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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7 Labour costs of fortifications and domestic structures

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

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

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

7.1 Material acquisition

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

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

Task	Material	Rate (m3/ph)	Rate (ph/m3)_	Method of extraction	Source	Type of source
Quarrying	conglomerate / limestone	0.089	11.236	channelling	Lehner 1997: 206-7	experiment
Quarrying	conglomerate / limestone	0.033	30.303	channelling	Lehner 1997: 206-7 (adapted for ancient circumstances) [66]	extrapolation from experiment
Quarrying	limestone	0.033	30.303	channelling	De Haan 2009: 3 (taken from Lehner 1997)	extrapolation from experiment
Quarrying	limestone	0.03	33.333	channelling	De Haan 2014: 153	extrapolation from experiment
Breaking material from bedrock	bedrock	0.09	11.111	Wedge and lever	Devolder 2013: 43	experiment (by Abrams 1994)
Sawing	Portland stone (limestone)	0.155	6.459	sawing	Hurst 1905: 382	observation (building manual)
Sawing	hard rock	0.001	1,000.000	sawing	Devolder 2013: 43	experiment (by Stocks 2001)
Sawing	soft rock	0.041	24.390	sawing	Devolder 2013: 43	experiment (by Stocks 2001)
Quarrying	marble	0.0082	121.951	channelling	DeLaine 1997: 121 n87	ancient sources
Quarrying	marble	0.011	90.909	channelling	DeLaine 1997: 121	ancient sources
Quarrying	marble	0.0056	178.571	channelling	DeLaine 1997: 121 n87	ancient sources
Quarrying	granite	0.00052	1,923.077	channelling	De Haan 2009: 3	experiment (by Goyen et al. 2004 and Lehner 1997)
Quarrying	limestone	0.1	10.000	unknown	Brysbaert 2015: 94	experiment (by Bessac 2007)
Quarrying	tuff	0.057	17.600	Wedge and lever (?)	Abrams 1994	experiment
Quarrying	tuff	0.113	8.800	Wedge and	Abrams 1994	experiment

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

				lever (?)		
Quarrying	limestone	0.04	25.000	channelling?	Pakkanen 2013: 11	inscriptions from Classical period
Quarrying	limestone	0.048	20.833	channelling?	Pakkanen 2013: 11	inscriptions from Classical period
Quarrying	conglomerate	0.0467	21.413	channelling	Cavanagh and Mee 1999: 100	estimation
Quarrying	conglomerate	0.0583	17.153	channelling	Cavanagh and Mee 1999: 100	estimation
Quarrying	*poros*	0.0099	101.000	channelling	Devolder 2013: 21, 43	average of 2 observed values (Pegoretti and Klabisch-Zuber)
Rubble quarrying/collecting	tuff	0.47	2.128		Abrams 1994	experiment
Rubble quarrying/collecting	tuff	0.64	1.563		Abrams 1994	experiment
Quarrying	tufa	0.4	2.500	pick	DeLaine 1997: 110-1	builders' manual (17-18th c)
Quarrying	chalk	0.38	2.632	excavating	Hurst 1905: 376	builders' manual (19th c)

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

To understand how the various methods differ from one another in terms of work rates, see figure 7.1. It is clear that Devolder's channelling (see chapter 3) rate (0.0099m^3/ph) on one side and Brysbaert's rate (0.1m^3/ph) on the other side, form the extreme values for quarrying limestone (with Abram's range (0.057 – 0.114m^3/ph) overlapping slightly with Brysbaert's rate). Lehner's adjusted rate (see above) sits at the same height as the top of de Haan's range (same value) and Pakkanen's top is close to the lower end of Abram's range. The difference between the methods in terms of labour cost is most clearly illustrated by the rates Devolder uses. One is based on the concept of simply breaking material from the bedrock, which could mean using natural cracks and beds to break away material. The other rate is based on channelling which is thus much more labour intensive. As mentioned above, though, channelling was likely not the employed method for the cyclopean style sections of wall. Although Devolder's range is directly based on Abram's experimental data, it is an attempt to gear it towards the specifics of the type of stone used. Because Abram's experiment involved tuff, the high end of his range may be too high to be applicable to the harder limestone used in the cyclopean-style walls. Considering the discussed unworked nature of the used stone material, breaking it away in whatever shape from the bedrock seems more likely. However, over-simplifying the quarrying should be avoided and thus **the range of 0.057 (low end of Abram's range) – 0.09m^3/ph (top end of Devolder's range) will be used as rate for quarrying the limestone** (see table 7.2)**.**

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

Task	**Rate (m^3/ph)**
Quarrying limestone blocks (cyclopean)	0.057-0.09
Quarrying conglomerate (façade)	0.03-0.048
Quarrying rubble	0.5

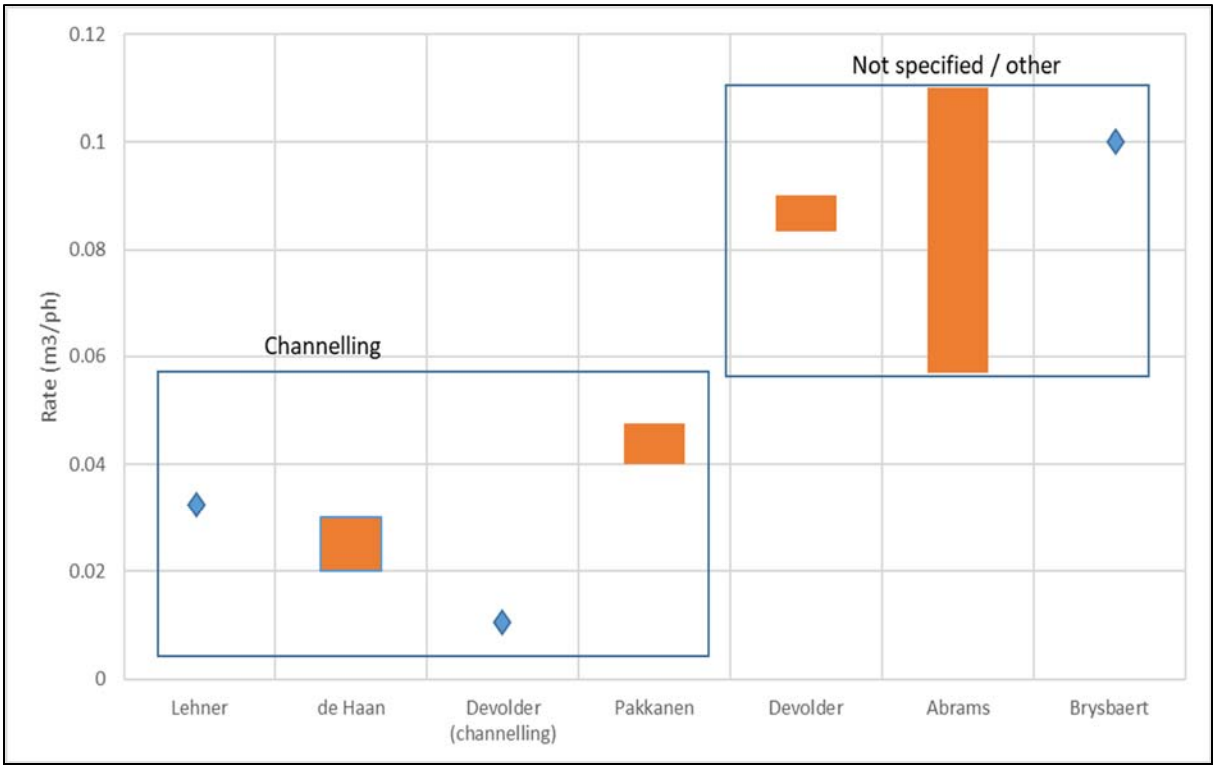

Figure 7.1 Overview of the various rates for quarrying limestone mentioned in the text. Single rates are represented by a diamond; ranges are, obviously, columns. Note that channelling was a more labour intensive method (graph by author).

For the acquisition of the conglomerate material a similar contemplation must take place in order to determine what might be a suitable rate to use in the analysis. If Devolder's quarry-rate formula is considered valid, it is important to take into account the density of conglomerate. As Brysbaert (2013: 78, n162) points out, the density of conglomerates varies widely, which has to do with their composition. Cavanagh and Mee (1999: 96) assume a density of 2.1 tonnes per cubic meter for the conglomerate used at the Treasury of Atreus.[67] This would result in a labour cost of (1 x 2,100) / 225 = 9.3ph for one cubic meter (0.11m^3/ph). However, the conglomerate façade has quite a different build-up than the limestone cyclopean-style walls. The blocks, as pointed out before, are well shaped. It is, therefore, likely that channelling was used as a method of extraction, rather than simply breaking the material from the bedrock (as is assumed in Devolder's quarrying formula, see Devolder 2013, 43).

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

On the other end is the quarry rate proposed by Cavanagh and Mee (1999: 100) whose low end is on par with the high end of Pakkanen's range and the high end is slightly above the minimum of Abram's range. This thus seems to be too high as it is also unclear how they determined this range other than estimating it. A range between 0.03 (de Haan/Lehner's rate) and 0.048m^3/ph (Pakkanen's maximum) is therefore used for the extraction of conglomerate stone material. Pakkanen's rate may suffer from some issues with inscriptions as they potentially involve more than just the costs of the quarrying (see also the discussion in section 7.3). However, he argues that his cross-checking of various sources solves that issue. His higher rate also allows that conglomerate might be quarried slightly faster than limestone (which is used in Lehner's experiment) as it is considered softer (although this depends on the matrix and the inclusions of the particular conglomerate). This range thus also includes the low end of Cavanagh and Mee's rate, who do consider a softer stone type. Finally, with regard to the conglomerate sections, because these are built with blocks that are well-shaped and cut to fit, more material will have been quarried than is finally used to build the wall. It is difficult to ascertain what amount of material is wasted in this process. Devolder (2013: 32) estimated a ratio of 15% of the originally quarried material being lost during dressing, which will also be used in this study. This is a rather low figure, but since channelling is already accepted as a quarry method, it is safe to assume that most blocks were already in roughly the right shape. **The range of 0.03 – 0.048m^3/ph is thus used as the rate for acquiring conglomerate blocks** (see table 7.2)**.**

Finally, the extraction of rubble needs to be explored. Abrams (1994: 46–47) stated that 7,200kg of rubble can be produced by a person in 8 hrs, based on an experiment. That means an average of 900kg/ph. If this is then translated into volume, based on the density of the rubble (between 1,535kg/m^3 (Hurst 1905: 338) and 1889kg/m^3 (Rosenstock et al. 2019: 1102)) this results in a rate between 0.64m^3/ph and 0.47m^3/ph. Pakkanen (2013: 6, n34), however, argues that DeLaine's (1997:

[67] "… some 1400 m^3, say 3000 tonnes of stone" and "… a huge block (..) measuring 6.3 x 1.2 x 1.9m, which might weigh up to 30 tonnes" (Cavanagh and Mee 1999, 96). These numbers result in 2.14 and 2.08 tonnes/m^3 respectively.

111) rate for quarrying tufa and Hurst's (1905: 376) rate for excavating chalk (0.4 and 0.38m^3/ph respectively) are representative for quarrying limestone rubble. Both rates are based on builders' manuals from the 17-18th century (DeLaine) and 19th century (Hurst). It is difficult to provide a qualitative assessment of which rate might be best suited. **An average rate of 0.5m^3/ph seems reasonable** (see table 7.2)**.** It must be noted that the acquisition of rubble as a separate task is only applicable when the fill of the cyclopean-style walls is considered a rubble fill. The small material used within the wall-faces is considered to be acquired as collateral while quarrying the larger blocks (therefore no waste is taken into account for the limestone quarrying).

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

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

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

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

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

7.2 Transport

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

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

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

Another difficulty is determining the total weight, which relates directly to the necessary traction. From literature examples some derivatives can be calculated. What is problematic in this is that often the weight of the *load* is given, whereas for proper calculation, the *total* weight is needed. In other words, the weight of the used transport device is also required. Very few researchers who write about non-motorized transportation deal with this. Those studies that deal with the topic, in particular in relation to building programs (e.g. Burford 1960, 1969; Loader 1995; DeLaine 1997; Devolder 2013; Brysbaert 2013, 2015a, 2015b; Harper 2016), ordinarily calculate the necessary traction based on the number of oxen / tonnes of weight. This results in values like 3,500lb (1,587kg) pulled "by 3 yoke of oxen" (Burford 1960: 5) (which comes to 529kg load / yoke) or 19 yokes for 10 tonnes (Burford 1960: 14) (526kg load / yoke) to 12 yokes for 10 tonnes (DeLaine 1997: 99) (833kg / yoke). However, a load of 1,587 kg does not need the same kind of wagon as a load of 10,000 kg. Hence, the weight of the wagon will likely be different. Nevertheless, it does influence the total weight and therefore the required traction. Thus, using the figures provided in the literature (loads of 1,587 and 10,000kg pulled by 3 and 12 yokes of oxen respectively), an attempt can be made to calculate the weight of the wagons. The oxen described by Burford and DeLaine must have comparable strength (see chapter 3, around 510N). Furthermore, to compare them, similar routes (and thus slopes) are assumed and the same yoking efficiency drop and friction coefficient are used. If these are kept the same, only the total weight influences the necessary traction and therefore the amount of animals: If the efficiency drop is 20% (as assumed by DeLaine (1997: 129)) and the friction coefficient is 0.05 (which is the maximum possible friction coefficient based on the figures presented by DeLaine and Burford),[68] then the wagons are 900 and 4500kg for Burford and DeLaine. Hence, the weight of the wagon can be a large portion of the total weight that needs to be moved and should therefore be taken into account.

Not only the weight, but also the friction coefficient (or rolling resistance in the case of wagons) is problematic as there is a large discrepancy in values given by various sources. Often cited is Atkinson's (1960, 1961) work on an experiment at Stonehenge with a sledge and a large block of stone. His most important statements that are often used are: (1) a sledge on rollers requires only 100lbs of force per tonne load (on level ground), (2) an incline of 9 degrees increases the necessary traction force by 450% (9 versus 2 people per tonne) and (3) the use of rollers decreases the necessary force by 56%. His first statement means that the friction coefficient is extremely low when using rollers: 0.045.[69] This implies that the rollers are very well rounded and that the surface on which they are used is quite smooth and hard to avoid extra friction. His final statement means that his sledge without the rollers has a friction coefficient of 0.19.[70] De Haan (2009) showed in his experiment that the friction coefficient of his sledge on pavement was 0.48. This is much higher, but

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

[69] 100lbs is 445N of traction. F_n = 1,000kg*9.81=9,810N. $F_{traction} = F_n \times \mu \rightarrow 445 = 9{,}810 \times \mu \rightarrow \mu = 0.045$.

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

Atkinson's experiment took place on grass, which may have a much lower friction coefficient (Cotterell and Kamminga (1990) cite a friction coefficient as low as 0.25 for grass). Other coefficients for friction (from 0.2 to 0.4 for a sledge on rollers and 0.02-0.04 for the same, but on a wooden track) (Shimotsuma et al. 2011: 176) and rolling (between 0.052 to 0.083) (Cotterell and Kamminga 1990: 204) show the large variability, yet few researchers take this into consideration. Moreover, not only does the friction influence the overall required force, but the lower the friction coefficient, the larger the impact of an increase in slope on the required force. This explains why Atkinson noted an increase of 450% while De Haan only noted a 17% increase (see also chapter 3) as their friction coefficient was 0.045 and 0.48, respectively. That is also why Atkinson's ratio for the increase in required labour for moving uphill should not be used as a rule of thumb for these kinds of calculations, especially when other modes of transport or conditions are considered (i.e. wagons instead of sledges).

As for the maximum weight with which a wagon can be loaded, G.R.H. Wright (2005a: 41) mentioned that wagons can only carry "several tonnes", but does not elaborate on what this is based. However, if the type of wood is known, the bending strength can be looked up in dedicated databases.[71] Arguably the weakest point of a wagon is its axles and with the bending strength known, it can be calculated how thick the axles need to be to withstand a certain load. Burford (1960, 1969) and DeLaine (1997) both mention examples of loads of 10 tonnes being moved by wagon. In the case of oak, the bending strength (which is the defining feature for determining the breaking point) is between 20 and 24 N/mm^2. [72] The formula for determining this is:

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

in which F is the gravitational force (weight), L the length of the entity being loaded, L_i the length of the loaded area, and R the radius of the axle. Since σ is known (20-24 N/mm^2, taking 22 as a middle value), and F is known (10,000kg = 98,100N[73]), R can be calculated if L is hypothesized. If a wagon was to be 2m wide, the axle would be longer to accommodate the wheels, so 2.40m would be reasonable.

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

$$22 = (3 \times 49{,}050\ (2{,}400-2{,}000)) / (2\pi R^3)$$
$$22 = 58{,}860{,}000 / (2\pi R^3)$$
$$44\pi R^3 = 58{,}860{,}000$$
$$R^3 = 425{,}812$$
$$R = 75.23 \text{ mm}$$

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

[72] This is the 'representative' value in the Dutch wood database website (http://www.houtdatabase.nl/?q=hout/gww/24/mechanisch - accessed 03/06/2019). The actual tested value is 97N/mm2, which is not too far from the 102 mentioned on the wood database website for holm and white oak (https://www.wood-database.com/holm-oak/ - accessed 03/06/2019). If the higher value of 102 is used then the diameter only needs to be about 9cm.

[73] This the total load, the load per axle would thus be divided by 2: 49,050N.

A wagon with axles that have a diameter of at least 16cm would suffice to carry a load of 10 tonnes,[74] which is not an unreasonable value (see also chapter 3). It may well be as Burford (1969: 187, n1) and Cavanagh and Mee (1999: 96) pointed out that wagons were specially built for such heavy transport perhaps by using thicker timbers for the platform, axles and possibly thicker wheels as well. Hence, it is likely that the wagons used for the heavier loads were themselves also heavier (as pointed out above). In the calculations below the use of oxen wagons is presumed, first, because it reduces the amount of required force tremendously in comparison to sledges or dragging the material. Secondly, using sledges with rollers is highly unlikely in the hilly terrain surrounding the sites. A maximum load of 5,000kg is assumed for the wagons weighing 1,000kg and a maximum of 10,000kg for wagons of 2,000kg.[75] Loads above 10,000kg are assumed to be transported on sledges *without* rollers. The use of rollers, as mentioned, is problematic (see also Atkinson 1960, 1961) and the use of sledges increases the friction coefficient quite a bit in comparison to wheeled transport (from 0.065 to 0.38 based on average values from Cotterell and Kamminga (1990) and de Haan (2009), respectively). Hence, it is only used for the largest blocks (in this case material used in the gate structures at Mycenae).[76]

As described in chapter 4, for Mycenae both the required conglomerate and limestone can be quarried nearby. Steffen (1884: 24) noted the greyish conglomerate comes from the modern town of Mycenae (Kharvati), where within and immediately outside the village there are numerous cuts into the rock. A yellowish conglomerate likely comes from the foot of the mountain of Profitis Ilias, which is a bit further away. Both the Lion and North Gate are built in grey conglomerate and it is thus likely that the material comes from around Kharvati. The modern town is, following the modern road, almost 2km from the Lion Gate. A recent study (Brysbaert 2021; Brysbaert et al. 2019) into quarry locations around Mycenae refers to some alternative locations. All the conglomerate quarries documented by Brysbaert et al. in the vicinity are located between Kharvati and Mycenae. It is beyond the scope of this research to ascertain which particular quarry or quarries were used for which construction. Hence, the location suggested by Steffen is considered the furthest local

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

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

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

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

conglomerate source and used in the calculations. The height profile of the modern road, based on Google Earth data, shows that over the path of 1.9 km there is a steady rise from 112 to 240m a.s.l. with a maximum slope of around 16% (a bit over 9°). A second route, using the, seemingly, older path slightly higher up the slope (going west of the Treasury of Atreus) is slightly shorter (1.8 km) and in places slightly steeper; up to 18%, which is a bit over 10°. This route is also marked on Steffen's (1884) map 1 and a route from Kharvati going north around Mycenae is marked on Pelet's (1832) map of the area. It has also been marked as a Mycenaean age road on the map comprising the roads in the area by Iakovidis and French (Iakovidis & French, 2003). This route is thus perhaps more reliable as a 'route of old' than the modern road (see figure 7.2). An analysis of the terrain, using a slope map (see chapter 6), confirms this route to involve the least steep areas of the (current) landscape. The distance remains somewhat subjective as 'in and around the village' (Steffen, 1884) meaning that there is a variety in distance of about 600 meter around the town (based on the current size of the town). The *shortest* distance to just outside the town along the mentioned path would then be 1.5 km and 2.1 km for the *longest* distance from the Lion Gate to the other side of the town. In the calculations of the transport cost, the distance is set at 1.8km for the Lion Gate and 2.2km for the North Gate.

The local geology shows predominantly limestone to the east (see 5.2.1). Again Brysbaert's (Brysbaert 2021; Brysbaert et al. 2019) study of local quarries has resulted in a number of possible locations close by to the north, east and south from the citadel. Based on the analysis of the terrain, focusing on the slope, a path from section 3 at Mycenae (the West Wall) to one of the nearby southern limestone quarries can be traced and is roughly 300m. For the North East Extension (section 4 at Mycenae) there is a potential quarry at about 210m away to the east. These distances will be used for calculating the cost of the transport for these sections.

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

The transport also includes the loading and unloading of the material onto the presumed means of carrying. This could be done by either levering the blocks up and across into the wagon, or using a small ramp on which the material could be dragged onto the wagon. As Hodges' (1989) experiments have shown, a block of 2.5 tonnes can be levered 0.8m in 200 seconds by four persons on levers, with an additional two people putting in supports (see also section 3.4.2). De Haan (2009: 7) used this rate as a basis and theorized that it would then take 20 minutes for loading to include fastening and unfastening the entire load, but admits this is rather high. Assuming 15 minutes per load of 2.5 tonnes, a wagon can be loaded and unloaded with 5 tonnes in 1 hour by 6 people, or 6ph for loading and unloading per trip.[77] Brysbaert (2015b: 96) uses de Haan's rate, but adds two people to the levers due to the fact that "The larger blocks at Tiryns are far more irregular, both in shape and size..". There are two issues with this: first, her category containing the largest blocks (defined as blocks between 2-13 tonnes) is reduced to an average weight of 2.5 tonnes per block (Brysbaert 2015b: 99), which is the exact same figure de Haan uses. Secondly, as Hodges (1989) and de Haan (2009) mention the required force per person on the lever is well below their maximum. There is thus no direct need to increase the number of people for blocks of the same size as those assumed by de Haan. Therefore, the above-described rate (6ph/trip), as adapted from de Haan's rate is used, rather than Brysbaert's method. Obviously, a major drawback of this method, as outlined above, is the fact that it reduces the variety in material size to one average 2.5 tonne stone. It is difficult to adjust to size or weight, as it is problematic to distil a ratio based on one figure.

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

An alternative way of calculating the labour costs for levering the material into a wagon is by taking the same rate for levering as mentioned above, and assuming that the material had to be levered up 0.8m and 1-2m across. Furthermore, if the actual stone size is taken into account the amount of people required for the levering can be equated to the ratio of 4 people / 2.5 tonnes.[78] Small material (up to 200kg), is not levered but carried (up to 50kg/person, based on DeLaine 1997) in that scenario. The number of person hours is depended on the size of the material and no fixed number is applicable.

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

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

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

Mycenae - Lion Gate						
Sub-section	**Oxen hours**		**Person hours**		**Max. number of oxen**	
External Eastern Façade	648		324		16	
External Western Façade	700		350		18	
Gate Façade	400		200		12	
Gate Structure*	313	*949*	156	*475*	54	*166*
Inner Eastern Façade	101		50		12	
Inner Bastion	262		131		12	

[78] Plus two people for inserting supports.

Total	**2424**	***3061***	**1212**	***1530***		
Mycenae - North Gate						
Sub-section	**Oxen hours**		**Person hours**		**Max. number of oxen**	
Inner Gate Façade	278		139		18	
Outer South Façade	162		81		12	
Outer North Façade	121		61		12	
Inner North Façade	32		16		12	
Total	**593**		**297**			

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

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

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

Besides the number of required animals and people, the labour costs are of course also determined by the amount of time that is needed. This is tied to the speed with which the transportation takes place and the distance that is covered. It should be remembered that the distances used here are optimal. For each section at Mycenae the closest documented quarry is assumed to be its source. However, there is no proof that the quarry was used during the time of the construction of that particular section close by. The same is true for Teichos Dymaion, where the source location is set at 100 metres. However, besides some quarry marks (as pointed out above), there is presently no way of knowing what material came from where exactly. It could thus be that the transportation costs were higher if sources were located further away.

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

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

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

7.3 Levelling the terrain

As described in section3.4.3), the cyclopean-style walls were built straight on to the bedrock. Levelling the terrain to the bedrock would not require much as it is close to the surface at both sites (Gazis, 2010; Iakovidis, 1983). Hence, the cost of preparing the terrain for the construction is not very high. Harper (2016: 226) assumed for the North East extension at Mycenae, that there was only a need to hammer the exposed bedrock to a more or less level path to build on. He (2016: 445) uses a rate of 0,232m^2/ph, using the wall's ground surface area to calculate the costs. Devolder (2013: 13, 44), on the other hand, considers clearing to be *excavating* soils and uses three rates, depending on the type of soil. For a hard and stony ground, she assumes a rate of 0.3-0.4m^3/ph. Considering the statement that the bedrock lies close to the surface, if not *being* the surface, a maximum depth of 1m can be assumed for the excavation rate, used by Devolder. Using the lower value of her range would make sense as it is close to Harper's value for hammering the bedrock. Therefore, for calculating the cost of levelling the terrain for building the walls on, the rates of 0.232m^3/ph and 0.3m^3/ph (max. 1m deep) are used. This probably underestimates the costs if additional clearing was required, or if the terrain was more steep, or additional volume had to be removed. Nor does it take into account whether any material had to be transported elsewhere. However, without making further assumptions about the past terrain, any vegetation or earlier constructions, this is the most basic cost involved in this process. The results are presented in table 7.7. Since the costs are directly related to the surface area, the high costs for section 3 at Mycenae and all the sections at Teichos Dymaion are thus due to the large size of these sections.

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

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

7.4 Dressing

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

Hurst (1905: 382) provides a number of observed rates for dressing stone: dressing *ashlar* masonry at a rate of $0.0175m^3$/ph and rates of $0.929m^2$ and $0.232m^2$/ph for dressing *rubble* masonry by using a chisel or a hammer, respectively (Harper uses these latter values in his labour cost study of Mycenaean structures). [79] As the type of stone influences the effort needed for dressing the blocks, Hurst (1905: 382) also observed rates for various stone types within a range of between $0.084m^2$/ph for Portland stone (a limestone) and $0.046m^2$/ph for “fine axed” Aberdeen granite. Devolder (2013: 32), basing herself on experiments by Abrams (1994) states a rate of $0.0162m^3$/ph for dressing stone. This value comes from taking 10% of the cost of cutting tuff (according to Fotou 2016: 65) as a value for dressing. Devolder also points to rates observed by Pegoretti (1869, I: 159, 280-283) and Klapisch-Zuber (1969: 147), 0.0133 and $0.0055m^3$/ph respectively, for dressing stone. These rates are somewhat problematic as they both refer to dressing marble, which may be quite hard to work and they seem too low in comparison with the other rates.

The total worked surface area for the conglomerate material at the Lion Gate comes to about $1,090m^2$. This includes front and back faces,[80] the top, bottom and side faces of the blocks, as these were clearly cut to fit the surrounding blocks. Considering the rates presented by Hurst the amount

[79] Please note that some of these rates are in cubic meters and some are in square meters.
[80] At those sections where the back is visible it seems that work was done on these back faces as well.

of work for dressing a *volume* of ashlar or dressing the *surface* area of the blocks are quite comparable (see table 7.8).

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

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

The total of the worked surface area for the conglomerate material at the North Gate is roughly 157m^2. This includes front and back faces,[81] the top, bottom and side faces of the blocks. Although the same approach has been used for the Lion Gate, it must be noted that, in general, the blocks at the North Gate are less finely worked than those at the Lion Gate. The results are shown in table 7.9.

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

	Dressing volume		**Dressing surface** *(Hurst)*	
Amount	48 m^3		157 m^2	
Rate	0.0175 m^3/ph *(Hurst)*	0.0162 m^3/ph *(Devolder/Abrams)*	0.084 m^2/ph *(limestone)*	0.071 m^2/ph *(marble)*
Labour cost	2,743 ph	2,963 ph	1,870 ph	2,212 ph

7.5 Building a ramp for constructing

De Haan (2009, 2010, 2014) has shown the likeliness of the use of ramps for building Egyptian pyramids. In combination with levering (de Haan, 2009) the conglomerate façade could be built to its proper height. The courses are quite regularly built; therefore, each course could have been used as a platform for the course on top. Hence, there was no need to have ramps at multiple locations to reach the entire wall. One or perhaps two ramps would theoretically suffice. Since no traces of such a ramp now exist, for obvious reasons, the cost, mostly dependent on its volume, is a rough estimate at best. The two deciding factors in determining its volume are the height of the wall and the slope, which would be acceptable to pull/push blocks up. De Haan (2014: 149) proposed a slope of $\tan \alpha = 0.3$ (which is 16.7°) for the ramps used at the pyramid of Menkaure for its construction.[82] Loader (1995: 59) hypothesized about a 20% (= 11.5°) slope for a ramp for construction, based on the same incline of 20% of the Great Ramp at Mycenae.[83] Brysbaert (2015b: 97) assumes a 10% slope for ramps used in construction or even a 3% slope (2015b: 98–9) for the "all around the citadel ramp" as suggested by Küpper (1996: 50–1). As described above, using a smaller inclination reduces the required force per load, but increases the work time as well as the amount of work required for the ramps themselves. Furthermore, de Haan (2014: 147) has pointed out that ramps with inclinations of

[81] Based on those sections where the back is visible at the *Lion Gate* it seems that work was done on these back faces as well.
[82] He (de Haan 2014, 147) even suggested that a "gradient of 21-26%" might be acceptable for smaller blocks. Although he does not specify what he may consider a "smaller block".
[83] The Great Ramp is, as the name says, a large ramp positioned in the citadel just past the Lion Gate leading up the slope (e.g. French 2002).

up to 26% are possible. This might seem extreme, but it may be considered that the steep slopes of some of the Greek cities, such as Delphi, have many constructions on steep slopes. For Ephesus it has even been suggested that building on slopes up to 30% was no problem (Groh, 2012).

With de Haan's figures, a ramp reaching 10m high would be 33 meters long. If the ramp was 2 meters wide, its volume would be 0.5 x 10 x 33 x 2 = 330m^3. Loader's example would result in a ramp that is 50m long and thus have a volume of 0.5 x 10 x 50 x 2 = 500m^3. A ramp with a 10% incline would be 100m long and be a 1,000m^3. Of course these volumes do not take into account the slope of the hill itself on which the ramp would be built to reach the top of the wall to build.[84] While a steeper slope means that more people would be needed to move the block up the ramp, a small gradient results in impractical long ramps. For example, a 100-meter long ramp from the Lion Gate would reach as far as the Lion Tomb. Although ramps could follow a zigzag course instead, reducing their length, in return they would require more space in width. The available space might still pose an issue. Therefore, a steeper slope is assumed here. Furthermore, allowing a wider base of the ramp provides it with a stable structure, even higher up. Thus, if a ramp, reaching 3 meters high and being 4 meters wide with a slope of 20%, was built after the lower courses were put in place using levers, it would have a volume of 0.5 x 3 x 14.7 x 4 = 88.2m^3. As construction on the wall progressed, the ramp would have to be enlarged to reach a height of 6 meters, which would increase the volume to 0.5 x 6 x 29.5 x 4 = 354m^3.[85] Sections that reach a height beyond this would require an additional enlargement of the ramp up to 9 meters high. This would bring the volume of the ramp to 0.5 x 9 x 44.2 x 4 = 795.6m^3. These volumes do not take into account additional material that might be needed to compensate for the slope of the ground on which the ramp is built.

The amount of material required for such ramps will need to be excavated and transported to the building site. Turner (2018: 198–199) has shown the large variety in rates for excavating earth. Based on his work, the average rate of 4.2 ph/m^3, or 0.24m^3/ph is used. Transportation could be done either manually with baskets or in wagons with oxen. Assuming that the material would be taken from down the hill on which Mycenae stands, the distance is about 250m and there is a height difference of 30m. A density of 1,500kg/m^3 is taken to calculate the weight of the material.[86] The material is either carried by person or moved by oxen-wagons. For the former a rate of 0.000444hr/m carrying 50kg (DeLaine 1997: 110, n7) is used. If the wagons are used, each trip would hold up to 5,000kg of material which would require 12 oxen per trip and 6 herders (DeLaine 1997: 108).

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

[84] Over a length of 50m, the current path has a height difference of about 9m.
[85] The length (29.5m instead of 14.7m) increases to maintain the same slope when the ramp is heightened from 3 to 6m. Hence, the volume quadruples as both length and height are doubled.
[86] Combination of earth and clay: https://www.engineeringtoolbox.com/dirt-mud-densities-d_1727.html (accessed 03/06/2019).

piling up the material (instead of 0.24m^3/ph for excavating the compacted soil) is assumed.[87] The results for the labour costs for such a ramp is shown in table 7.10, below.

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

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

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

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

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

7.6 Wall assembly

The assembly of the wall entails moving the blocks over a short stretch on the ground from where they were unloaded to their place in the wall and levering them into place, horizontally. For higher courses, it is assumed that up to about 3 *courses* of stones would be levered vertically, and above that, a ramp is used (see above) to drag the stones up to various heights.[88] In between the heightening of a ramp, blocks can also be levered to reach higher courses. The smaller material does not need to be dragged or levered but could be carried by individuals or small groups of people. As this would not require carrying over long distances, it seems a realistic solution and a lot quicker than either of the other options.

The required work force for moving stones up the ramp is similar in computation as the calculation of the transport cost, in that it is dependent on weight, pulling force, slope and friction. Assuming that there was only limited space around the building site, it might be more realistic to assume that human power, instead of animal power was used for this. The friction coefficient for dragging material is higher than when a wagon is used for the transport. The slope, as described above, is assumed around 20% or 11.5°. Hodges (1989) showed that it was possible to lever a 2.5 tonne stone with four people 0.813m in 200 seconds and move it horizontally 0.19m in 20 seconds. An additional two persons were required to slide in supports during the lifting. De Haan (2009: 6) calculated that blocks of 2.5 tonnes could thus be moved at a speed of 0.0041m/s vertically and 0.0095m/s horizontally.

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

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

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

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

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

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

4. A three-meter high ramp with a 20% slope has a length of 15m. The force calculation is similar to step 1;
5. A six-meter high ramp with a 20% slope has a length of 30m. The force calculation is similar to step 1.

An alternative to trying to reconstruct the individual steps in the assembly is the use of construction rates. Harper (2016: 447) uses Hurst's (1905: 381) rate for building in rubble masonry (0.159m^3/ph) for the cyclopean construction. The main issue with this is obviously the sheer size of the blocks used for the cyclopean construction, which would make the construction quite hard in comparison to building with rubble-sized material (which in general would be light enough to be handled by a single person). Devolder (2013) uses rates of 0.1m^3/ph for ashlar and 0.1274m^3/ph for rubble. Both of these are problematic for the size of the material used in cyclopean-style constructions. Mayes (1862: 24) presented rates for building ashlar, differentiating between block size in the following categories: up to 0.2m^3 (0.034m^3/ph), up to 0.5m^3 (0.024m^3/ph) and blocks over 0.5m^3 (0.019m^3/ph). Furthermore, there are also separate building rates for the fill of walls. An applicable rate depends on the build-up of the fill itself. While it has been often described as a rubble and earth fill, there are also researchers who argue that the fills of the cyclopean fortifications are actually much more similar to the build-up of the wall's faces (thus with large blocks and smaller stones in between) (Brysbaert, pers. comm.). If the former is the case, possible useful rates are presented by Murakami (2015: 269), whose rates come to 0.8375 and 0.4625m^3/ph for 'major pyramids' and 'other structures' respectively. If the latter is the case, the building rates should be assumed the same as those for the walls' faces. The process described above as well as the fixed construction rates described here are used to calculate the labour costs. This way the total range of possible labour costs can be grasped. An overview is presented in table 7.11.

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

Rate (ph/m^3)	Source	How the rate was determined
0.159	Hurst (1905)	Observed
0.1274	Devolder (2013)	Based on experiment by Abrams
0.1	Devolder (2013)	Based on experiment by Abrams
0.034	Mayes (1862)	Observed
0.024	Mayes (1862)	Observed
0.019	Mayes (1862)	Observed
0.8375	Murakami (2015)	Experiment
0.4625	Murakami (2015)	Experiment

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

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

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

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

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

The differentiation between the costs including and excluding the eastern section (top table 7.12) has to do with the fact that this section is built on a stone outcrop and therefore only starts above the first four courses of the rest of the façade. Putting in the limestone threshold, lintel, posts and relief will need to be added to this for the assembly. The threshold will ideally be transported as closely as possible to its position as it comes from the quarry. Subsequently, like with the blocks above, it is assumed that the final 2 meters are left for manoeuvring in place, perhaps through a combination of levering and dragging (higher friction coefficient than during the transport from the quarry). Moving the threshold takes 318 persons only a few minutes once the block is near its final position and all the people are in place. Moving the lintel up an 11.5° slope up to a height of 3m takes 479 people a few minutes and moving the Lion relief up to its height on a ramp takes 276 people. The doorjambs need about 73 people to move them, but more to put them upright. It is safe to assume that it takes about an hour to move each of these blocks into position including putting on ropes and getting all those involved in place. Obviously, the threshold was put in first as the jambs are put on top and the lintel lies on top of the two walls flanking the gate. Overall, the assembly totals 260 + 52 + 1,219 = 1,531ph for the wall *as it stands today*.

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

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

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

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

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

For sections 3 and 4 at Mycenae, the assembly of the wall includes two faces and a fill. Due to the nature of the walls, there are no real courses present. However, the walls still needed to be built in such a way that the height gradually grew. The same kind of steps could therefore be considered in reconstructing the building process. As the steps involved in the assembly are determined by the weight of the blocks, the cost varies depending on the used scenario for reconstructing the block size. Therefore, the assembly costs result in ranges. Alternatively, the construction rates mentioned above by Hurst, Devolder, Mayes and Murakami, are also used for calculating the labour costs. These rates assume a more or less uniform rate regardless of stone size (except for Mayes' approach). The results of the reconstructed process (top) and the various single building rates (bottom) are shown in tables 7.14 – 7.16 below.

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

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

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

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

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

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

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

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

The same observations that were made for the assembly costs for sections 3 and 4 at Mycenae can be made for the sections at Teichos Dymaion. The largest difference, though, is that at Teichos Dymaion the range of the costs based on the set-up with the rubble fill in the bottom table is far larger than at Mycenae. This has to do with the fact that some of the scenarios used to reconstruct the size of the stones seem to create volumes that do not fit well at Teichos Dymaion, yet these do not create illogical values at Mycenae. For example, in scenario IV the reconstruction of the stone sizes results in volumes of the wall faces that are larger than the volume of the fill at Teichos Dymaion,[89] whereas, the same scenario does not create that issue at Mycenae. It shows that some of the reconstruction scenarios are therefore not applicable to Teichos Dymaion (as mentioned at the start of the chapter). This is a further indication that the material used at the two sites is clearly different, in that the assumed ratios between surface area and volume is dissimilar, which might have to do with the overall difference in shape of the blocks.

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

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

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

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

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

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

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

7.7 Total labour costs of sections of cyclopean-style fortification

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

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

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

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

7.8 Labour costs of LH III domestic structures

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

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

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

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

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

Some of the rates were originally published as quantity/person-day, rather than person-hour as is used as a standard in this study. Based on DeLaine (1997: 106) person-days have been taken as 10 working hours per day. Using the calculated volumes and the rates presented above, the costs for building domestic structures of various sizes are presented in table 7.22. Obviously, this is a very generalising method as it assumes that the costs are directly proportional to the size of the building.[90] Even though the calculated costs are thus somewhat precarious, the used sizes and rates are widely used, therefore, provide a reliable order of magnitude estimate for the labour costs of the real subject of this dissertation: the fortifications. Hence, any deviations from the suggested design,

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

materials and sources might alter the outcome of the calculated investment required for the domestic structures. The use of the ranges adopted here, should still provide an adequate figure for comparison to the fortifications, though.

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

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

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

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

7.8.1 West House, Mycenae

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

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

7.8.2 House 7-X, Kalamianos

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

7.9 Concluding remarks

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

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