	0.54	0.8004	2,000.96	56	44.82	112,054.00	
	Group 4	1.88	2.5765	6,441.34	55	141.71	354,273.90	
	Total				222	189.31	473,279.57	
Scenario V	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.03	0.0045	11.23	56	0.25	628.79	
	Group 2	0.08	0.0207	51.76	55	1.14	2,847.04	
	Group 3	0.54	0.4002	1,000.48	56	22.41	56,027.00	
	Group 4	1.88	2.5765	6,441.34	55	141.71	354,273.90	
	Total				222	165.51	413,776.74	

Scenario VI	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.10	0.0097	24.23	126	1.22	3,052.48
	Group 2	0.33	0.1666	416.60	20	3.33	8,332.05
	Group 3	0.81	0.6519	1,629.83	49	31.94	79,861.47
	Group 4	1.88	2.2553	5,638.27	27	60.89	152,233.18
	Total				222	97.39	243,479.18

Scenario VII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.10	0.0603	150.83	126	7.60	19,004.35
	Group 2	0.33	0.3848	962.03	20	7.70	19,240.56
	Group 3	0.81	1.4713	3,678.21	49	72.09	180,232.44
	Group 4	1.88	2.5765	6,441.34	27	69.57	173,916.28
	Total				222	156.96	392,393.63

Scenario VIII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.10	0.0302	75.41	126	3.80	9,502.18
	Group 2	0.33	0.1924	481.01	20	3.85	9,620.28
	Group 3	0.81	0.7356	1,839.11	49	36.05	90,116.22
	Group 4	1.88	2.5765	6,441.34	27	69.57	173,916.28
	Total				222	113.26	283,154.95

Section 4

Scenario I	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0003	0.87	43	0.01	37.30
	Group 2	0.02	0.0010	2.60	42	0.04	108.99
	Group 3	0.16	0.0657	164.27	42	2.76	6,899.38
	Group 4	0.97	0.4849	1,212.25	42	20.37	50,914.50
	Total				169	23.18	57,960.17

Scenario II	Size group	Max. weight / group	% of total	Max. weight / group	Max. weight / stone	Max. vol. / stone	Max. depth / stone
	Group 1	37.30	0.0644	40.06	0.93	0.00	0.04
	Group 2	108.99	0.1880	117.06	2.79	0.00	0.05
	Group 3	6,899.38	11.9037	7,410.03	176.43	0.07	0.43
	Group 4	50,914.50	87.8439	54,682.85	1,301.97	0.52	0.54
	Total	57,960.17		62,250.00			

Scenario III	Size group	Max. surface area / block	Max. vol.	% total volume	Max. vol. / group	Max. weight / group	# of stones	Max. weight / stone
	Group 1	0.10	0.0048	0.93	0.23	581.78	43	13.53
	Group 2	0.33	0.0333	2.54	0.63	1,581.09	42	37.65
	Group 3	0.81	0.6519	11.54	2.87	7,180.58	42	170.97
	Group 4	1.88	2.2553	84.99	21.16	52,906.55	42	1,259.68
	Total				24.90	62,250.00	169	

Scenario IV	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0016	4.04	43	0.07	173.72
	Group 2	0.02	0.0060	14.96	42	0.25	628.15
	Group 3	0.16	0.1332	332.90	42	5.59	13,981.72
	Group 4	0.97	0.9550	2,387.61	42	40.11	100,279.59
	Total				169	46.03	115,063.18

Scenario V	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0008	2.02	43	0.03	86.86
	Group 2	0.02	0.0030	7.48	42	0.13	314.07
	Group 3	0.16	0.0666	166.45	42	2.80	6,990.86
	Group 4	0.97	0.9550	2,387.61	42	40.11	100,279.59
	Total				169	43.07	107,671.39

Scenario VI	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.12	0.0119	29.69	125	1.48	3,711.75
	Group 2	0.37	0.1839	459.73	22	4.05	10,114.09
	Group 3	0.60	0.4791	1,197.82	15	7.19	17,967.30
	Group 4	0.97	0.9698	2,424.43	7	6.79	16,971.01
	Total				169	19.51	48,764.15

Scenario VII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.12	0.0819	204.67	125	10.23	25,584.27
	Group 2	0.37	0.4461	1,115.22	22	9.81	24,534.87
	Group 3	0.60	0.9270	2,317.46	15	13.90	34,761.91
	Group 4	0.97	0.9550	2,387.51	7	6.69	16,712.54
	Total				169	40.64	101,593.59

Scenario VIII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.12	0.0409	102.34	125	5.12	12,792.14
	Group 2	0.37	0.2230	557.61	22	4.91	12,267.43
	Group 3	0.60	0.4635	1,158.73	15	6.95	17,380.95
	Group 4	0.97	0.9550	2,387.51	7	6.69	16,712.54
	Total				169	23.66	59,153.07

Teichos Dymaion

Section 1

Scenario I	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.02	0.0008	2.01	86	0.07	172.86
	Group 2	0.07	0.0068	17.05	86	0.59	1,466.68
	Group 3	0.30	0.1810	452.44	85	15.38	38,457.47
	Group 4	1.84	2.2059	5,514.68	85	187.50	468,748.14
	Total				342	203.54	508,845.15

Scenario II	Size group	Max. weight / group	% of total	Max. weight / group	Max. weight / stone	Max. vol. / stone	Max. depth / stone	
	Group 1	172.86	0.0340	120.26	1.40	0.00	0.03	
	Group 2	1,466.68	0.2882	1,020.36	11.86	0.00	0.07	
	Group 3	38,457.47	7.5578	26,754.59	314.76	0.13	0.42	
	Group 4	468,748.14	92.1200	326,104.79	3,836.53	1.53	0.83	
	Total	508,845.15		354,000.00				
Scenario III	Size group	Max. surface area / block	Max. vol.	% total volume	Max. vol. / group	Max. weight / group	# of stones	Max. weight / stone
	Group 1	0.10	0.0048	1.20	1.70	4,252.85	86	49.45
	Group 2	0.33	0.0333	4.06	5.75	14,374.17	86	167.14
	Group 3	0.81	0.6519	24.00	33.98	84,958.13	85	999.51
	Group 4	1.88	2.2553	70.74	100.17	250,414.85	85	2,946.06
	Total				141.60	354,000.00	342	
Scenario IV	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.02	0.0041	10.20	86	0.35	876.81	
	Group 2	0.07	0.0356	89.09	86	3.06	7,661.47	
	Group 3	0.30	0.3313	828.28	85	28.16	70,403.59	
	Group 4	1.84	2.4923	6,230.73	85	211.84	529,612.22	
	Total				342	243.42	608,554.10	
Scenario V	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.02	0.0020	5.10	86	0.18	438.41	
	Group 2	0.07	0.0178	44.54	86	1.53	3,830.74	
	Group 3	0.30	0.1657	414.14	85	14.08	35,201.79	
	Group 4	1.84	2.4923	6,230.73	85	211.84	529,612.22	
	Total				342	227.63	569,083.16	
Scenario VI	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.14	0.0142	35.46	205	2.91	7,270.07	
	Group 2	0.37	0.1871	467.67	68	12.72	31,801.22	
	Group 3	0.72	0.5736	1,433.90	59	33.84	84,599.86	
	Group 4	1.84	2.2059	5,514.68	10	22.06	55,146.84	
	Total				342	71.53	178,817.99	
Scenario VII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.14	0.1069	267.14	205	21.91	54,763.45	
	Group 2	0.37	0.4577	1,144.21	68	31.12	77,806.56	
	Group 3	0.72	1.2141	3,035.30	59	71.63	179,082.65	
	Group 4	1.84	2.4923	6,230.73	10	24.92	62,307.32	
	Total				342	149.58	373,959.98	

Scenario VIII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.14	0.0534	133.57	205	10.95	27,381.73
	Group 2	0.37	0.2288	572.11	68	15.56	38,903.28
	Group 3	0.72	0.6071	1,517.65	59	35.82	89,541.32
	Group 4	1.84	2.4923	6,230.73	10	24.92	62,307.32
	Total				342	87.25	218,133.65

Section 2

Scenario I	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0004	0.89	153	0.05	136.76
	Group 2	0.02	0.0019	4.70	152	0.29	714.02
	Group 3	0.05	0.0253	63.33	152	3.85	9,626.45
	Group 4	1.26	1.2584	3,146.01	152	191.28	478,193.14
	Total				609	195.47	488,670.37

Scenario II	Size group	Max. weight / group	% of total	Max. weight / group	Max. weight / stone	Max. vol. / stone	Max. depth / stone
	Group 1	136.76	0.0280	55.89	0.37	0.00	0.02
	Group 2	714.02	0.1461	291.79	1.92	0.00	0.04
	Group 3	9,626.45	1.9699	3,933.94	25.88	0.01	0.20
	Group 4	478,193.14	97.8560	195,418.38	1,285.65	0.51	0.41
	Total	488,670.37		199,700.00			

Scenario III	Size group	Max. surface area / block	Max. vol.	% total volume	Max. vol. / group	Max. weight / group	# of stones	Max. weight / stone
	Group 1	0.10	0.0048	1.19	0.95	2,376.35	153	15.53
	Group 2	0.33	0.0333	3.38	2.70	6,740.03	152	44.34
	Group 3	0.81	0.6519	9.17	7.33	18,315.35	152	120.50
	Group 4	1.88	2.2553	86.26	68.91	172,268.26	152	1,133.34
	Total				79.88	199,700.00	609	

Scenario IV	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0012	3.02	153	0.19	462.61
	Group 2	0.02	0.0052	12.88	152	0.78	1,957.51
	Group 3	0.05	0.0228	57.02	152	3.47	8,667.27
	Group 4	1.26	1.4117	3,529.15	152	214.57	536,430.19
	Total				609	219.01	547,517.57

Scenario V	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0006	1.51	153	0.09	231.30
	Group 2	0.02	0.0026	6.44	152	0.39	978.75
	Group 3	0.05	0.0114	28.51	152	1.73	4,333.63
	Group 4	1.26	1.4117	3,529.15	152	214.57	536,430.19
	Total				609	216.79	541,973.88

Scenario VI	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.07	0.0072	18.00	485	3.49	8,731.09	
	Group 2	0.23	0.1161	290.18	55	6.38	15,959.76	
	Group 3	0.54	0.4283	1,070.79	44	18.85	47,114.94	
	Group 4	1.26	1.5101	3,775.21	25	37.75	94,380.23	
	Total				609	66.47	166,186.01	
Scenario VII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.07	0.0386	96.62	485	18.74	46,858.88	
	Group 2	0.23	0.2237	559.24	55	12.30	30,758.37	
	Group 3	0.54	0.7835	1,958.77	44	34.47	86,185.97	
	Group 4	1.26	1.4117	3,529.15	25	35.29	88,228.65	
	Total				609	100.81	252,031.87	
Scenario VIII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.07	0.0193	48.31	485	9.37	23,429.44	
	Group 2	0.23	0.1118	279.62	55	6.15	15,379.18	
	Group 3	0.54	0.3918	979.39	44	17.24	43,092.99	
	Group 4	1.26	1.4117	3,529.15	25	35.29	88,228.65	
	Total				609	68.05	170,130.26	
Section 3								
Scenario I	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group	
	Group 1	0.01	0.0004	1.12	100	0.04	112.01	
	Group 2	0.03	0.0033	8.13	100	0.33	812.55	
	Group 3	0.21	0.1046	261.44	100	10.46	26,143.88	
	Group 4	2.19	2.1912	5,477.95	99	216.93	542,317.05	
	Total				399	227.75	569,385.49	
Scenario II	Size group	Max. weight / group	% of total	Max. weight / group	Max. weight / stone	Max. vol. / stone	Max. depth / stone	
	Group 1	112.01	0.0197	48.22	0.48	0.00	0.02	
	Group 2	812.55	0.1427	349.77	3.50	0.00	0.04	
	Group 3	26,143.88	4.5916	11,254.00	112.54	0.05	0.22	
	Group 4	542,317.05	95.2460	233,448.01	2,358.06	0.94	0.43	
	Total	569,385.49	245,100.0000	245,100.00				
Scenario III	Size group	Max. surface area / block	Max. vol.	% total volume	Max. vol. / group	Max. weight / group	# of stones	Max. weight / stone
	Group 1	0.10	0.0048	0.76	0.75	1,869.91	100	18.70
	Group 2	0.33	0.0333	2.74	2.68	6,711.44	100	67.11
	Group 3	0.81	0.6519	13.31	13.05	32,622.00	100	326.22
	Group 4	1.88	2.2553	83.19	81.56	203,896.64	99	2,059.56
	Total				98.04	245,100.00	399	

Scenario IV	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0017	4.24	100	0.17	424.14
	Group 2	0.03	0.0117	29.30	100	1.17	2,929.78
	Group 3	0.21	0.1913	478.26	100	19.13	47,825.54
	Group 4	2.19	3.2435	8,108.81	99	321.11	802,772.13
	Total				399	341.58	853,951.59
Scenario V	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0008	2.12	100	0.08	212.07
	Group 2	0.03	0.0059	14.65	100	0.59	1,464.89
	Group 3	0.21	0.0957	239.13	100	9.57	23,912.77
	Group 4	2.19	3.2435	8,108.81	99	321.11	802,772.13
	Total				399	331.34	828,361.86
Scenario VI	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.16	0.0163	40.70	288	4.69	11,720.23
	Group 2	0.48	0.2381	595.37	64	15.24	38,103.92
	Group 3	0.90	0.7162	1,790.54	32	22.92	57,297.22
	Group 4	2.19	2.1912	5,477.95	15	32.87	82,169.25
	Total				399	75.72	189,290.62
Scenario VII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.16	0.1314	328.38	288	37.83	94,573.19
	Group 2	0.48	0.6574	1,643.57	64	42.08	105,188.80
	Group 3	0.90	1.6942	4,235.46	32	54.21	135,534.64
	Group 4	2.19	3.2435	8,108.81	15	48.65	121,632.14
	Total				399	182.77	456,928.77
Scenario VIII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.16	0.0657	164.19	288	18.91	47,286.60
	Group 2	0.48	0.3287	821.79	64	21.04	52,594.40
	Group 3	0.90	0.8471	2,117.73	32	27.11	67,767.32
	Group 4	2.19	3.2435	8,108.81	15	48.65	121,632.14
	Total				399	115.71	289,280.46
Section 4							
Scenario I	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0003	0.85	70	0.02	59.37
	Group 2	0.02	0.0018	4.46	69	0.12	308.07
	Group 3	0.06	0.0310	77.62	69	2.14	5,355.95
	Group 4	1.18	1.1800	2,949.98	69	81.42	203,548.28
	Total				277	83.71	209,271.66

Scenario II	Size group	Max. weight / group	% of total	Max. weight / group	Max. weight / stone	Max. vol. / stone	Max. depth / stone
	Group 1	59.37	0.0284	23.90	0.34	0.00	0.02
	Group 2	308.07	0.1472	124.02	1.80	0.00	0.04
	Group 3	5,355.95	2.5593	2,156.24	31.25	0.01	0.20
	Group 4	203,548.28	97.2651	81,945.84	1,187.62	0.48	0.40
	Total	209,271.66		84,250.00			

Scenario III	Size group	Max. surface area / block	Max. vol.	% total volume	Max. vol. / group	Max. weight / group	# of stones	Max. weight / stone
	Group 1	0.10	0.0048	0.99	0.33	836.75	70	11.95
	Group 2	0.33	0.0333	2.91	0.98	2,450.23	69	35.51
	Group 3	0.81	0.6519	8.96	3.02	7,552.53	69	109.46
	Group 4	1.88	2.2553	87.13	29.36	73,410.49	69	1,063.92
	Total				33.70	84,250.00	277	

Scenario IV	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0011	2.79	70	0.08	195.61
	Group 2	0.02	0.0048	11.93	69	0.33	823.39
	Group 3	0.06	0.0309	77.37	69	2.14	5,338.70
	Group 4	1.18	1.2818	3,204.48	69	88.44	221,109.09
	Total				277	90.99	227,466.79

Scenario V	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.01	0.0006	1.40	70	0.04	97.81
	Group 2	0.02	0.0024	5.97	69	0.16	411.69
	Group 3	0.06	0.0155	38.69	69	1.07	2,669.35
	Group 4	1.18	1.2818	3,204.48	69	88.44	221,109.09
	Total				277	89.72	224,287.94

Scenario VI	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.10	0.0099	24.83	219	2.18	5,437.82
	Group 2	0.27	0.1346	336.39	22	2.96	7,400.58
	Group 3	0.52	0.4198	1,049.59	27	11.34	28,338.88
	Group 4	1.18	1.1800	2,949.98	9	10.62	26,549.78
	Total				277	27.09	67,727.06

Scenario VII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.10	0.0626	156.51	219	13.71	34,274.86
	Group 2	0.27	0.2792	698.02	22	6.14	15,356.50
	Group 3	0.52	0.7603	1,900.87	27	20.53	51,323.59
	Group 4	1.18	1.2818	3,204.48	9	11.54	28,840.32
	Total				277	51.92	129,795.28

Scenario VIII	Size group	Max. surface area / block	Max. vol. / block	Max. weigh / block	#blocks	Max. vol. / group	Max. weight / group
	Group 1	0.10	0.0313	78.25	219	6.85	17,137.43
	Group 2	0.27	0.1396	349.01	22	3.07	7,678.25
	Group 3	0.52	0.3802	950.44	27	10.26	25,661.80
	Group 4	1.18	1.2818	3,204.48	9	11.54	28,840.32
	Total				277	31.73	79,317.80

Appendix 3 Overview of the quarrying calculations

This appendix provides an overview of the costs of material acquisition based on the various scenarios used for the volume calculations as well as the different rates, as presented in chapter 7. All volumes are in cubic metres and all labour costs are in person-hours (ph). Since no reconstructions of the volume are used for sections 1 and 2 at Mycenae, these are not present in the table below.

Mycenae											
Section 3											
Scenario	Vol. per face	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ph	Vol. fill	Vol. fill no voidage	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ph	Rubble quarry rate 0.5 m3 / ph	Rubble quarry rate 0.5 m3 / ph	Total minumum (ph)	Total maximum (ph)
I	148.8	3,306.7	5,221.1	695.9	899.4	7,732.2	12,208.8	1,391.8	1,798.8	4,698.5	17,429.8
II	189.3	4,206.7	6,642.1	614.9	818.4	6,832.2	10,787.7	1,229.8	1,636.8	5,436.5	17,429.8
III	189.3	4,206.7	6,642.1	614.9	818.4	6,832.2	10,787.7	1,229.8	1,636.8	5,436.5	17,429.8
IV	189.3	4,206.9	6,642.5	614.9	818.4	6,832.0	10,787.4	1,229.8	1,636.8	5,436.6	17,429.8
V	165.5	3,677.8	5,807.0	662.5	866.0	7,361.1	11,622.8	1,325.0	1,732.0	5,002.8	17,429.8
VI	97.4	2,164.4	3,417.5	798.7	1,002.2	8,874.4	14,012.3	1,597.4	2,004.4	3,761.8	17,429.8
VII	157.0	3,488.9	5,508.8	679.5	883.0	7,550.0	11,921.1	1,359.0	1,766.0	4,847.9	17,429.8
VIII	113.3	2,517.8	3,975.4	766.9	970.4	8,521.1	13,454.4	1,533.8	1,940.8	4,051.6	17,429.8
No size differenti-ation	189.3	4,206.7	6,642.1	614.9	818.4	6,832.2	10,787.7	1,229.8	1,636.8	5,436.5	17,429.8
Section 4											
Scenario	Vol. per face	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ph	Vol. fill	Vol. fill no voidage	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ph	Rubble quarry rate 0.5 m3 / ph	Rubble quarry rate 0.5 m3 / ph	Total minumum (ph)	Total maximum (ph)
I	23.2	515.6	814.0	144.4	183.4	1,603.9	2,532.5	288.7	366.8	804.3	3,346.5
II	24.9	553.3	873.7	141.0	180.0	1,566.1	2,472.8	281.9	360.0	835.2	3,346.5
III	24.9	553.3	873.7	141.0	180.0	1,566.1	2,472.8	281.9	360.0	835.2	3,346.5
IV	46.0	1,022.2	1,614.0	98.8	137.8	1,097.2	1,732.5	197.5	275.6	1,219.7	3,346.5
V	43.1	957.8	1,512.3	104.6	143.6	1,161.7	1,834.2	209.1	287.2	1,166.9	3,346.5
VI	19.5	433.3	684.2	151.8	190.8	1,686.1	2,662.3	303.5	381.6	736.8	3,346.5
VII	40.6	902.2	1,424.6	109.6	148.6	1,217.2	1,921.9	219.1	297.2	1,121.3	3,346.5
VIII	23.7	526.7	831.6	143.4	182.4	1,592.8	2,514.9	286.7	364.8	813.4	3,346.5
No size differenti-ation	24.9	553.3	873.7	141.0	180.0	1,566.1	2,472.8	281.9	360.0	835.2	3,346.5

Teichos Dymaion											
Section 1											
Scenario	Vol. per face	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Vol. fill	Vol. fill no voidage	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Rubble quarry rate 0.5 m3 / ph	Rubble quarry rate 0.5 m3 / ph	Total minumum (ph)	Total maximum (ph)
I	203.5	4,522.2	7,140.4	197.2	237.6	2,191.6	3,460.4	394.5	475.3	4,916.7	10,600.7
II	141.6	3,146.7	4,968.4	321.0	386.8	3,567.1	5,632.3	642.1	773.6	3,788.7	10,600.7
III	141.6	3,146.7	4,968.4	321.0	386.8	3,567.1	5,632.3	642.1	773.6	3,788.7	10,600.7
IV	234.4	5,208.9	8,224.6	135.4	163.2	1,504.9	2,376.1	270.9	326.4	5,479.8	10,600.7
V	227.6	5,057.8	7,986.0	149.0	179.6	1,656.0	2,614.7	298.1	359.1	5,355.9	10,600.7
VI	71.5	1,588.9	2,508.8	461.2	555.7	5,124.9	8,091.9	922.5	1,111.4	2,511.4	10,600.7
VII	149.6	3,324.4	5,249.1	305.0	367.5	3,389.3	5,351.6	610.1	735.0	3,934.5	10,600.7
VIII	87.3	1,940.0	3,063.2	429.6	517.6	4,773.8	7,537.5	859.3	1,035.3	2,799.3	10,600.7
No size differenti- ation	141.6	3,146.7	4,968.4	321.0	386.8	3,567.1	5,632.3	642.1	773.6	3,788.7	10,600.7
Section 2											
Scenario	Vol. per face	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Vol. fill	Vol. fill no voidage	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Rubble quarry rate 0.5 m3 / ph	Rubble quarry rate 0.5 m3 / ph	Total minumum (ph)	Total maximum (ph)
I	195.5	4,344.4	6,859.6	72.4	87.2	803.9	1,269.3	144.7	174.3	4,489.1	8,128.9
II	79.9	1,775.6	2,803.5	303.6	365.7	3,372.8	5,325.4	607.1	731.4	2,382.7	8,128.9
III	79.9	1,775.6	2,803.5	303.6	365.7	3,372.8	5,325.4	607.1	731.4	2,382.7	8,128.9
IV	219.0	4,866.7	7,684.2	25.4	30.5	281.7	444.7	50.7	61.1	4,917.4	8,128.9
V	216.8	4,817.8	7,607.0	29.8	35.8	330.6	521.9	59.5	71.7	4,877.3	8,128.9
VI	66.5	1,477.8	2,333.3	330.4	398.0	3,670.6	5,795.6	660.7	796.0	2,138.5	8,128.9
VII	100.8	2,240.0	3,536.8	261.8	315.4	2,908.3	4,592.1	523.5	630.7	2,763.5	8,128.9
VIII	68.1	1,513.3	2,389.5	327.2	394.2	3,635.0	5,739.5	654.3	788.3	2,167.6	8,128.9
No size differenti- ation	79.9	1,775.6	2,803.5	303.6	365.7	3,372.8	5,325.4	607.1	731.4	2,382.7	8,128.9
Section 3											
Scenario	Vol. per face	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Vol. fill	Vol. fill no voidage	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Rubble quarry rate 0.5 m3 / ph	Rubble quarry rate 0.5 m3 / ph	Total minumum (ph)	Total maximum (ph)
I	227.8	5,062.2	7,993.0	0.1	0.1	0.8	1.2	0.1	0.2	5,062.4	7,994.2
II	98.0	2,177.8	3,438.6	259.7	312.9	2,885.2	4,555.6	519.3	625.7	2,697.1	7,994.2
III	98.0	2,177.8	3,438.6	259.7	312.9	2,885.2	4,555.6	519.3	625.7	2,697.1	7,994.2
IV	341.6	7,591.1	11,986.0	-227.5	-274.1	-2,528.1	-3,991.8	-455.1	-548.3	7,136.1	7,994.2
V	331.3	7,362.2	11,624.6	-206.9	-249.3	-2,299.2	-3,630.4	-413.9	-498.6	6,948.4	7,994.2
VI	75.7	1,682.2	2,656.1	304.3	366.6	3,380.8	5,338.1	608.5	733.2	2,290.8	7,994.2
VII	182.8	4,062.2	6,414.0	90.1	108.5	1,000.8	1,580.2	180.1	217.0	4,242.4	7,994.2
VIII	115.7	2,571.1	4,059.6	224.3	270.2	2,491.9	3,934.6	448.5	540.4	3,019.7	7,994.2
No size differenti- ation	98.0	2,177.8	3,438.6	259.7	312.9	2,885.2	4,555.6	166.5	200.5	2,344.2	7,994.2

Section 4											
Scenario	Vol. per face	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Vol. fill	Vol. fill no voidage	Quarry rate 0,09m3/ph	Quarry rate 0,057m3/ ph	Rubble quarry rate 0.5 m3 / ph	Rubble quarry rate 0.5 m3 / ph	Total minumum (ph)	Total maximum (ph)
I	83.7	1,860.0	2,936.8	14.5	17.5	161.6	255.1	29.1	35.0	1,889.1	3,191.9
II	33.7	748.9	1,182.5	114.5	138.0	1,272.7	2,009.5	229.1	276.0	978.0	3,191.9
III	33.7	748.9	1,182.5	114.5	138.0	1,272.7	2,009.5	229.1	276.0	978.0	3,191.9
IV	91.0	2,022.2	3,193.0	-0.1	-0.1	-0.7	-1.1	-0.1	-0.1	2,022.1	3,191.9
V	89.7	1,993.3	3,147.4	2.5	3.1	28.2	44.6	5.1	6.1	1,998.4	3,191.9
VI	27.7	615.6	971.9	126.5	152.5	1,406.0	2,220.0	253.1	304.9	868.6	3,191.9
VII	51.9	1,153.3	1,821.1	78.1	94.1	868.2	1,370.9	156.3	188.3	1,309.6	3,191.9
VIII	31.7	704.4	1,112.3	118.5	142.8	1,317.1	2,079.6	237.1	285.6	941.5	3,191.9
No size differenti-ation	33.7	748.9	1,182.5	114.5	138.0	1,272.7	2,009.5	229.1	276.0	978.0	3,191.9

Appendix 4 Overview of the transport calculations

This appendix consists of the calculation overviews of the transport costs, based on the parameters as described in chapter 4. There are three separate tables: table 1 consists of the calculations of the number of oxen- and person-hours per section, scenario and size group as subsequently used in the second table. Table 2 provides an overview of the oxen-hours and person-hours for each section and scenario. Table 3 is an overview of the loading and unloading per section and scenario. In the tables all weights are in kilograms, distances are in kilometres, volume in cubic metres and labour is in oxen- and person-hours. The following abbreviations have been used in the tables:

- LG Lion Gate
- NG North Gate
- int interior
- ext exterior
- Swall southern wall
- Nwall northern wall

Table 1. Overview of the transport cost per size category.
In this table a number of constant values are left out:

1. The speed (loaded 1.67 km/h, unloaded 2.5 km/h)
2. The actual calculated force that is required, this is dependent on the weight, slope and friction coefficient, see chapter 3.
3. The slope, which as explained can be up to 10 degrees with the same animals if on flat terrain they can use 14 % of their body weight as traction and up to 50 % for short stretches.
4. The weight per ox is taken as an average of 375 kg, see chapter 3.
5. The force taken as percentage of the oxen's body weight, see chapter 3 and point 3 above.
6. The multiple yoking efficiency loss, as described in chapter 3 is set at 36 %.

Mycenae												
Section 1	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
Conglomerate LG total	6000	6,000	0	0.005	52	0.005	200.24	1.00	0.00	0.26	0.05	
	682500	3,500	1,000	1.8	10	1.80	0.56	195.00	350.58	3,155.22	3,505.80	
Conglomerate LG FE	2,258.82	5,000	1,000	1.8	12	1.80	0.56	0.45	0.81	9.75	9.75	4.87
	29,520.00	5,000	1,000	1.8	12	1.80	0.56	5.90	10.61	127.37	127.37	63.69
	72,000.00	5,000	1,000	1.8	12	1.80	0.56	14.40	25.89	310.67	310.67	155.33
	41,788.24	6,000	2,000	1.8	16	1.80	0.56	6.96	12.52	200.34	200.34	100.17
Total												648.13
Conglomerate LG FW	26,929.41	5,000	1,000	1.8	12	1.80	0.56	5.39	9.68	116.20	116.20	58.10
	34,552.94	5,000	1,000	1.8	12	1.80	0.56	6.91	12.42	149.09	149.09	74.54
	56,809.41	5,000	1,000	1.8	12	1.80	0.56	11.36	20.43	245.12	245.12	122.56
	36,956.47	6,300	2,000	1.8	18	1.80	0.56	5.87	10.55	179.29	189.83	94.92
Total												700.24
Conglomerate LG gate	49.41	5,000	1,000	1.8	12	1.80	0.56	0.01	0.02	0.21	0.21	0.11
	23,761.18	5,000	1,000	1.8	12	1.80	0.56	4.75	8.54	102.53	102.53	51.26
	26,728.24	5,000	1,000	1.8	12	1.80	0.56	5.35	9.61	115.33	115.33	57.66
	42,260.00	5,000	1,000	1.8	12	1.80	0.56	8.45	15.20	182.34	182.34	91.17
Total												400.41
Posts	11,677.98	5,838.99	2,000	1.8	90	1.80	0.56	2.00	3.60	320.02	323.61	161.81
Threshold	25,570.59	25,570.59	2,000	1.8	312	1.80	0.56	1.00	1.80	560.93	560.93	280.46
Lintel	25,570.59	25,570.59	2,000	1.8	312	1.80	0.56	1.00	1.80	560.93	560.93	280.46
Lion relief	14,720.59	14,720.59	2,000	1.8	190	1.80	0.56	1.00	1.80	341.59	341.59	170.80
Total												1,787.06
Conglomerate LG gate INT	9,620.00	5,000	1,000	1.8	12	1.80	0.56	1.92	3.46	41.51	41.51	20.75
	8,680.00	5,000	1,000	1.8	12	1.80	0.56	1.74	3.12	37.45	37.45	18.73
	12,581.18	5,000	1,000	1.8	12	1.80	0.56	2.52	4.52	54.29	54.29	27.14
	14,828.24	5,000	1,000	1.8	12	1.80	0.56	2.97	5.33	63.98	63.98	31.99
Total												197.23
Conglomerate LG int Ewall	4,469.41	5,000	1,000	1.8	12	1.80	0.56	0.89	1.61	19.28	19.28	9.64
	5,168.24	5,000	1,000	1.8	12	1.80	0.56	1.03	1.86	22.30	22.30	11.15
	6,081.18	5,000	1,000	1.8	12	1.80	0.56	1.22	2.19	26.24	26.24	13.12
	7,578.82	5,000	1,000	1.8	12	1.80	0.56	1.52	2.73	32.70	32.70	16.35
Total												100.53
Conglomerate LG Int Bastion	3,735.29	5,000	1,000	1.8	12	1.80	0.56	0.75	1.34	16.12	16.12	8.06
	13,337.65	5,000	1,000	1.8	12	1.80	0.56	2.67	4.80	57.55	57.55	28.77
	14,882.35	5,000	1,000	1.8	12	1.80	0.56	2.98	5.35	64.21	64.21	32.11
	28,797.65	5,000	1,000	1.8	12	1.80	0.56	5.76	10.35	124.26	124.26	62.13
Total												262.14

Section 2	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
Conglomerate LG in+out	141,750.00	5,000	1,000	2.20	12	2.20	0.46	28.35	62.30	747.54	747.54	
	141,750.00	5,000	1,000	2.20	10	2.20	0.46	28.35	62.30	747.54	622.95	
NG_intStructure	181.18	5,000	1,000	2.20	12	2.20	0.46	0.04	0.08	0.96	0.96	0.48
	4,010.59	5,000	1,000	2.20	12	2.20	0.46	0.80	1.76	21.15	21.15	10.58
	9,054.12	5,000	1,000	2.20	12	2.20	0.46	1.81	3.98	47.75	47.75	23.87
	13,096.47	5,000	1,000	2.20	12	2.20	0.46	2.62	5.76	69.07	69.07	34.53
	22,918.82	6,500	2,000	2.20	18	2.20	0.46	3.53	7.75	131.71	139.46	69.73
Total											277.43	138.71
NG_ext_Swall	27.06	5,000	1,000	2.20	12	2.20	0.46	0.01	0.01	0.14	0.14	0.07
	4,803.53	5,000	1,000	2.20	12	2.20	0.46	0.96	2.11	25.33	25.33	12.67
	8,834.12	5,000	1,000	2.20	12	2.20	0.46	1.77	3.88	46.59	46.59	23.29
	17,062.35	5,000	1,000	2.20	12	2.20	0.46	3.41	7.50	89.98	89.98	44.99
Total											162.04	81.02
NG_ext_Nwall	129.41	5,000	1,000	2.20	12	2.20	0.46	0.03	0.06	0.68	0.68	0.34
	7,290.59	5,000	1,000	2.20	12	2.20	0.46	1.46	3.20	38.45	38.45	19.22
	4,210.59	5,000	1,000	2.20	12	2.20	0.46	0.84	1.85	22.21	22.21	11.10
	11,398.82	5,000	1,000	2.20	12	2.20	0.46	2.28	5.01	60.11	60.11	30.06
Total											121.45	60.72
NG_intNwall	6,000.00	5,000	1,000	2.20	12	2.20	0.46	1.20	2.64	31.64		
Total											31.64	15.82

Section 3	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
	1,052,726	5,000	1,000	0.3	12	0.30	3.34	210.55	63.09	757.05	757.05	378.53
	473,250	5,000	1,000	0.3	12	0.30	3.34	94.65	28.36	340.33	340.33	170.17
Scenario I	191	5,000	1,000	0.3	12	0.30	3.34	0.04	0.01	0.14	0.14	0.07
	1,037	5,000	1,000	0.3	12	0.30	3.34	0.21	0.06	0.75	0.75	0.37
	60,823	5,000	1,000	0.3	12	0.30	3.34	12.16	3.65	43.74	43.74	21.87
	310,105	6,000	2,000	0.3	16	0.30	3.34	51.68	15.49	247.79	247.79	123.89
Total											292.41	146.21
Scenario II	243	5,000	1,000	0.3	12	0.30	3.34	0.05	0.01	0.17	0.17	0.09
	1,319	5,000	1,000	0.3	12	0.30	3.34	0.26	0.08	0.95	0.95	0.47
	77,345	5,000	1,000	0.3	12	0.30	3.34	15.47	4.64	55.62	55.62	27.81
	394,345	7,200	2,000	0.3	18	0.30	3.34	54.77	16.41	295.40	295.40	147.70
Total											352.15	176.07
Scenario III	6,369	5,000	1,000	0.3	12	0.30	3.34	1.27	0.38	4.58	4.58	2.29
	18,274	5,000	1,000	0.3	12	0.30	3.34	3.65	1.10	13.14	13.14	6.57
	104,308	5,000	1,000	0.3	12	0.30	3.34	20.86	6.25	75.01	75.01	37.51
	344,301	6,000	2,000	0.3	16	0.30	3.34	57.38	17.19	275.11	275.11	137.56
Total											367.84	183.92

Scenario IV	1,258	5,000	1,000	0.3	12	0.30	3.34	0.25	0.08	0.90	0.90	0.45
	5,695	5,000	1,000	0.3	12	0.30	3.34	1.14	0.34	4.10	4.10	2.05
	112,054	5,000	1,000	0.3	12	0.30	3.34	22.41	6.72	80.58	80.58	40.29
	354,274	6,500	2,000	0.3	18	0.30	3.34	54.50	16.33	277.64	293.97	146.98
Total											379.55	189.77
Scenario V	629	5,000	1,000	0.3	12	0.30	3.34	0.13	0.04	0.45	0.45	0.23
	2,848	5,000	1,000	0.3	12	0.30	3.34	0.57	0.17	2.05	2.05	1.02
	56,027	5,000	1,000	0.3	12	0.30	3.34	11.21	3.36	40.29	40.29	20.15
	354,274	6,500	2,000	0.3	18	0.30	3.34	54.50	16.33	277.64	293.97	146.98
Total											336.76	168.38
Scenario VI	3,053	5,000	1,000	0.3	12	0.30	3.34	0.61	0.18	2.20	2.20	1.10
	8,333	5,000	1,000	0.3	12	0.30	3.34	1.67	0.50	5.99	5.99	3.00
	79,862	5,000	1,000	0.3	12	0.30	3.34	15.97	4.79	57.43	57.43	28.72
	152,234	5,700	2,000	0.3	16	0.30	3.34	26.71	8.00	120.04	128.04	64.02
Total											193.66	96.83
Scenario VII	19,005	5,000	1,000	0.3	12	0.30	3.34	3.80	1.14	13.67	13.67	6.83
	19,241	5,000	1,000	0.3	12	0.30	3.34	3.85	1.15	13.84	13.84	6.92
	180,233	5,000	1,000	0.3	12	0.30	3.34	36.05	10.80	129.61	129.61	64.81
	173,917	5,700	2,000	0.3	16	0.30	3.34	30.51	9.14	137.14	146.28	73.14
Total											303.40	151.70
Scenario VIII	9,503	5,000	1,000	0.3	12	0.30	3.34	1.90	0.57	6.83	6.83	3.42
	9,621	5,000	1,000	0.3	12	0.30	3.34	1.92	0.58	6.92	6.92	3.46
	90,117	5,000	1,000	0.3	12	0.30	3.34	18.02	5.40	64.81	64.81	32.40
	173,917	5,700	2,000	0.3	16	0.30	3.34	30.51	9.14	137.14	146.28	73.14
Total											224.84	112.42
Section 4	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
	197,400	5,000	1,000	0.21	12	0.21	4.77	39.48	8.28	99.37	99.37	49.69
	62,250	5,000	1,000	0.21	12	0.21	4.77	12.45	2.61	31.34	31.34	15.67
Scenario I	38	5,000	1,000	0.21	12	0.21	4.77	0.01	0.00	0.02	0.02	0.01
	109	5,000	1,000	0.21	12	0.21	4.77	0.02	0.00	0.05	0.05	0.03
	6,900	5,000	1,000	0.21	12	0.21	4.77	1.38	0.29	3.47	3.47	1.74
	50,915	5,000	1,000	0.21	12	0.21	4.77	10.18	2.14	25.63	25.63	12.82
Total											29.18	14.59
Scenario II	41	5,000	1,000	0.21	12	0.21	4.77	0.01	0.00	0.02	0.02	0.01
	118	5,000	1,000	0.21	12	0.21	4.77	0.02	0.00	0.06	0.06	0.03
	7,411	5,000	1,000	0.21	12	0.21	4.77	1.48	0.31	3.73	3.73	1.87
	54,683	5,000	1,000	0.21	12	0.21	4.77	10.94	2.29	27.53	27.53	13.76
Total											31.34	15.67
Scenario III	582	5,000	1,000	0.21	12	0.21	4.77	0.12	0.02	0.29	0.29	0.15
	1,582	5,000	1,000	0.21	12	0.21	4.77	0.32	0.07	0.80	0.80	0.40
	7,181	5,000	1,000	0.21	12	0.21	4.77	1.44	0.30	3.61	3.61	1.81
	52,907	5,000	1,000	0.21	12	0.21	4.77	10.58	2.22	26.63	26.63	13.32
Total											31.34	15.67

Scenario IV	174	5,000	1,000	0.21	12	0.21	4.77	0.03	0.01	0.09	0.09	0.04
	629	5,000	1,000	0.21	12	0.21	4.77	0.13	0.03	0.32	0.32	0.16
	13,982	5,000	1,000	0.21	12	0.21	4.77	2.80	0.59	7.04	7.04	3.52
	100,280	5,000	1,000	0.21	12	0.21	4.77	20.06	4.21	50.48	50.48	25.24
Total											57.92	28.96
Scenario V	87	5,000	1,000	0.21	12	0.21	4.77	0.02	0.00	0.04	0.04	0.02
	315	5,000	1,000	0.21	12	0.21	4.77	0.06	0.01	0.16	0.16	0.08
	6,991	5,000	1,000	0.21	12	0.21	4.77	1.40	0.29	3.52	3.52	1.76
	100,280	5,000	1,000	0.21	12	0.21	4.77	20.06	4.21	50.48	50.48	25.24
Total											54.20	27.10
Scenario VI	3,712	5,000	1,000	0.21	12	0.21	4.77	0.74	0.16	1.87	1.87	0.93
	10,115	5,000	1,000	0.21	12	0.21	4.77	2.02	0.42	5.09	5.09	2.55
	17,968	5,000	1,000	0.21	12	0.21	4.77	3.59	0.75	9.05	9.05	4.52
	16,972	5,000	1,000	0.21	12	0.21	4.77	3.39	0.71	8.54	8.54	4.27
Total											24.55	12.27
Scenario VII	25,585	5,000	1,000	0.21	12	0.21	4.77	5.12	1.07	12.88	12.88	6.44
	24,535	5,000	1,000	0.21	12	0.21	4.77	4.91	1.03	12.35	12.35	6.18
	34,762	5,000	1,000	0.21	12	0.21	4.77	6.95	1.46	17.50	17.50	8.75
	16,713	5,000	1,000	0.21	12	0.21	4.77	3.34	0.70	8.41	8.41	4.21
Total											51.14	25.57
Scenario VIII	12,793	5,000	1,000	0.21	12	0.21	4.77	2.56	0.54	6.44	6.44	3.22
	12,268	5,000	1,000	0.21	12	0.21	4.77	2.45	0.51	6.18	6.18	3.09
	17,381	5,000	1,000	0.21	12	0.21	4.77	3.48	0.73	8.75	8.75	4.37
	16,713	5,000	1,000	0.21	12	0.21	4.77	3.34	0.70	8.41	8.41	4.21
Total											29.78	14.89

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Section 1	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
	449,400	5,000	1,000	0.1	12	0.10	10.01	89.88	8.98	107.73	107.73	53.86
	354,000	5,000	1,000	0.1	12	0.10	10.01	70.80	7.07	84.86	84.86	42.43
Scenario I	173	5,000	1,000	0.1	12	0.10	10.01	0.03	0.00	0.04	0.04	0.02
	1,467	5,000	1,000	0.1	12	0.10	10.01	0.29	0.03	0.35	0.35	0.18
	38,458	5,000	1,000	0.1	12	0.10	10.01	7.69	0.77	9.22	9.22	4.61
	468,749	5,000	1,000	0.1	12	0.10	10.01	93.75	9.36	112.37	112.37	56.18
Total											121.98	60.99
Scenario II	121	5,000	1,000	0.1	12	0.10	10.01	0.02	0.00	0.03	0.03	0.01
	1,021	5,000	1,000	0.1	12	0.10	10.01	0.20	0.02	0.24	0.24	0.12
	26,755	5,000	1,000	0.1	12	0.10	10.01	5.35	0.53	6.41	6.41	3.21
	326,105	5,000	1,000	0.1	12	0.10	10.01	65.22	6.51	78.17	78.17	39.09
Total											84.86	42.43
Scenario III	4,253	5,000	1,000	0.1	12	0.10	10.01	0.85	0.08	1.02	1.02	0.51
	14,375	5,000	1,000	0.1	12	0.10	10.01	2.88	0.29	3.45	3.45	1.72
	84,959	5,000	1,000	0.1	12	0.10	10.01	16.99	1.70	20.37	20.37	10.18
	250,415	5,000	1,000	0.1	12	0.10	10.01	50.08	5.00	60.03	60.03	30.01
Total											84.86	42.43

Scenario IV	877	5,000	1,000	0.1	12	0.10	10.01	0.18	0.02	0.21	0.21	0.11
	7,662	5,000	1,000	0.1	12	0.10	10.01	1.53	0.15	1.84	1.84	0.92
	70,404	5,000	1,000	0.1	12	0.10	10.01	14.08	1.41	16.88	16.88	8.44
	529,613	6,230	2,000	0.1	16	0.10	10.01	85.01	8.49	135.85	135.85	67.93
Total											154.78	77.39
Scenario V	439	5,000	1,000	0.1	12	0.10	10.01	0.09	0.01	0.11	0.11	0.05
	3,831	5,000	1,000	0.1	12	0.10	10.01	0.77	0.08	0.92	0.92	0.46
	35,202	5,000	1,000	0.1	12	0.10	10.01	7.04	0.70	8.44	8.44	4.22
	529,613	6,230	2,000	0.1	16	0.10	10.01	85.01	8.49	135.85	135.85	67.93
Total											145.32	72.66
Scenario VI	7,271	5,000	1,000	0.1	12	0.10	10.01	1.45	0.15	1.74	1.74	0.87
	31,802	5,000	1,000	0.1	12	0.10	10.01	6.36	0.64	7.62	7.62	3.81
	84,600	5,000	1,000	0.1	12	0.10	10.01	16.92	1.69	20.28	20.28	10.14
	55,147	5,000	1,000	0.1	12	0.10	10.01	11.03	1.10	13.22	13.22	6.61
Total											42.87	21.43
Scenario VII	54,764	5,000	1,000	0.1	12	0.10	10.01	10.95	1.09	13.13	13.13	6.56
	77,807	5,000	1,000	0.1	12	0.10	10.01	15.56	1.55	18.65	18.65	9.33
	179,083	5,000	1,000	0.1	12	0.10	10.01	35.82	3.58	42.93	42.93	21.46
	62,308	6,230	2,000	0.1	16	0.10	10.01	10.00	1.00	15.98	15.98	7.99
Total											90.69	45.35
Scenario VIII	27,382	5,000	1,000	0.1	12	0.10	10.01	5.48	0.55	6.56	6.56	3.28
	38,904	5,000	1,000	0.1	12	0.10	10.01	7.78	0.78	9.33	9.33	4.66
	89,542	5,000	1,000	0.1	12	0.10	10.01	17.91	1.79	21.46	21.46	10.73
	62,308	6,230	2,000	0.1	16	0.10	10.01	10.00	1.00	15.98	15.98	7.99
Total											53.34	26.67

Section 2	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
	424,970	5,000	1,000	0.1	12	0.10	10.01	84.99	8.49	101.87	101.87	50.94
	199,750	5,000	1,000	0.1	12	0.10	10.01	39.95	3.99	47.88	47.88	23.94
Scenario I	137	5,000	1,000	0.1	12	0.10	10.01	0.03	0.00	0.03	0.03	0.02
	715	5,000	1,000	0.1	12	0.10	10.01	0.14	0.01	0.17	0.17	0.09
	9,627	5,000	1,000	0.1	12	0.10	10.01	1.93	0.19	2.31	2.31	1.15
	478,194	5,000	1,000	0.1	12	0.10	10.01	95.64	9.55	114.63	114.63	57.31
Total											117.14	58.57
Scenario II	56	5,000	1,000	0.1	12	0.10	10.01	0.01	0.00	0.01	0.01	0.01
	292	5,000	1,000	0.1	12	0.10	10.01	0.06	0.01	0.07	0.07	0.03
	3,934	5,000	1,000	0.1	12	0.10	10.01	0.79	0.08	0.94	0.94	0.47
	195,419	5,000	1,000	0.1	12	0.10	10.01	39.08	3.90	46.84	46.84	23.42
Total											47.87	23.94
Scenario III	2,377	5,000	1,000	0.1	12	0.10	10.01	0.48	0.05	0.57	0.57	0.28
	6,741	5,000	1,000	0.1	12	0.10	10.01	1.35	0.13	1.62	1.62	0.81
	18,316	5,000	1,000	0.1	12	0.10	10.01	3.66	0.37	4.39	4.39	2.20
	172,269	5,000	1,000	0.1	12	0.10	10.01	34.45	3.44	41.30	41.30	20.65
Total											47.87	23.94

Scenario IV	463	5,000	1,000	0.1	12	0.10	10.01	0.09	0.01	0.11	0.11	0.06
	1,958	5,000	1,000	0.1	12	0.10	10.01	0.39	0.04	0.47	0.47	0.23
	8,668	5,000	1,000	0.1	12	0.10	10.01	1.73	0.17	2.08	2.08	1.04
	536,431	6,230	2,000	0.1	16	0.10	10.01	86.10	8.60	137.60	137.60	68.80
Total											140.26	70.13
Scenario V	232	5,000	1,000	0.1	12	0.10	10.01	0.05	0.00	0.06	0.06	0.03
	979	5,000	1,000	0.1	12	0.10	10.01	0.20	0.02	0.23	0.23	0.12
	4,334	5,000	1,000	0.1	12	0.10	10.01	0.87	0.09	1.04	1.04	0.52
	536,431	6,230	2,000	0.1	16	0.10	10.01	86.10	8.60	137.60	137.60	68.80
Total											138.93	69.47
Scenario VI	8,732	5,000	1,000	0.1	12	0.10	10.01	1.75	0.17	2.09	2.09	1.05
	15,960	5,000	1,000	0.1	12	0.10	10.01	3.19	0.32	3.83	3.83	1.91
	47,115	5,000	1,000	0.1	12	0.10	10.01	9.42	0.94	11.29	11.29	5.65
	94,381	5,000	1,000	0.1	12	0.10	10.01	18.88	1.89	22.62	22.62	11.31
Total											39.84	19.92
Scenario VII	46,859	5,000	1,000	0.1	12	0.10	10.01	9.37	0.94	11.23	11.23	5.62
	30,759	5,000	1,000	0.1	12	0.10	10.01	6.15	0.61	7.37	7.37	3.69
	86,186	5,000	1,000	0.1	12	0.10	10.01	17.24	1.72	20.66	20.66	10.33
	88,229	6,230	2,000	0.1	16	0.10	10.01	14.16	1.41	22.63	22.63	11.32
Total											61.90	30.95
Scenario VIII	23,430	5,000	1,000	0.1	12	0.10	10.01	4.69	0.47	5.62	5.62	2.81
	15,380	5,000	1,000	0.1	12	0.10	10.01	3.08	0.31	3.69	3.69	1.84
	43,093	5,000	1,000	0.1	12	0.10	10.01	8.62	0.86	10.33	10.33	5.16
	88,229	6,230	2,000	0.1	16	0.10	10.01	14.16	1.41	22.63	22.63	11.32
Total											42.27	21.13
Section 3	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
	363,538	5,000	1,000	0.1	12	0.10	10.01	72.71	7.26	87.14	87.14	43.57
	245,000	5,000	1,000	0.1	12	0.10	10.01	49.00	4.89	58.73	58.73	29.36
Scenario I	113	5,000	1,000	0.1	12	0.10	10.01	0.02	0.00	0.03	0.03	0.01
	813	5,000	1,000	0.1	12	0.10	10.01	0.16	0.02	0.19	0.19	0.10
	26,144	5,000	1,000	0.1	12	0.10	10.01	5.23	0.52	6.27	6.27	3.13
	542,318	5,500	1,000	0.1	14	0.10	10.01	98.60	9.85	128.03	137.88	68.94
Total											134.52	72.18
Scenario II	49	5,000	1,000	0.1	12	0.10	10.01	0.01	0.00	0.01	0.01	0.01
	350	5,000	1,000	0.1	12	0.10	10.01	0.07	0.01	0.08	0.08	0.04
	11,254	5,000	1,000	0.1	12	0.10	10.01	2.25	0.22	2.70	2.70	1.35
	233,448	5,000	1,000	0.1	12	0.10	10.01	46.69	4.66	55.96	55.96	27.98
Total											58.75	29.38
Scenario III	1,870	5,000	1,000	0.1	12	0.10	10.01	0.37	0.04	0.45	0.45	0.22
	6,712	5,000	1,000	0.1	12	0.10	10.01	1.34	0.13	1.61	1.61	0.80
	32,622	5,000	1,000	0.1	12	0.10	10.01	6.52	0.65	7.82	7.82	3.91
	203,897	5,000	1,000	0.1	12	0.10	10.01	40.78	4.07	48.88	48.88	24.44
Total											58.75	29.38

Scenario IV	425	5,000	1,000	0.1	12	0.10	10.01	0.09	0.01	0.10	0.10	0.05
	2,930	5,000	1,000	0.1	12	0.10	10.01	0.59	0.06	0.70	0.70	0.35
	47,826	5,000	1,000	0.1	12	0.10	10.01	9.57	0.96	11.46	11.46	5.73
	802,773	8,200	2,000	0.1	20	0.10	10.01	97.90	9.78	195.56	195.56	97.78
Total											207.83	103.92
Scenario V	213	5,000	1,000	0.1	12	0.10	10.01	0.04	0.00	0.05	0.05	0.03
	1,465	5,000	1,000	0.1	12	0.10	10.01	0.29	0.03	0.35	0.35	0.18
	23,913	5,000	1,000	0.1	12	0.10	10.01	4.78	0.48	5.73	5.73	2.87
	802,773	8,200	2,000	0.1	20	0.10	10.01	97.90	9.78	195.56	195.56	97.78
Total											201.70	100.85
Scenario VI	11,721	5,000	1,000	0.1	12	0.10	10.01	2.34	0.23	2.81	2.81	1.40
	38,104	5,000	1,000	0.1	12	0.10	10.01	7.62	0.76	9.13	9.13	4.57
	57,298	5,000	1,000	0.1	12	0.10	10.01	11.46	1.14	13.74	13.74	6.87
	82,170	5,500	1,000	0.1	14	0.10	10.01	14.94	1.49	19.40	20.89	10.45
Total											45.08	23.28
Scenario VII	94,574	5,000	1,000	0.1	12	0.10	10.01	18.91	1.89	22.67	22.67	11.34
	105,189	5,000	1,000	0.1	12	0.10	10.01	21.04	2.10	25.22	25.22	12.61
	135,535	5,000	1,000	0.1	12	0.10	10.01	27.11	2.71	32.49	32.49	16.24
	121,633	8,200	2,000	0.1	20	0.10	10.01	14.83	1.48	29.63	29.63	14.82
Total											110.01	55.00
Scenario VIII	47,287	5,000	1,000	0.1	12	0.10	10.01	9.46	0.94	11.34	11.34	5.67
	52,595	5,000	1,000	0.1	12	0.10	10.01	10.52	1.05	12.61	12.61	6.30
	67,768	5,000	1,000	0.1	12	0.10	10.01	13.55	1.35	16.24	16.24	8.12
	121,633	8,200	2,000	0.1	20	0.10	10.01	14.83	1.48	29.63	29.63	14.82
Total											69.82	34.91

Section 4	Total Weight (kg)	Weight per trip (kg)	Weight of wagon/ sledge (kg)	Distance (km)	Number of oxen (even)	hour/ trip	trips/ hour	# trips	# hours	oh	oh roundup even	ph round up even
	160,356	5,000	1,000	0.1	12	0.10	10.01	32.07	3.20	38.44	38.44	19.22
	84,250	5,000	1,000	0.1	12	0.10	10.01	16.85	1.68	20.20	20.20	10.10
Scenario I	60	5,000	1,000	0.1	12	0.10	10.01	0.01	0.00	0.01	0.01	0.01
	309	5,000	1,000	0.1	12	0.10	10.01	0.06	0.01	0.07	0.07	0.04
	5,356	5,000	1,000	0.1	12	0.10	10.01	1.07	0.11	1.28	1.28	0.64
	203,549	5,000	1,000	0.1	12	0.10	10.01	40.71	4.07	48.79	48.79	24.40
Total											50.17	25.08
Scenario II	24	5,000	1,000	0.1	12	0.10	10.01	0.00	0.00	0.01	0.01	0.00
	125	5,000	1,000	0.1	12	0.10	10.01	0.03	0.00	0.03	0.03	0.01
	2,157	5,000	1,000	0.1	12	0.10	10.01	0.43	0.04	0.52	0.52	0.26
	81,946	5,000	1,000	0.1	12	0.10	10.01	16.39	1.64	19.64	19.64	9.82
Total											20.20	10.10
Scenario III	837	5,000	1,000	0.1	12	0.10	10.01	0.17	0.02	0.20	0.20	0.10
	2,451	5,000	1,000	0.1	12	0.10	10.01	0.49	0.05	0.59	0.59	0.29
	7,553	5,000	1,000	0.1	12	0.10	10.01	1.51	0.15	1.81	1.81	0.91
	73,411	5,000	1,000	0.1	12	0.10	10.01	14.68	1.47	17.60	17.60	8.80
Total											20.20	10.10

Scenario IV	196	5,000	1,000	0.1	12	0.10	10.01	0.04	0.00	0.05	0.05	0.02
	824	5,000	1,000	0.1	12	0.10	10.01	0.16	0.02	0.20	0.20	0.10
	5,339	5,000	1,000	0.1	12	0.10	10.01	1.07	0.11	1.28	1.28	0.64
	221,110	5,000	1,000	0.1	12	0.10	10.01	44.22	4.42	53.00	53.00	26.50
Total											54.53	27.26
Scenario V	98	5,000	1,000	0.1	12	0.10	10.01	0.02	0.00	0.02	0.02	0.01
	412	5,000	1,000	0.1	12	0.10	10.01	0.08	0.01	0.10	0.10	0.05
	2,670	5,000	1,000	0.1	12	0.10	10.01	0.53	0.05	0.64	0.64	0.32
	221,110	5,000	1,000	0.1	12	0.10	10.01	44.22	4.42	53.00	53.00	26.50
Total											53.77	26.88
Scenario VI	5,438	5,000	1,000	0.1	12	0.10	10.01	1.09	0.11	1.30	1.30	0.65
	7,401	5,000	1,000	0.1	12	0.10	10.01	1.48	0.15	1.77	1.77	0.89
	28,339	5,000	1,000	0.1	12	0.10	10.01	5.67	0.57	6.79	6.79	3.40
	26,550	5,000	1,000	0.1	12	0.10	10.01	5.31	0.53	6.36	6.36	3.18
Total											16.24	8.12
Scenario VII	34,275	5,000	1,000	0.1	12	0.10	10.01	6.86	0.68	8.22	8.22	4.11
	15,357	5,000	1,000	0.1	12	0.10	10.01	3.07	0.31	3.68	3.68	1.84
	51,324	5,000	1,000	0.1	12	0.10	10.01	10.26	1.03	12.30	12.30	6.15
	28,841	5,000	1,000	0.1	12	0.10	10.01	5.77	0.58	6.91	6.91	3.46
Total											31.11	15.56
Scenario VIII	17,138	5,000	1,000	0.1	12	0.10	10.01	3.43	0.34	4.11	4.11	2.05
	7,679	5,000	1,000	0.1	12	0.10	10.01	1.54	0.15	1.84	1.84	0.92
	25,662	5,000	1,000	0.1	12	0.10	10.01	5.13	0.51	6.15	6.15	3.08
	28,841	5,000	1,000	0.1	12	0.10	10.01	5.77	0.58	6.91	6.91	3.46
Total											19.01	9.51

Appendix 5 Overview of the assembly calculations

This appendix comprises two tables: table 1 shows the costs for assembly based on the reconstruction of the building process as described in chapter 7, for all sections and scenarios. Table 2 shows calculated costs using the combination of the rates of Mayes and Murakami, see chapter 7. All labour is in person-hours and all volumes are in cubic metres. Since no reconstructions of the volume are used for sections 1 and 2 at Mycenae, these are not present in the table below (they are described in chapter 7).

Table 1. Overview of calculations using the reconstructed process.
In the table the described steps are expressed as person-hours (ph).

Reconstruction											
Mycenae											
	Section 3					face	contin-ued fill	Total	rubble fill (0,159m3/ph)	Total	
Scenario	Step 1	2	3	4	5	Total	Ratio Face/fill	cost fill		cost fill	
I	31.6	48.7	205.9	11.2	22.3	319.7	4.6	1,462.1	2,101.5	5,655.8	6,295.2
II	40.2	61.9	261.8	14.1	28.3	406.3	3.4	1,387.8	2,200.4	5,147.2	5,959.8
III	40.3			14.2	28.6	83.1	3.4	283.8	450.0	5,147.2	5,313.4
IV	40.2	68.5	136.3	14.2	28.3	287.5	3.5	1,003.8	1,578.8	5,147.0	5,722.0
V	35.1	48.7	201.3	12.4	24.8	322.3	4.2	1,338.7	1,983.3	5,446.4	6,091.0
VI	20.7	48.3	83.3	7.3	14.6	174.2	8.6	1,493.1	1,841.5	6,303.2	6,651.6
VII	33.4	48.3	111.5	11.7	23.5	228.4	4.7	1,076.0	1,532.8	5,554.0	6,010.8
VIII	24.1	48.3	75.3	8.5	17.0	173.2	7.2	1,250.8	1,597.2	6,103.6	6,450.0
one size	40.1	75.6	150.4	14.3	28.6	309.0	3.4	1,055.3	1,673.3	5,147.2	5,765.2

	Section 4								face	contin-ued fill	Total	rubble fill (0,159m3/ph)	Total	
Scenario	Step 1	2	3	for 3 cours-es	4	per course	5	per course	Total	Ratio Face/fill	cost fill		cost fill	
I	5.0	11.5	19.8	9.9	9.6	1.6	19.3	3.2	34.4	6.2	214.1	283.0	1,153.8	1,222.7
II	5.3	11.5	19.8	9.9	10.3	1.7	20.7	3.5	35.3	5.7	199.8	270.4	1,132.2	1,202.8
III	12.2			0.0		0.0		0.0	12.2	5.7	69.1	93.5	1,132.2	1,156.6
IV	9.8	29.8	39.4	19.7	18.5	3.1	37.1	6.2	74.7	2.1	160.4	309.9	866.5	1,016.0
V	9.2	16.4	29.7	14.9	16.0	2.7	32.1	5.4	53.8	2.4	130.5	238.1	903.7	1,011.3
VI	4.2	9.0	17.2	8.6	7.3	1.2	14.7	2.5	27.9	7.8	217.1	272.9	1,200.1	1,255.9
VII	8.7	18.7	26.1	13.1	16.4	2.7	32.9	5.5	54.1	2.7	146.1	254.3	934.3	1,042.5
VIII	5.1	12.1	17.3	8.7	7.6	1.3	15.1	2.5	32.2	6.0	194.6	258.9	1,147.8	1,212.1
one size	5.3	10.0	19.8	9.9	10.0	1.7	20.1	3.4	33.6	5.7	189.9	257.0	886.8	953.9

Teichos Dymaion												
	Section 1								face	contin-ued fill	Total	
Scenario	Step 1	2	3	per course	4	per course	5	per course	Total	Ratio in volume	cost fill	
I	43.5	70.4	78.2	7.8	124.5	12.5	249.0	24.9	318.0	1.0	308.3	944.3
II	30.3	55.3	78.0	7.8	86.6	8.7	173.2	17.3	244.1	2.3	553.5	1041.7
III	30.3			0.0	84.7	8.5	169.5	17.0	132.0	2.3	299.2	563.2
IV	51.7	85.7	119.7	12.0	146.1	14.6	292.3	29.2	396.6	0.6	229.1	1022.2
V	48.7	85.7	119.7	12.0	137.5	13.8	274.9	27.5	383.2	0.7	250.9	1017.2
VI	15.3	49.3	96.5	9.7	43.9	4.4	87.9	8.8	184.9	6.5	1192.6	1562.3
VII	32.0	70.0	97.1	9.7	89.8	9.0	179.6	18.0	277.7	2.0	566.3	1121.8
VIII	21.0	53.2	97.1	9.7	59.3	5.9	118.5	11.9	213.3	4.9	1049.7	1476.3
one size	30.0	56.6	112.5	11.3	85.5	8.6	171.0	17.1	268.0	2.3	607.5	1143.4
	Section 2								face	contin-ued fill	Total	
Scenario	Step 1	2	3	per course	4	per course	5	per course	Total	Ratio in volume	cost fill	
I	41.8	82.6	160.6	40.2	121.9	30.5	243.9	61.0	296.2	0.4	109.6	701.9
II	17.1	36.8	96.4	24.1	54.1	13.5	108.1	27.0	142.7	3.8	541.9	827.2
III	17.1			0.0	47.8	12.0	95.6	23.9	53.0	3.8	201.2	307.1
IV	46.8	82.7	160.6	40.2	137.4	34.4	274.9	68.7	312.9	0.1	36.2	662.0
V	46.4	81.7	160.5	40.1	135.5	33.9	271.0	67.8	310.0	0.1	42.5	662.5
VI	14.2	31.2	85.3	21.3	44.7	11.2	89.5	22.4	121.6	5.0	604.1	847.3
VII	21.6	41.0	88.7	22.2	62.1	15.5	124.2	31.1	153.5	2.6	398.7	705.7
VIII	14.6	33.0	85.4	21.4	42.4	10.6	84.7	21.2	122.1	4.8	586.4	830.6
one size	16.9	31.9	63.5	15.9	48.3	12.1	96.5	24.1	116.8	3.8	443.5	677.0
	Section 3								face	contin-ued fill	Total	
Scenario	Step 1	2	3	per course	4	per course	5	per course	Total	Ratio in volume	cost fill	
I	48.7	82.0	195.7	39.1	138.8	27.8	277.6	55.5	331.4	0.0	0.1	662.9
II	21.0	25.2	69.8	14.0	63.1	12.6	126.1	25.2	125.9	2.6	333.6	585.5
III	21.0			0.0		0.0		0.0	21.0	2.6	55.6	97.6
IV	73.1	134.8	300.2	60.0	205.6	41.1	411.2	82.2	511.4	-0.7	-340.6	682.1
V	70.9	134.6	300.2	60.0	200.5	40.1	401.1	80.2	505.9	-0.6	-316.0	695.9
VI	16.2	24.4	77.5	15.5	47.0	9.4	93.9	18.8	115.3	4.0	463.4	693.9
VII	39.1	90.3	311.9	62.4	112.5	22.5	225.1	45.0	384.1	0.5	189.2	957.4
VIII	24.8	44.2	95.9	19.2	73.0	14.6	146.1	29.2	170.4	1.9	330.2	670.9
one size	20.7	39.2	77.9	15.6	59.2	11.8	118.3	23.7	142.1	2.6	376.6	660.9

	Section 4								face	contin-ued fill	Total	
Scenario	Step 1	2	3	per course	4	per course	5	per course	Total	Ratio in volume	cost fill	
I	17.9	44.8	80.1	16.0	52.8	10.6	105.6	21.1	252.8	0.2	43.9	549.5
II	7.2	16.7	32.4	6.5	23.0	4.6	46.0	9.2	106.7	3.4	362.7	576.1
III	7.2			0.0		0.0		0.0	7.2	3.4	24.5	38.9
IV	19.5	44.9	72.9	14.6	56.2	11.2	112.5	22.5	266.7	0.0	-0.2	533.3
V	19.2	37.1	72.9	14.6	55.4	11.1	110.7	22.1	255.7	0.0	7.2	518.7
VI	5.8	14.4	27.4	5.5	18.0	3.6	36.1	7.2	85.0	4.6	388.4	558.4
VII	17.0	60.8	53.8	10.8	48.5	9.7	97.1	19.4	252.4	1.5	380.0	884.9
VIII	10.6	26.4	46.1	9.2	31.8	6.4	63.7	12.7	151.5	3.7	566.5	869.5
one size	7.1	13.5	31.3	6.3	20.4	4.1	40.7	8.1	94.0	3.4	319.6	507.6

Table 2. Overview of calculations using Mayes and Murakami assembly rates.

Mycenae											
Section 3											
Scenario	Volume (m3)	# blocks	max. tot. vol.	Labour rate	Costs (ph)	Ratio of vol. / tot. vol.	Vol. fill (with spaces)	Costs fill (ph)	Total(2xface+fill)	Fill build rate	
I	up to 0,2	111	0.5	0.034	14.4	0.003	2.5	72.4		0.4625	0.8375
	up to 0,5	56	24.3	0.024	1,013.7	0.163	122.0	5,082.8			
	over 0,5	55	124.0	0.019	6,528.5	0.833	622.0	32,734.3		1,944.4	1,073.8
	Subtotal		148.9		7,556.7	1.000		37,889.4	53,002.8	17,057.7	16,187.1
II	up to 0,2	111	0.6	0.034	18.4	0.003	2.2	65.9			
	up to 0,5	56	30.9	0.024	1,289.1	0.163	111.0	4,625.7			
	over 0,5	55	157.7	0.019	8,302.0	0.833	566.0	29,790.3		1,769.5	977.2
	Subtotal		189.3		9,609.4	1.000		34,481.9	53,700.7	20,988.4	20,196.1
III	up to 0,2	111	9.9	0.034	289.9	0.052	35.4	1,040.3			
	up to 0,5	56	41.7	0.024	1,738.5	0.220	149.7	6,238.2			
	over 0,5	55	137.7	0.019	7,248.4	0.728	494.2	26,009.8		1,769.5	977.2
	Subtotal		189.3		9,276.8	1.000		33,288.3	51,841.9	20,323.1	19,530.8
IV	up to 0,2	111	2.8	0.034	81.8	0.015	10.0	293.4			
	up to 0,5	56	44.8	0.024	1,867.6	0.237	160.8	6,700.8			
	over 0,5	55	141.7	0.019	7,458.4	0.749	508.5	26,760.8		1,769.5	977.2
	Subtotal		189.3		9,407.7	1.000		33,755.1	52,570.6	20,585.0	19,792.7
V	up to 0,2	111	1.4	0.034	40.9	0.008	6.0	177.6			
	up to 0,5	56	22.4	0.024	933.8	0.135	97.3	4,055.1			
	over 0,5	55	141.7	0.019	7,458.4	0.856	615.4	32,389.5		1,872.4	1,034.0
	Subtotal		165.5		8,433.1	1.000		36,622.3	53,488.4	18,738.5	17,900.2
VI	up to 0,2	146	4.6	0.034	133.9	0.047	38.9	1,144.0			
	up to 0,5	49	31.9	0.024	1,331.0	0.328	272.8	11,368.5			
	over 0,5	27	60.9	0.019	3,204.9	0.625	520.1	27,373.7		2,167.0	1,196.7
	Subtotal		97.4		4,669.9	1.000		39,886.2	49,225.9	11,506.7	10,536.4
VII	up to 0,2	126	15.3	0.034	449.9	0.097	71.4	2,101.1			
	up to 0,5	20	72.1	0.024	3,003.9	0.459	336.7	14,027.5			
	over 0,5	76	69.6	0.019	3,661.4	0.443	324.9	17,098.0		1,909.4	1,054.4
	Subtotal		157.0		7,115.2	1.000		33,226.6	47,457.1	16,139.8	15,284.8

VIII	up to 0,2	146	7.6	0.034	225.0	0.068	54.4	1,599.9			
	up to 0,5	49	36.0	0.024	1,501.9	0.318	256.4	10,681.5			
	over 0,5	27	69.6	0.019	3,661.4	0.614	494.7	26,039.1		2,098.3	1,158.8
	Subtotal		113.3		5,388.3	1.000		38,320.5	49,097.1	12,874.9	11,935.4

Section 4

Scenario	Volume (m3)	# blocks	max. tot. vol.	Labour rate	Costs (ph)	Ratio of vol. / tot. vol.	Vol. fill (with spaces)	Costs fill (ph)	Total(2xface+fill)	Fill build rate	
I	up to 0,2	127	2.8	0.034	82.9	0.122	18.5	544.4		0.4625	0.8375
	up to 0,5	42	20.4	0.024	848.6	0.878	133.8	5,573.3			
	over 0,5			0.019	0.0	0.000	0.0	0.0		396.7	219.1
	Subtotal		23.2		931.5	1.000		6,117.7	7,980.6	2,259.6	2,082.0
II	up to 0,2	127	3.0	0.034	89.0	0.122	18.2	534.2			
	up to 0,5	42	21.9	0.024	911.4	0.878	131.3	5,469.0			
	over 0,5			0.019	0.0	0.000	0.0	0.0		389.2	215.0
	Subtotal		24.9		1,000.4	1.000		6,003.3	8,004.1	2,390.1	2,215.8
III	up to 0,2	85	0.9	0.034	25.4	0.035	5.2	152.7			
	up to 0,5	42	2.9	0.024	119.7	0.115	17.2	718.2			
	over 0,5	42	21.2	0.019	1,113.8	0.850	127.0	6,683.9		389.2	215.0
	Subtotal		24.9		1,258.9	1.000		7,554.7	10,072.6	2,907.1	2,732.8
IV	up to 0,2	127	5.9	0.034	173.9	0.128	14.7	432.1			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	42	40.1	0.019	2,111.1	0.872	99.7	5,245.3		297.9	164.5
	Subtotal		46.0		2,285.1	1.000		5,677.4	10,247.6	4,868.0	4,734.7
V	up to 0,2	127	3.0	0.034	87.0	0.069	8.2	240.8			
	up to 0,5	56		0.024	0.0	0.000	0.0	0.0			
	over 0,5	42	40.1	0.019	2,111.1	0.931	111.1	5,846.0		310.7	171.6
	Subtotal		43.1		2,198.1	1.000		6,086.8	10,483.0	4,706.9	4,567.8
VI	up to 0,2	147	5.5	0.034	162.7	0.284	44.9	1,320.7			
	up to 0,5	15	7.2	0.024	299.5	0.368	58.4	2,431.4			
	over 0,5	7	6.8	0.019	357.3	0.348	55.1	2,901.0		412.6	227.8
	Subtotal		19.5		819.4	1.000		6,653.1	8,291.8	2,051.4	1,866.6
VII	up to 0,2	125	10.2	0.034	301.0	0.252	31.0	913.2			
	up to 0,5	22	9.8	0.024	408.9	0.242	29.8	1,240.7			
	over 0,5	22	20.6	0.019	1,083.7	0.507	62.5	3,287.9		321.2	177.4
	Subtotal		40.6		1,793.6	1.000		5,441.8	9,029.0	3,908.3	3,764.5
VIII	up to 0,2	147	10.0	0.034	294.8	0.424	64.2	1,887.4			
	up to 0,5	15	7.0	0.024	289.7	0.294	44.5	1,854.5			
	over 0,5	7	6.7	0.019	351.8	0.283	42.8	2,252.5		394.6	217.9
	Subtotal		23.7		936.3	1.000		5,994.4	7,867.1	2,267.3	2,090.6

Teichos Dymaion											
Section 1											
Scenario	Volume (m3)	# blocks	max. tot. vol.	Labour rate	Costs (ph)	Ratio of vol. / tot. vol.	Vol. fill (with spaces)	Costs fill (ph)	Total(2xface+fill)	Fill build rate	
I	up to 0,2	257	16.0	0.034	471.7	0.079	21.0	617.3		0.4625	0.8375
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	85	187.5	0.019	9,868.4	0.921	245.4	12,914.6		693.9	383.2
	Subtotal		203.5		10,340.1	1.000		13,531.9	34,212.2	21,374.1	21,063.4
II	up to 0,2	257	11.2	0.034	328.2	0.079	29.1	855.6			
	up to 0,5	42		0.024	0.0	0.000	0.0	0.0			
	over 0,5	85	130.4	0.019	6,865.4	0.921	340.1	17,899.6		961.7	531.1
	Subtotal		141.6		7,193.5	1.000		18,755.2	33,142.3	15,348.8	14,918.2
III	up to 0,2	172	7.5	0.034	219.1	0.053	19.4	571.4			
	up to 0,5	85	34.0	0.024	1,416.0	0.240	88.6	3,691.8			
	over 0,5	85	100.2	0.019	5,271.9	0.707	261.2	13,745.0		961.7	531.1
	Subtotal		141.6		6,907.0	1.000		18,008.2	31,822.2	14,775.7	14,345.1
IV	up to 0,2	172	3.4	0.034	100.5	0.014	2.8	82.6			
	up to 0,5	85	28.2	0.024	1,173.4	0.116	23.2	964.9			
	over 0,5	85	211.8	0.019	11,149.7	0.870	174.2	9,168.2		521.4	287.9
	Subtotal		243.4		12,423.6	1.000		10,215.6	35,062.8	25,368.6	25,135.1
V	up to 0,2	257	15.8	0.034	464.4	0.069	15.7	461.8			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	85	211.8	0.019	11,149.7	0.931	210.7	11,087.8		589.7	325.7
	Subtotal		227.6		11,614.1	1.000		11,549.6	34,777.8	23,817.9	23,553.8
VI	up to 0,2	273	15.6	0.034	459.7	0.218	106.1	3,120.0			
	up to 0,5	59	33.8	0.024	1,410.0	0.473	229.7	9,570.6			
	over 0,5	10	22.1	0.019	1,161.0	0.308	149.7	7,880.4		1,264.7	698.4
	Subtotal		71.5		3,030.6	1.000		20,571.1	26,632.4	7,326.0	6,759.7
VII	up to 0,2	205	21.9	0.034	644.3	0.146	52.1	1,533.0			
	up to 0,5	68	31.1	0.024	1,296.8	0.208	74.1	3,085.6			
	over 0,5	69	96.6	0.019	5,081.9	0.645	229.8	12,092.2		927.2	512.0
	Subtotal		149.6		7,022.9	1.000		16,710.9	30,756.8	14,973.1	14,557.9
VIII	up to 0,2	273	26.5	0.034	779.8	0.304	139.6	4,105.9			
	up to 0,5	59	35.8	0.024	1,492.4	0.410	188.6	7,857.4			
	over 0,5	10	24.9	0.019	1,311.7	0.286	131.2	6,906.4		1,196.7	660.9
	Subtotal		87.3		3,583.9	1.000		18,869.7	26,037.5	8,364.6	7,828.7

Section 2											
Scenario	Volume (m3)	# blocks	max. tot. vol.	Labour rate	Costs (ph)	Ratio of vol. / tot. vol.	Vol. fill (with spaces)	Costs fill (ph)	Total(2xface+fill)	Fill build rate	
I	up to 0,2	457	4.2	0.034	123.3	0.021	3.0	87.6		0.4625	0.8375
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	152	191.3	0.019	10,067.2	0.979	135.9	7,152.3		361.8	199.8
	Subtotal		195.5		10,190.5	1.000		7,239.8	27,620.8	20,742.7	20,580.7

II	up to 0,2	457	1.7	0.034	50.4	0.021	7.1	208.6			
	up to 0,5	152	78.2	0.024	3,257.0	0.979	323.7	13,485.6			
	over 0,5			0.019	0.0	0.000	0.0	0.0		861.6	475.8
	Subtotal		79.9		3,307.3	1.000		13,694.2	20,308.9	7,476.3	7,090.5
III	up to 0,2	305	3.6	0.034	107.3	0.046	15.1	444.1			
	up to 0,5	152	7.3	0.024	305.3	0.092	30.3	1,263.9			
	over 0,5	152	68.9	0.019	3,626.7	0.863	285.3	15,016.5		861.6	475.8
	Subtotal		79.9		4,039.2	1.000		16,724.5	24,802.9	8,940.0	8,554.2
IV	up to 0,2	457	4.4	0.034	130.4	0.020	2.0	59.4			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	152	214.6	0.019	11,293.3	0.980	97.8	5,146.0		260.0	143.6
	Subtotal		219.0		11,423.7	1.000		5,205.5	28,052.9	23,107.4	22,991.0
V	up to 0,2	457	2.2	0.034	65.2	0.010	1.1	31.1			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	152	214.6	0.019	11,293.3	0.990	102.4	5,390.4		269.6	148.9
	Subtotal		216.8		11,358.5	1.000		5,421.6	28,138.5	22,986.5	22,865.8
VI	up to 0,2	540	9.9	0.034	290.5	0.149	52.4	1,542.5			
	up to 0,5	44	18.8	0.024	785.2	0.284	100.1	4,169.9			
	over 0,5	25	37.8	0.019	1,987.0	0.568	200.5	10,551.3		919.6	507.8
	Subtotal		66.5		3,062.7	1.000		16,263.8	22,389.2	7,044.9	6,633.2
VII	up to 0,2	540	31.0	0.034	913.1	0.308	91.2	2,681.1			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	69	69.8	0.019	3,671.9	0.692	204.8	10,781.1		771.1	425.8
	Subtotal		100.8		4,585.0	1.000		13,462.2	22,632.3	9,941.1	9,595.9
VIII	up to 0,2	540	15.5	0.034	456.6	0.228	79.9	2,350.8			
	up to 0,5	44	17.2	0.024	718.2	0.253	88.7	3,697.9			
	over 0,5	25	35.3	0.019	1,857.4	0.519	181.7	9,563.5		912.7	504.1
	Subtotal		68.1		3,032.2	1.000		15,612.1	21,676.6	6,977.2	6,568.5

Section 3											
Scenario	Volume (m3)	# blocks	max. tot. vol.	Labour rate	Costs (ph)	Ratio of vol. / tot. vol.	Vol. fill (with spaces)	Costs fill (ph)	Total(2xface+fill)	Fill build rate	
I	up to 0,2	300	10.8	0.034	318.5	0.048	3.7	108.5		0.4625	0.8375
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	99	216.9	0.019	11,417.2	0.952	73.9	3,889.9		202.1	111.6
	Subtotal		227.8		11,735.7	1.000		3,998.4	27,469.8	23,673.5	23,582.9
II	up to 0,2	300	4.7	0.034	137.1	0.048	13.9	409.6			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	99	93.4	0.019	4,914.7	0.952	279.0	14,684.1		763.1	421.4
	Subtotal		98.0		5,051.8	1.000		15,093.7	25,197.2	10,866.6	10,525.0
III	up to 0,2	200	3.4	0.034	101.0	0.035	10.3	301.6			
	up to 0,5	100	13.0	0.024	543.7	0.133	39.0	1,624.5			
	over 0,5	99	81.6	0.019	4,292.6	0.832	243.7	12,825.3		763.1	421.4
	Subtotal		98.0		4,937.2	1.000		14,751.4	24,625.8	10,637.5	10,295.8

IV	up to 0,2	300	20.5	0.034	602.1	0.060	-6.7	-196.3			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	99	321.1	0.019	16,900.5	0.940	-104.7	-5,509.5		-290.1	-160.2
	Subtotal		341.6		17,502.6	1.000		-5,705.8	29,299.4	34,715.1	34,845.0
V	up to 0,2	300	10.2	0.034	301.1	0.031	-2.9	-85.7			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	99	321.1	0.019	16,900.5	0.969	-91.4	-4,813.0		-245.8	-135.7
	Subtotal		331.3		17,201.5	1.000		-4,898.7	29,504.3	34,157.2	34,267.3
VI	up to 0,2	352	19.9	0.034	586.2	0.263	86.9	2,554.6			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	47	55.8	0.019	2,936.1	0.737	243.1	12,796.1		859.6	474.7
	Subtotal		75.7		3,522.3	1.000		15,350.6	22,395.2	7,904.2	7,519.3
VII	up to 0,2	288	37.8	0.034	1,112.6	0.207	31.5	926.9			
	up to 0,5	64	42.1	0.024	1,753.1	0.230	35.1	1,460.6			
	over 0,5	47	102.9	0.019	5,414.0	0.563	85.7	4,510.5		396.7	219.1
	Subtotal		182.8		8,279.8	1.000		6,898.0	23,457.6	16,956.3	16,778.7
VIII	up to 0,2	288	18.9	0.034	556.3	0.163	43.1	1,267.3			
	up to 0,5	64	21.0	0.024	876.6	0.182	47.9	1,996.8			
	over 0,5	47	75.8	0.019	3,987.4	0.655	172.6	9,083.0		686.7	379.2
	Subtotal		115.7		5,420.2	1.000		12,347.1	23,187.6	11,527.1	11,219.7

Section 4

Scenario	Volume (m3)	# blocks	max. tot. vol.	Labour rate	Costs (ph)	Ratio of vol. / tot. vol.	Vol. fill (with spaces)	Costs fill (ph)	Total(2xface+fill)	Fill build rate	
I	up to 0,2	208	2.3	0.034	67.3	0.027	1.2	34.6		0.4625	0.8375
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	69	81.4	0.019	4,285.2	0.973	41.8	2,200.2		112.0	61.8
	Subtotal		83.7		4,352.6	1.000		2,234.8	10,939.9	8,817.1	8,767.0
II	up to 0,2	208	0.9	0.034	27.1	0.027	3.4	101.3			
	up to 0,5	69	32.8	0.024	1,365.8	0.973	122.5	5,106.2			
	over 0,5			0.019	0.0	0.000	0.0	0.0		328.2	181.3
	Subtotal		33.7		1,392.9	1.000		5,207.5	7,993.3	3,114.0	2,967.0
III	up to 0,2	139	1.3	0.034	38.7	0.039	4.9	144.6			
	up to 0,5	69	3.0	0.024	125.9	0.090	11.3	470.6			
	over 0,5	69	29.4	0.019	1,545.5	0.871	109.8	5,778.1		328.2	181.3
	Subtotal		33.7		1,710.0	1.000		6,393.3	9,813.3	3,748.3	3,601.3
IV	up to 0,2	208	2.5	0.034	74.8	0.028	0.9	25.4			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	69	88.4	0.019	4,654.9	0.972	30.0	1,580.8		80.5	44.4
	Subtotal		91.0		4,729.7	1.000		1,606.2	11,065.6	9,539.9	9,503.9
V	up to 0,2	208	1.3	0.034	37.4	0.014	0.5	13.8			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	69	88.4	0.019	4,654.9	0.986	32.5	1,712.7		86.0	47.5
	Subtotal		89.7		4,692.3	1.000		1,726.4	11,111.1	9,470.6	9,432.1

VI	up to 0,2	241	5.1	0.034	151.0	0.190	26.0	763.6			
	up to 0,5	27	11.3	0.024	472.3	0.418	57.3	2,387.9			
	over 0,5	9	10.6	0.019	558.9	0.392	53.7	2,825.9		356.8	197.0
	Subtotal		27.1		1,182.3	1.000		5,977.4	8,342.0	2,721.4	2,561.6
VII	up to 0,2	241	19.9	0.034	583.9	0.382	36.6	1,076.9			
	up to 0,5			0.024	0.0	0.000	0.0	0.0			
	over 0,5	36	32.1	0.019	1,687.7	0.618	59.1	3,112.5		249.4	137.7
	Subtotal		51.9		2,271.6	1.000		4,189.4	8,732.5	4,792.6	4,680.9
VIII	up to 0,2	241	9.9	0.034	291.9	0.313	40.4	1,189.5			
	up to 0,5	27	10.3	0.024	427.7	0.324	41.8	1,742.6			
	over 0,5	9	11.5	0.019	607.2	0.364	47.0	2,473.8		336.7	186.0
	Subtotal		31.7		1,326.8	1.000		5,406.0	8,059.6	2,990.4	2,839.6

Appendix 6 Overview of the calculations of the total costs

This appendix consists of two tables. Table 1 provides an overview of the costs per process per section and scenario for the fortifications. In table 2, the costs per process and scenario for the domestic structures are presented. All labour costs are expressed in person-hours (ph).

Table 1. Overview of the calculations for the total costs of the fortification

Mycenae			
		min	max
Section 1	Acquisition	5,813	9,300
	Transport	1,212	1,530
	Loading/unloading	62	821
	Levelling	88	114
	Dressing	12,976	15,352
	Ramp	971	1,208
	Assembly	1,531	7,484
	Total	22,652	35,809
Section 2	Acquisition	1,181	1,890
	Transport	297	297
	Loading/unloading	16	284
	Levelling	68	87
	Dressing	1,870	2,943
	Ramp	971	1,208
	Assembly	327	1,216
	Total	4,729	7,925

Section 3								
Scenario		Acquisition	Transport	(Un)loading	Levelling	Ramp	Assembly	Total
I	min	4,698.5	736.5	157.8	420.0	970.7	2,101.5	9,085.0
	max	17,429.8	961.0	2,424.1	543.1	1,207.7	53,002.8	75,568.5
II	min	5,436.5	780.0	162.5	420.0	970.7	2,200.4	9,970.1
	max	17,429.8	953.4	2,307.1	543.1	1,207.7	53,700.7	76,141.8
III	min	5,436.5	795.7		420.0	970.7		7,622.9
	max	17,429.8	996.0	2,697.0	543.1	1,207.7	54,841.0	77,714.6
IV	min	5,436.6	814.7	164.8	420.0	970.7	1,578.8	9,385.6
	max	17,429.8	1,042.0	2,570.1	543.1	1,207.7	52,570.6	75,363.3
V	min	5,002.8	785.3	258.5	420.0	970.7	1,983.3	9,420.6
	max	17,429.8	1,036.3	2,436.9	543.1	1,207.7	53,488.4	76,142.2
VI	min	3,761.8	716.4	317.1	420.0	970.7	1,841.5	8,027.5
	max	17,429.8	1,023.8	2,854.2	543.1	1,207.7	49,255.9	72,314.5
VII	min	4,847.9	778.2	322.1	420.0	970.7	1,532.8	8,871.7
	max	17,429.8	1,018.0	2,979.6	543.1	1,207.7	47,457.1	70,635.3
VIII	min	4,051.6	739.1	341.2	420.0	970.7	1,597.2	8,119.8
	max	17,429.8	1,036.5	2,877.1	543.1	1,207.7	49,097.1	72,191.3
one size	min	5,436.5	768.2	160.0	420.0	970.7	1,673.3	9,428.7
	max	17,429.8	921.4	2,980.8	543.1	1,207.7	52,290.0	75,372.8

Section 4								
Scenario		Acquisition	Transport	(Un)loading	Levelling	Ramp	Assembly	Total
I	min	804.3	93.9	32.9	222.5	970.7	283.0	2,407.3
	max	3,346.5	120.0	953.8	287.7	1,207.7	7,980.6	13,896.3
II	min	835.2	94.8	30.6	222.5	970.7	270.4	2,424.2
	max	3,346.5	119.9	888.6	287.7	1,207.7	8,004.1	13,854.5
III	min	835.2	94.8		222.5	970.7		2,123.2
	max	3,346.5	119.9	551.6	287.7	1,207.7	10,072.6	15,586.0
IV	min	1,219.7	106.5	33.2	222.5	970.7	310.0	2,862.6
	max	3,346.5	120.0	945.5	287.7	1,207.7	10,247.6	16,155.0
V	min	1,166.9	104.8	31.0	222.5	970.7	238.1	2,734.0
	max	3,346.5	119.9	513.4	287.7	1,207.7	10,483.0	15,958.2
VI	min	736.8	91.8	29.3	222.5	970.7	272.9	2,324.0
	max	3,346.5	119.8	1,173.8	287.7	1,207.7	8,291.8	14,427.3
VII	min	1,121.3	103.5	32.9	222.5	970.7	254.3	2,705.2
	max	3,346.5	120.0	587.3	287.7	1,207.7	8,029.0	13,578.2
VIII	min	813.4	94.1	32.2	222.5	970.7	258.9	2,391.8
	max	3,346.5	119.9	990.0	287.7	1,207.7	7,867.1	13,818.9
one size	min	835.2	94.8	30.7	222.5	970.7	257.0	2,410.9
	max	3,346.5	119.9	572.4	287.7	1,207.7	10,039.5	15,573.7

Teichos Dymaion								
Section 1								
Scenario		Acquisition	Transport	(Un)loading	Levelling	Ramp	Assembly	Total
I	min	4,916.7	161.9	98.9	381.9	970.7	944.3	7,474.4
	max	10,600.7	181.1	1,817.2	493.8	1,207.7	34,212.2	48,512.7
II	min	3,788.7	149.8	99.0	381.9	970.7	1,041.7	6,431.8
	max	10,600.7	181.1	2,126.4	493.8	1,207.7	33,142.3	47,752.0
III	min	3,788.7	149.8		381.9	970.7	418.6	5,709.7
	max	10,600.7	181.1		493.8	1,207.7	31,822.2	44,305.5
IV	min	5,479.8	182.2	101.8	381.9	970.7	1,022.2	8,138.6
	max	10,600.7	199.5	1,987.2	493.8	1,207.7	35,062.8	49,551.7
V	min	5,355.9	175.5	97.7	381.9	970.7	1,017.2	7,998.9
	max	10,600.7	192.9	1,937.5	493.8	1,207.7	34,777.8	49,210.4
VI	min	2,511.4	136.2	100.6	381.9	970.7	1,562.3	5,663.1
	max	10,600.7	181.3	2,846.3	493.8	1,207.7	26,632.4	41,962.2
VII	min	3,934.5	152.4	96.9	381.9	970.7	1,121.8	6,658.2
	max	10,600.7	183.2	3,017.2	493.8	1,207.7	30,756.8	46,259.4
VIII	min	2,799.3	140.2	103.1	381.9	970.7	1,476.3	5,871.5
	max	10,600.7	184.5	2,267.5	493.8	1,207.7	26,037.5	40,791.7
one size	min	3,788.7	149.8	107.8	381.9	970.7	1,143.4	6,542.3
	max	10,600.7	181.1	1,952.4	493.8	1,207.7	34,248.4	48,684.1

Section 2								
Scenario		Acquisition	Transport	Loading/unloading	Levelling	Ramp	Assembly	Total
I	min	4,489.1	131.8	78.2	676.7	970.7	701.9	7,048.4
	max	8,128.9	138.8	1,469.9	875.0	1,207.7	27,620.8	39,441.1
II	min	2,382.7	109.3	85.8	676.7	970.7	827.2	5,052.4
	max	8,128.9	138.9	1,985.0	875.0	1,207.7	20,308.9	32,644.4
III	min	2,382.7	109.3		676.7	970.7	239.2	4,378.6
	max	8,128.9	138.9		875.0	1,207.7	24,802.9	35,153.4
IV	min	4,917.4	145.4	78.7	676.7	970.7	662.0	7,450.9
	max	8,128.9	148.4	1,312.6	875.0	1,207.7	28,052.9	39,725.5
V	min	4,877.3	144.9	78.0	676.7	970.7	662.5	7,410.1
	max	8,128.9	148.4	1,325.3	875.0	1,207.7	28,138.6	39,823.9
VI	min	2,138.5	106.6	85.7	676.7	970.7	847.3	4,825.5
	max	8,128.9	138.7	2,091.0	875.0	1,207.7	22,389.2	34,830.5
VII	min	2,763.5	114.8	80.0	676.7	970.7	705.7	5,311.4
	max	8,128.9	142.3	1,473.3	875.0	1,207.7	22,632.3	34,459.5
VIII	min	2,167.6	108.5	79.6	676.7	970.7	830.6	4,833.7
	max	8,128.9	143.9	2,054.1	875.0	1,207.7	21,676.6	34,086.2
one size	min	2,382.7	109.3	76.7	676.7	970.7	677.0	4,893.1
	max	8,128.9	138.9	1,390.2	875.0	1,207.7	24,388.9	36,129.6

Section 3								
Scenario		Transport	Loading/unloading	Levelling	Ramp	Assembly	Total
I	min	134.5	74.4	405.1	970.7	662.9	7,310.0
	max	134.5	1,433.6	523.8	1,207.7	27,469.8	38,763.6
II	min	111.3	80.0	405.1	970.7	585.5	4,849.7
	max	136.7	1,367.0	523.8	1,207.7	25,197.2	36,426.6
III	min	111.3		405.1	970.7	97.6	4,281.8
	max	136.7		523.8	1,207.7	24,625.8	34,488.2
IV	min	207.8	73.4	405.1	970.7	682.1	9,475.2
	max	138.6	1,582.6	523.8	1,207.7	29,299.4	40,746.3
V	min	201.7	73.9	405.1	970.7	695.9	9,295.7
	max	138.7	1,541.1	523.8	1,207.7	29,504.3	40,909.8
VI	min	106.6	77.0	405.1	970.7	693.9	4,544.1
	max	135.7	1,619.8	523.8	1,207.7	22,395.3	33,876.5
VII	min	128.2	74.8	405.1	970.7	957.4	6,778.6
	max	137.1	2,428.4	523.8	1,207.7	23,457.6	35,748.8
VIII	min	115.2	80.7	405.1	970.7	670.9	5,262.3
	max	137.4	1,380.0	523.8	1,207.7	23,187.6	34,430.7
one size	min	111.3	75.5	405.1	970.7	660.9	4,567.7
	max	136.7	1,366.8	523.8	1,207.7	23,982.6	35,211.8

Section 4								
Scenario		Acquisition	Transport	Loading/unloading	Levelling	Ramp	Assembly	**Total**
I	min	1,889.1	53.2	31.1	360.0	970.7	549.5	**3,853.6**
	max	3,191.9	54.6	547.8	465.5	1,207.7	10,939.9	**16,407.4**
II	min	978.0	43.4	34.0	360.0	970.7	576.1	**2,962.2**
	max	3,191.9	54.5	840.6	465.5	1,207.7	7,993.3	**13,753.5**
III	min	978.0	43.4		360.0	970.7	38.9	**2,391.0**
	max	3,191.9	54.5		465.5	1,207.7	9,813.3	**14,732.9**
IV	min	2,022.1	54.5	30.4	360.0	970.7	533.3	**3,971.0**
	max	3,191.9	54.5	564.4	465.5	1,207.7	11,065.6	**16,549.6**
V	min	1,998.4	54.3	30.2	360.0	970.7	518.7	**3,932.3**
	max	3,191.9	54.6	571.6	465.5	1,207.7	11,111.1	**16,602.4**
VI	min	868.6	41.8	32.8	360.0	970.7	558.4	**2,832.3**
	max	3,191.9	53.2	821.7	465.5	1,207.7	8,342.0	**14,082.0**
VII	min	1,309.6	46.9	48.0	360.0	970.7	884.9	**3,620.1**
	max	3,191.9	54.5	943.0	465.5	1,207.7	8,732.5	**14,595.1**
VIII	min	941.5	43.0	51.7	360.0	970.7	869.5	**3,236.4**
	max	3,191.9	54.5	1,438.9	465.5	1,207.7	8,059.6	**14,418.1**
one size	min	978.0	43.4	30.1	360.0	970.7	507.6	**2,889.8**
	max	3,191.9	54.5	546.0	**465.5**	1,207.7	9,575.6	**15,041.2**

Table 2. Overview of the calculations of the total costs of the domestic structures.

Scenario	Procurement	Transport	Manufacture	Assembly	Total cost
1	456.0	1,965.0	318.5	1,053.9	3,793.4
2	1,073.8	4,005.9	843.6	1,965.3	7,888.5
3	541.8	2,463.6	17.5	1,162.3	4,185.2
4	256.5	1,386.6	8.8	681.5	2,333.4
5	874.3	3,427.5	533.8	1,664.2	6,499.8
6	565.5	2,441.7	416.4	1,306.6	4,730.3
7	669.5	2,885.8	468.3	1,545.7	5,569.4
8	1,576.4	5,879.1	1,239.6	2,882.4	11,577.6
9	796.1	3,617.1	28.0	1,704.7	6,145.9
10	376.9	2,037.6	14.0	999.5	3,428.0
11	1,283.8	5,030.9	785.2	2,440.8	9,540.7
12	830.2	3,585.1	611.8	1,916.4	6,943.5
13	973.2	4,193.9	680.1	2,248.2	8,095.4
14	2,291.5	8,547.8	1,800.8	4,192.6	16,832.7
15	1,156.6	5,257.6	38.5	2,479.5	8,932.2
16	547.6	2,960.1	19.3	1,453.8	4,980.7
17	1,865.9	7,313.9	1,139.9	3,550.2	13,870.0
18	1,206.9	5,210.9	888.8	2,787.5	10,094.1
19	1,216.7	5,243.8	850.6	2,810.3	10,121.4
20	2,864.9	10,686.1	2,251.9	5,240.8	21,043.8
21	1,446.3	6,573.4	49.0	3,099.4	11,168.1
22	684.7	3,701.5	24.5	1,817.3	6,228.1
23	2,332.9	9,143.9	1,425.8	4,437.8	17,340.4
24	1,508.9	6,515.1	1,111.5	3,484.4	12,619.8
25	1,520.4	6,551.8	1,062.4	3,512.9	12,647.5
26	3,580.0	13,354.8	2,813.1	6,551.0	26,298.9
27	1,806.7	8,213.9	59.5	3,874.3	13,954.4
28	855.4	4,624.0	29.8	2,271.6	7,780.7
29	2,915.0	11,426.9	1,780.5	5,547.2	21,669.7
30	1,885.5	8,141.0	1,388.4	4,355.5	15,770.4
31	1,824.0	7,859.9	1,274.1	4,215.5	15,173.5
32	4,295.1	16,023.4	3,374.3	7,861.2	31,554.1
33	2,167.1	9,854.4	70.0	4,649.1	16,740.7
34	1,026.0	5,546.5	35.0	2,725.9	9,333.4
35	3,497.1	13,710.0	2,135.2	6,656.7	25,999.1
36	2,262.2	9,766.9	1,665.4	5,226.6	18,921.1
37	2,244.3	9,666.7	1,563.3	5,199.1	18,673.4
38	5,286.8	19,735.1	4,145.4	9,695.5	38,862.8
39	2,662.3	12,126.6	70.0	5,733.9	20,592.8
40	1,260.1	6,813.6	35.0	3,362.0	11,470.7
41	4,302.6	16,881.9	2,617.1	8,209.9	32,011.5
42	2,784.8	12,018.7	2,045.9	6,446.1	23,295.4

LABOURING WITH LARGE STONES

This book explores the cost, expressed in labour, of constructing fortifications during the Late Bronze Age in Greece (ca. 1600 – 1050 BCE). The underlying question for this study is whether the cost of large scale constructions, built with large, unwieldy blocks, may have overstretched the (economic) capabilities of communities, leading to their collapse.

In order to determine the labour costs, the building process is deconstructed and for each sub-process, the costs are determined. The costs for these sub-processes are based on the amount of material that is required and the speed with which the tasks associated with these processes can be performed. However, a simplistic number expressing the labour (in person-hours, for example), gives limited insight into the impact such building projects may have had on the communities. Hence, elaborate comparisons are made to put these labour costs into context. This involves, for instance, comparisons between different fortifications, different building styles, as well as between types of structures. It is in these comparisons where the true strength of labour cost studies lie.

This study on its own cannot definitively answer the question whether these construction projects led to the downfall of the Mycenaean communities. However, based purely on the results of the labour cost analyses, it is shown that, despite the impressive nature of the walls, both due to their size as well as due to the size of the stones used, communities seem to have been able to cope with the stress it may have put on their economies. This study, therefore, provides insights into building processes, the impact of material and building styles on construction costs as well as the large varieties that exist within a context collectively known as 'Mycenaean'.

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