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'Set in stone'? Constructed symbolism viewed through an architectural energetics' lens at Bronze Age Tiryns, Greece

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Between c. 1400 and 1200 BC, concentrations of Mycenaean centres emerged in the Argive Plain, such as the site of Mycenae and the citadels of Tiryns, Midea and Argos. This region features a breath-taking amount and quality of large-scale architectural and engineering projects: huge 'Cyclopean' walls, corbelled vaults, amazingly modern drainage systems, and still working waterworks (Dam at Nea Tirynta). These features could not have been accomplished without a high level of special skills and knowledge, careful long-term forward planning, and the possibility of mobilizing large work forces. All these requirements had to be coordinated by a body of palatial staff comprising architects, engineers and supervisors.

Employing architectural energetics, I focus on the physical nature of this built environment, specifically on the 'Cyclopean' construction of the Lower Citadel wall at Tiryns, and how it linked in with the surrounding landscape while it was constructed during the final 50 years of the 13th century BC. A series of physical and social construction activities of several groups of people are analysed and quantified in order to improve our understanding of the efforts that went into constructing at such a scale and the implicated meanings of such massive fortification walls.

I explore the building experiences at Tiryns which incorporate builders' choices in materials and techniques employed, and investigate how these building activities were embedded in the socio-political context of that period which allows multiple meanings associated with the Tiryns Lower Citadel fortification wall to be recognized.

1 Introduction

In the prehistoric East Mediterranean and Greek context, monumental architecture as an expression of power by the ruling class over their subjects has been well argued (Maran 2006a; Tiryns' post-palatial phases: Maran 2012; for prehistoric Cyprus: Fischer 2009), and many insightful studies have shown several ways and contexts in which the power symbols were transferred from one social class to another, while such transfers were not always without difficulties (Maran 2006b). Social aspects of power and symbolism have also been studied in relation to mortuary contexts in the Argolid, more specifically at Mycenae. Simultaneously, few scholars have touched upon what large-scale structures may have meant for the ordinary people who saw and interacted with them on a regular basis (but see Adams 2007), and potentially even worked on them (Brysbaert 2013; 2015; in press). In discussing the social role of Bronze Age palatial structures beyond their defensive character, Maran has focused on their performative space, whereby he emphasizes the dialectical relation between social practices and architectural spaces (Maran 2006b, 76; 2012).

This paper explores the role of the Lower Citadel wall, how it was constructed and by whom, and how it achieved its defensive, socio-political and symbolic meanings. Both performative and military characteristics embedded in 'Cyclopean' architecture of this kind have been emphasized and discussed by Grossmann (1967; 1980) among others, who connected the niches and openings to the defensive role of the wall. Iakovidis (1983) saw store rooms in the niches, and Kilian (1988) discussed the cult room in one of them. However, the practical logistics involved in building such large-scale and complex constructions have, so far, been largely overlooked while these aspects stand directly in relation to how the structures were imbued with meaning, to whom was involved in producing such meanings and why.

This paper explores these questions in some detail by employing an architectural energetics approach. The method translates construction activities into labour time units, most often expressed in man-days (hereafter: md). Abrams and Bolland (1999) give a full description of the definition and method and refer to md as person-days but since construction work was/is often done by men, as DeLaine (1997) asserts, I employ the more standard term of man-day: md. Architectural energetics takes into account each step executed in the building process (from quarrying to constructing and decorating) and, as such, it is very compatible with a *chaîne opératoire* approach, as applied in other socio-technological contexts (Brysbaert 2008; 2011; in press), and also, for instance, employed in detail in the important work done by M. Devolder (2013 with further references to her work; 2015). The paper does not, however, address the question of site preparation for construction, such as clearing away standing buildings, levelling the terrain where needed, nor does it discuss the older LH IIIB1 stone rubble wall of the Lower Citadel (Kilian 1988, 139; Maran 2010) since this is beyond the scope of this paper. These aspects are, however, dealt with in a larger ongoing study of the site by the author. The energetics approach then estimates costs involved in the labour that was needed to complete each task, and the volume of materials needed to accomplish this. Over the last 80 years, several opinions on the labour involved in the constructions at Tiryns have been expressed. Müller (1930, 208) referred to several decades, Grossmann (1967) thinks that Müller's estimate is far too high but does not offer an alternative while Loader (1998, 65, 69) suggested 5–5.5 years for specific parts of Tiryns but she was not always systematic in her approach. Due to these largely disparate attempts and due to the lack of a systematic architectural study employing this combined systematic method I present here some preliminary results as a first attempt to address this issue.

The hill outcrop of Tiryns is about 300 m long, 100 m wide and lies about c. 22-26 m above sea level, sloping from south to north where the Lower Citadel and its circuit wall is located (fig. 1). This wall was constructed in the second half of the 13th century BC but several alterations to the original structure took place soon afterwards. A very detailed description on these changes is provided by Maran (2008). Moreover Maran (2010, 726–9) indicated that this massive wall was part of the first phase of the LH IIIB2 building programme and, as such, defensive in character, while in a second phase, but before the catastrophic end around 1200 BC, several alterations (*e.g.* insertion of the larger North Gate) suggested potential political stability and thus counteracted the defensive purpose of the wall structure at that point in time. The military purpose for which the Lower Citadel wall was constructed has been discussed at length by many others. Grossmann (1980, 480) described the shooting holes found in the niches and their changing use; these were apparently constructed to be smaller and narrower on the outside of the Lower Citadel wall than they were on the inside. These shooting holes were the clearest indication that the Lower Citadel wall was intentionally built with a strong defensive purpose in mind (Grossmann 1980, 489-491). These shooting holes became visible in Grossmann's last campaigns and some of the niches make the military aspect (and its failure or change of tactic, see how many niches had already been filled in LH IIIB Final) of the wall crystal-clear. Grossmann (1967, 96; 1980, 481–3) equally discussed the military aspect of the North Gate but recently Maran (2008, 88–9) reassessed the uses of the North Gate in LH IIIB Final, and Maran (2010) presented convincing arguments on the niches and their infill. His recent work in the area of the Lower Citadel has thus clarified many aspects of its circuit wall.

Based on architectural drawings of the Lower Citadel wall which were available through the Tiryns Archive and through several published plans (esp. Schnuchel 1983, figs 1–2; Grossmann 1980, fig. 2), I took a series of calibrated measurements that formed the basic data sets from which I was able to quantify several aspects of the construction activities as accurately as possible (table 1). These were complemented, combined and compared with existing literature on the natural resources that people at Tiryns had at their disposal, and with several sources on architectural energetics, employed both in the Old and New World. What follows are my investigations on aspects of quarrying, transporting materials from quarries to the construction site and the work carried out on the site itself.

2 Quarrying

Several types of limestone employed at the citadel of Tiryns have been observed by geologists: lithofacies A (the hill outcrop of Tiryns' citadel itself), B (unknown origin), E and F (hill adjacent to Profitis Ilias, Varti-Matarangas *et al.* 2002). These materials differ greatly from what is known from the palace of Pylos (Nelson 2001, 48–58, esp. 55–8). Unfortunately, Varti-Matarangas *et al.* 2002 were not specific about which lithofacies were employed where Wright (1978, 202, 204, 205–216), on the one hand, refers to different stones used in relation to the First, Second and Third Citadels but he actually opposes the three citadel phases (Wright 1978: 207-8; also Küpper 1996). Lithofacies A was likely to be the major extraction source for the first phase construction of Tiryns Upper Citadel's walls in LH IIIA1 (see also Loader 1998, 45).

During the entire remodelling of the citadel, the Lower Citadel wall, the Western staircase area, the East and South galleries and possibly the North wall of the Middle Citadel which were all done in LH IIIB, were executed in 'Cyclopean-style' stonework. The fact that the staircase was built possibly a little later than the Lower Citadel wall as indirectly suggested by Grossmann (1980, 41) goes against any large-scale usage of lithofacies A for the Lower Citadel wall since there would be no good practical reason to extract stones from an area which was going to be built up, so by LH IIIB2, this outcrop may not have contributed significantly to the large stone mass needed for the Lower Citadel wall (see also Brysbaert 2015), at least on its west side. Moreover, the stones used at the Lower Citadel wall do not correspond to the colour description of lithofacies A as being dark beige when freshly exposed and light beige when exposed for ages (Varti-Matarangas *et al.* 2002, 479). The stones employed are dark steel blue/grey and some are reddish (Grossmann 1967; 1980, 492; Wright 1978, 215–16). Those that were exposed in more recent excavations show both reddish and blue-grey hues, predominantly blue-grey. This fresh stone colour description fits well with lithofacies E and F, and partially with B. Until a more thorough (and petrographic) study of

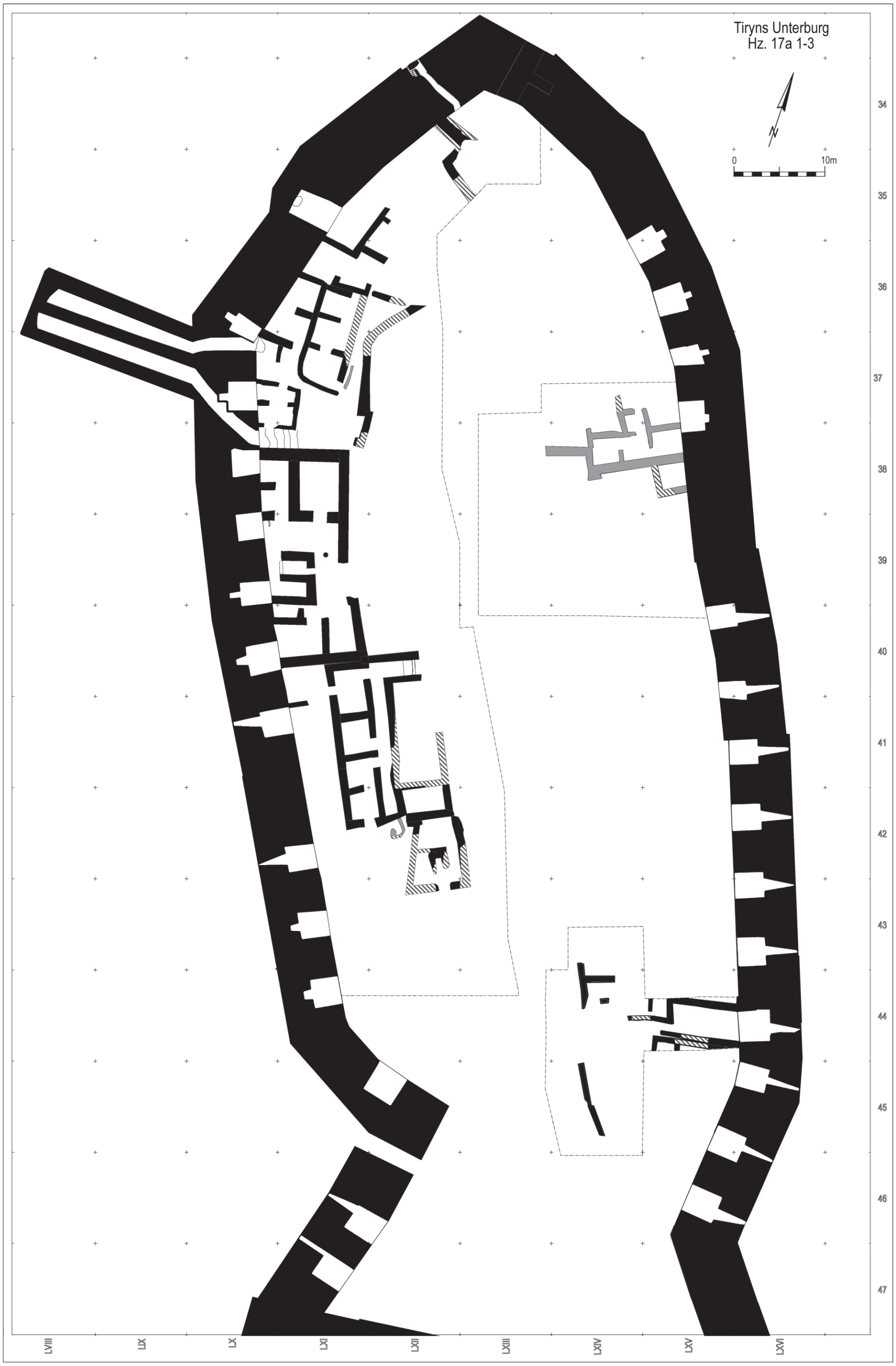

Figure 1 Plan of Tiryns' Lower Citadel wall (Hor. 17 a1–3) (with kind permission of Professor J. Maran and kindly provided by M. Kostoula)

Total length	350 m (T_15) [a]
Average thickness	7.5 m [b] (10 measurements) (T_8, T_76)
Average preserved height (W side)	6.5 m [c]
Limestone density factor	2,700 kg/m³
Large block size (0.8–5+ m³)	2–13 tonnes
Medium block size (0.2–0.8 m³)	500 kg–2 tonnes
Small block size (0.01–0.2 m³)	30–500 kg
Large block size average	2.5 tonnes
Medium block size average	1 tonne
Small block size average	250 kg
Large block size % of total wall	65% [d]
Medium block size % of total wall	25%
Small block size % of total wall	10%
Total volume of stone mass (17,060/21,000 m³) [e]	46,070/57,700 tonnes

Table 1 General information on the Lower Citadel wall, fot notes a–e: see endnotes, p. 103

the stones employed can be matched with specific extraction locations, the most likely scenario is that stones for the Lower Citadel wall may have come from lithofacies A and B, but many could have come from E and F, the latter originating from quarries in the hill adjacent to Profitis Ilias, about 1 km south-east of Tiryns.

In reference to the total volume in cubic metres or mass in tonnes (Table 1), the cost for quarrying the limestone can be calculated as follows (*contra* Loader 1998, 67 who thinks that it is impossible to calculate this). In his colossal work done at Petra, Bessac (2007, 136) suggests limestone extraction costs at 1.0 md/m³ (unworked blocks). He suggests that 1 man-day (md) entails 10 hours (Bessac 2007, 135, n. 495). This figure is similar to De Haan (2009, 3) who suggests 1.1 md/m³ for masonry blocks, based on a modern experiment with very experienced workers. Abrams (1994) worked with 1.1 to 2.2 md/m³ for unworked small stones based on modern experiments, while Pakkanen (2013) suggests similar numbers (1.1 to 2.2 md/m³) for Athenian limestone masonry blocks. For quarrying, Pakkanen calculated one skilled and one unskilled worker and added 0.2 unit for supervision, based on inscriptional evidence and ethnographical comparanda. Most of these authors use a 10-hour workday (also DeLaine 1997, 106; Hurst 1902, 376). This seems to be a realistic suggestion since it corresponds to the working days of agricultural workers (allowing for shorter days in the winter and longer ones in the summer). In following Bessac and De Haan, although the carefully cut corner blocks are not yet taken into account for these preliminary calculations, I employ one man-day per cubic metre (hereafter: md/m³) because mainly roughly worked or unworked blocks were employed throughout. While some of the blocks are larger than 2.5–2.7 tonnes and may thus have needed more effort (De Haan's 2009, 3, 6 refers to blocks of 2.5 tonnes), it is at this preliminary stage impossible to estimate how many such blocks left the quarries, so the average of 2.5–2.7 tonnes or 1.0 m³ is employed here. Moreover, no real difference in labour costs is to be calculated for quarrying large or medium-size blocks (but see Brysbaert 2013 on the bathroom floor block of 23 tonnes). The rubble that was used mostly inside the wall but also in between blocks on the outside of the facades, was likely collected from the waste incurred during quarrying itself and during the rough dressing of the blocks, carried out in the quarry or later. Grossmann (1980, 496) mentions that further stone dressing was rarely done for the Lower Citadel wall in comparison with the Upper Citadel materials, and that specific diorite stone pounders may have been employed for such a task. Such work has not been taken into the basic calculations presented here but is being incorporated as part of the larger project aims, together with the efforts involved in filling up the gaps between the larger stones with various materials, and covering the walls with mortar material (Grossmann 1980, 498).

For the total amount of 17,060/21,000 m³ limestone material (or 46,070/57,700 tonnes) at a rate of one md/m³, the same number in man-days would have been required in the quarries. This could translate into 100 men quarrying 171/210 man-days respectively. Since at least three different lithofacies may have been employed in the Lower Citadel wall, possibly three groups of 30 men could have been working in three different quarry areas simultaneously, assuming that the quarry location allows for this number of people to work alongside one other, an aspect currently under investigation. In contrast to this model, one group of 30 men may have gone from quarry to quarry, providing an ongoing stone supply *during* the actual construction activities, thus keeping the workflow steady and efficient, rather than causing massive amounts of stone to accumulate at the quarry or construction end. This would, independent of the economically efficient workflow, hinder and even endanger other day-to-day activities in and around the citadel. This model would spread the quarrying over longer periods of time but would have provided stone when and where needed, and it would reduce the number of people needed for the quarrying. It also corresponds better to the later Greek quarry practices of ordinary small numbers of blocks at a time.

3 Transporting from the quarry to the site

3.1 Transport options

Before any figures are given for transporting the stone from the quarries to the building site, the means of transport needs to be considered. Without coming to a definite conclusion, Loader (1998, 54-61) discusses this aspect in some detail and cast doubt over Wright's assertion (1978, 159, 229) that transport was not an important factor since most materials came from nearby. I agree with her that getting blocks of 2–5 tonnes from even as close as 50 m–1 km away poses logistic and practical challenges, and involves efforts which cannot be ignored for the sheer stone volume needed to construct the Lower Citadel wall (details in Brysbaert 2013).

Two options for transporting blocks can be considered here: manpower and animal traction, combined with wheeled vehicles or sledges. The Linear B tablets refer to the presence of draft animals in association with wall builders on major construction sites (Palaima 2010, 367; on wall-builders or masons: Pylos An series, An 35; Chadwick 1976, 138) and mention the ox as a working animal. Ventris and Chadwick (1956, 42), Killen (1992/3; 1998) and Halstead (2001) discuss how oxen spans in agricultural contexts seem to have been managed by the palatial administration, probably due to their high cost of maintenance, and seem to have been allocated to the *dāmos* for agricultural tasks while the body of the *dāmos* may have been providing the human labour for agricultural work (Killen's share-cropping model). Also De Fidio (1992, 183–4) discusses the allocation of working oxen by the Knossos palatial administration for ploughing purposes. One may wonder then whether a similar organization may have been set up and shared between palace and *dāmos* with its landholders when it came to organizing and recruiting both skilled and unskilled workers for construction purposes.

Since oxen were known in Mycenaean contexts and their use in the transport of such masses of stone would have severely reduced the needed human labour, I have calculated the man-day cost it would have taken oxen yokes to bring the required stone mass to the site, one kilometre away. The literature provides various numbers in relation to the weight one oxen pair can move. Burford (1960, 8) suggests that 19 yokes at full strength could have pulled 10 tonnes. DeLaine (1997, 99) suggests that 12–18 yokes are needed for 10–15 tonnes respectively (see also Mannoni and Mannoni 1984, figs 136–8). DeLaine's figures infer that one oxen yoke could move about 800 kg of material while Burford (1960, 3–6) suggests about 500 kg only; Burford revised this number in 1969. Heavier loads are carried, such as building blocks from 2 tonnes onwards, and up to 6–8 tonnes blocks are mentioned for Eleusis. The most realistic estimation is that one yoke could have transported 800 kg to 1 tonne which fits DeLaine's and Loader's (1998, 60) suggestions and this is also used here. Several painted ceramic oxcart figurines have been found in Kilian's excavations (1988) of the LH IIIB Middle Building in the southwest Lower Citadel. These date to the 13th century BC while an EH II example from Tiryns has been mentioned too (Brysbaert 2013, 62 with refs). The figurines indicate that oxcarts must have been an important resource to people all through the Bronze Age.

Table 1 shows the percentages of large, medium and small size blocks counted over half the length of the Lower Citadel wall. These numbers come into play for transport since a single pair of oxen or one yoke can only transport part of the medium to small size material. The large size blocks, minimally 2 tonnes with an average range of 2.5–3.5 tonnes, needed quadruple yokes, or eight oxen, per cart load or sledge. Loader (1998, 60–1) describes the average weight of a massive block at being under two tonnes using Wright's (1978) average block measurements, some of which actually add up to 4 tonnes. In my block calculations quite a few were larger than Wright's measurements for the Lower Citadel wall, with at least one dimension up to and more than 2–2.5 m. Furthermore, the difference between the use of a wheeled vehicle and sledge may result in different friction on the road surface, slowing the movement down. Consiglio (1949, 92) discusses the practical use of lubricants to transport the Carrara marble blocks and while calculating the friction coefficient (μ) is beyond this paper's scope its influence is under investigation at the moment of writing (see *e.g.* the water poured over the sand as lubricant in the transport of Djehutihutep's statue; Koutsoumpas and Nakas 2013).

The movement of the two different volume types (see Table 1) has been calculated separately and despite the logically suggested model of employing both single and quadruple yokes, it is, in effect, impossible to be sure of the size of load that would have been transported in one trip, or how many oxen pairs were used per trip. I have, therefore, employed the minimum rate of 0.7 md/tonne/km. Pakkanen (2013, n. 45) calculates this rate, based on Greek inscriptional evidence. It needs to be pointed out, however, that calculations of both oxen yokes and people involved in transport will depend on their availability at the given time of the year, especially during the periods where agricultural tasks also require the presence of oxen. Seasonality is thus a crucial factor to be taken into account and potentially conflicting activities may, therefore, have been spread out to ensure that they would not overlap, suggesting a well-organized body of people that played a pivotal role in forward planning (also Brysbaert 2013; Devolder 2015). The rate of 0.7 md/tonne/km number incorporates the number of oxen pairs needed related to the load carried.

3.2 Loading and unloading blocks

A crucial factor that has cost implications is the loading and unloading of the carts (table 2). Burford (1960, 12, 15, 17) indirectly points out the importance of this activity in Classical times by referring to the experience one needed in loading heavy blocks onto carts, the payments that were accounted for doing so, and the officials that were in charge of organizing such work, especially the unloading of heavy blocks (also Loader 1998, 65–73). De Haan (2009, 7) reports that the loading and unloading of 2.5 tonnes blocks can be done in a matter of 20 minutes. While this may well be the case, it still requires several people per large-size block and, as such, it involves labour input at a rather important scale for the Lower Citadel wall, considering its block size. Hodges (1989, 133, 139) refers to four men at the levers and two people inserting supports but we should not forget that the blocks here are regular and evenly weighted blocks each of 2.5 tonnes. The larger blocks at Tiryns are far more irregular, both in shape and size and will, in all likelihood, have required two extra people at the levers, thus a total of eight people per work team around one average block. The medium to smaller blocks may have been helped by four people per team (also Loader 1998, 67). Loading heavy blocks thus entails both levering and hauling efforts to be carried out by teams of well-coordinated people. If each block of 2.5–3.5 tonnes took 20 minutes to load in the quarry, and again to unload on site (De Haan 2009, 7), 65% of the Lower Citadel wall block volume falls in that category while 35% medium to small material can be handled in the same time by four people. Dorka (2002, 13, 21) halves this time because he allows the use of lifting devices with counterweights for this sort of work in Egypt. While there is no evidence for such devices the option of this method for lifting blocks is attractive and its possibilities will be explored in the near future. Based on this double task, an extra total amount of 10,700/13,400 md is required to fulfil this important step. In order to avoid strong people idling, the large loads may have relied on the four guides accompanying the quadruple yokes while relying on four quarrymen and four builders on either end of the transport trail and the same may have applied to the single yoke set-up.

Table 3 summarizes the calculations for the block transport activities with oxen. The speed of a yoke return journey is c. 2 km/h. According to DeLaine (1997, 108) such loads moved at 1.67 km/hour one way. So each yoke, single or quadruple, could have gone loaded and returned empty to the quarries in 1 hour, so, in an ideal 10 hour working day, 10 trips/day could be achieved. Loader (1998, 69) similarly refers to 1.8–2.5 km/h. The number of return trips that would have to be made sounds very high but this number would be decreased if several yokes, *e.g.* five groups, were set up to work in rotation to achieve a constant flow of stone provision to the construction site. Such work, however, may have become difficult, if not impossible, if rainfall turned some of the roads muddy and slippery, thus making transport work impossible during parts of the winter and early spring. Taking such environmental factors into account already indicates that constructing such large-scale works may not have continued uninterruptedly for years on end. Agricultural activities may have delayed this further (Brysbaert 2013).

65% large blocks: 30,000/37,500 tonnes	6 at levers + 2 inserting supports	20 minutes/action	**6,400/8,000 md** [f]
35% medium/small blocks	4 at levers and inserting supports	20 minutes/action	**4,300/5400 md** [g]
100% block loading and unloading	-	-	10,700/13,400 md

Table 2 Block loading/unloading, for notes f–g: see endnotes p. 103

65% large stones	30,000/37,500 tonnes	c. 3.5 tonnes/trip	8570/10,715 cart load trips/4 yokes
35% medium/small stones [h]	16,124/20,195 tonnes	c. 1 tonne/trip	16,125/20,195 cart load trips/single yoke
Total nbr of trips	-	-	24,695/30,900 trips
Total trip days	-	-	**2,470/3100 trip days**

Table 3. Block transport from quarry to site, for note h: see endnotes p. 103

Moreover, each oxen pair needed one guiding person alongside it and such a highly complex level of transport provision needed complex levels of organization and supervision throughout (Burford 1960, 16–17). The Società Editrice Apuana (1970, 147) published fascinating images of the multiple oxen yoke transport of an immense Carrara marble block where each yoke has a guide (*contra* Loader 1998, 69).

The figures given here did not take into account the quality of the road surfaces (and if repairs/reinforcements were needed), the time of year when this can be done (likely not in the rainy season), or any of the friction coefficients (*e.g.* Consiglio 1949, 90, 92) that play a role in the efficiency of the transport. These figures, although preliminary and indicating minimal efforts only (full economic costing is underway, see *e.g.* Brysbaert *et al.* submitted), clearly indicate that transport efforts, thus labour costs, cannot be ignored even if only one kilometre is to be covered (see also DeLaine 1997, 217). Blocks much larger than 3.5 tonnes and up to 13 tonnes, as a few are, would then need a different approach altogether. A minimum of 16 yokes would have been required for 13 tonnes (after DeLaine 1997, 99) or, if pulled by pure man power, it may have taken a similar collaboration as was required for the bathroom floor block (Brysbaert 2013). If one kilometre needed to be traversed, moving a 13 tonnes block may have taken 50 people 1.5–3 days to reach Tiryns.

4 Building the Lower Citadel wall

Extensive accounts of the building activities at the Tiryns citadel have been published but very few details cover the actual day-to-day process of getting the blocks there, lifting them and building them into the wall. Dörpfeld (1886) discussed many construction elements early on while Müller (1930), Grossmann (1967, 1980) and Schnuchel (1983) cover various aspects of the construction of the Lower Citadel. The most detailed account of construction techniques, tools and processes is Küpper (1996, 31–52) who includes a discussion of the term ‘Cyclopean’ and of the use of a binder material applied in the Tiryns walls. None, however, apart from Loader (1998), detail how the work may have been organized by actually looking at the builders and their supervisors. Küpper (1996, 33) does refer to the stepped wall construction in segments and to the high level of skill required to achieve perfect joints. Such display of skill confirmed, for him, the clear defensive purpose of the construction, next to how the construction symbolizes the power behind such works, a point I totally agree with (see discussion). Grossmann (1967, 98) agreed with both Dörpfeld and Müller that the Lower Citadel wall was constructed as one unit at one time and that the size of its stones by far surpassed those employed at Mycenae. He suggested that the wall was built up in horizontal courses over its entire thickness instead of in two faces with a space in between and filled later, since it would not have been possible to carry this out for the entire 350 m of the wall. It was, moreover, achieved in segments and the joints between such segments are visible in the outside façade. These joints do not pass perpendicularly through the wall thickness. Instead, they are stepped on the inside and thus form a stronger connection between each segment (Grossmann 1967, 100–1; Küpper 1996, 50).

4.1 Hauling up the blocks

The Lower Citadel wall was constructed on the bedrock: the foundation trench was cut through older settlement layers and the bedrock surface (Küpper 1996, 49–50 for details). Once the latter was ready, an earthen ramp has been postulated to facilitate the transport of blocks to the actual wall surface and to put them in place. While this point seems quite certain, Küpper did not agree with Grossmann’s suggestion of an orthogonal ramp, or several, which could be moved from segment to segment when needed, based on the fact that it was not economical given the amount of earth being moved, and such ramps would not have aided in constructing the niches. Instead, Küpper (1996, 50) argues that the ramp must have been at least 4.5 m wide to allow for the size of the transported blocks and workspace on either side. In relation to the ramp discussion, Maran (2008, 47-8) describes a stone platform found underneath Room 78c of Building XI in the northern tip of the Lower Citadel which, stratigraphically, dates between LH IIIB Developed and LH IIIB Final and is thus contemporary with the wall construction. He suggests its potential usage by the builders of the Lower Citadel wall as an option and this will be looked at in more detail in the near future.

Table 4 presents the calculated man-days for Grossmann’s ramp system; figures based on Küpper’s system are given in table 5 and are discussed below because the matter is crucial to the wall construction itself. The figures, based on DeLaine’s extensive research, and corroborated by Hurst (1902), indicate that one person could move c.1.8 m^3 earth in one day, which is almost double the 1 m^3 employed by Fitzsimons (2011, 80), who based his calculations on Wright (1987, 174).

According to Küpper who worked out the figures of Grossmann’s ramp, the initial volume of earth of 281.25 m^3 needed to be doubled (i.e. 562.5 m^3, see its costing as calculated in Table 4) when an inclination of 10% is used for hauling up the blocks. All factors for these calculations are based on DeLaine’s (1997, 107, 268) detailed work on soil movement. Hurst (1902, 377) provides the md rate for ramming earth in place, a factor not taken into account by Küpper’s calculations. If this ramp needed to be moved a minimum of four times, 2,250 m^3 of earth would have had to

Digging soil and throwing behind	0.15 md/m³	42.2
Loading into baskets	0.06 md/m³	16.9
Carry 100 m: md/trip + md/m³	 0.0045 (x trip nbr) + 0.075 md/m³ (x volume)	 48.7 21.1
Ramming of earth	0.0367 md/m³	10.3
Supervision	10% of total md	
Total work for 281.25 m³		139 md (unskilled) 153 md (with supervision) [i]

Table 4 Cost calculations of Grossmann's ramp, based on 281.25 m³, for note [i]: see endnotes p. 103

Digging soil and throwing behind	0.15 md/m³	1,969
Loading into baskets	0.06 md/m³	788
Carry 100 m (md/trip + md/m³)	 0.0045 (× trip nbr) + 0.075 md/m³ (× volume)	 2,272 984
Ramming of earth	0.0367 md/m³	482
Supervision	10% of total md	
Total work		6,500 md (unskilled) 7,140 md (with supervision)
Total work (supervised) 6.5 m 8 m		 **4,640 md** **5,710 md**

Table 5 Cost calculations of Küpper's ramp, based on 13,125 m³ for 10 m height

have been moved. If the wall is taken to have been 10 m high, a volume of 9,000 m³ would have been required and if that needed to be moved four times, thus a volume of 36,000 m³ of earth, the cost would have been 19,600 md (based on Küpper 1996, 50–1). A hundred people would have been shifting just earth for 196 days.

Instead, Küpper suggested a 350 m long ramp all along the planned wall circuit starting on the south-east side, moving alongside the trajectory of the developing wall northwards and then to the west and south while sloping up. This ramp would also have allowed two groups of ramp builders either working towards each other or away from each other. Thus, fewer people would have been required since building would only have needed to be done day-by-day as the wall grew. When it reached a height of 10 m at one end, the inclination would only be 2.9 cm/m or c. 3 %. Küpper (1996, 50–1) suggests that the ramp started on the east side from where it climbs up counter-clockwise towards the north, then west and south, and the 2.9 % inclination is convenient for block transport. Once the first segment of the wall on the west side is constructed over a width of X m, that earth ramp section of 10 m high can be taken down and redistributed over the remaining 350 m – X m and placing the X m before the original zero point where the ramp started. That way, the ramp keeps its 350 m length which is the only prerequisite to maintain the 2.9% inclination on the ramp. This pattern is repeated until all segments of the wall are built to their full height which, in fact, means that the same volume as the initial 350 m of ramp was constructed, piecemeal, out of the same amount of initial earth volume of 6,562.5 m³. The total earth volume to be shifted would thus be double, i.e. 13,125 m³. The total volume of earth for this ramp would be 6,560 m³ but used twice.

Table 5 converts this part of the construction activities into costs. If again 100 people were working purely on moving this amount of earth, they would spend c. 72 days altogether. This stands in sharp contrast to the total of 196 days based on Grossmann's earth ramp model (see above and Table 4). What also makes Küpper's model more attractive than Grossmann's is that the former sees this work as integrated in the actual stone wall construction itself and, as such, no entire work group is solely moving earth around, and a more realistic inclination to haul blocks up is achieved.

As far as the actual stone wall construction itself is concerned Loader comments: ‘Little consideration has been given to how the blocks were placed in positions in the walls.’ She (Loader 1998, 61-9) gives examples of other cultural settings and worked out cost calculations for activities to be done by manpower and by animal traction. De Haan (2009) refers to pyramid building with standard blocks of 2.5 tonnes, all cut perfectly to the same size to be fitted tightly throughout. Without wanting to underestimate the work involved, construction with massive unworked boulders is to be seen as a far more irregular task, and exactly because of the irregular block size and shape, extra work/care needs to be provided in placing them as tightly as possible while providing a technically sound and strong wall. Loader’s model of using a wooden roller ramp in combination with oxen to pull blocks up and place them in position is attractive. However, no evidence exists to prove that this system had been invented and used by the Mycenaean builders and it would have meant that turning points for oxen yokes would have been needed on the ramps.

4.2 Placing the blocks in the wall

So far, the blocks were already transported to the site and unloaded, but they still had to be moved up the ramp and be put in place. While constructing with irregular massive blocks cannot be quantified as easily as for the Egyptian masonry blocks the latter figures can be used as a guide and be modified. For this purpose, I have modified Atkinson’s and Hodges’ figures of human hauling labour and placing blocks by levering to fit the Mycenaean case as closely as possible. Atkinson (1961, 297) suggests that 2 men can haul 1 tonne on a sledge over a flat surface. If 2.5 tonnes is taken as an average for the massive blocks, 5–6 people would be needed. To further allow for a 3% inclination of the 350 m ramp, 6–7 people would be required to pull such a sledge up the ramp to its final location. Based on Atkinson (1979, 120–1), Loader (1998, 68) suggests that it took 4 men 11.19 hours to pull a 2.5 tonnes block from the quarry to the site, covering 1 km distance. Translating this into pulling this weight up the 350 m ramp with 3% inclination with 7/8 men at hand would reduce the time to just over 2 hours per block while, in reality, no ramp would be needed at the start and the full one would been needed only towards the end of the construction. Therefore, I worked with an average ramp length of 175 m throughout and one block per hour would be hauled up on average. The hauling of one 2.5 tonnes block up the ramp could be achieved by eight people in one hour, so eight md would have brought up 25 tonnes of stone material to the top of the wall under construction. Table 6 brings the total figures together.

These then need to be placed in the wall which can, in my view, only have taken place by careful and controlled

Weight in tonne	people	Time
2.5	8	1 hr
25	8	10 hrs = 1 day
46,070/57,700	8	1,842.5/2,308 days
46,070/57,700	1	14,740/18,464 md
46,070/57,700	**8 × 5**	**368.4/462 days**

Table 6. Hauling blocks up the ramp, see also note j in the endnotes p. 103

levering (Loader 1998, 64 basing herself on Hodges 1989, 139; see also De Haan 2009, 7). For this task, I employ the same number of people as were required for levering the blocks during loading and unloading since placing each block from the sledge in the wall is a very similar action (see Table 2). Conveniently, c. 7/8 people, required to haul up each block, are needed to lever it in place. A 2.5 tonnes block can be moved horizontally 190 mm in 20 seconds by 6 people (Hodges 1989, 133–9). I employ 8 to account for more irregular blocks in size and shape, so a distance of c. 60 cm can be traversed in 1 minute. Over the thickness of the wall of 7.5 m the average distance for blocks to be moved is 4 m. Table 7 sums up the calculations done for this part of the construction.

Table 8 brings all costs together and shows that the man-day estimates for hauling the blocks up the ramp are high compared to other costs, as already noted by Loader (1998, 68-69). This is why she she reverted to using oxen to haul up the blocks on a hypothetical wooden roller system. However, these are based purely on human power, thus they are expected to be high.

5 Discussion

How should these calculations be understood? Relating them to each other is the most logical way of interpreting them since none of the tasks outlined were done in isolation or in a linear way. Abrams and Bolland (1999) developed a very convenient ‘spread-sheet’ model, adapted here for these preliminary results. DeLaine (1997, 105–6) suggests that a working year on the building site of the Caracalla Baths in Rome consists of 220 working days (April–November) and work outside, such as quarrying, could be conducted for 290 days per year. At Tiryns the quarrying was probably linked with directly transporting the blocks to the site, so I have used a maximum of 220 days for all activities. As already indicated, environmental and other factors, such as seasonal changes, and agricultural tasks of working the land with oxen and ploughs, may have had a direct impact on the number of days that people and animals could have been available to work in construction at *any* given season, unless certain agricultural and other craft tasks were temporarily taken over

	Horizontal speed	mass	Block type	People needed	Distance required
Giza pyramid	190 mm/20 m-sec.	2.5 tonnes	Masonry	6	-
Tiryns wall	190 mm/20 sec = 60 cm/m-min.	2.5 tonnes	Irregular	8	
Tiryns wall	6,666 m-min.	2.5 tonnes	Irregular	8	4 m (400 cm)
Full wall circuit volume	**204.7/256.44 m-days**	46,070/57,700 tonnes	Irregular	8	4 m
Total cost	1,637.6/2,051.5 m-days			1	

Table 7 Positioning the blocks in the wall, see also note k in the endnotes p. 103

Action	6.5 m wall	8 m wall	Team work nbrs for 6.5/8m wall
Quarrying	17,060 md	21,000 md	30 × 568.75/700 md
Loading and unloading:			
Large	6,400 md	8,000 md	8 × 800/1,000 md
Medium & small	4,300 md	5,385 md	4 × 1,075/1,346 md
Transport with oxen	2,470 trip days	3,010 trips days	
Ramp building	4,643 md	5,714 md	8 × 580/714 md 16 × 290/357 md
Hauling blocks up the ramp	14,740 md	18,464 md	8 × 1,842.5/2,308 md (8 × 5) × 368/462 md
Positioning blocks in wall	1,637.6 md	2,051.5 md	8 × 204.7/256.4 md

Table 8 The basic Lower Citadel wall operation summarized

by others. The need of oxen for ploughing, however, would have remained and while we cannot answer seasonality-related questions with any degree of certainty at this stage such considerations were explored elsewhere (Brysbaert 2013 and the ongoing work). Table 9 visualizes the different tasks spread over a specific time period.

Everything became more labour intensive towards the end of the construction: the ramp became higher thus more people were needed for hauling up blocks. Only the quarrying took up the full three years while other tasks started later, often with fewer people at the start than later on. All figures are thus locked into each other out of necessity: the rate of bringing blocks up should match the rate of placing them in the wall *and* the rate by which they are brought to the site, hence also quarried, in order to avoid accumulation of materials which could block construction and everyday life. For that reason, I suggest multiple teams of eight people hauling the blocks up the ramp, in a rotational chain, as was also suggested for the block transport by oxen yoke teams. Building the ramp and positioning the blocks in the wall are closely linked. Since these teams' maximum work rate is determined by the quarrying and transport rate, the tasks of constructing the ramp, hauling the blocks up and positioning them in the wall could have been done by the same shifting teams as three parts of one task.

With the data employed, Table 9 demonstrates that the Lower Citadel wall could have been constructed, by less than an average of 100 men and five teams of oxen, in about three years. This stands in contrast to Müller (1930, 208) who referred to several decades but that was commented upon by Grossmann (1967, 101).

My calculated statements reflect, first, the 'ideal sketch' of the basic wall construction produced here in calculating *minimum* numbers of people, animals and divisions per task over time. In this paper, no niches or any later alterations could yet be taken into account, (details in Maran 2010; and Schnuchel 1983, 404-410). The numbers may equally work for a more realistic picture whereby several external factors (*e.g.* seasonality) and internal factors (more or fewer workers and oxen available depending on the season) would be taken into account. These factors would necessarily stretch the numbers calculated, and would especially affect the suggested time lines. However, the number of 100 workers, referred to in relation to several tasks may have been higher or lower in reality, depending on many external factors, but would have to be somehow linked up to the real needs of the task at hand and all other embedded tasks. As such, drastically different numbers, especially when linked together as in Table 9, may not be that realistic either when seen from a purely practical viewpoint and based on the types of data

Activity	Year 1	Year 2	Year 3
Quarrying	36 × 220 md	30 × 220 md	30 × 220 md
Transport	5 oxen teams × 180 trip days	5 oxen teams × 220 trip days	5 oxen teams × 220 trip days
Loading/unloading:			
Large	13 × 175 md +	13 × 220 md	13 × 220 md
Medium/small	9 × 175 md	9 × 220 md	9 × 220 md
Ramp building + positioning blocks	8 × 175 md	12 × 220 md	17 × 220 md
Hauling blocks up	16 × 165 md	32 × 220 md	40 × 220 md
Total in man-years and oxen teams	82 men + 5 oxen teams (partial year)	96 men + 5 oxen teams	109 men + 5 oxen teams

Table 9 Activity time-line per year, expressed in man-days and trip days

that were used (see introduction). These strings, thus, of embedded activities (ramp and wall building, quarrying and loading, unloading and building, Table 9) indicate sophisticated levels of human resource management and planning (DeLaine 1997, 192-193) which are integral and embedded links in the construction activities themselves.

Some remarks are necessary: all figures given are *minimum estimates* and do not take into account certain aspects of working, as outlined above (*e.g.* niche construction, the slightly later North Gate alterations [Maran 2008, 88-91, 2010, 726-729], weight of carts). Further fieldwork will refine these minimum estimates by taking each factor, action and alteration into account. Especially the unskilled labour forces may have shifted from one task to another. Also these aspects are being quantified in the larger ongoing study now funded by an ERC Consolidator Grant (2015-2020). Finally, these numbers only refer to the workforces involved in pure construction processes per step, but nowhere are the people who support these workforces in terms of food provision, tool production, repair and provision calculated (but see Brysbaert 2013). To illustrate the sort of knock-on effect such large-scale building projects may have had on a living community, the archival records of Versailles during the periods of its large construction activities are particularly revealing (Lepetit 1978, 606–7).

Inefficiencies must have been present throughout the work too and detailed fieldwork aims at picking up on the material evidence for these. Grossmann already mentioned, for instance, that the offsets in the wall may have been caused by changing numbers of available workers, irregular available finances and other work interruptions. While some segments are constructed with high regularity, such as parts of the Upper Citadel, others, such as the Lower Citadel wall, are rather irregular, courses running in bends and with unequally thick courses (see already Müller 1930). According to Grossmann (1967, 101; 1980, 493), these irregularities were likely not the consequence of fast work done under time pressure but had to do with flaws in the delivery of materials. Finally, I also consider the effects of higher and lesser skilled labour involved in each task. Any inefficiency would have obstructed the workflow, causing delays and extra 'costs'. These irregularities are documented in the ongoing work at Tiryns and are being investigated in terms of their potential causes.

Crucial to the smoothness of the workflow and its efficiency would have been the role played by the supervisors and managers who, when experienced, would know how to avoid obstructions or, when these occurred, would know how to restore the workflow. They would also be responsible for indicating when certain groups of people had to start working in order to provide a constant workflow and would thus necessarily have been socially close to them. Considering their potential social organization in terms of recruitment is thus important and can be usefully compared to contemporary work gangs both on construction sites and excavations. These usually work tightly together as one team under one master-builder/excavator, and have often built up solid work experiences together for years, sometimes for decades, in the same team, where recruitment of new members is carefully discussed by all. Finally, some sections of the Lower Citadel wall have been restored over time with blocks that were no longer *in situ*. (see Grossmann 1980, 477–8 with further references and personal observations on current conservation work on site). How such activities may have influenced the calculations presented here is being investigated and compared to field-based data collected (see Brysbaert *et al.* submitted).

6 Conclusions

This paper investigated the Lower Citadel wall construction and its logistics at Tiryns, as only one part of a much larger building programme conducted from the 14th into the second

half of the 13th century BC. This short study, selective of the basic shape of the Lower Citadel wall only, exemplifies how preliminary cost calculations can give an indication about the interactive involvement of different groups of people working closely together, the minimum time it took them, the organization it required and the socio-political and economic implications it certainly will have had on all involved.
I would like to reiterate that future considerations of the niche constructions and their subsequent infill will not only change and fine-tune the calculations presented here but will also tie in these features and the efforts made for military purposes into the social role that such constructions played at specific phases of the final palatial LH IIIB period (see Grossmann 1980, 489–90; Maran 2010).

That the wall was constructed for defensive purposes, among other reasons, cannot be doubted and much effort went into it, as I have aimed to show. However, if the minimum numbers calculated still required at least three years (and likely more, see Brysbaert 2013) for a substantial workforce to complete the basic task, the defensive nature of the construction cannot have been put in place to counteract or protect from *imminent* threatening danger. It was clear, however, that difficulties were on the horizon and this is also seen in the fact that in those last decades of the 13th century BC, efforts were made to bring craft activities of importance to the palatial administration under closer spatial and managerial control and thus within the LH IIIB citadel walls. Such examples are visible in Tiryns Lower Citadel North in Building XI (Maran 2008; Brysbaert and Vetters 2010), and indirectly through the intense recording in the Linear B tablets. A similar trend may be noted at Pylos in the activities of weapon and chariot production management in the northeast building during roughly the same period (*e.g.* Lupack 2008, 122–7), and at Mycenae where the LH IIIB wall now extended to surround the craft activities at the Cult Centre (Lupack 2008, 167).

Efforts in realising these citadel complexes came from several groups with likely different social status: the ruler who presumably ordered the task and may have checked it regularly himself or through supervisors/architects, the supervisors themselves likely present at each stage of the work to be done, the different groups of workers, some of higher specialization than others (both skilled and unskilled), and the people who provided tools, equipment, food and other necessities. In all calculations provided in the tables, I took the difference between skilled and unskilled labour (indirectly hinted at in the Pylos Linear B tablets) into account in the same way as DeLaine (1997, 104–7) does for her work which also includes figures linked to supervision of such work. It remains, of course, not easy to determine specific numbers relating to both skilled or unskilled workers but DeLaine bases herself on historical, ethnological and textual accounts to arrive at a ratio of 1:10, which is probably influenced by the nature of the task (also Pakkanen 2013, n. 27).

Of equal interest is that two types of economic strategies seemed to have been at work more or less simultaneously. On the one hand, we note the building of a formidable fortification wall, whose construction forms in itself a display spectacle, involving the mobilization of substantial work forces and bringing materials from several locations. Taking these factors together, building this wall cannot be considered a low budget undertaking and this was clearly not what elites tried to portray. On the other hand, the use of local stones and the efficiency with which many, if not all, tasks must have been organised to interlock into each other to achieve a smooth workflow, does show that these works, despite their overt display character, had to be carried out economically viable but without losing the rich possibilities to play out subtle messages in their stone choices and usages (Brysbaert 2015). As such, the Lower Citadel fortification wall fulfilled its defensive purposes preventively, by having been constructed, *and* through the way it was done. It may thus have created or enhanced a sense of community-belonging by having many people involved in this 'Cyclopean' task, but it had, at the same time, the power to intimidate. The wall's multiple meanings thus sat in the socio-political power display that went hand-in-hand with its construction from a socio-economic perspective, while employing and bringing together large human, animal and natural resources. Comparatively, the Società Editrice Apuana (1970, 146) shows a spectacle admired by onlookers while caravans of oxen, pulling the largest block ever quarried, pass through the village (also Mannoni and Mannoni 1984, fig. 137 and 248; see also Santillo-Frizell 1997–8 for such arguments).

The possible economic considerations for the wall construction itself then stand in contrast to the efforts and costs involved in, for instance, bringing in the conglomerate blocks for the entrance ways at the Upper Citadel, to be brought from a distance of 15–18 km away (Brysbaert 2015). Similarly, the quarrying, transporting and putting in place of the bathroom floor (Kilian 1988 suggesting that the date of laying this slab could have been earlier than LH IIIB2 and thus be part of an earlier palace phase), in itself a tour-de-force, consisted of an effort that did not follow the usual economic considerations at all. That task alone was performed purely to display power, to show who had it, to perform it, and to demonstrate it to all who were able to observe and admire it.

The quarry for this turbiditic limestone has not been not located yet (Varti-Matarangas *et al*. 2002, 480). However, if the quarry was, hypothetically, 10 km away – a number chosen to be in between the nearest quarries at 1 km distance of the site and the quarries for the conglomerate stone, *c*. 15–18 km away – the transport of this block, if done by pure and extremely well-coordinated human power, would have taken 200 people 17 to 33 days to move the block over 10 km. These figures reflect the efforts done in a recent experiment moving a 25-tonnes Egyptian obelisk, under the direction of Dr M. Lehner (Lehner 1997, 202-225 mentions the use of 6-8 men per tonne, arriving at 200 men for his 25 tonnes obelisk). DeLaine (1997, 100–1) contrasts strongly the bulk material extraction and transport which was done as cost-effectively as possible, versus the use, extraction and transport of, for example, marble, meant to form a display of imperial power, contributing to the overall 'magnificentia' of the construction. The sheer difficulties, in Rome, of moving such massive items around, made a public spectacle out of the generating process of public building. The activities around the bathroom floor thus will have produced an immense spectacle to be discussed and admired, and the contrast, then, between both economic strategies, for the Lower Citadel all and the bathroom floor, was likely intended.

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Notes in tables

[a] T_ nbr: refers to the drawings in the Tiryns Archive that were employed to produce calibrated measurements

[b] Compare to earliest published figure by Dörpfeld 1886, 203: 7.60 m.

[c] An original wall height of up to 10 m has been suggested (Grossmann 1967, 1969; Schnuchel 1983; Küpper 1996), even 12.5 m was mentioned: Loader 1998, 71.

[d] Based on block counts on the outside surface carried out over a length of c. 185 m out of the 350 m, so just over half. Grossmann noted that larger blocks were used more often on the outside versus the inside façade and even less in the centre of the wall. The percentages given here take this into account. This count was done combined on T_31, T_61, T_63, T_66, T_68, T_76, T_105

[e] For the volume and mass in tonnes two figures are given: the first corresponds to a wall height of 6.5 m, the second of 8 m as an average, see *e.g*. Loader 1998, 61, 72 for the latter figure. Both figures are used, as such, throughout the text.

[f] *E.g*. 30,000 tonnes divided by 2.5 tonnes = 12,000 tonnes. Each 2.5 tonnes needs 8 people for 40 minutes = 320 man-minutes or 5.333 man-hours × 12,000 = 64,000 man-hours or 6,400 md.

[g] *E.g*. 16,124 tonnes, loaded per tonne, need 4 people for 40 minutes = 160 man-minutes or 2.666 man-hours × 16,124 = 43,000 man-hours or 4,300 md.

[h] Medium and small-size stones are calculated together since they both can be transported by a single yoke.

[i] This figure is very similar to Küpper (1996, 50) who came to 150 working days but that did not include ramming the earth.

[j] Having compared this cost with the suggestion made by De Haan (2009, 6) and with reduced friction of 0.1 μ (see Consiglio 1949, 90, 92), a higher result, 2.4 hours employing 6 people, was achieved.

[k] I did not take the niches, ubiquitous in the Lower Citadel wall, into consideration for these preliminary construction calculations since Küpper's hypotheses (1996, 51-52) on their construction cannot, at this stage, be tested without further investigations at the site, if it is possible at all

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