# Labouring with large stones: A study into the investment and impact of construction projects on Mycenaean communities in Late Bronze Age Greece

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# 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. The late date of the construction is seen by some researchers 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. In the Argolid there is 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 are 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 power. Thus seeing the fortifications as conspicuous consumption would indicate that besides (or even instead of) the tangible, practical use 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.

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

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. So 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,[18] 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.[19] 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 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),

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

[19] 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 (57.2 million dollars).

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 a nay 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). Underwriting 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 and 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 more 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

*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).*

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).[20] 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

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[20] *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.

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.

Also Loader (1998) 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 more 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.[21] At many sites, various 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.

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.

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[21] Except for her Type V, which only occurs in the Isthmian wall (Loader 1998: 32) of which we know that the date is not Mycenaean (e.g. Morgan 1999).

### 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,[22] it is clear that the material was quarried nearby at an accessible location (e.g. Loader 1995: 37). Furthermore, due to the fact that 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). But 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,

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[22] 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 chapter 8.

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. Similar findings are reported by Soles, who studied the Bronze Age quarry near Mochlos, in eastern Crete (Soles, 1983). His study focusses on a quarry within a small ravine near the coast in which at various sections, rectangular blocks are 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: in prep.; Brysbaert et al. 2019) 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 (a little more than 20m$^2$), 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 time 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 due to the fact that 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 basically the friction that needs to be overcome (de Haan 2009: 4). Friction is determined by the normal force ($F_n$ which 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, the path is even and straight over remaining limestone. $F_n = 1{,}000 \times 9.81 = 9{,}810$ N. The friction coefficient for limestone on limestone used here is 0.60.[23] $F_f = 0.60 \times 9{,}810 = 5{,}886$ 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.[24]

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: $F_f = 0.60 \times 9{,}689.2 = 5{,}813.5$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).

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[23] 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) 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.

[24] 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.

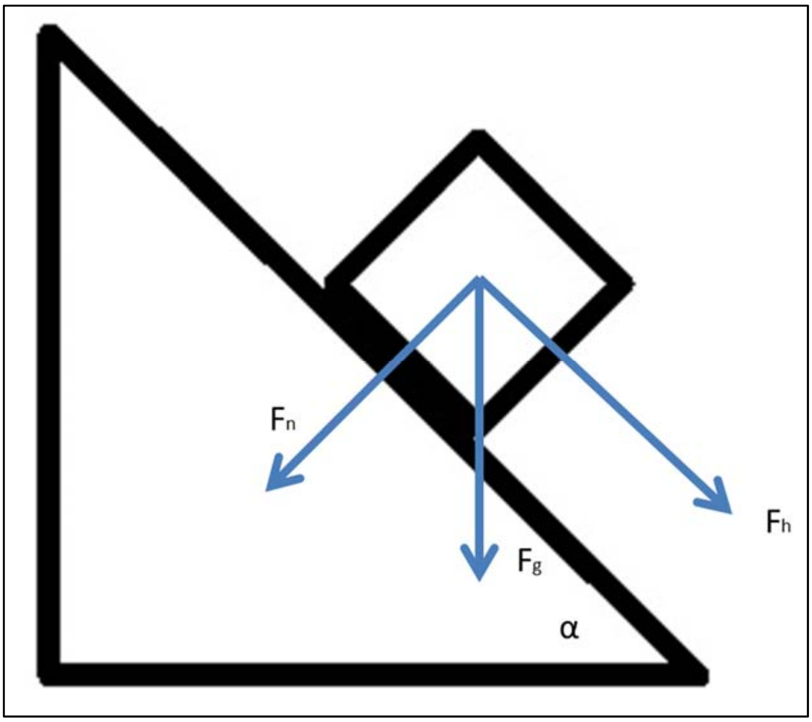

*Figure 3.3 Forces that work on an object on a slope with angle α (drawing by author).*

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 closerto 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 ground-breaking 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 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.

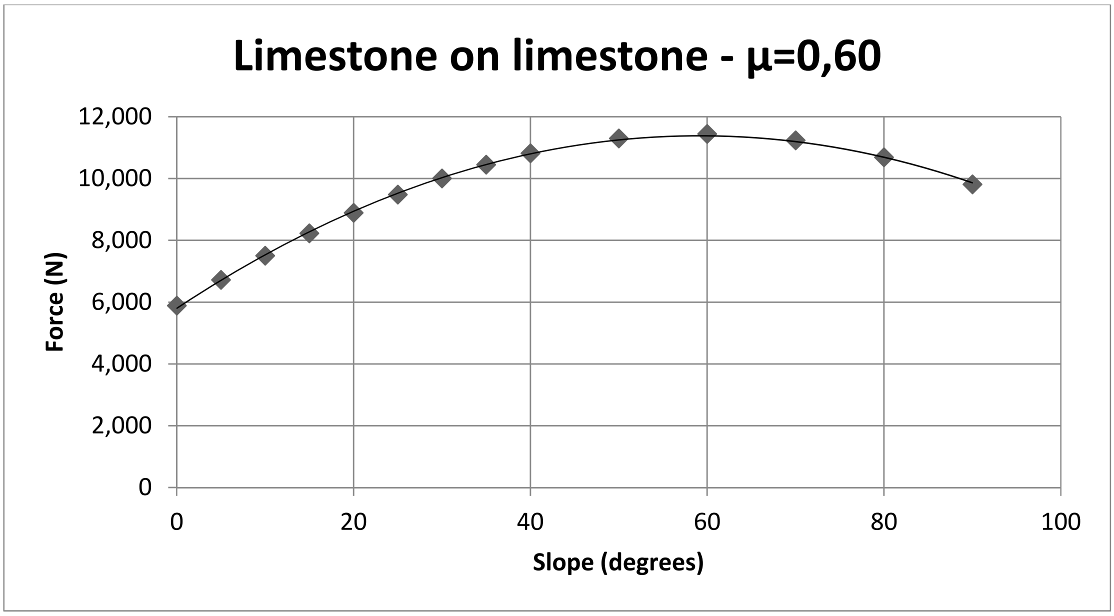

*Figure 3.4 The distribution of required force on different slopes when hauling a 1 tonne block over the ground, with friction force μ=0.60. Note that the total required force lessens after a 60 degree angle, as the friction* <u>*force*</u> *becomes less on such steep slopes even though the friction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

### 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. The frictional resistance of wheels and rollers is determined by a number of factors. 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 1.00m, while the width is between 0.03 and 0.09m (see table 3.1).

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

| **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 |

### 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 (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.

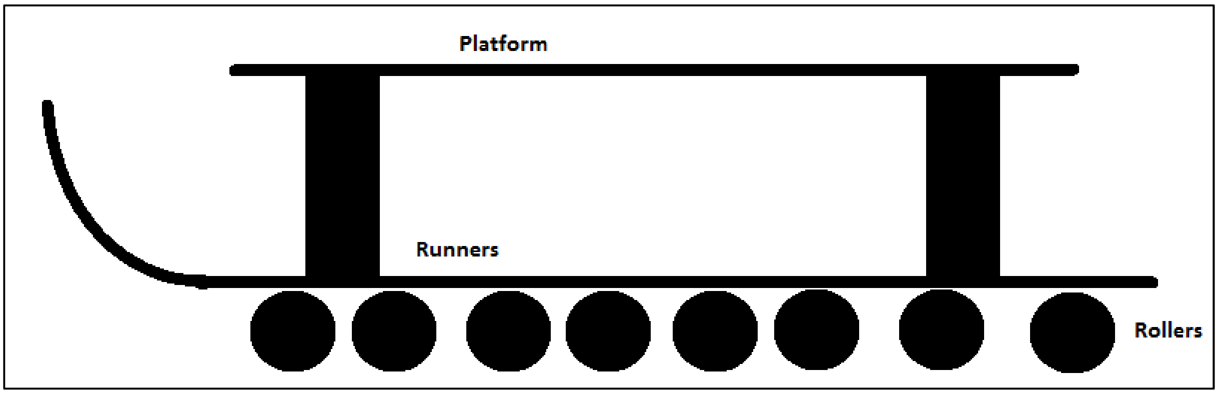

*Figure 3.5 Schematic drawing of a sledge. The runners are the bottom part of the sledge actually sliding over the ground or rollers. In some cases, like a fork shaped sledge, the runners are also the platform on which the load is placed (e.g. Atkinson 1961; Shimotsuma et al. 2011) (drawing by author).*

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).[25] This is on par with what was found in research on the use of water as a lubricant for

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[25] 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 $F_t$ = 18,000×300 = 5.40MN, $F_n$ = $F_g$ = 1,000 ton×9.81 = 9.81MN. $F_f = F_n\mu \rightarrow 5.40 = 9.81\times\mu \rightarrow \mu = 5.40/9.81 = 0.55$. The friction coefficient is actually lower as this calculation does not take into account the weight of the sledge.

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 1,000kg 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 $F_n = F_g = 9{,}810N$. The friction force is then $F_f = 0.55 \times 9{,}810 = 5{,}395.5N$, which is an 8.3% decrease from the 5,886N 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 [26] which would mean a force between 1,962 – 3,924N 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.[27] 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 could be either 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, it requires 920N per tonne. This coincides with Clark’s (1878: 962) figure of 927N per tonne.[28] 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 3,260kg, bringing the total to 4,260kg. A total of 4.26[29] x 920 = 3,919.2N 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.[30] It could also be argued that a 1 tonne block does not need such a large wagon

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

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

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

[29] 4,260kg / 1,000 = 4.26 tonnes.

[30] 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 = 743N. A decrease of 87% of the required force to move the 1 tonne block by dragging it over the ground.

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 x 920 = 1,840N, 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/mm$^2$, thus the difference between an axle of 25 or 75mm, means a difference in surface area of a factor 9 (1,963 vs 17,671mm$^2$) and thus 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 – 0.16m (see table 3.1 above), which gives a range of cross-section surfaces of 3,318 – 20,106mm$^2$. 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.[31] 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 0.8m/s or 2.9km/h. In comparison, horses will go 1.1m/s or 4km/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 = 4km/h) (1878: 962) as well as Rankine's figures for horses (3-3.6ft/s = 0.9-1.1m/s) and oxen (2.4ft/s = 0.7m/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 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).[32] 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 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 of all, she focusses on the use of oxen

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[31] 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).

[32] This is the ridge between the shoulder blades.

carts (instead of wagons) which, as she writes are limited to carrying a maximum weight of between 400-500kg (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 more 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 630N 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 500-1,000kg[33] 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.[34] 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 2,100kg 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 410N, based on Rankine (1889: 251), yet Rankine mentions an effort of 120 pounds (~ 534N) in his 1866 paper. Raepsaet (1993: 260) comes to the highest mentioned effort in relation to ancient oxen of 630N. 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

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[33] 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).

[34] Devolder gives an example for the Gournia palace in which she uses that number of 2,100kg to divide the total load of stone into loads that could be drawn and thus calculate the number of trips. If a wagon weighed 1,000kg, the maximum load would be 1,100kg, 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.

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.[35] 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.[36] 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 549N.[37] 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 118N. Hertzberg (1972: 552), writes that while pushing horizontally against a stationary object, a human can exert 40 pounds of force, or 178N. 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 104.4W. This is close to de Haan's (2010: 17–21) figure of 70-100W 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 125N. 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 300N (de Haan, 2009).[38]

#### 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 in large part also depend 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, n.d. in press; Harper, 2016; Jansen, 2002; e.g. Steffen, 1884), but the close proximity of the quarry locations

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[35] 450 x 1/7 = 64.3 kgf which is 64.3 x 9.81 = 630.6N.

[36] It is odd that Devolder argues that the maximum pulling force is 630 N, based on Raepsaet who assumes that oxen weigh about 450kg, 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.

[37] 350 x 14% x 9.81~ 481 and 400 x 14% x 9.81~ 549N.

[38] 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 more precise methods are used.

(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 manpower 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 till 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 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 limestones are bedded differently and thus break away differently, this determines the size and shape of the blocks used. Therefore, this influences the way techniques like 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 not consider these sections as 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 which 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 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.

*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 might not be 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.*

### 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 perhaps also 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 50m long.[39] 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 of all, 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

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

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).

### 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.